Task Constraints and Infant Grip Configurations

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The prehensile grip configurations of infants aged 4 through 8 months were examined as they grasped objects that varied in size and shape. The findings revealed that infants as young as 4 months systematically differentiate grip configurations as a function of the object properties in essentially the same way that 8-month-old infants do. However, the younger 4-month-old infants predominantly used the haptic system in addition to the visual system for information pick-up regarding object properties, whereas 8-month-old infants predominantly used information from the visual system alone to differentiate grip configurations according to the object properties. Infants apparently perceive the same action-relevant information through different emphases of the sensory modes to drive the action system with a similar grip configuration for a given object. It is proposed that the traditional description of an orderly sequence to the development of infant prehension (e.g., Halverson, 1931) is too conservative and inflexible to capture the functionally adaptive prehensile behavior of infants to changing task constraints.

The hand is one of the major organs of the body through which exploratory and instrumental activity is effected. Indeed, the special adaptive qualities of prehensile activity are often regarded as unique reflections of man's intelligence in that they embody the essence of the link between knowing and doing. Our understanding of the development of prehension in infancy rests largely on the work of Halverson (1931, 1932, 1937) who reported an orderly and regular sequence to the onset of distinct infant grip configurations, in much the same way that relatively invariant developmental sequences have been reported for the other major phylogenetic activity categories of posture and locomotion (e.g., Shirley, 1931).

The normative developmental progression for infant prehension extends from a primitive grasp reflex to a voluntary type of prehension and from a circle clawing

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type of hand closure to a precise index finger–thumb opposition (Gesell, 1928; Halverson, 1931; Hooker, 1938; Twitchell, 1970). Halverson (1931) noted that a primitive power grip squeeze of an object was available at 20 weeks of age, with further differentiation allowing a superior-palm grasp at 32 weeks of age, and finally a superior-forefinger precursor type grasp at 52 weeks of age. This orderly sequence to the development of grip configurations is still the prevailing account of the development of prehension in infants. Furthermore, the idea that there is a progressive sequence to the development of grip configurations has been extended through the age range of early childhood by Connolly and Elliott (1972), based on their characterization of grip configurations during this age period.

Traditionally, this relatively invariant order to the age-related changes in grip configuration has been viewed as a reflection of the tenets of maturation theory (Gesell, 1928, 1946). More recent studies have attributed this step-like sequence in grasping to the increased cognitive capacity of the child and the acquisition of an increasing number of motor programs for prehensile activity (Connolly & Elliott, 1972). Both the maturational and cognitive accounts of the development of prehension assume that the onset of new grip configurations is due to the availability of an increasing range of prescriptions for action, although the interpretations differ as to how these prescriptions for grasping emerge. These prescriptive views of the development of coordination fall prey to several lines of criticism but particularly germane is the difficulty of handling the emergence of new movement forms as a function of, for example, changes in the constraints to action (see arguments in Kugler, Kelso, & Turvey, 1980, 1982; Newell, 1986; Newell & van Emmerik, 1987).

Infant (like early childhood) prehension studies published to date have been limited to a very narrow range of task constraints (Newell, 1984a, b; Newell & Scully, 1989). Task constraints may be viewed as including the goal of the task, rules that specify or constrain the response dynamics, and objects that specify or constrain the response dynamics (Newell, 1986). The object properties of size, shape, mass, texture, etc., are examples of task constraints.

The classic infant grip configuration findings of Halverson (1931) rest primarily on the use of a 1-in. (2.54-cm) cube to assess age-related trends in grip configuration. It is reasonable to suppose that had Halverson used a different set of object properties, a different set of grip configurations would have emerged. The impact of task constraints on the development of prehension has not been studied systematically in spite of the early recognition (but not manipulation) of their role by McGraw (1943), Napier (1962), and Shirley (1931).

However, in a recent paper, Newell, Scully, Tenenbaum, and Hardiman (1989) showed that when the object size is scaled to hand size for a given set of task constraints, there are grasping patterns and limb orientations common to preschooler and adult prehensile activity. These findings reveal a strong role for the impact of body scale on the development of coordination and provide preliminary evidence that the development of prehension is driven significantly by the interaction of the constraints imposed on action (Newell, 1986; Newell & Scully, 1989). In this study, a common set of five grip configurations accounted for the majority of grip variance in both age groups. This finding suggests that there are only a few optimal boundary points that reflect preferred regions of stability for modes of coordination within a given set of constraints in grasping actions (Kugler, 1986; Kugler & Turvey, 1987; Kugler et al., 1980, 1982).

In the experiment reported here, we examined whether infants differentiate grip configurations as a function of the object properties of shape and size. Most studies examining reaching or so-called prereaching movements have been limited to testing whether or not the infant grasps the object presented. For example, Bruner and Koslowski (1972) have reported that 3-month-old infants differentiate between an object that is graspable and an object that is too large to grasp by not attempting to grasp an object in the latter category. There have been no studies reported of infant grip differentiations as a function of task constraints, although Bower (1972) and von Hofsten and Ronnqvist (1988) have shown that the range of motion and timing, respectively, of the closure of the infant's hand varies as a function of object size.

