Relation of Stable Hand-Use Preferences to the Development of Skill for Managing Multiple Objects From 7 to 13 Months of Age

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Abstract:

Expression of multiple object management skills (manual acquisition and storage of objects) was examined longitudinally at 7, 9, 11, and 13 months for38 infants (19 females) whose hand use preference was either stable (consistently right or left across the ages) or nonstable (either no hand-use preference exhibited or inconsistent preference across the ages). Four separate sets of four distinctive objects each were presented singly to the infant's right and left side, with the presentation of each subsequent object contingent on the infant manipulating the previous object. Expression of multiple object management skills significantly increased with age. Infants with stable hand-use preferences produced more object acquisition and storage acts than those without a stable hand-use preference. Older infants with stable hand-use preferences exhibited more ''sophisticated'' sequences of multiple object management acts than those without. The role of stable hand-use preference in the development of manual skill and cognition is discussed. ß 2008Wiley Periodicals, Inc. Dev Psychobiol 50: 519–529, 2008.

Keywords: handedness | manual skill | laterality | infancy | cognitive development

Article:

Introduction

The manual skills established during infancy underlie a wide range of human abilities, including the intelligent behavior associated with tool construction and use (Lockman, 2000), representational reasoning (Streri &Feron, 2005; Needham, 2000; Piaget, 1952), and the adaptive comprehension of the environment (Striano &Bushnell, 2005). Manual actions are both an expression of knowledge and a means of acquiring it. Although there has been a great deal of research on the development of manual skill in infants, one aspect, the management of multiple objects, has been relatively neglected despite Bruner's (1973) contention that acquisition of this skill fundamentally changes the infant's transactions with the environment.

Bruner (1973, pp. 254–258) proposed that multiple object management skills are composed of two sub-skills, each of which is exhibited during manipulation of single objects.

The two sub-skills are: acquisition (grasping for and holding an object) and storage (retaining control of an object by transferring it to another hand or placing, without haphazardly dropping, an object within reach). Storage, in particular, allows the accumulation of an indefinite number of objects, whereas acquisition alone is unlikely to accumulate more than two objects (one in each hand). In Bruner's original cross-sectional study, mastery of the sub-skills of multiple object management varied across infants of different ages. Therefore, he proposed that the sub-skills of storage and acquisition of objects are mastered gradually and combined gradually into the larger pattern of managing multiple objects.

Since placement and other storage acts allow the accumulation of more objects than can be acquire d by the use of two hands, several objects become available for play. This permits both practice with the simultaneous use of both hands and the examination of the effect of one object on another (e.g., holding one object and placing another object inside if it, or using one object as a tool to manipulate another object). Additionally, haptic information about differences and/or similarities between object properties is acquired when handling objects simultaneously or successively. Thus, the ability to acquire (and subsequently to manage) more than one object at a time may be an important element in the development of several bimanual skills (Fagard, 1998) and perceptual skills (Bushnell & Boudreau, 1998).

Although Bruner's study focused on the age of appearance of multiple object management skills, it was across-sectional examination of 4–17 months of age. These infants were seated and presented with four toys in succession. When the first toy was grasped (from the experimenter's hand), a second was similarly presented to the same hand as the first toy. If the infant did not retrieve the second toy after 15–20 s, the toy was shifted to a midline position and placed on the table in front of the infant. The third and fourth toy were presented similarly but always to midline (it is not clear from Bruner's account whether the objects were placed on the table or handed to the infants in the same manner as the first two objects). A total of four sets of four toys each were presented to the infant. Multiple object management skill was defined as the ability of an infant to grasp and hold and/or ''store'' two or more small objects simultaneously. Bruner noted that intermanual object transfer skills and the employment of the free hand to retrieve an object were typical early elements of the infant's ability to acquire more than one object.

