Body Scale and Infant Grip Configurations

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This study examined whether hand/object size ratios define common boundaries to the grip configuration patterns of infants and adults. A group of 5- to 8-month-old infants and a group of adults engaged in a displacement grasping task with inverted cups that varied in size. The findings showed that infant and adult grip configurations varied systematically with object size: More digits were brought into the contact grip configurations with increasing object size. Furthermore, when object size was scaled to hand size, common dimensionless ratios defined the grasping patterns and transitions between grasping patterns in a similar manner for both adults and infants. Consistent with a dynamical view of the development of coordination, the strong role of body scale on the developmental prehensile coordination pattern was observed for a given set of task constraints.

Grasping is usually affected by the union of the hand(s) with an object in the realization of a particular task goal. The nature of the particular grip configuration utilized depends on the confluence of constraints that arise from the interaction of the organism, environment, and task (Newell, 1986). Consequently, given a particular set of task constraints and object properties, each individual will tend toward the utilization of a preferred grip configuration. This article addresses the form of these preferred grip patterns in infants and adults, and the congruence of grip forms across these two age groups when prehension is considered within a common and appropriate frame of reference.

In previous experimental work, we have shown that a major source of constraint that specifies grip configurations in humans as young as 3 years of age is

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Received for publication 18 August 1992
Revised for publication 14 December 1992
Accepted for publication 4 January 1993

Developmental Psychobiology 26(4):195–205 (1993)

CCC 0012-1630/93/040195-11

the ratio of the object size to hand size (Newell, Scully, Tenenbaum, & Hardiman, 1989). Furthermore, there is a particular set of critical ratios that specify the transitions of grip configurations over increments of object size. These findings suggest a strong role for body scale in determining prehensile grip configuration modes across the life span, although direct evidence of this proposition in infant prehension is not available.

Infant prehension has traditionally been characterized by an orderly and regular sequence that develops through the first year of life either as a reflection of the principles of maturation theory (Gesell, 1928; Halverson, 1931; Hooker, 1938) or the cognitive construct of motor programs (Connolly, 1973; Connolly & Elliott, 1972). This work on infant prehension has been limited by the narrow range of experimental conditions used that has led to an underestimation of the functional grip configurations that infants can and do use in prehension. For example, Newell, Scully, McDonald, and Baillargeon (1989) have shown that infants as young as 4 months differentiate object properties of size and shape as reflected in their systematic use of different grip configurations for different objects. In addition, Bower (1972), and von Hofsten and Ronnquist (1988) have shown that the range of motion and timing, respectively, of the closure of the infants' hands varies as a function of object size.

In this study, we examine directly the role of body scale in determining infant grip configurations. Our previous prehension experiment showed that infants differentiate grasping according to object size and shape (Newell, Scully, McDonald, & Baillargeon, 1989), but a direct test of the body scaling hypothesis could not be conducted due to the limited number of object conditions. In the experiment reported here, a range of object sizes within a given object geometry (inverted cup) was presented to infants. The data arising from this manipulation were then contrasted with data from adults grasping a similar relative range of sizes of the same shaped objects.

The motivation for pursuing the body scaling hypothesis arises from a recognition of the importance of determining an appropriate frame of reference for the analysis of action. Gibson (1979) recognized this problem while discussing the notion of affordances and proposed that environmental properties "have to be measured relative to the animal" (pp. 127–128). This method of determining an intrinsic frame of reference has been widely used in biology and has led to dimensionless relations of system variables known as *pi* numbers and *froude* numbers (Buckingham, 1914; Stahl, 1961, 1963). By using such procedures one can determine a unitless measurement of the relation between an animal and its environment. In the study of humans, a number of attempts have been made to account for behavioral transitions and preferred regions of behavior via scaling with certain anthropometric features. For example, dimensionless body-scaled ratios that correspond to shifts in gait patterns (Warren, 1984), sitting height (Mark, 1987), and the perception of passable apertures in walking (Warren & Whang, 1987) have previously been demonstrated. Furthermore, the onset of independent walking in infancy also appears to be related to the weight/height ratio and leg/trunk ratio (Norval, 1947; Shirley, 1931).