An issue related to the grip differentiation is the way in which the infant explores the object and picks up object-relevant information for subsequent differentiated action. Haptic exploration is generally presumed to precede visual exploration in the infant (see Gibson & Spelke, 1983, for a review). In relation to this description of the changing priorities of sensory modes for information pick-up in the developing infant, we determined whether the hand was shaped prior to object contact through information from the visual system or only after object pick-up through input from the haptic system. Haptic-visual asymmetry in the control of reaching has been shown previously with respect to the orientation in space of the object to be grasped (von Hofsten & Fazel-Zandy, 1984; Lockman, Ashmead, & Bushnell, 1984).

In summary, we examined the grip configuration of infants (4–8 months old) as a function of the object properties of size and shape. We anticipated: (a) systematic grip differentiation in infants as a function of changes in object size and shape; and (b) differential use of the haptic and visual systems for information pick-up as a function of age. We reasoned that the demonstration of differentiated grip configurations would suggest that task constraints play an important role in determining the development of prehension (Newell 1984a, 1984b, 1986; Newell et al., 1989), and more generally, that the motor development sequence identified by Halverson and others is a reflection of the narrow range of constraints tested rather than a rigid consequence of biological or cognitive prescriptions for action.

Method

Subjects

The subjects were 107 infants between the ages of 119 and 289 days. Five subjects were not tested due to excessive fussiness. The participating subjects were divided into five age groups that were approximately 1 month apart, and the age mean (standard deviation) in days of the increasing age groups was, respectively, 136 (8.6); 161 (8.5); 204 (7.1); 224 (8.7); and 264 (14.7). These groups were subsequently labeled as the 4, 5, 6, 7, and 8 month groups, respectively. There were 21, 22, 21, 22, and 16 subjects in each respective age group.

Apparatus and Procedures

The infants were tested individually in a soundproof testing room at the university. Measures of hand length and width were recorded using standard anthropometric procedures (Snyder et al., 1977). The measures were taken to the nearest .5 cm. The means (standard deviations) for hand length were 7.0 (.51), 7.0 (.53), 7.5 (.55), 7.5 (.57) and 8.0 (.78) for the increasing age groups, respectively. For hand width, the means (standard deviations) were 5.0 (.72), 5.0 (.38), 5.0 (.49), 5.0 (.65) and 5.0 (.32) for the increasing age groups, respectively. Thus there were no strong differences in hand width among the infant groups, but there was a 1-cm average gain in hand length over the approximately 5-month age span of the subjects.

The infants sat on the lap of a first experimenter who was sitting on a hard backed chair of normal table height. Each infant was positioned with his or her back to the first experimenter to form a common saggital plane of motion. The first experimenter provided postural support for the infant without impeding arm and hand movements. The grasping routine was videotaped by a camera camouflaged behind a black cloth curtain placed directly in front of the infant. This arrangement allowed full view of the infant, the object presentation, and the infant's grip configuration.

The object for each trial was presented by a second experimenter who stood to the right and slightly to the back of the seated infant. The object was placed in the middle of the open and flat hand of the second experimenter and moved to the midline of the infant, at a comfortable reaching distance in front of the infant's torso. If the presentation of the object did not draw the infant's attention, the second experimenter would move the hand with the object into the infant's field of view and return the hand to the common starting position. A 10-sec presentation period was allowed for the infant to make contact with the object. On most trials, the object was readily grasped by the infant and then used as part of some activity. After the grasp was complete and before the play activity became too involved, the second experimenter took the object away from the infant. There was about a 10-sec intertrial interval.

Four objects were used in the experiment. One object was a 2.54-cm (1-in.) wooden cube identical to that used in the Halverson (1931) experiment. In addition, there were three lightweight toy cups (diameters 1.25, 2.50, and 8.50 cm). The cups were presented both in an "open" mode with the cup opening face up and in a "closed" mode with the cup opening face down and in contact with the experimenter's hand. Thus, there were seven combinations of object shape and size in each round of object presentation. Subjects completed three rounds of testing with the seven objects presented in random order within a round of grasping.

The videotaping of the prehension trials was coded by one assistant on a number of hand dimensions following the procedures of Newell et al. (1989). These dimensions included: grasp/touch/no touch; hand(s) used (right, left, both) in grasping; number and type of fingers along with thumb in contact with object during a grasp; and whether hand(s) shaping appeared prior to or only after object contact. This categorization system allowed us to qualitatively characterize a grip configuration for a given set of task constraints.