Bruner found that only by 6–8monthsofagewereinfants able to take possession of two objects. This was accomplished by the infant either transferring the object to the other hand in order to take possession of the second object or reaching across midline with the ''free'' hand to take possession of a second object. Thereafter, subsequent objects were acquired by the dropping of objects already possessed. Infants aged 9–11 months were occasionally able to take possession of a third, and sometimes a fourth, by "'storing" an object. That is, one of the first objects was placed either on the lap or the armrest of the chair for a brief moment. This permitted the object to be within reach or available for play in combination with subsequent objects. Nevertheless, 9–11-month-old infants still frequently dropped the first and/or second object in order to acquire another. By 12–14 months, the preferred method of storing objects was to hand over (deposit) an acquired object to the parent or the experimenter and frequently leave it with the other person until the end of the test session. Although this action is comparable to the social game of "offer and accept" (Ross & Lollis, 1987) that is frequently observed at this age, Bruner considered it a storage act.

Before a deposited object can be stored, the infant must manifest the ability to delay responding to this object placed within reach and subsequently return to the object after another has been acquired. Bruner (1973) proposed that the increase in the infant's ability to delay the retrieval of items within reach is related to the ability to "internally" represent the stored items thereby allowing later retrieval and subsequent manipulation with other objects. However, since there has been very little research investigating the development of multiple object management, the factors underlying the development of this skill are unknown. The ability to store multiple items represents a transition from simply responding to the presence of objects to managing the availability of objects for subsequent manipulation.

The present study renews investigation of the development of multiple object management skills by expanding on Bruner's study in several ways. First, a longitudinal sample of infants was examined for whom information about their hand-use preference was known. Observations for this study were begun at 7 months of age because the spontaneous manipulation of more than one object at a time is unlikely until this age (Bruner, 1973; Fensen, Kagan, Kearsley, & Zelazo, 1976). Also, at this age infant hand-use preferences may be assessed quite reliably (Michel, 2002).

Knowing the infant's hand-use preference is relevant because skilled manual tasks requiring the integration of movement speed, timing precision, and the control of graded forces between the hands and presumably the cerebral hemispheres, differs as a function of hand-use preference. Possession of a hand-use preference, irrespective of whether it is a right or left preference, has been associated with the exhibition of more sophisticated manual skills in children and adults (Bishop, 1990; Bryden, Roy, Rohr, & Egilo, 2007; Dellatolas et al., 2003; Flowers, 1975; Kaufman, Zalma, & Kaufman, 1978; Roy, Bryden, & Cavill, 2003; Tan, 1985). Infants with stable hand-use preferences also exhibit more sophisticated sensorimotor skills than infants without stable hand-use preference (Michel, 1988; Tan, 1985). And infants that possess a broad range of manipulation styles are more likely to engage in haptic exploration faster, spend twice as much time handling objects, and demonstrate considerably more multimodal exploration than those infants with less varied manipulation actions (Eppler, 1995).

An infant's handedness status, by ensuring differences in haptic experience between the two hands, can contribute to the establishment of differences in the processes of sensorimotor control and patterns of perceptual-motor organization between the two hemi-spheres (Michel, 1988). Th ese asymmetrical differences between the hemispheres may account for the differences between the hands both in patterns of tactual exploration of objects and in sensitivity to differences in tactile stimuli among children as young as 2 years (Rose, 1984). Thus, itis conceivable that a hand-use preference will have a significant impact on how infants manage the possession and exploration of multiple objects.

The present study allowed the examination of the relationship between infant hand-use preference (those with a stable preference compared to those without a stable preference) and multiple object management skills. In order to reliably as certain whether an infant exhibited a stable hand-use preference, the infant's preference was assessed at 7, 9, 11, and 13 months of age. An accurate description of handedness during infancy depends on longitudinal assessments of hand-use. Manual skills emerge at different points during development and differ in terms of their pattern of expression. Therefore, a reliable assessment technique for handedness is needed that is sensitive to the changes in manual skill that occur during the period of infancy (Michel, Ovrut, & Harkins, 1985). It was hypothesized that infants with a stable hand-use preference would exhibit more acquisitive and storage skills than those without a hand-use preference.