Given our previous work (Newell, Scully, McDonald, & Baillargeon, 1989; Newell, Scully, Tenenbaum, & Hardiman, 1989), it was projected that the body scaling principle would accommodate a significant portion of the variance determining the common ratios of object and body size that specified changes in infant and adult grip configurations as a function of object size. This would provide evidence that the metric specifying grip patterns can be determined from the dynamics arising from the organism–environment interaction and that the prehensile grip configurations of infants and adults alike are organized in a consistent and lawful manner.

The body/object scaling ratios that define the boundaries to grip configurations are critical points in the emerging dynamics of grasping. These ratios reflect boundary regions to stable modes of prehension for the changing object dimensions (Kugler, Kelso, & Turvey, 1982; Kugler, 1986; Newell, 1986; Newell, Scully, McDonald, & Baillargeon, 1989). While only object dimensions were varied in this investigation, the boundary ratios are also dependent upon other sources of constraint, including the goal of the action. Thus, although grip configurations may appear static to the observer, they can be characterized as part of a general dynamical action system. Hence, the demonstration of a consistent set of scaling ratios in both infant and adult prehension is evidence for a sensitivity to a similar set of dynamical states in the perceptual–motor workspace.

Method

Subjects

The subjects were 31 infants with an age range of 5 months, 14 days to 8 months, 14 days (*M* = 7 months, 2 days) and 31 adults ranging from 18–44 years (*M* = 28 years, 5 months). In the infant group there were 8 females and 23 males. In the adult group there were 21 females and 10 males. Data on some trials were lost due to the fussiness of 5 infants, but all the completed trials from these infants were included in the analysis.

Apparatus and Procedures

The infants and adults were tested individually in a soundproof testing room at the University of Illinois. Measures of hand lengths and widths (to the nearest mm) were recorded using standard anthropometric procedures (Snyder et al., 1977). Calipers were used to measure hand length (wrist crease to the tip of the middle finger parallel to the fingers with the hand extended) and hand width (across the knuckles of the four fingers with the hand extended). In the infants the mean (standard deviation) was 7.24 (.62) cm for hand length and 4.38 (.39) cm for hand width. In the adults the mean hand length was 17.75 (1.04) cm and the mean hand width 7.68 (.60) cm.

During the testing each infant was seated on the lap of an experimenter. This experimenter sat on a hard back chair of normal adult table height. The infant was positioned with his or her back to the experimenter to form a common sagittal plane of motion. The 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 a comfortable reaching distance in front of the infant's torso on the sagittal plane. If the presentation of the object did not draw the infant's attention, the second experimenter moved the hand with the object into the infant's field of view and returned the hand to the common starting position. A 10-s presentation period was allowed for the infant to make contact with the object. On the majority of 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-s intertrial interval.

The testing situation for the adults was similar to that of the infants. Each adult sat on a straight back chair of normal table height immediately in front of a table. The experimenter presented the objects individually to the subject on a tray. The tray was placed on the table with the object in the middle sagittal line of the adult at a comfortable reaching distance from the torso. The experimenter placed objects on the tray behind the subject's field of view so that the subject could not model the experimenter's grip configurations for a particular object. Again, a 10-s presentation period was allowed for the adult to make contact with the object. The adults were instructed to pick up the object as effectively and efficiently as they could to bring the object to the mouth (without making contact). This instructional strategy was used because the predominant activity employed by the infants was the bringing of the object to the mouth for haptic exploration. Thus, the attempt here was to match the intentional goal of the subjects across the two age groups and, to realize this goal, we constrained the adults with a direct instruction.