A grasp was defined as the hand(s) fixing the object relative to the hand(s) and displacing the object from its initial place of presentation on the second experimenter's hand. A touch was defined as the hand(s) making contact with the object but without fulfilling the additional criteria listed above for a grasp. No touch was defined as no contact being made with the object during the 10-sec presentation period for the object. The definition of the hand(s) used to form the grasp was based on which hand(s) were used to meet the grasp criteria described above. The digits used by the hand(s) in the grasp were determined by their contact with the object during a grasp.

Visual control was associated with a change in hand shape appropriate to the object shape and size during the approach trajectory to the object so that the grasp of the object and the subsequent displacement limb motion occurred without hesitation in a deliberate and controlled manner. Visual plus haptic control was associated with approach trajectories in which the hand appeared not to be shaped in any particular manner but rather just "flopped" onto the object and then was moulded to grasp as a consequence of haptic exploration. Visual plus haptic control was also inferred for large objects if first only one hand moved and only after contact with the object did the other hand move to grasp the object.

A second assistant coded data from 20 randomly drawn subjects to provide an index of inter-rater reliability of the data coding. On the grasp/touch/no touch dimension there was 97% agreement between raters, there was 90% agreement on the number of fingers used, 97% agreement on the number of hands used and 97% agreement on the vision/vision-plus-touch criterion for grip configuration. Thus, the assessments of grip configuration for a given set of task constraints appear reliable.

Results

Grip Differentiation

The percentage of trials per age group employing each grip dimension was calculated for each of the objects presented. The percentage data thus reflect a group mean total over the three rounds of object presentation. Inferential statistics were not employed because the number of data points per subject per condition was small (3) and the group frequency trends were very robust. This data presentation technique is similar to that used by Gesell with limited individual subject data per condition (see also Newell et al., 1989).

The *first* analysis focused on whether the infants actually grasped the objects. The data were coded for the frequency of the general grip properties of grasp, touch, and no touch as a function of object shape and size (see Figure 1). The overall percentage of trials on which the objects were grasped, touched, and not touched were 90.35, 4.61, and 5.04, respectively. Only in the 4-month age group was there a substantial number of objects not grasped, but even here about 71% of the objects were grasped. The proportion of grasp, touch, and no touch trials per age group did not change with the object conditions in the 5- through 8-month age groups; there was a trend for the small cup to be grasped less by the 4-month age group.

