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HAPTIC PROCESSING BY INFANTS DURING SIMULTANEOUS VISUAL AND MANUAL INSPECTION OF OBJECTS

by

William G. Parker

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled HAPTIC PROCESSING BY INFANTS DURING SIMULTANEOUS VISUAL AND MANUAL INSPECTION OF OBJECTS submitted by William G. Parker in partial fulfilment of the requirements for the degree of Master of Arts.

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Supervisor

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William Whyte..................................

Date. June 22, 1979 ....

To my wife, Louise, whose love, support, and encouragement allowed me to put so much of myself into this project.

ABSTRACT

The present study was designed to investigate how infants obtain haptic knowledge about objects. Specifically, it was proposed that beyond 6 months of age, infants engage in increasingly coordinated visual and manual inspection of objects and that during this coordinated inspection the infant processes the haptic features of the object. The study was also designed to investigate the influence of haptic familiarity with objects on differential responding to a 2D and 3D stimulus. To investigate these issues, 60 six, nine and twelve month-olds were observed while they looked at and handled, or only looked at repeatedly presented 2D and 3D stimuli. Analysis of the looking and handling records yielded the following findings.

All infants in the study tended to touch objects they were already looking at more than objects they were not looking at. Older infants were more coordinated in this regard than younger infants. This finding implies that manual inspection becomes increasingly visually guided as infants grow older. In addition, infants tended to look at a particular object for most of the time they handled it. Infants who were allowed to handle the stimuli tended to remain visually interested longer than infants who could only look at the objects. Furthermore, infants who had only looked at the objects showed renewed visual interest when they were permitted to handle them for the first time.

Handling the objects appeared to increase differential handling and reaching for the 3D stimulus but neither of these trends was statistically significant. However, older infants tended to reach for the 3D object at the onset of a trial, moreso than younger infants.

These results indicate that, in the second six months of life, infants engage in highly coordinated visual and manual inspection of objects and that during this inspection haptic information is processed. The influence of this haptic familiarity on subsequent differential responding is not clear. The implications of these results for our understanding of how infants integrate visual and haptic input are discussed and suggestions for further research are offered.

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I. INTRODUCTION

For the human infant, learning to associate the appearance of an object with the feel of an object is an important achievement. This learning enables the infant to know more completely an object's properties. In a more technical sense, the learning consists of an integration of visual information with haptic information (i.e., information derived from handling an object). Recent research reveals that infants as young as one year of age can integrate separate visual and haptic experiences (Bryant, Jones, Claxton & Perkins, 1972; Gottfried, Rose & Bridger, 1977). For example, Bryant and his associates allowed one-year-olds to handle a noisemaker toy but prevented them from looking at the toy while handling it. On a subsequent reaching test, the infants recognized the toy they had handled previously. This recognition indicates the beginings of cross-modal integration, in that features that were felt are identified when seen. The development of this type of integration has not been the subject of systematic study, although it is of obvious importance to sensorimotor intelligence. In contrast, the development of visually guided reaching and grasping which occurs by six months of age, is well described in both theoretical and empirical terms (White, Castle & Held, 1964; Piaget, 1952; Bruner, 1967). The purpose of this study is to explore how infants who are capable of visually directed reaching and grasping engage in coordinated visual and manual inspection of objects. Of particular interest is the age at which this coordinated inspection results in the simultaneous processing of visual and haptic information. A review of the literature on hand-eye functioning points to several important ways infants may begin to integrate information from vision and touch.

The development of hand-eye functioning is described by contemporary theorists as an increasingly sophisticated abstraction of information obtained from both the hand and the eye (Gibson, 1969; Piaget, 1952). The integration of input from each of the two sense systems apparently develops concurrently with an improvement in processing within each system. One fundamental issue in the analysis of perceptual development has been the relative primacy of the two information sources; that is, it has not been resolved whether or not one sense system teaches the other about the environment. Research dealing with adults indicates that when visual and tactile sensations conflict, the visual information tends to dominate the individual's perception of the object's shape, size and position (Rock & Victor, 1964; Rock & Harris, 1967). This implies that the development of hand-eye functions consists of learning to coordinate haptic input to visual information. Keeping this progression in mind, an examination of the developmental literature is revealing.

Longitudinal Studies of Hand-Eye Behaviour in the First Six Months

Several classic descriptions of sensorimotor development demonstrate the powerful influence of vision on manual behaviour. White, Castle & Held (1964) describe the earliest form of hand-eye coordination as a visually elicited swipe. According to these authors, this behaviour emerges at approximately 2 to 3 months and consists of the ballistic launching of the arm toward a visually fixated target. Visually elicited swiping is often inaccurate, and a swipe is not corrected in mid flight if the aim is inaccurate. Neither is there any indication that the infant expects to grasp the fixated object, as the hand usually remains closed even if contact occurs. By 3 to 4 months, the infant often watches his hands grasping one another at midline. At this age, infants may also reach for an object while shifting their glance back and forth from object to hand until the object is grasped. By 5 to 6 months the infant is able to correct the trajectory of a reach in midflight. At this age, the infant may also open his hand to accommodate the size of the fixated object once contact occurs and both object and hand are in the visual field. In other words, according to White and his associates, manual behaviour becomes increasingly refined under the direction of visual input.

The cognitive-structuralist theories of development are also relevant to the study of hand-eye coordination. For example, Piaget (1952) considers hand-eye coordination as a fundamental example of a sensorimotor schema. In this analysis, a schema consists of behavioural elements organized in a planful structure and executed under appropriate circumstances. Sensorimotor development is the construction and elaboration of these schemata and their integration with one another to form more complex schemata. In this vein, Piaget describes the development of visually guided reaching as the integration of the visual schema with the reaching schema. The reaching schema develops independently of the visual schema until the infant is capable of executing an efficient reaching motion. In the initial stage of schema integration, reaching for objects is visually elicited but the grasping of objects is not controlled visually. Grasping is instead elicited by the tactile stimulation experienced when the hand contacts the object. The grasping schema is said to be incorporated into the reaching schema after a developmental stage during which the infant repeatedly observes the opening and closing of his hand. Ultimately, the infant is able to fixate an object and bring his hand from outside of the field of vision to the vicinity of the object, grasp it, and deliver the object to his mouth. True reciprocity in this eye-hand schema, then, occurs when things felt are brought forward to be seen, and things seen are reached for and felt. According to Piaget, this reciprocity of eye-hand function is fundamental to cognitive development.