A second modification of Bruner's protocol included successively placing all four objects of a set (four sets total) to one side of the infant, on the table, with none of the objects placed to the infant's midline or handed to the infant (thereby eliciting "offer and accept"). The act of placing the object to the midline or handing it to the infant engages the infant in a social pattern that is more likely to elicit "offer and accept". Our method, like Bruner's, still results in a situation of "both hands full" by the immediate presentation of an object subsequent to any presented object manually manipulated by the infant. However, the change in technique (placing objects to the side of the infant) allows for better assessment of the infant's own capacity for multiple object management by removing any support that may be provided when objects are placed into the hand of the infant by the experimenter. Placing the objects to the side of the infant forces the infant to evoke a visually guided reach and to acquire an object off the table as opposed to having an object easily placed in his/her hand. In addition, it requires the infant to coordinate a sequence of actions in response to an object that has been asymmetrically placed relative to the position of the hands.

It was expected that infants would acquire more objects with increasing age. Younger infants were expected to either drop acquired objects upon the presentation of another object or ignore subsequently presented objects and consequently exhibit fewer acquisitions. This would result in fewer objects being acquired and subsequently stored. In Bruner's study (1973, p. 255), the transfer of objects was classified as a way to acquire more objects. However, in the present study, transfer is categorized as a "storage" skill because placing an object in the other hand allows retrieval of a subsequent object while still retaining control of the previously acquired object.

A final modification of Bruner 's procedure involved using an events analyzer that allowed for both analysis of the frequency of actions as well as the examination of the sequential pattern of manual acts. The added advantage of using sequential analyses is that it allows identification of nonrandom contingencies among the acts of multiple object management. Sequential analyses address the question of whether the ways in which infants assemble multiple objects management acts differs with age or between handedness groups. For example, do older infants "store" objects in more efficient sequential patterns, with fewer actions, than younger infants? Or, do infant s with a stable hand-use pattern show a consistent sequence of acts during storage of objects when compared to infants without a stable hand-use preference? It was hypothesized that older infants, and those who exhibit stable hand-use preferences, would perform more "sophisticated" sequences of acts than younger infants, or those without stable hand-use preferences. Although the ability to transfer an acquired object between the hands is a skill available before 7 months of age, using transfer to obtain a second object is a more "sophisticated" pattern than that in which a previously acquired object is dropped before obtaining the second object with the same hand.

Thus, the objective of the study was to identify and describe: longitudinal changes in the frequencies of the acts that comprise multiple object management as infants age; the relation of the infant's handedness status to the frequency of expression of multiple object management acts; and the ways in which sequences of multiple object management acts are contingently organized during the last half of the infant 's first year.

Method

Subjects

Thirty-eight subjects (19 males, 19 females) were recruited using the birth lists of Columbus Hospital in the Lincoln Park area of Chicago. Columbus Hospital has a diverse population from Latino, African-American, and Middle-European backgrounds. All participants were from lower- to middle-income families. Only infants from full-term pregnancies and with uneventful vaginal deliveries, birth weights greater than3000 g and Apgar scores greater than seven were included. Upon signing the informed consent, parents brought their infant to the Infant Development Center within 5 days of the infant's 7, 9, 11, and 13 months birth date. Parents received a stipend of $10.00 per visit. The procedure was approved by the Institutional Review Board for the protection of human subjects of DePaul University.

Procedure

Upon arriving to the center, infants were seated in a high-chair which provided freedom of movement of their hands above the table. All infants were able to support themselves in the high-chair without any additional reinforcement. The parent was seated behind the infant. A Panasonic 6200 VCR with a split screen device recorded the infant's actions from an overhead video camera and a camera placed in front of the infant. The experimenter was situated in front of the infant but below the camera angle. The infant received an adaptation of the Bruner task and then a handedness assessment. Handedness was assessed using the reliable and validated procedure described in Michel et al. (1985).