In the *second* analysis the trials on which the object was grasped were coded

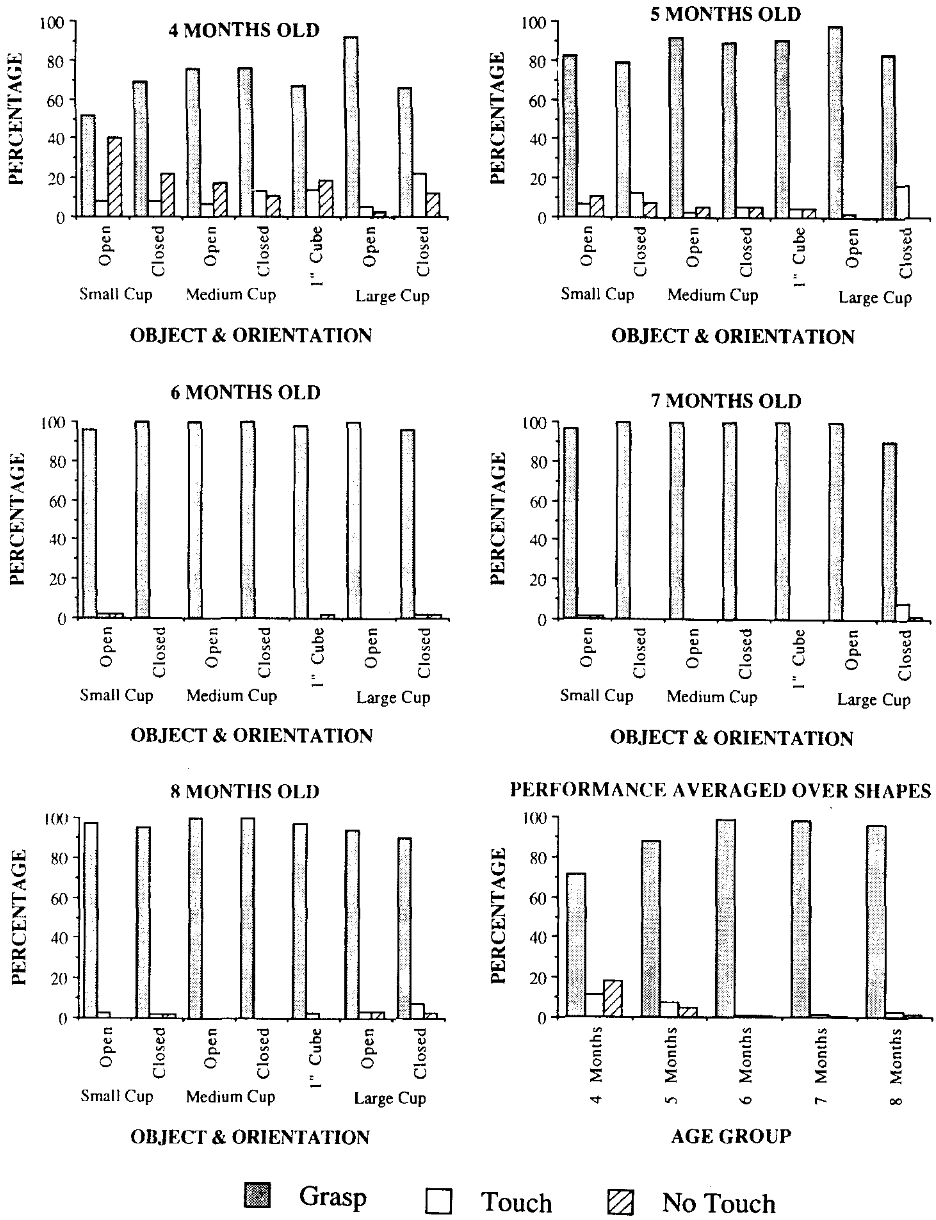

Fig. 1. Percentage of grasp, touch, and no touch trials as a function of age and object properties.

for the frequency of one- versus two-hand use as a function of object properties (see Figure 2). One hand only was used on over 95% of the smaller objects (1.25 and 2.50 cups, irrespective of shape configuration, and 1-in. cube). However, on the large cup, one hand was predominantly used when the cup was in the open mode and two hands were predominantly used when the cup was in the closed mode. Thus, the infants differentiated one- and two-hand prehensile activity as a

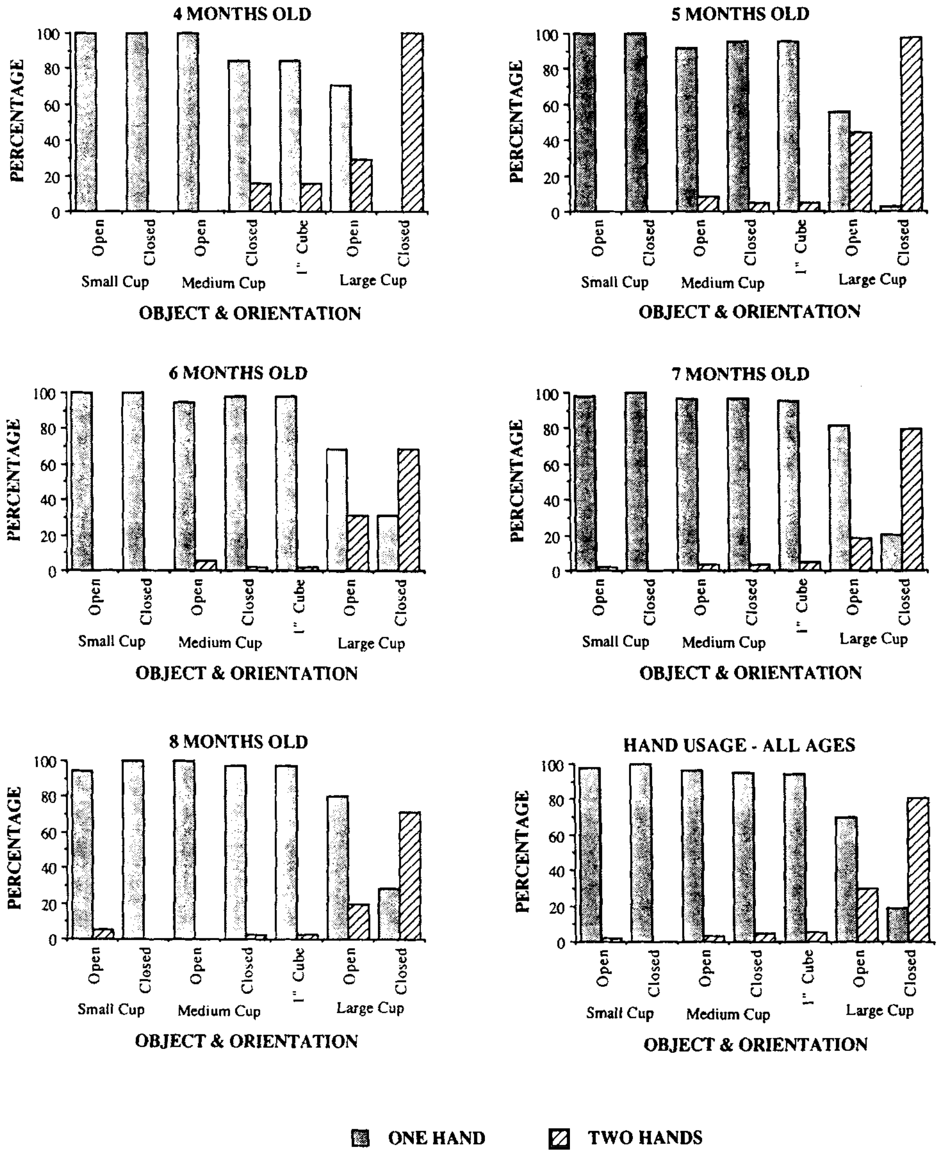

Fig. 2. Percentage of one- and two-hand usage in objects grasped as a function of age and object properties.

function of the object properties of size and shape. Figure 2 shows that this differentiation of grip configuration was evident in all age groups.