Bruner's (1973) account of the development of eye-hand coordination is similiar to Piaget's in its emphasis on the cognitive underpinnings of sensorimotor adaptions. Bruner considers eye-hand coordination a fundamental component of intentional and planful problem solving. He also suggests that the early components of reaching, such as ballistic reaching and hand opening, are innate. Development consists of coordinating and sequencing these "modules" of innate behaviour into a problem solving skill. (For Bruner, the ultimate eye-hand skill may even involve the extension of the hand with tools.) Visual information is crucial for this coordination because it provides the infant with both an initial assessment of the layout of the immediate space, and a moving, continuous form of feedback as to the position of the hand in relation to the object. Bruner suggests that as the reaching skill is exercised, it becomes more visually guided, and less kinesthetic feedback is required. As in the previous descriptions, the progression is said to be toward integration of sensory information with motor skill, with visual information described as the most influential form of perceptual information.

Studies of the Stimulus Determinants of Hand-Eye Coordination

Piaget's and Bruner's descriptions evolve from an underlying theoretical orientation which assumes that we can make inferences about early thinking from observation of eye-hand behaviour. The work of White et al. represents a more atheoretical description, although their data do not provide a detailed analysis of stimulus determinants of eye-hand coordination. Studies conducted more recently attempt to analyse the infant's use of visual cues when reaching for objects. This research examines how infants decide that objects are in fact solid and located somewhere in space. The recent studies are aimed at determining if infants detect when visual and haptic perceptions are in conflict, and how they use visual cues as to the radial locus and distance of objects.

Bower, Broughton, & Moore (1970) were the first to investigate the infant's reaction to a conflict between visual and haptic input. They presented virtual images of objects to infants ranging in age from 7 days to 4 months. (Virtual images are comparable to 3D movie images, in that they have many of the visual properties of solid, graspable objects but are in fact only patterns in projected light.) Bower's rationale was that if infants judged such visual images to be solid, they should react when their grasps failed to produce appropriate feedback. Bower et al. reported that all infants reached for the image and anticipated the size of the projected object by opening their hand appropriately. They also reported that the babies became upset when they attempted to grasp the virtual image. These results are interesting for two reasons. First, they suggest that infants can visually adjust their grasping at a much younger age than previously reported. Secondly, these results suggest that visual information dominates haptic information from the earliest point in development. In other words, Bower and his associates suggest that the infant's distress was the result of a failure to confirm an expectancy based on visual information.

A series of subsequent studies have questioned both Bower's interpretation of his results and the reliability of the results themselves. With regard to reliability, several attempts to replicate the observations of newborn reaching and grasping have failed (Field, 1977; Ruff & Halton, 1978; Dodwell, Muir & Difranco, 1976). In fact, most researchers report the first signs of consistent reaching at about 4 to 5 months of age. With reference to the infant's reaction to the intangibility of the object, Gordon & Yonas (1976) offered an alternative explanation which involves a conflict between visual cues: binocular convergence and motion parallax. They suggest that the virtual images produced abnormal motion parallax which upset the infant as he or she moved forward to reach. Gordon & Yonas (1976) also investigated the age at which infants would limit their reaches to objects within arm's length. Specifically, they measured infants' reaching to virtual images which were projected within reach or out of reach. They report that only five-and-a-half month-olds showed reaches, and that these infants reached one-and-one-half times as often to virtual images that were within arms reach than to the more distant images. Field (1977) conducted a similiar study and found that 7-month-old infants inhibited reaching to distant virtual images and 3 and 5-month old infants showed very little reaching for either stimulus. In an earlier study, Field (1976) had reported that 5-month-old infants adjusted to stimulus distance when reaching for solid objects. Taken together, Field's findings may indicate that, before 6 months of age, infants need more depth information to control their reaching than is provided by a virtual image.

Researchers have also studied the influence of other types of depth information on infants' reaching behaviour. Yonas, Cleaves & Pettersen (1978) investigated infants' sensitivity to pictorial depth cues. They found that 26 to 30 week-old infants directed their reaching to the closer side of a window which was photographed as slanting into space. Infants from 20 to 22 weeks of age did not reach to the nearer side of the photographed window, but did direct their reaches appropriately to the frame of a real window rotated in space. These findings suggest that, by approximately 26 weeks, infants can use pictorial depth information in determining the distance of objects. This is evidence of a developmental increase in the use of visual cues when reaching.

By approximately 6 months of age, visually guided reaching and grasping becomes so skilled that the infant reaches for objects on a selective basis. With this competence, infants not only restrict their reaching to those objects which are within arm's length, but are influenced in their reaching by the visual attractiveness of objects. The coordination of reaching with visual selective attention is an important step in perceptual motor development (Shaffer & Parry, 1970; Schaffer & Parry, 1969). The early research focused on infants' response to familiar and novel objects. It is well known that at 6 months of age infants prefer to look at novel visual patterns (Fantz, 1964). If infants are coordinating their visual and manual inspection of objects, they should tend to reach more to objects with a novel appearance. Schaffer suggests that this is not the case until approximately 8 months of age. Schaffer & Parry (1970) conducted a study in which they demonstrated that 6-month-olds showed increased visual attention to novel objects but did not show increased latencies to reach for novel objects, while 9 and 12-month-olds did show increased latencies to reach for novel objects. Schaffer interprets a delay in reaching for unfamiliar objects as an index of concordant visual and motor behaviour. The rationale for this interpretation is that a hesitation to touch an object until it has been studied is a functional example of vision and touch working together. Schaffer and Parry (1970) also found that 6-month-olds tended to look at a novel object more than a familiar object but they handled novel and familiar objects for the same length of time. These two findings led Schaffer to conclude that 6-month-olds cannot coordinate manual behaviour with visual selectivity.