Seven objects were used for each age group in the experiment. The objects were plastic cups that were inverted for presentation so that the open part of the cup was face down on the experimenter's hand. The cups were brightly colored objects that were made of very light plastic material. For the infants, the diameter (height) of the lightweight toy cups in increasing size were 1.2 (1.9), 2.6 (2.8), 3.9 (3.6), 5.1 (4.5), 6.5 (5.4), 7.5 (6.0), and 9.0 (9.5) cm. For the adults, a different combination of seven plastic cups were used. The object sizes selected attempted to capture the very small sizes used by infants and, to accommodate a similar range of object/hand scaling ratios for infants and adults, the absolute size of the cups was increased to at least 3 times the size of the largest infant cup presented. The diameter (height) sizes of the adult cups used were 1.2 (1.9), 3.9 (3.6), 5.4 (6.3), 7.0 (8.1), 11.0 (10.5), 16.3 (12.6), and 20.6 (19.4) cm. The seven combinations of each object size were presented over three rounds of object presentation for each group. Thus, each subject completed 21 grasping actions. The order of presentation of the seven objects within each of the three rounds of grasping trials was randomly determined for each subject in each group.

The grip configurations used in the prehension trials were coded by one assistant on a number of hand dimensions following the procedures of Newell and colleagues (1989). These dimensions included: grasp/touch/no touch; hand(s) used (right, left, both) in grasping; and number and types of fingers along with the thumb in contact with the object during a grasp. The nature of the activity undertaken by the infants following the grasp was also coded. That is, the grasp was classified as to whether the object was brought to the mouth, halfway to the mouth or was not lifted from the hand at all. This categorization scheme allowed us to characterize qualitative properties of the grip configurations over the increasing object size manipulation.

As in our previous work (Newell, Scully, McDonald, & Baillargeon, 1989; Newell, Scully, Tenenbaum, & Hardiman, 1989), a grasp was defined as fixing the object relative to the hand(s) and displacing the object from its initial place of presentation. A touch was defined as the hand(s) making contact with the object but without fulfilling the additional criteria listed above for grasp. No touch was defined as no contact being made with the object during the 10-s presentation period for the object. The definition of the hands used to form the grasp was based on which hands were used to meet the grasp criteria described above. The digits used by the hands in the grasp were determined by their contact with the object during a grasp.

A second assistant coded data from 6 randomly drawn infants and 6 randomly drawn adults to provide an index of interrater reliability on about 20% of the data coding. On the grasp/touch/no touch dimension there was 98% and 100% agreement for the infant and adults respectively. There was 92% (infants) and 95% (adults) agreement on the number of fingers used, 97% (infants) and 100% (adults) agreement on the vision/vision-plus-touch dimension, and 99% (infants) and 100% (adults) agreement on the number of hands used.

Results

Grip Differentiation

The percentage of trials for both infants and adults on each grip dimension was calculated. The individual frequency data were grouped into age group total frequencies. As the number of data points per subject per condition was small (3) and the group frequency means were in the main robust, no inferential statistical analyses were conducted. This analysis strategy has been used in our previous work on children's prehension (Newell, Scully, McDonald, & Baillargeon, 1989; Newell, Scully, Tenenbaum, & Hardiman, 1989) and in Gesell's (1928) accounts of the motor development norms.

The trials were initially coded for no touch, touch (but no grasp), and grasp. For the infants, on 76% of the trials the objects were grasped, on 22% of the trials the objects were touched, and on 2% of the trials the objects were not touched. There was no systematic trend for object size to influence the percentage of trials grasped by the infants. All the objects presented were grasped by adults. Only the trials on which the objects were grasped were used in the following analyses.

Hands

Figure 1 shows the group total frequency of one-versus two-hand use as a function of both cup size (Fig. 1a) and the ratio of object to hand size (Fig. 1b). The mean hand length of each group was used to scale the objects to the

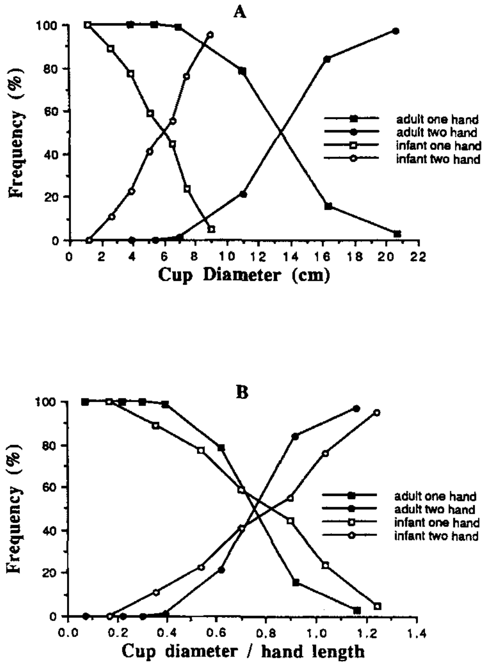

Fig. 1. Frequency of hand use (one vs. two hands) as a function of age group and object size (a) and age group and object/hand size (b).