For the adaptation of the Bruner task, four separate sets of four objects in each set were placed successively on the table within easy reach of the infant. The presentation of a subsequent object was contingent upon the acquisition of the previous object by the infant. The four objects in each set differed from one another in color (e.g., red, green, blue, yellow), geometric shape (e.g., cubic, cylindrical, rectangular) and size (4 or 8 cm). The order of presentation was pseudo-randomized so that each new set began with the presentation of an object that differed from the previous set in terms of color and geometric shape. Objects were made of either wood or rigid plastic and were equivalently graspable.

Each of the objects in two of the four sets was placed on the table to the infant's right side (i.e., slightly to the right of the infants right shoulder). In the other two sets, each object was placed on the table to the infant's left side (slightly to the left of the infant's left shoulder). In contrast to Bruner's procedure, no objects were presented in midline or placed in the infant's hand. The left and right sides of presentation alternated across the four sets presented to an infant and the initial side of presentation alternated between infants to control potential bias in side of presentation. Each presented object of a set was continuously available to the infant during the task (e.g. objects dropped by the infant over the edge of the highchair were replaced, and objects "offered" by the infant to the experimenter were not "accepted"). The objects from the previous presentation set were removed before the next set of objects was presented.

After the infant had manipulated the presented object, the next object was immediately placed to that side, and so on until all four objects had been presented. Presentations were partly contingent on the infant's grasping the previous object. If an infant was not interested in a particular object, the experimenter "wiggled" and tapped the object in the infant's field of vision. If the infant still was not interested after 10 s, the objects were placed a bit further to that side of the infant, and the next object was presented. The objects were presented in relatively rapid succession to entice the infant to acquire more than one object at a time. Immediately following the acquisition of one object, the next object was presented.

Next, the hand-use preference task was administered and recorded on videotape. The infant remained in the high-chair as26 toy-like objects (e.g., rubber rings, rattles, and mechanical mice) were presented to the infant. A wide range of objects were selected that were attractive to infants because of their colorful and noisy characteristics. There were a total of 28 presentations to the seated infant. Ten of the objects were placed singly in midline (between the infant 's shoulders and in line with the nose) on the high-chair table in front of the infant. Six of the objects were presented in the midline in the air at eye level. Because of the characteristics of the toys, two of these objects were presented twice. There were also 10 identical items presented simultaneously as dual presentations. These presentation variations were included to reduce any preference bias that may occur between the infant and specific objects. The experimenter retrieved each object before the next one was presented.

The software program ‘‘Observer’’ (Noldus ß) was used to code the videotapes for frequency of appearance of the various manual acts of interest for the multiple object management task. The program permits precise frame-by-frame coding of events. All videotapes were coded by two observers in slow motion (1/16th real time) to ensure the capturing of very fast and/or simultaneous events. The behavioral acts that were coded are described in Table 1. The coders were trained to a minimum inter-rater reliability of 87% agreement (Cohen's Kappa) for each action. Actions that comprised a category of manual action were combined during analysis.

The singular acts listed in Table 1 were combined into three superordinate categories and their frequencies were calculated for analysis of variance. The three categories were: (1) Acquisition of objects; (2) Storage of objects; and (3) Loss of previously acquire objects. Acquisition of objects referred to the ability to pick-up an object from the table (i.e., coded in the data as the sequence of object ‘‘touch’’ consecutively followed by object "hold"). Because the coding scheme permitted multiple acquisitions per object (e.g., an object is acquired, dropped, and then acquired again) there were sets of presentations in which there were more acquisitions than objects presented (i.e., # of acquisitions >4 for a set). To remove bouts of object banging (which appeared as sequences of successive "touch-hold" couplets without any other acts coded between them), the frequency of object acquisitions was calculated by counting the number of object ‘‘drops’’ and object ‘‘places’’. Logically a ‘‘drop’’ or a "place" cannot occur without an initial acquisition. Storage of objects was defined by any of four actions: (1) a "place" (the infant places a previously held object down on the table and releases grasp); (2) a "transfer" (the infant transfers an object that is held in one hand to the opposite hand—if a two-handed acquisition resulted in the object ending up in one hand, this was not counted as transfer); (3) a "store in mouth" (the infant places an object into the mouth and releases grasp); or (4) the infant holds two or more objects simultaneously in one hand. This coding scheme allowed multiple storage acts for a single object. That is, infants had the potential to use various storage strategies on any given object in a set. Therefore, infants may have displayed more storage acts than objects presented. The third superordinate category, loss of previously acquired objects, was defined by the infant's releasing of a held object ("dropping" the held object) or releasing an object that was stored in the mouth (e.g., "spitting it out"). In each case the object falls.