Schaffer's conclusion was challenged by Rubenstein (1974), who criticized Schaffer's use of latency to reach as a measure of visual-motor concordance. She presented data indicating that an infant's visual and manual response to novel objects is concordant if one compares the length of time infants look at and touch novel objects with the length of time they look at and handle familiar objects. This comparison revealed that children tend to look at and manipulate a novel object more than a familiar object. As her measure of concordance was essentially the same as Schaffer & Parry's, Rubenstein's conclusions appeared to directly contradict their findings. In a follow-up study, Ruff (1976) also found that 6-month-old infants both touch and look at novel objects more than familiar ones when both are available. Ruff also pointed out the need for clear definitions of visual and manual concordance and offered some suggestions to this end. These suggestions will be discussed below.

A recent study has apparently reconciled the discrepancies between Schaffer's findings and those of Rubenstein and Ruff. Steele and Pederson (1977) pointed out that while Schaffer varied novelty in terms of colour, Rubenstein and Ruff both varied novelty in terms of colour, texture, and form. These researchers suggest that for young infants, new texture, or shape cues, or both, are needed before babies will handle novel objects more than familiar ones. Steele and Pederson replicated Schaffer's results when novel objects differed from familiar ones in colour alone. Infants in this condition looked at the novel object more, but showed no preference to handle it. When the novel and familiar objects differed in texture or shape, the infants demonstrated both visual and manual preference for the novel object. This result replicated Rubenstein's and Ruff's findings. The Steele & Pedersen study did more than determine the effects of methodological differences. Their results also indicate that as early as 6 months of age infants' manipulation of objects is influenced by previous visual and manual contact with the stimulus. This suggests that not only can 6-month-olds direct manual contact in accord with visual preference, but they may be processing haptic information pertaining to the texture and form of objects while visually fixating the objects.

Multimodal Processing

A recent study by Gottfried, Rose and Bridger (1978) also indicates that 6-month-olds may be processing haptic information. Gottfried and his associates conducted a study in which one group of 6-month-olds was permitted to touch and look at an object while a second group of infants was only allowed to look at the object. Both groups were then shown the object paired with an object of a different shape. Infants who had only looked at the original object preferred to look at the novel object, while subjects who had both looked at and handled the original object showed no visual preference for either object. Gottfried concluded that manual contact interfered with the infant's ability to process visual information and thus the infant never became familiar with the test object. While this may be true, their results may be interpreted in other ways. For instance, the infant may prefer to look at a familiar object simply because he or she enjoys handling it. This preference may neutralize the usual tendency to look at an alternative object because it is visually novel. Both of these interpretations imply the processing of haptic information whether this processing leads to a memory for the handled object or interferes with ongoing visual processing.

Collectively, the research provides a good description of the stimulus determinants of hand-eye functioning during the first six months of life. The infant first reaches with little regard for spatial information such as depth cues. However, the infant soon learns to use spatial cues more appropriately. By about 6 months of age, the visual attractiveness of objects elicits reaching. However, visual information is not the sole determinant of differential reaching. There is evidence that by 6 months of age the infant begins to augment visual knowledge by encoding the haptic properties of objects while handling them. These findings imply that 6-month-olds may be processing visual and haptic information simultaneously.

The present study is designed to demonstrate that, after 6 months of age, infants increasingly coordinate their reaching and touching with their looking and that during this coordinated inspection the infant is processing haptic information. A careful monitoring of looking and touching will contribute to our understanding of how infants come to know objects in terms of visual information, in terms of haptic information, or in terms of both simultaneously.

Measures of Visual-Manual Coordination and Concordance

A close temporal association between visual and manual attention may be important to match input from the two sensory channels. In the past, researchers have measured the coordination of manual and visual attention primarily to investigate the infant's response to novel objects (Schaffer & Parry, 1970; Rubenstein, 1974; Ruff, 1976; Steele & Pederson, 1977). The measures vary, and in some cases there is confusion in terminology (Ruff, 1976). Ruff took a step toward clarifying the measures when she distinguished between visual-manual coordination and visual-manual concordance. She defined visual-manual coordination as the percentage of all manual contacts with a stimulus which were preceded by and overlapped with visual fixation of the stimulus. Visual-manual concordance occurred if the infant both fixated and contacted the novel stimulus more than 50% of the time it was presented or fixated and contacted the novel stimulus less than 50% of the time. She determined whether or not her subjects were concordant on the basis of a sign test. Ruff reported that the reaches of 6-month-olds were preceded by visual fixation 78% of the time, and that their visual and manual behaviour was significantly concordant.

In the present study visual-manual coordination is defined as the percentage of all contacts in which the infant fixated the object during the .5 sec period prior to the contact and continued to fixate the object for at least .5 sec during the contact. This measure is similar to that used by Ruff, but more precise.

Visual-manual concordance is defined as the percent of the manual contact time in which visual fixation is also occurring. (The use of percentages allows for comparisons between studies involving different stimuli or presentation procedures).

Haptic Processing

Several of the studies reviewed above suggest that infants as young as 6 months of age may be processing manual input while looking at and handling objects. The present study was designed to confirm the ability of 6-month-olds to process haptic information and to monitor the development of this ability over the second six months of life. The ability of 6, 9, and 12-month-olds to process haptic information was investigated in the present experiment by analysing the looking and touching directed to a repeatedly presented pair of stimuli: a three dimensional (3D) object and and a two dimensional (2D) colour representation of the object. One half of the infants at each age were allowed to handle and look at the stimuli for a series of trials (visual/haptic familiarization) while the other half of the infants were only permitted to look at the stimuli (visual familiarization). After this familiarization phase all subjects were given additional presentations of the stimuli in which touching and looking were permitted.

Evidence of haptic processing was sought by comparing visual interest in the stimuli when handling was permitted with visual interest in the stimuli when it was not permitted. If haptic information is being processed while infants handle objects, handling the objects should influence overall visual interest in the stimuli.