dimensionless metric. In general, both groups show a systematic trend over increments of object size for the switch from one- to two-hand use. Furthermore, when the hand size is scaled to object size, there is a high degree of overlap in the function for total frequency (%) of one-versus two-hand use across both age groups. The 50% level for the switch from one to two hands occurred around the same object/hand dimensionless value (75–80%) for each age group.

Digits

Figure 2 plots the average number of digits used by each age group as a function of hand/object size. Again, scaling the object to hand size produces essentially a common regression line through which the average number of fingers effective in the grip configuration increases with object size. This average analysis masks the exact qualitative grip configuration used, but it demonstrates the power of the body scaling principle in determining grip configurations as a function of hand size in infants and adults.

The frequency plots for particular numbers of digits used as a function of age group and object/hand size ratio are shown in Figure 3. Figure 3a shows the frequency plots for 2- and 3-digit use, Figure 3b the frequency plots for 4- and 5-digit use, and Figure 3c the frequency plots for 9- and 10-digit use. The use of 6, 7, or 8 digits is not presented due to the infrequent occurrence of these configurations. In general, both groups show a systematic increase in the number of digits used to grasp the object as size of the object increased. The frequency trends for

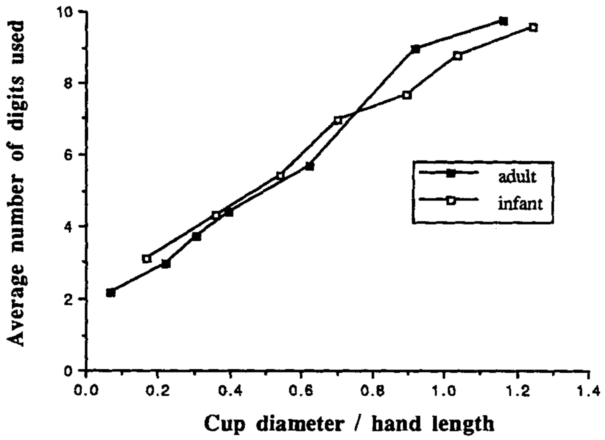

Fig. 2. Frequency of average number of digit use as a function of age group and object size (a) and age group and object/hand size (b).

digits show a similar function for each age group. The commonality of the age group frequency trends is stronger at the extreme object size manipulations, namely, those object sizes that lead to 2- and 10-digit use. This is consistent with the findings from our previous work contrasting 3 year olds with adults (Newell, Scully, McDonald, & Baillargeon, 1989) which showed that the commonality of critical points defining the grip configurations is greater at the more extreme object conditions.

It is revealing to examine the extact grip configurations used with the given number of digits. As in our previous work (Newell, Scully, McDonald, & Baillargeon, 1989; Newell, Scully, Tenenbaum, & Hardiman, 1989), subjects in both groups gravitated toward using only a small set of grip configurations. For the infant and adult groups respectively, 91% and 95% of the grip configurations were accounted by five grips which in ascending order of digits involved were: thumb and index finger; thumb, index finger, and middle finger; thumb, index finger, middle finger, and ring finger; all digits of one hand; all digits of both hands. Figure 4 shows the frequency of a given grip configuration as a function of age group and object size. Thus, five grip configurations accommodated a very high percentage of the variance which suggests that object size is a strong constraint on grip configurations.

Discussion

The findings of this experiment demonstrate the strong role of body scale in determining grip configurations over the life span to changes in object size. The data also confirm that infants as young as 5–6 months differentiate grip configurations according to object size (Newell, Scully, McDonald, & Baillargeon, 1989). It appears that there may be common dimensionless ratios for infants through adults that define the boundaries to stable grip configurations.