The videotapes of hand-use preference were coded in real time by raters filling out forms that listed the items presented during the test. The video player also provided the capability to slow down the playback speed in order to view the video frame-by-frame. Raters identified which hand initially contacted each specific item. The slower playback speed was used for the rare instances in which coders were unable to identify which hand made the initial contact with the presented object. For presentations that consisted of pairs of objects, only the first hand to make contact with an object was coded. Inter-rater reliability, based on 15% of the coded observations, was greater than 95%. A hand-use preference score was calculated for each testing session by computing the frequency of right-hand use for the 28 presentations divided by the combined frequency of left- and right-hand use. Bimanual hand-use seldom occurred and was therefore not included in the analyses. Any calculated score of .32 or less was (9 or fewer right hand-uses, $p < .05$) was classified as a left hand-use preference and any score more than .68 (more than 19 right hand-uses, $p < .05$) was classified as a right hand-use preference (Michel et al., 1985). Other scores were classified as no preference.

Stable handedness refers to those infants with consistent right or left hand-use preferences across the four age groups visits. Infants were classified as having a non-stable hand-use preference if the infant failed to show a hand-use preference across the four age groups (i.e., their handedness assessment scores were always between .32 and .66). The non-stable preference category also included six infants for whom their monthly assessment of handedness exhibited alterations of hand-use preference across the four assessment periods. The number of infants with a stable left hand-use preference (n = 6) was too small for comparative analyses with right-handed infants (n = 14) so the two handedness groups were combined to form the stable handedness group. Ten females had stable handedness and nine females were identified as having non-stable handedness. Ten males had stable handedness, and nine males had non-stable handedness. Thus, there were a total of 20infants with stable hand-use preferences across the four ages and18 infants without stable hand-use preferences.

Behavioral Act	Events Analyzer Code	Description
Present object	Pres	Presentation of 1st–4th object
No manipulation	not	Infant not touching object (code needed for mutually exclusive/exhaustive coding)
Touch	tch	Object on table is touched by infant's hand, palmar side, wrist to fingertips
Hold	hld	Object is in infant's hand (palmar side, wrist to fingertips) and off the table
Place	plc	Object that has been held is placed on a planar surface, hand releases object (not dropped or thrown)
Hold two or more	h1+	Infant is holding two or more objects in the same hand simultaneously
Store in mouth	strmth	Object that is held by infant is placed in mouth and hand releases grasp
Drop	drp	Originally held object is released and falls due to gravity (not placed)
Drop from mouth	drpmth	Object falls out of mouth without the hands touching it
Incidental touch	itch	Object on table is touched by any part of infant's hand except palmar side (needed for mutually exclusive/exhaustive coding)
Transfer	trf	Sequence of acts created by combining contingent acts: unimanual hold-bimanual hold-opposite unimanual hold

Note: Acts were recorded for right, left, and both hand-use. "Not" events were removed prior to lag-sequential analyses.

Table 1. Multiple Object Management Act Codes and Descriptions

Sequential Analyses. In order to identify the storage act "transfer of objects" in the raw data files (so that the frequency of this act could be calculated for analysis of variance), lag-sequential analyses were conducted. The storage act of object transfer was represented by the sequences of events: "hold" in one hand, immediately followed by a ''hold'' in both hands, immediately followed by a "hold" in the opposite hand (e.g., coded as right-hold RHLD, both-hold BHLD, left-hold LHLD).