A second way of testing for evidence of haptic processing is to monitor the preference to look at, reach for, or handle the 3D object over trials. We might expect that, over a series of trials, infants who can process haptic information should come to look at, reach for, and handle the more haptically complex 3D object more than a flat representation. However, it is possible that this preferential responding may result exclusively from visual information. That is, a 3D stimulus appears more complex and variable than a 2D representation. To determine the role of visual familiarity in the development of any preferences, the preferential looking, reaching, and handling of those infants in the visual familiarization condition were compared with the preferences for the 3D object shown by the infants in the visual/haptic familiarization condition on the last trials when both groups could handle the objects. If infants demonstrated a stronger tendency to look at, reach for, or handle the 3D object after visual/manual familiarization then after visual familiarization alone, then the difference must be based on information processed while handling the objects.

Summary

In the present study, a pair of stimuli was repeatedly presented to infants and their looking and handling behaviours were recorded. Five behavioural variables were of specific interest: differential looking, indicated by duration of head-eye orientation to a 2D and 3D stimulus; differential manual contact with the stimuli; differential reaching as indicated by the first stimulus touched; visual-manual coordination; and visual-manual concordance. Analyses of these measures were directed toward three general questions.

1. Do infants show improved visual-manual concordance or improved visual-manual coordination, or both, as a function of age?
2. Is visual attention influenced by the opportunity to manually explore the stimuli?
3. Do infants show differential manual contact,

differential reaching, or differential visual attention as a result of haptic experience with paired 2D and 3D stimuli?

II. METHOD

Subjects

Subjects were 60 healthy, full-term infants with no physical or visual impairments. Specifically, the sample included 10 female and 10 male infants between 22 and 26 weeks of age (M = 25 weeks 2 days); 10 males and 10 females between 34 and 38 weeks of age (M = 36 weeks, 1 day); and 10 males and 10 females between 50 and 54 weeks (M = 52 weeks, 6 days). Subjects at each age level were randomly assigned to the visual/haptic or visual familiarization groups with the restriction that equal numbers of males and females be included in each condition. Subjects were recruited from a file of parents who had indicated willingness to participate in infant research. An additional 12 infants were not included in the experiment because they failed to reach for the stimuli at least three times in the visual/haptic familiarization condition or at least once after visual familiarization. The data from three 6-month-old males and two 6-month-old females in the visual/haptic familiarization condition, one 6-month-old male and one 6-month-old female in the visual familiarization condition, two 9-month-old males and one 9-month-old female in the visual/haptic familiarization condition and one 9-month-old male and one 9-month-old female in the visual familiarization condition, were excluded for failing to meet the above requirements.

Stimuli

A commercially available rubber doll face was mounted to the centre of a 10 cm square of black painted aluminum. The doll face projected approximately 4 cm from the aluminum base. This was the 3D stimulus. A life-sized colour photograph of the doll face, frontal pose, was centred in a black background and glued onto a similiar plaque. The photograph was of the same brightness as the actual face, when viewed under normal room light. This was the 2D stimulus. Pieces of solid aluminum .12 cm by .12 cm, were attached to the back of each plaque. The male components of two electrical banana clips were threaded into these pieces of aluminum and protruded downward, beyond the bottom of the plaque. These clips permitted easy detachment and alternation of the stimuli between presentations.

Apparatus

The clips were plugged into holes drilled into a plywood tray which measured 50 cm x 34 cm. The plaques were positioned such that, when mounted, the stimuli were centred 8 cm apart and flush with one edge of the 50 cm side of the tray. The tray rested on the floor of a plywood box, 34 cm high, 54 cm wide across the front and 35 cm deep. Across the top of the front side of the box was a piece of plywood .5 cm thick and 13 cm high. The front of the box below this piece of plywood was open during presentations of the stimuli but curtained between presentations of the stimuli.

Curtaining between presentations was achieved by attaching a draw-string to the back of the tray so that when the tray was pushed forward a white flannel curtain was raised and when the tray was withdrawn the curtain was lowered. The back of the box was open. A piece of plywood, .5 cm thick x 34 cm wide x 54 cm long was attached at right angles to the back edge of the tray so that when the tray was pushed forward this piece of plywood covered the back of the box. A peephole, .6 cm in diameter, was centred 10 cm from the bottom of this piece of plywood. The peephole allowed an experimenter to monitor head-eye orientations from directly behind the box. The front 24 cm of the top of the box was covered with plywood. Grooves were cut in the front of the box to accommodate a piece of clear acrylic plastic, 32 cm x 53 cm and 3 cm thick. When in place, this clear plastic completely covered the front of the box. The occurrence and duration of head-eye orientations and the occurrence and duration of manual contacts were recorded on a four-track, Rustrac event recorder by means of electric switches. A left-right, normally off, toggle switch was used by one observer, who recorded head-eye orientations, and a pair of on-off handheld pushbuttons was used by a second observer, who recorded manual contacts.

<u>Procedure</u>

The experiment was conducted in the infants' homes. Infants sat on their mother's or father's lap facing the presentation box centred on a table before them. The box was positioned so that, when presented, the stimuli would be centred in front of the infant, slightly below eye-level, and within arms reach. In a few cases, infants sat on cushions to achieve this positioning.

In the experimental condition, the paired stimuli were presented to each infant a total of 12 times. Each trial lasted 10 seconds and intertrial intervals were standardized at 5 seconds. The relative positions of the stimuli alternated intermittently according to a schedule which was uniform for all babies. Each stimulus appeared to the right and to the left of each infant on an equal number of trials. The occurrence and duration of head-eye orientations to the stimuli were recorded during each trial, by an observer looking through the peephole at the back of the presentation box. The occurrence and duration of manual contacts to the stimuli were recorded by a second observer who stood behind and slightly to one side of the infant. The exact position of this observer varied slightly due to variations in room layouts.

Infants in the visual familiarization condition received the same 12 trials as the experimental infants with the major exception that, for the first eight trials, a piece of clear plastic was positioned in front of the box and this prevented manual contact with the stimuli. The clear plastic was removed at the end of the eighth trial and the subjects were permitted both visual and manual contact with the stimuli for the last four trials. Prior to all sessions, parents were told not to interfere with their infant's reaching and to hold their baby in such a way that easy access to the stimuli was possible. The two experimenters alternated duties so that each recorded the looking and touching of half the subjects. The experimenters were trained to record head-eye orientations and manual contacts in the following manner. Prior to the main experiment, a pilot study was conducted in which 12 infants touched and looked at a pair of objects for 40 seconds. Each experimenter recorded the head-eye orientations of six infants and the manual contacts of six infants. Subsequent analyses revealed no significant difference between either the looking or manual contacts of the separate groups, as recorded by the two experimenters, $t < 1$.