The data on infant grip configurations extend the finding from our earlier infant prehension study (Newell, Scully, McDonald, & Baillargeon, 1989) and the

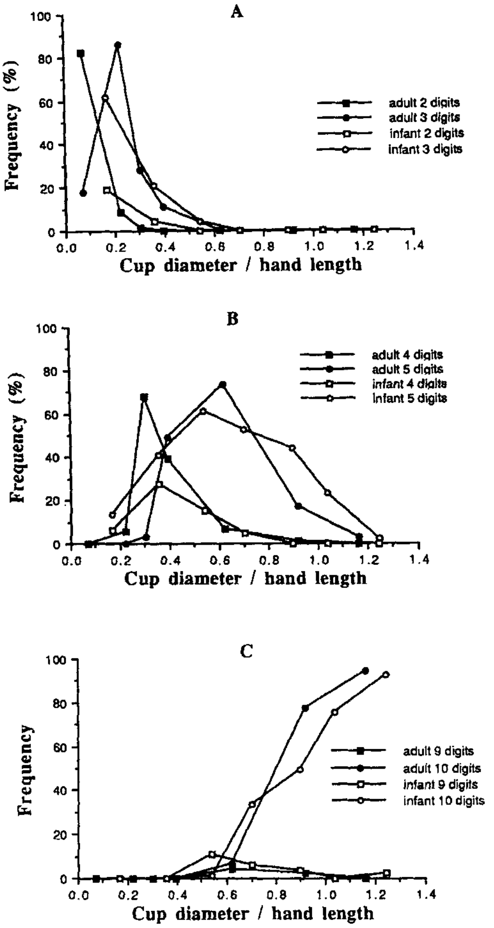

Fig. 3. Frequency of particular numbers of digits used as a function of age group and object/hand size ratio: (a) 2 and 3 digits; (b) 4 and 5 digits; (c) 9 and 10 digits.

examination of the influence of body scale on 3-year-old versus adult grasping (Newell, Scully, Tenenbaum, & Hardiman, 1989). Infants systematically introduced more digits into the contact grip configuration as object size increased. For both infants and adults, there was strong evidence of common dimensionless boundaries on the object/hand size scale specifying the transitions in grip configurations. There is some variance in the age group frequency between these boundaries that is due to at least three factors. First, not all infants bring the object to the mouth and, therefore, the task goal constraint probably was not entirely common within the infant age group. Second, the parameter of hand length only accounts for part, albeit a large part, of the scaling of the dynamics of hand to object. Third, body scaling was conducted on a group rather than an individual basis. Nevertheless, the findings overall are generally consistent with the notion that there are common relative boundary conditions across infants and adults to the grip dynamics. The findings also encourage the conduct of further experimentation that teases out some of the sources of grip variance in the current study so