Additionally, lag-sequential analysis was used to examine the types and frequencies of non-random contingencies of acts that occurred at each age, between hand-use preference groups, and between male and female infants. Sequences are defined as ordered successions of behavioral acts (Fagen & Young, 1978). Behaviors that occur closely together in time may have the same underlying causal factors. If the behavioral acts exhibit temporal dependence in that the identity or probability of future events depend on past events, then it can be assumed that a new pattern of behavior has emerged. Furthermore, the frequency of transitions across events can be examined to test hypotheses about transition probabilities. That is, it can be determined if the pattern of behavioral acts is non-random or unlikely to have occurred by chance.

The hand used for an action (right, left, or both hands) was included in the analyses. Contingent relations among objects were identified by a computer program written using the Foxpro Database software (Kotwica, 1994). The sequential contingency program generated distribution matrices of lag-sequential sequences of acts. The method for calculating the expected frequencies in a test of sequential dependence in behavior is exactly that used for testing independence between rows and columns in a contingency table. Each act (hold, touch, place, holding two or more object simultaneously, store in mouth, dropping, and drop from mouth) was examined as both a preceding and a following act for right, left and both hand-use. "Not" events and ''incidental touch,'' used for mutually exclusive/exhaustive coding, were removed prior to analysis.

The program generated possible sequences of acts for three levels (1st-, 2nd-, and 3rd-order contingencies). 1st-ordercontingencies assume that the probability of a given act depends only on the identity of the act immediately preceding that act. Likewise, 2nd-order contingencies assume that the probability of a given act depends jointly on the identities of the two acts immediately preceding the act. At each level all possible permutations of successive act orderings are computed. For example, for a fictitious raw data sequence consisting of "rtch-rhld-bhld-lhld" (right touch- right hold- both hold- left hold), at the 1st-order level there would be 1 count of rtch-rhld, 1 count of rhld-bhld, and 1 count of bhld-lhld entered into the frequency matrix. This method was used because the possible types of sequences of acts representing the simultaneous and/or successive manipulations of multiple objects were unknown and therefore we did not want to predetermine the onset of a sequence. For each frequency distribution thus formed, a chi-square test was conducted to determine if a distribution matrix was significantly nonrandom. If a distribution was found to be significant ($p < .05$), the program conducted a post-hoc test to report the significant contingencies within a frequency distribution (e.g., see Tab. 2 for the significant 2nd-order level contingencies for 13-month-old infants).

To test for the significant contingencies that contributed to a significant frequency distribution, the equation $A = (n_{ij}–e_{ij})^2/(e_{ij})$was used, where n_{ij} is the observed frequency an e_{ij} is the expected frequency of the transition in cell ij (Andrews, 1956 as reported in Fagen & Mankovich, 1980). Any result greater than 3(i.e., if $A > 3$) was considered significant. Fagen and Mankovich (1980) argues that $A > 3$ corresponds to $Z > 3$ which equates to a significance level of .0026.

The most meaningful significant sequences of acts were next contrasted across age, between hand-use preference, or between sex of the infant using the chi-square method. Goodman's simultaneous confidence interval procedure (see Jaccard &Becker, 1990) was used for post-hoc analyses at the $p < .05$ level.