Interrater reliability for the manual contact measures was then established by having both experimenters simultaneously record an infant's manual contact with a pair of stimuli over 12 trials. This resulted in two records of the same infant's manual contact with the paired stimuli. The two records were compared in the following way: number of contacts to the 2D stimulus per trial, number of contacts with the 3D stimulus per trial, duration of contact with the 2D stimulus per trial, duration of contact with the 3D stimulus per trial. Pearson product moment correlation coefficients calculated between the two records exceeded .9 for all four measures.

The Measures

In the main experiment the records of each infant's looking and touching over the 12 trials were collapsed into three blocks of four trials. Within each trial block the following six dependent measures were examined.

1. Visual-manual concordance, defined as the percentage derived by dividing time spent simultaneously touching and looking at a stimulus by the total time spent in manual contact with either stimulus.
2. Visual-manual coordination, defined as the percentage derived by dividing the number of times an infant looked at a stimulus for the .5 seconds prior to and .5 seconds during a manual contact by the total number of manual contacts exceeding .5 seconds.
3. Time in seconds spent visually fixating the stimuli.
4. Differential looking, defined as the percentage derived by dividing the time spent looking at the 3D stimulus by the total time spent looking at either stimulus.
5. Differential manual contact defined as the percentage derived by dividing the time spent in manual contact with the 3D stimulus by the total time spent in manual contact with either stimulus.
6. Differential reaching, defined as the percentage derived by dividing the number of times the 3D object was touched first in a trial by the number of trials in a trial block in which reaching occured.

III. RESULTS

Visual-Manual Concordance

As can be seen from Table 1, infants at every age visually monitored over 60% of their manual contact with a stimulus. (Infants in the visual familiarization condition also showed this high level of concordance on the third trial block, M = 70%). A 3(Age) x 3(Trial Blocks) analysis of variance with repeated measures was performed on these data. This analysis revealed no significant main effect or interaction. (see Appendix 1A).

Table 1 also includes the total amount of time in each 40 second trial block that infants spent handling the stimulus.

Visual-Manual Coordination

Infants in this study tended to restrict their reaches to the object they were looking at. In fact, even for the youngest group, over 60% of their manual contacts were to objects they were already looking at. (Again, on the third trial block, infants in the visual familiarization condition showed highly coordinated reaching, M = 77%). Table 2 gives the mean coordination measures by trial block for infants at each age. A 3(Age) x 3(Trial Block) analysis of variance with repeated measures revealed a significant increase in coordination over age, $F(2, 27) = 3.5$, $p < .05$. The main effect for trial block and the Age x Trial Block interaction were not significant (see Appendix 1B). All significant

Table 1

Visual-Manual Concordance Scores[a] of Infants Who Manually Contacted the Stimuli on All Trial Blocks[b]

	Trial Block			
Age	1	2	3	$\bar{X}$
6 Months	58 (23.7)	75 (16.9)	62 (16.5)	65 (19.0)
9 Months	64 (21.6)	64 (16.7)	65 (22.3)	64 (20.2)
12 Months	79 (19.2)	77 (16.2)	71 (22.0)	76 (19.1)
$\bar{X}$	67 (21.5)	72 (16.6)	66 (20.3)	70 (19.8)

[a]Defined as the percentage derived by dividing the time spent simultaneous touching and looking at a stimulus by the total time spent in manual contact with either stimulus.

[b]Numbers in brackets are the mean number of seconds spent handling the stimuli.

Table 2

Visual-Manual Coordination Scores[a] of Infants Who Manually Contacted the Stimuli on All Trial Blocks[b]

	Trial Block			
Age	1	2	3	$\bar{X}$
6 Months	59 (11.2)	79 (9.3)	60 (10.0)	66 (10.2)
9 Months	79 (12.3)	81 (9.1)	77 (6.9)	79 (9.4)
12 Months	74 (5.6)	83 (7.2)	86 (7.5)	81 (6.8)
$\bar{X}$	70 (9.7)	81 (8.5)	74 (8.1)	75 (8.7)

[a]Defined as the percentage derived by dividing the number of times the infant looked at a stimulus for the .5 seconds prior to and .5 seconds during a manual contact by the total number of touches exceeding 15 seconds in duration.

[b]Number in brackets are the mean number of contacts with either stimulus.

effects for this dependant measure and those that follow were investigated using an *a priori* multiple comparison method and a per comparison error rate. This procedure is admittedly liberal and was only utilized to clarify significant main effects and interactions. Subsequent analysis indicated that the significant age effect consists essentially of a significant difference between the coordination scores of the 6-month-old group (*M* = 66%) and those of the 9-month-olds (*M* = 79%) and 12-month-olds (*M* = 81%), $F(1, 27) = 7.4$, $p < .05$. This analysis implies that, between 6 months and 9 months, the reaching becomes more visually controlled, but after 9 months there is no further increase.

Table 2 also includes the mean number of times in each trial block that infants at each age touched either stimulus.

Visual Attention to the Stimuli

Visual attention to the stimuli appeared to vary as a function of whether or not babies were permitted manual contact with them. This is indicated in the data presented in Table 3. A 3(Age) x 3(Trial Block) x 2(Condition) analysis of variance with repeated measures was performed on the looking data (see Appendix 1C). There was a significant age effect, $F(2, 54) = 3.4$, $p < .05$. Also the trial block main effect was significant, $F(2, 54) = 10.1$, $p < .05$. The most interesting finding was a significant Trials x

Table 3

Seconds of Visual Attention by Infants With and Without Manual Contact on the First Two Trial Blocks

Age	Trial Block 1	2	3	$\bar{X}$
	With Manual Contact			
6 Months	33.4	32.8	31.1	32.4
9 Months	30.5	27.6	27.5	28.5
12 Months	30.4	27.1	26.6	28.0
$\bar{X}$	31.4	29.1	28.4	29.7
	Without Manual Contact			
6 Months	32.7	29.3	32.6	31.5
9 Months	31.4	27.5	31.9	30.2
12 Months	30.1	23.8	33.3	29.1
$\bar{X}$	31.4	26.8	32.6	30.3

Condition interaction $F(2, 18) = 8.8$, $p < .05$. The tests for other effects and interactions indicated nothing of significance.