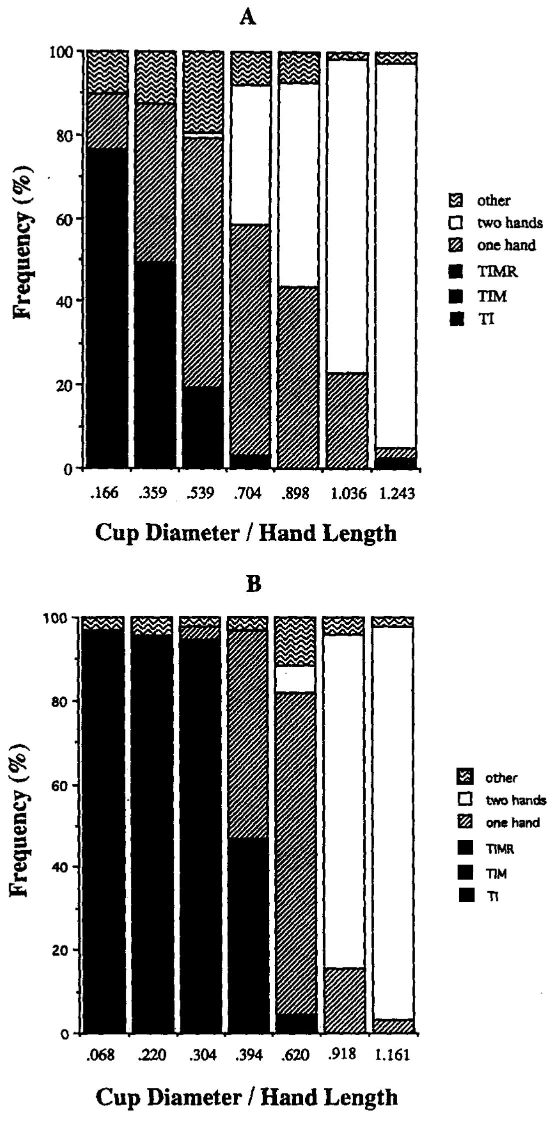

Fig. 4. Frequency of grip configuration as a function of age group and object/hand size: (a) infants; (b) adults. (T = thumb, I = index finger, M = middle finger, R = ring finger)

that more precise estimates of the critical points defining grip configurations may be determined.

Another index of the influence of body scale on grip configuration is the finding that there are very few preferred grip configurations used by infants or adults for a given object size. Thus, not only is the number of digits used influenced by object/hand size ratio, but more significantly, the exact digit combination used in the grip configuration. The finding that there are five preferred grips across the object sizes is consistent with our data contrasting 3-year-old children with adults (Newell, Scully, Tenenbaum, & Hardiman, 1989). All the objects, including the smallest, could have been picked up by several grip configurations, but both infants and adults gravitate to use a preferred grip configuration for a given object with a certain task constraint.

On the basis of these data, we conclude that infant prehensile behavior is consistent with the body-scaling hypothesis. Thus, the infants are able to coalesce action system capacity and the constraints of the task (available as perceptually accessible information) with their intentions for realizing the task goal. Together these sources of constraint give rise to a perceptual–motor workspace in which there are systematic boundaries for action. One instance of these boundaries emerges in the sensitivity to change in the grip configuration. In this sense, these data illustrate a similar degree of perceptual–motor sophistication as those presented by Gibson and colleagues (1987) who examined the detection of traversability of surfaces by crawling and walking infants.

What is the nature of the physical constraints that fashion the grip configurations in a displacement prehension task? This is not known at present, but clearly the size or geometry of the object cannot be considered sufficient indices on which to scale the object and hand dynamics. The mass of the object must also be a factor together perhaps with other object variables such as the object coefficient of friction, temperature of the object, and so on that relate to the opposition forces of the object and hand. It is projected that object length works well as a scalar with the objects used in the current experiment in part because their mass is relatively low and within the comfortable opposing force range for each grip configuration used by each age group. Clearly, more systematic work needs to be conducted on the dynamical invariants specifying infant through adult grip configurations, and the findings from this study encourage such an approach. If infant prehension were shown to be sensitive to these additional object variables, this would constitute evidence for a higher dimensional perceptual–motor workspace reflective of even greater perceptual–motor sophistication in the infant.

Finally, it should be recognized that the data provided here and elsewhere (Newell, Scully, McDonald, & Baillargeon, 1989; Newell, Scully, Tenenbaum, & Hardiman, 1989) are difficult for either a maturational or cognitive programming perspective to accommodate. The findings suggest that the order and regularity in infant grip configurations are due to the constraints imposed on action and the emerging dynamics of the organism and the environment in realizing task goals. Thus, the rigidity of the order and regularity in infant grip configurations as proposed in maturational (Halverson, 1931) or cognitive accounts (Connolly & Elliott, 1972) of prehension is as much, if not more, due to the particular constraints imposed by the experimenter on the infant than they are limitations of the infant per se. This is not to say that infants do not bring boundary conditions (constraints) to grasping or other activities, because clearly they do. Rather, the findings from this study are consistent with the idea that the extant infant prehension studies have not yet revealed the essential constraints to the development of prehension.

Notes

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