Event 1		Event 2	Observed	Expected	Post-HOC
BHLD	BTCH	BHLD	11	2	6.201
BHLD	LHLD	BHLD	35	8	9.276
BHLD	LHLD	RTCH	67	41	4.035
BHLD	RHLD	BHLD	45	10	10.81
BHLD	RHLD	LTCH	56	29	5.101
BHLD	RHLD	RDRP	23	7	6.282
BTCH	BHLD	LHLD	21	5	7.31
BTCH	BHLD	RHLD	18	9	3.021
LDRP	LTCH	LHLD	48	7	14.912
LHLD	BHLD	BTCH	13	1	11.257
LHLD	BHLD	LHLD	23	10	4.027
LHLD	BHLD	RHLD	57	19	8.86
LHLD	LDRP	LTCH	60	16	11.028
LHLD	LTCH	LHLD	196	36	26.559
LHLD	LTCH	LPLC	82	7	28.655
LPLC	LTCH	LHLD	47	8	13.608
LTCH	LHLD	LDRP	76	13	17.866
LTCH	LHLD	LTCH	275	96	18.324
LTCH	LPLC	LTCH	63	18	10.612
RDRP	RTCH	RHLD	89	25	12.924
RH1+	RTCH	RHLD	18	5	5.374
RHLD	BHLD	BTCH	10	2	6.804
RHLD	BHLD	LHLD	63	14	13.039
RHLD	BHLD	RHLD	57	26	6.111
RHLD	RDRP	RTCH	117	47	10.244
RHLD	RH1+	RTCH	21	9	4.131
RHLD	RTCH	RHLD	427	144	23.535
RHLD	RTCH	RPLC	230	40	30.284
RPLC	RTCH	RHLD	133	38	15.421
RTCH	RHLD	RDRP	133	42	13.935
RTCH	RHLD	RH1+	25	9	5.618
RTCH	RHLD	RTCH	649	322	18.221
RTCH	RPLC	RTCH	185	79	11.941

Note: Post-hoc tests were calculated by the formula: $A = (n_{ij} - e_{ij})^2/(e_{ij})$, where n_{ij} is the observed frequency and e_{ij} is the expected frequency of the transition in cell ij. Only significant contingencies are reported (see text).

Table 2. List of Significant 2nd-Order Contingencies for 13-Month-Old Infants

Analysis of Variance. For the frequency data generated from the three superordinate categories of multiple object management acts, four separate two (handedness: stable and non-stable) x four (age: 7, 9, 11, and 13 months) x two (side of presentation: right or left) x two (sex) x two (hand-use preference: right or left) analyses of variance were conducted using the statistical package "CRUNCH" (1991). The three dependent variables were frequency of object storage, object acquisition, and loss of previously acquired objects. The variables of sex and side of presentation of objects were included to detect potential sex differences in rate of development or differences in the ability to pick up objects presented to one side or the other. The results of the analyses for sex and side of presentation are not reported because they failed to reveal any significant effects. The results of the analyses for handedness by side of presentation interaction also failed to reveal any significant effects and are not presented. Tukey HSD test was used for post-hoc analyses of means.

Results

The ability to acquire objects varied significantly with age, $F(3, 108) = 9.74$, $p < .01$ (see Tab. 3). Post-hoc testing revealed that at 7 and 9 months infants showed significantly less ability to acquire objects than at13 months, $p < .03$. Additionally, infants at 7 months of age showed significantly fewer instances of object acquisition than at 11 and 13 months of age, $p < .001$.There were no other significant main effect or interaction effects for object acquisition.

There was a significant age effect for frequency of storing objects (Tab. 3). Post-hoc testing revealed that 7and 9-month infants showed significantly less ability to store objects than at 13 months, $p < .003$. Also, infants at7 months showed significantly fewer instances of object storage than at 11 and 13 months of age, $p < .006$. There was a significant effect of handedness group for storage skill, $F(1,36) = 5.94$, $p < .03$ (see Tab. 4). Infants with stable hand-use preferences exhibited a higher mean frequency of storing objects than infants without stable hand-use preferences. Thus, there was no difference between the handedness groups for object acquisition skill but the stable handedness group exhibited more storage skills than the unstable handedness group.

Although there was no significant age by handedness interaction for object storage, a trend analysis was conducted to assess whether the two handedness groups exhibited similar age trends. Results revealed that both infants with and without stable hand-use preferences demonstrated a significant linear age trend, $F(1,36) = 23.20$, $p < .001$. No other trends were significant (i.e., quadratic and cubic). However, there was a significant difference in the rate of development of object storage skill between the two handedness groups, $F (3,108) = 4.001$, $p < .02$ (statistical procedure—see Bruning & Kintz, 1987, pp. 140–145). Although infants in both handedness groups were developing storage skills in the same manner, infants with stable hand-use preferences were developing them at a more accelerated rate (Fig. 1).