Within the one-hand grips, there was no bias toward hand dominance across the age groups. Thus, about 50% of the one-hand grasps were performed with the right hand and 50% with the left hand, in spite of the fact that object presentation was always initiated from the right side of the seated infant. Current evidence suggests that infant hand preference may well be task specific (Young, Segalowitz, Misek, Alp, & Boulet, 1983). It is unlikely that the infants had a common goal on all trials in the grasping experiment, although transporting the object to the mouth appeared to be the predominant action.

The *third* analysis examined the grip differentiation as a function of object properties with respect to the number of digits (thumbs and fingers) used to grasp each object (see Figure 3). The data reveal that the preferred number of digits used to grasp the object increased as a function of object size but that this trend was also influenced by the object shape at the large cup size. With the "open" and "closed" small cup, the predominant digit frequency was 3, while with the "open" and "closed" medium cup and the cube the predominant digit frequency was 4. Five digits were predominantly used with the "open" large cup whereas, there was a biomodal 5- but predominantly 10-digit preference with the "closed" large cup. These data on finger usage are consistent with those on hand usage, but they also show that infants as young as 4 months exhibit differentiation of digit usage as a function of object properties. Indeed, infants in all the age groups demonstrated a similar digit profile as a function of object size and shape properties, although the 4-month-old infants were more variable in finger grip configurations than the older infants.

The *fourth* analysis coded the grip configuration for the exact digit combination used. Five grip configurations accounted for most of the digit combinations used. These five grips were: "thumb and index finger of same hand; thumb, index finger, and middle finger of same hand; thumb, index finger, middle finger, and ring finger of same hand; all five digits of one hand; and all ten digits of the two hands. The percentage of these predominant grip configurations as a function of age and object properties is displayed in Figure 4. Within the objects grasped, these five grips accounted for 95.4%, 96.3%, 96.0%, 96.5% and 90.4% of the grips used in the 4- through 8-month age groups, respectively. Thus, even though there are 1023 possible combinations of digits that could be used for grasping, the infants primarily used 5 grips in a systematic way according to the size and shape of the object. As Figure 4 reveals, there were even examples of infants of all ages using a precision thumb–index finger configuration on the small "open" cup condition. This finding reveals once again how strongly infant grip configurations are driven by task constraints.

Overall, the data on hand and digit usage suggest that there is essentially no age difference among 4- to 8-month-old infants in the grip configuration used to grasp the objects. Differentiation of grip configuration as a function of object properties was common across all the age groups tested, although the 4-month-old group was somewhat more variable in using the five primary grip configurations. There were, however, clear and consistent age differences in the way in which the younger and older infants picked up the object-relevant information.

Visual and Haptic Control

To examine whether information from the haptic system was used to supplement that from the visual system in differentiating grip configurations, a *final* analysis coded the act of prehension for whether the infant shaped the hand(s) prior to, or only after, object contact. Figure 5 shows the frequency of grasps that