Subsequent analyses of the significant main effects and the significant interaction were performed. The age effect consisted essentially of a linear decrease in visual attention over the three ages, $F(1, 54) = 11.6$, $p < .05$. The trial block main effect consisted of an overall reduction of visual interest from trial block one (M = 31.4 sec) to trial block two (M = 28.0 sec), $F(1, 108) = 19.1$, $p < .05$, and a subsequent resurgence of visual attention between trial block two and trial block three (M = 30.5 sec) $F(1, 108) = 10.4$, $p < .05$.

The Trial Block x Condition interaction was initially examined by comparing the mean looking times of infants in the two conditions in each of the three trial blocks. In the first trial block, visual interest in the stimuli was not significantly different whether or not infants were permitted manual contact with the stimuli, $F(1, 108) < 1$. On the second trial block, visual interest in the stimuli is lower for both groups but infants who were not permitted manual contact with the stimuli show significantly less interest (M = 26.8 sec) than infants who were permitted manual contact with the stimuli (M = 29.1 sec) $F(1, 108) = 4.2$, $p < .05$. On the final trial block, when infants in both conditions were allowed manual contact with the stimuli, infants who had never touched the stimuli show significantly more visual interest in them (M = 32.6 sec) than babies who had both looked at and manually contacted the stimuli (M = 28.4 sec) $F(1, 108) = 14.3$, $p < .05$. Two additional within group comparisons were conducted, revealing that the drop in visual attention between trial block two and trial block three for the infants in the visual/haptic familiarization group was not significant, $F(1, 108) < 1$, but that the increase in visual attention between the second and third trial block for the infants in the visual familiarization group was significant, $F(1, 108) = 26.0$, $p < .05$.

Differential Looking

The percent of looking at either stimulus in a trial block that was directed at the 3D object is presented in Table 4 as a function of age and condition. As indicated in Table 3, there is an overall preference to look at the 3D stimulus. A 3(Age) x 3(Trial Block) x 2(Condition) analysis of variance with repeated measures was performed on the differential looking scores. The Age x Trial Block x Condition interaction was significant $F(4, 18) = 2.70$, $p < .05$. All other tests for main effects and interactions were not significant (see Appendix 1D). The significant three-way interaction was uninterpretable and not investigated further.

Differential Manual Contact

Differential manual contact scores were analyzed in two

Table 4

Differential Looking[a] by Infants With and Without Manual Contact on the First Two Trial Blocks

Age	Trial Block 1	2	3	$\bar{X}$
	With Manual Contact			
6 Months	62	52	51	55
9 Months	56	51	62	56
12 Months	57	59	58	58
$\bar{X}$	58	54	57	56
	Without Manual Contact			
6 Months	50	54	60	55
9 Months	60	58	60	59
12 Months	63	50	58	57
$\bar{X}$	58	54	60	57

[a]Defined as the percentage derived by dividing the time spent looking at the 3D stimuli by the time spent looking at either stimulus.

ways. The differential manual contact scores for infants who were permitted to contact the objects on all trial blocks are presented in Table 5. These means indicate an overall increase in the proportion of time spent in manual contact with the 3D object. However, a 3(Age) x 3(Trial Block) analysis of variance with repeated measures indicated no significant main effects or interactions (see Appendix 1E)

The differential manual contact scores of all subjects on the last block are summarized in Table 6. The difference between these means is in the direction of a preference to manually contact the 3D object after visual/manual familiarization (*M* = 63.7 sec) but not after visual familiarization (*M* = 57.4 sec) Nonetheless, a 3(Age) x 2(Condition) analysis of variance did not reveal any significant main effect or interaction (see Appendix 1F).

Differential Reaching

Differential reaching scores consisted of the ratio of trials in which the 3D object was touched first, divided by the number of trials in a trial block in which any manual contact occurred. As there are only four trials in any trial block, there are only four opportunities to manually contact the 3D object first. The limited number of trials means that the differential reaching scores consist of a rather limited number of percentage scores. This could result in heterogeneity of variance among the cells. For this reason each infant's scores were transformed into arcsines.

Table 5

Differential Manual Contact[a] by Infants Who Manually

Contacted the Stimuli on All Trial Blocks

	Trial Blocks			
Age	1	2	3	$\bar{X}$
6 Months	51	52	56	53
9 Months	60	53	69	60
12 Months	61	71	66	66
$\bar{X}$	57	58	64	60

[a]Defined as the percentage derived by dividing the time spent manually contacting the 3D object by the time spent manually contacting either stimulus.

Table 6

Differential Manual Contact[a] in Trial Block Three by Infants With and Without Manual Contact on the First Two Trial Blocks

Age	With Manual Contact	Without Manual Contact	$\bar{X}$
6	56	58	57
9	69	55	62
12	66	60	63
$\bar{X}$	64	58	61

[a]Defined as the percentage derived by dividing the time spent manually contacting the 3D object by the time spent manually contacting either stimulus.

Differential reaching was then analyzed by the same two ways the differential manual contact scores were analysed. The nontransformed differential reaching scores of infants who could handle the stimuli on all trial blocks are presented in Table 7. A 3(Age) x 3(Trial Block) analysis of variance with repeated measures was performed on the arcsines of these scores. This analysis revealed a significant main effect for age, $F(2, 27) = 3.9$, $p < .05$. The trial block main effect and the Trial Block x Age interaction were not significant (see Appendix 1G). Subsequent analysis indicated that the arcsine transformed differential reaching scores of the 9 and 12-month-olds were significantly larger than the scores of the 6-month-olds $F(1, 27) = 7.9$, $p < .05$. There was no significant difference between the scores of the 9 month-olds and those of the 12 month-olds $F(1, 27) < 1$.

Differences in differential reaching by infants in the two familiarization conditions were also analyzed. The nontransformed differential reaching scores of all infants on the last trial block are presented in Table 8. A 3(Age) x 2(Condition) analysis of variance was performed on the arcsines of these scores. No significant main effect or interaction was revealed (see appendix 1H).

Table 7

Differential Reaching[a] by Infants Who Manually Contacted the Stimuli on All Trial Blocks

	Trial Blocks			
Age	1	2	3	$\bar{X}$
6 Months	41	42	39	41
9 Months	64	48	68	60
12 Months	63	59	64	62
$\bar{X}$	56	50	57	54

[a]Defined as the percentage derived by dividing the number of times the 3D object was touched first in a trial by the number of trials in a trial block in which reaching occured.

Table 8

Differential Reaching[a] in Trial Block Three by Infants With or Without Manual Contact on the First Two Trial Blocks

Age	With Haptic Contact	Without Haptic Contact	$\bar{X}$
6 Months	39	53	46
9 Months	60	51	55
12 Months	64	60	62
$\bar{X}$	54	54	54

[a]Defined as the percentage derived by dividing the number of times the 3D object was touched first in a trial by the number of trials in a trial block in which reaching occured.

IV. Discussion

The results of this experiment point to an increase in coordinated hand-eye functioning with age. Handling prolonged the visual interest of infants at all ages and all infants who had only looked at the objects showed a resurgence of visual interest when permitted to handle them for the first time. Neither type of familiarization led to significantly increased differential looking, differential reaching, or differential handling, but the older infants in the visual-haptic familiarization condition tended to reach for the 3D objects first more than the younger infants. These results are relevant to the general issues of how looking and touching are related in the second six months of life and the degree to which infants in this age range can process haptic information. Also these results permit some speculation as to how coordinated visual and manual inspection contribute to cross-modal knowledge of objects.

It is clear from the results that, at 6 months of age infants engage in relatively coordinated visual and manual inspection of objects (i.e., even at 6 months, 60% of manual contacts were coordinated) and that this bimodal inspection becomes even more coordinated. Specifically, the a priori tests indicated that visual-manual coordination scores increased significantly between 6 months and 9 months. It is thus reasonable to conclude that either infants are beginning to reach more for objects they are looking at or that they are inhibiting random arm motions which were causing many contacts to nonfixated objects. The fact that the number of discrete contacts made by 9-month-olds is only slightly less than the number of contacts made by 6-month-olds suggests that infants are truly coming to coordinate touching with looking. While visual-manual concordance scores did increase somewhat over age, especially between 9 and 12 months, this increase was not statistically significant. It is interesting, however, that while concordance did not increase significantly between 9 and 12 months, 12 month-olds made fewer contacts but contacts of longer duration. The finding suggests that the nature of manual inspection may change between 9 and 12 months. Specifically, older infants may spend longer periods touching a particuliar object because they are more interested in exploring the physical features of the object and less concerned with establishing the solidity and location of the object. In any case, there is some evidence that infants become more coordinated in their looking and touching after 6 months of age. It is also evident that the analysis of simultaneous looking and touching records is a promising method of investigating the development of hand-eye functioning.

The results of this experiment are also relevant to the issues of when infants are able to haptically process information and how knowledge gained in this modality influences subsequent reaching. When the pattern of results is considered, the fact that handling the stimuli prolonged even the 6-month-old's visual interest in the objects is evidence that these infants were processing haptic information. An alternative explanation is that manual contact interferred with visual processing and thus delayed familiarization with the handled object. However, this explanation is less attractive in light of the finding that infants in the looking only condition showed a significant renewal of visual interest in the objects when permitted to handle them for the first time. Infants who had handled the objects previously did not show a renewal of visual interest during the third trial block. In fact, these infants showed a further loss of visual interest. I suggest that haptic information must be processed by these infants given that both visual and haptic familiarity with the orjects is necessary for attenuation of interest in the stimuli to occur. The reader is once again reminded that liberal comparison methods were used to investigate the above interaction.

In the case of the infants in the visual familiarization condition, two alternative explanations exist for the recovery of their visual interest on the third trial block. One possibility is that the recovery of visual interest is simply due to dishabituation of visual responding. Dishabituation is the recovery of a habituated response due to a change in the stumulus or the introduction of another (usually strong) stimulus (Thompson & Spencer, 1966). In this instance, the removal of the clear plastic at the end of the second trial block might have constituted both a change in the visual array (i.e., a reduction in glare), and the introduction of an additional stimulus (the experimentor's hand, the plastic rattling). This alternative explanation is not compelling, however, as it seems unlikely that the removal of the clear plastic would precipitate dishabituation. The change in the visual array would be slight under conditions of diffuse room lighting. In fact, during the visual familiarization condition, many infants often attempted to reach through the plastic barrier, as if they could not see it was there. Also, the removal of the plastic was a relatively inconspicuous event, since between all 12 trials the curtain was lowered and raised, and between most of the trials the sounds of the stimuli being switched could be heard.

The dishabituation explanation also fails to account for the infant's subsequent highly concordant and coordinated manual contact with the stimuli. This integrated behaviour suggests a second alternative explanation for the recovery of visual interest during the third trial block. It is possible that the introduction of the hands into the visual array caused the resurgence of visual interest. In other words, the hands may have been visually interesting even if the infant was not processing haptic information. This explanation must also be disputed, however, for the simple reason that during the first two trial blocks the infants in the visual familiarization condition had ample opportunity to watch their hands near the stimuli, yet during this time visual interest in the stimuli dropped dramatically. It was not until the infants were able to handle the actual objects that visual interest in the hands and the stimuli increased. The most plausible account for the increase in visual attention to the stimuli is the additional haptic feedback available to the infant on the third trial block. Therefore, it is concluded that the visual attention data, taken overall, supports the notion that infants as young as 6 months actively seek the opportunity to haptically encode the physical properties of objects.

The effect of handling on discriminative responding to 2D and 3D stimuli is less clear. The failure of infants to develop a preference to look at or handle a 3D object during either visual/haptic or visual familiarization can be explained in several ways. It is possible that infants do not use haptic information as the basis for differential touching or looking. This being the case, infants could learn the difference between 2D and 3D objects by handling them, but not show a preference to look at or touch either object.