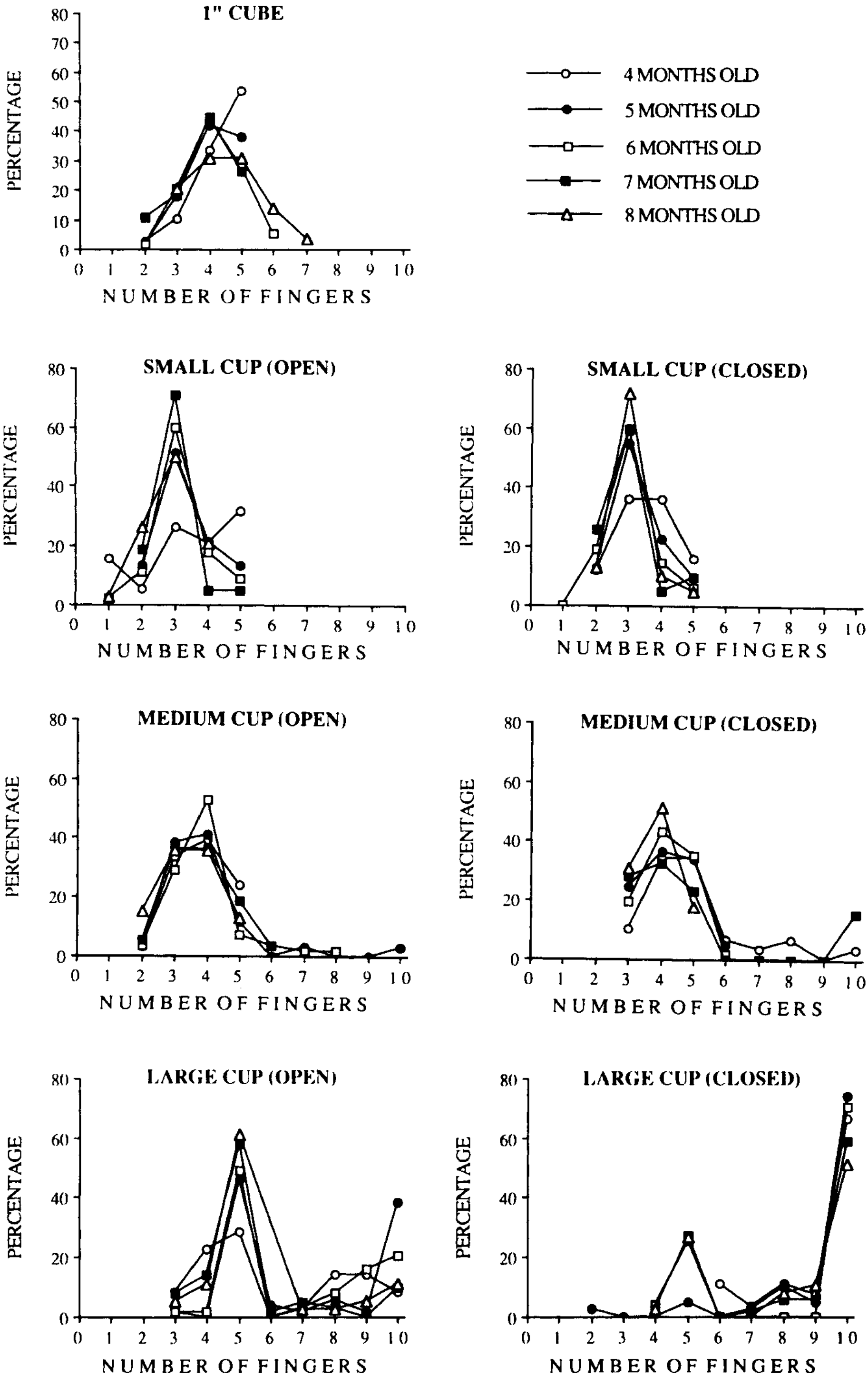

Fig. 3. Percentage of digit use in objects grasped as a function of age and object properties.

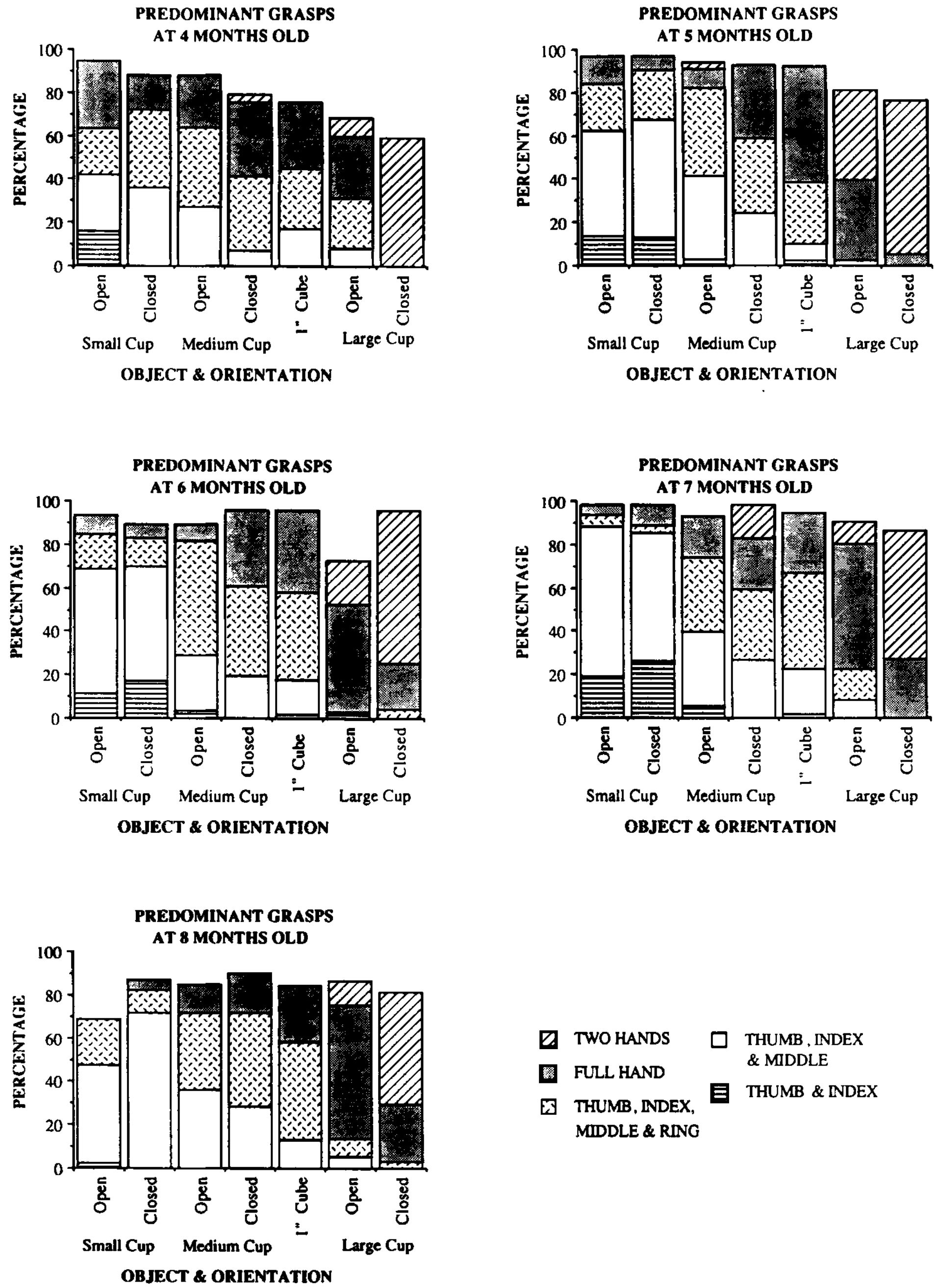

Fig. 4. Percentage of the 5 predominant grip configurations as a function of age and object properties (T = thumb, I = index finger, M = middle finger, and R = ring finger).

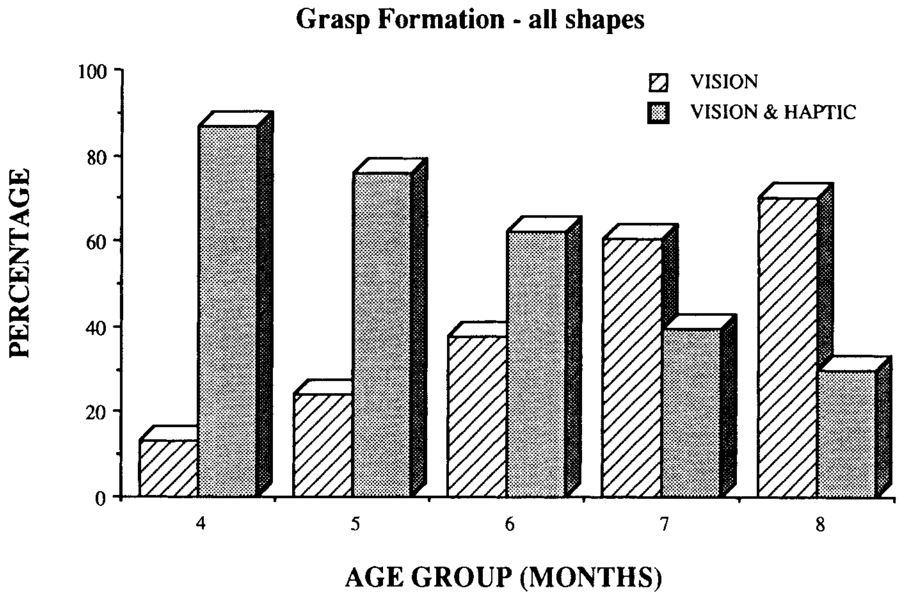

Fig. 5. Percentage of grip differentiation as a function of age and sensory mode for information pick-up (vision/vision + haptic).

were shaped by vision or vision plus touch as a function of age. The graph shows that the 4-month-old age group predominantly required the addition of information from the haptic system to determine the grip configuration, whereas with increasing age, there was a gain in the anticipatory role of vision in shaping the hand prior to object contact. Indeed, by 8 months of age, the infants predominantly used information from the visual system to differentiate the appropriate grip configuration prior to contact with the object. Thus, infants from 4 to 8 months old apparently perceive the same information through different emphases of the vision and haptic sensory modes to drive the action system with a similar grip configuration for a given set of object properties.

Discussion

The findings of this experiment revealed that infants as young as 4 months differentiate grip configurations as a function of the object properties of shape and size. In fact, there was remarkable similarity in the grip configuration used by each of the 4- to 8-month age groups for each object presented. The main age-related differential finding was that the younger 4-month-old infants required the addition of the haptic system for information pick-up, whereas the 8-month-old infants principally used information from the visual system to differentiate grip configurations according to the object properties.