It is also possible that aspects of the experimental method did not permit any preference to emerge clearly. For instance, the amount of reaching for and handling of objects varied considerably from infant to infant, and, even though a minimum of reaching was required for inclusion of a baby's data in the study, many of the babies who were included demonstrated relatively little reaching or handling. This meager experience with the stimuli may have been insufficient for the baby to develop a preference for either object. In this case responding would have been random, and given that the preference scores were percentages, it is possible for these infants to show a fortuitously high or low preference for the 3D object. While these extreme scores should not influence cell means in a biased way, they will tend to increase variance within cells. The possibility that high error variance may be an artifact of the scoring system is interesting in light of the fact that infants who had handled the 2D and 3D objects demonstrated greater differential touching of the 3D object in the third trial block than in the first. Also the 9 and 12 month-olds in this condition showed more differential touching of the 3D object in the third trial block than did the 9 and 12 month-olds who had only looked at the stimuli to that point. Nonsignificant trends such as the above are always difficult to defend but the possibility of inflated error variance is worthy of note in this instance.

Another possible explanation of the infants' failure to increase their differential looking, touching, or reaching, is that both stimuli were mounted on solid plaques so that even the 2D photograph had some of the properties of a solid object. With both stimuli, infants could grasp the plaques, rattle them at their bases, and explore their edges. Thus the 2D stimulus was only relatively less complex or manipulable than the 3D object. It is possible that a more distinct physical difference between the doll face and the photograph would have led to a more pronounced preference to handle the 3D object. Mounting both the photograph and doll on the same flat wall is suggested for future studies.

Differential reaching did significantly increase with age for infants in the visual/haptic familiarization condition. Given that infants did not show increased differential reaching to the 3D object over trials, it can only be concluded that older infants were more visually attracted to the 3D object at the onset of a trial.

Collectively, the results of this study partially support the notion that, in the second six months of life, infants engage in increasingly coordinated visual and manual inspection of objects. The results also suggest that, during this inspection, some aspects of the objects are being encoded haptically. This means that, while looking at and handling an object, the infant is receiving both visual and haptic information about the object and can compare these two inputs with one another. Prolonged experience of this kind may lead to a simple association between features of the object as they are perceived in the two modalities. In this way the infant, through coordinated looking and handling, may come to possess a rudimentary cross-modal knowledge of objects of the kind demonstrated by 12 month-olds (Bryant et al., 1972; Gottfried et al., 1977).

More research is necessary to substantiate this possibility. For instance, future research must investigate more carefully the influence of haptic knowledge on discriminative responding. In this way we can determine the specific dimensions of objects (i.e., shape, size, or texture) encoded haptically. Also, further investigations must more directly demonstrate a relationship between coordinated visual and manual inspection and cross-modal knowledge of objects. While the present study has left many questions unanswered, the results have suggested useful directions future research should take and offered several original methodologies which might be employed in these pursuits.

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APPENDIX 1. SUMMARIES OF THE ANALYSES OF VARIANCE

Appendix 1A

Summary of the Analysis of Variance on Concordance Scores of Infants With Manual Contact on All Trial-Blocks

Source	Degrees of Freedom	Mean Square	F
Age	2	1205.01	1.61
Trials	2	282.81	.90
Error	27	750.34	
Age x Trials	4	308.61	.98
Error	54	315.07	

Appendix 1B

Summary of the Analysis of Variance on Coordination Scores of Infants With Manual Contact on All Trial Blocks

Source	Degrees of Freedom	Mean Square	*F*
Age	2	1985.70	3.75*
Trials	2	938.10	2.13
Error	27	531.24	
Age x Trials	4	444.33	1.01
Error	54	439.60	

Appendix 1C

Summary of the Analysis of Variance for the Visual Fixation Scores of Infants With and Without Manual Contact on the First Two Trial Blocks

Source	Degrees of Freedom	Mean Squares	F
Age	2	192.07	3.40*
Conditions	1	16.74	.30
Trials	2	189.49	10.12*
Age x Conditions	2	27.79	.49
Age x Trials	4	19.38	1.03
Conditions x Trials	2	164.75	8.80*
Error	54	56.53	
Age x Conditions x Trials	4	13.31	.71
Error	108	18.73	

*$p < .05$

Appendix 1D

Summary of the Analysis of Variance for the Differential Looking Scores of Infants With and Without Manual Contact on the First Two Trial Blocks

Source	Degrees of Freedom	Mean Square	F
Age	2	124.37	.37
Condition	1	16.81	.05
Trials	2	311.93	1.84
Age x Condition	2	66.17	.20
Age x Trials	4	38.97	.23
Condition x Trials	2	45.83	.27
Error	54	334.35	
Age x Condition x Trials	4	457.56	2.70*
Error	108	169.56	

*$p < .05$

Appendix 1E

Summary of the Analysis of Variance for the Differential Manual Contact Scores of Infants With Manual Contact on All Trial Blocks

Source	Degrees of Freedom	Mean Square	F
Age	2	1257.70	1.65
Trials	2	357.50	.63
Error	27	762.35	
Age X Trials	4	322.00	.56
Error	54	571.95	

Appendix F

Summary of the Analysis of Variance for the Differential Manual Contact Scores of All Infants on the Last Trial Block

Source	Degrees of Freedom	Mean Square	F
Age	2	221.32	.34
Condition	1	576.60	.89
Age x Condition	2	293.55	.46
Error	54	644.89	

Appendix 1G

Summary of the Analysis of Variance for the Arcsine Transformed, Differential Reaching Scores of Infants With Manual Contact on All Trial Blocks

Source	Degrees of Freedom	Mean Square	F
Age	2	3.75	3.90*
Trials	[illegible]	.52	.86
Error	27	.96	
Age x Trials	4	.24	.40
Error	54	.59	

Appendix 1H

Summary of the Analysis of Variance for the Arcsine Transformed,

Differential Reaching Scores of All Infants on the Last Trial Block

Source	Degrees of Freedom	Mean Square	*F*
Age	2	.79	1.42
Condition	1	.86	.15
Age x Condition	2	1.32	2.38
Error	54	.56	