The demonstration of the differentiation of grip configurations in infant prehension is consistent with the proposal previously advanced (Newell, 1984b, 1986; Newell & Scully, 1989; Newell et al., 1989), that traditional descriptions of the development of infant prehension are task limited. The functionally adaptive infant grip configurations shown in this study suggest very strongly that the previously established rigid orderly sequence for infant prehension (Halverson, 1931, 1932, 1937) is due to the narrow set of task constraints imposed, particularly the predominant use of a 1-in. cube for object shape and size. Clearly, maturational organismic constraints provide boundaries to infant prehension, but it appears that the traditional estimates of the so-called milestones of the development of coordination are too conservative and inflexible. This is not to say that manipulation of task constraints could induce a precision grip prior to the emergence of a power grip, and thus reverse the ontogenetic trend described by Napier (1956, 1962); neurological development may still provide the key boundary constraint (e.g., Lawrence & Hopkins, 1972, 1976; Lawrence & Kuypers, 1968a, b). However, even this traditionally held power-precision distinction of the ontogenetic development of infant grip formation could certainly be examined more rigorously through a broader manipulation of task constraints.

The very high percentage of objects grasped as opposed to just touched or not touched in this study, in comparison to the findings of Halverson (1931), is probably due to the significant postural support provided the infant in the current study. This postural support, together with the presentation of the object in a more dynamic interactive environment (Ruff, 1982), provided a more appropriate set of task constraints to examine the developmental aspects of prehension than has often been available in previous infant prehension studies (see Newell & Scully, 1989). Another and perhaps more striking example of the impact of postural support and dynamic stimuli on infant reaching behavior is the precocious anticipatory reaching behavior of 1-week-old infants reported by von Hofsten (1982).

The experimental conditions used in this study did not provide for a full test of the body scaling principle in infant prehension in a vein similar to the study previously conducted with 3-year-old children and adults (Newell et al., 1989). However, the finding of a strong differentiation of grip configurations according to object properties and of relatively few grip categories per object suggests that infant actions may be scaled to a few optimal boundary points in the perceptual-motor workspace that reflect preferred regions of stability (Kugler, 1986; Kugler & Turvey, 1987). This finding is even more remarkable when one considers that there was not a uniform externally defined task goal for infants to achieve through grasping the object, although transporting the object to the mouth was a common activity. The demonstration of grip differentiation from a relatively limited range of object conditions suggests that a more broad-range examination of the body-scaling question in infant grip configurations would be useful. It is also of interest that the five predominant grip configurations used by infants are congruent with those used by 3-year-old and adults grasping objects with similar task constraints (Newell et al., 1989).

Differentiation in prehensile action implies perceptual differentiation of the object properties. It appears that infants from 4 to 8 months old pick up the same information for prehensile activity, but that they achieve this goal through the use of information gleaned from a different emphasis of input from the visual and haptic sensory channels. The younger 4-month-old infants predominantly used a combination of the haptic system and the visual system, with great emphasis on haptic information, to determine grip configurations, whereas by 8 months of age the visual system was predominantly used to determine the grip configuration.

This finding is consistent with the earlier report of Lockman et al. (1984) that a similar asymmetry guides the orientation of the hand to an object. Of course, picking up the relevant information from the visual system affords object-scaled hand shaping prior to contact with the object. As the infant ages, it appears that she increasingly takes advantage of this more anticipatory mode of action. Thus, there is a changing emphasis in the role of the sensory modes for information pick-up for prehensile activity in the aging infant, but remarkably, the movement output is commonly differentiated according to object properties.

Even though the 4-month-old infants did predominantly use information from the haptic system to supplement that from the visual system in differentiating the grip configurations, there were some examples of this age group shaping the hand prior to contact in a fashion consistent with that recently reported by von Hofsten and Ronnqvist (1988). Our findings suggest, however, that the predominant strategy of the 4-month infant grasp requires the use of information from the haptic system to help shape the hand appropriately to the task constraints provided by object properties. What action-relevant information the visual system provides for prehensile acts, such as grasping objects, is still poorly understood. It may well be that the continuing refinement of visual acuity in the 4- and 5-month infant (Dobson & Teller, 1978) contributes to the need for supplemental information from the haptic system to guide grip differentiation.

In summary, the findings of our study provide a challenge to both the traditionally held maturational view and the contemporary cognitive view of the sequential "dictionary-like" grip configurations of the development of prehension. The sudden emergence of new grip configurations as a consequence of changes in, for example, task constraints is very difficult to reconcile with a prescriptive account of the development of coordination (see Kugler et al., 1980, 1982; Newell, 1984b, 1986; Newell & van Emmerik, 1987). We believe our findings are more consistent with a dynamical view to the development of coordination (Kugler, 1986; Kugler et al., 1980, 1982; Thelen, Kelso, & Fogel, 1987) and the role that constraints may play in channeling the dynamics to produce new configurations of coordination at the behavioral level (Newell, 1984b, 1986).

Notes

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