An additional analysis of the storage act ‘‘transfer of object’’ was conducted to examine separately whether this bimanual skill differed across age or between handedness groups. This analysis did not reveal any significant main effects or interaction effects. However when “type of transfer” (right-to-left-hand transfer versus left-to-right-hand transfer) was included as a within measure variable there was a significant interaction effect of type of transfer and hand- use preference of the infant, $F(1,36) = 4.48$, $p < .05$ (see Tab. 4). Post-hoc testing was revealed that infants with stable hand-use preferences performed more right-to-left-hand transfers than left-to-right-hand transfers, $p < .05$. In contrast, infants without stable hand-use preference failed to show a significant difference between the two types of transfer. Moreover, infants with stable hand-use preferences exhibited more frequent right-to-left-hand transfers than did the non-stable hand-use preference group, $p < .05$.

Since there were more right-handed infants (14 of 20) in the stable group, the high mean frequency of right-to-left transfers may have resulted from infants transferring objects to their non-preferred left hand so that they could acquire more objects with their preferred right hand. The sample of left-handed infants was too small to determine whether right-handed and left-handed infants differed in the direction of their transfer actions.

There were no significant main effects or interaction effects for the loss of previously acquired objects (object “drops”).

A separate lag-sequential matrix was generated for each age group (7, 9, 11, and 13 months) according to handedness group (stable and unstable) and sex, using the sequential contingency program, resulting in eight different distributions for each level of analysis.

Age (Months)	7	9	11	13
Acquisition	12.29 (1.12)	16.37 (1.72)	19.53 (1.86)	21.68 (1.78)
Storage	9.16 (.97)	12.13 (1.30)	15.42 (1.64)	18.5 (1.69)

Table 3. Mean Frequencies and (Standard Errors) of Object Acquisition and Object Storage as a Function of Age

Hand-Use Preference	Stable	Nonstable
Storage	62.9 (2.05)	46.6 (2.20)
Transfer type		
Right–left	9.6 (.53)	6.11 (.38)
Left–right	7.9 (.46)	7.0 (.49)

Table 4. Mean Frequencies (and Standard Errors) of Object Storage and Type of Object Transfer as a Function of Hand-Use Preferences

Age (Months)	Pass-Between	Unsuccessful	Place-Pick-Up	Drop-Pick-Up
7	156	193	32	66
9	169	152	69	108
11	109	82	147	177
13	120	80	180	137

Table 5. Frequency of Pass-Between-Hands, Unsuccessful Transfer, Place-Pick-Up, and Drop-Pick-Up Sequences of Acts According to Infant Age

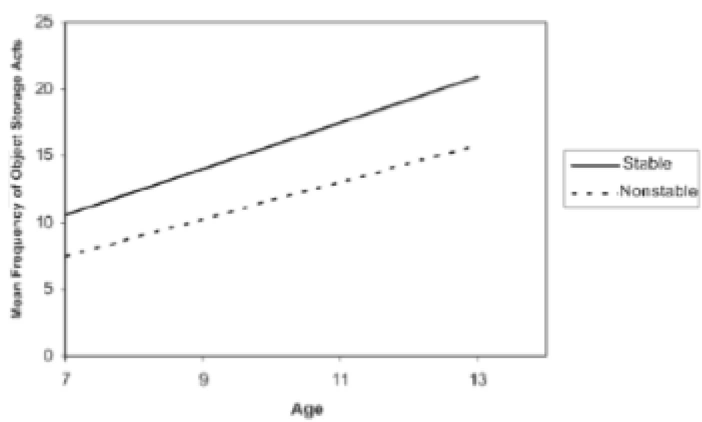

FIGURE 1 Regression estimates based on the trend analysis of object storage acts according to infant age and hand-use preference.

The matrices generated for each group, at each level of contingency analysis (1st-order, 2nd-order, and 3rd-order) were found to be significant (each distribution differed significantly from chance). Each matrix contained more than 20% of expected values (x2) that were less than 5. Unfortunately, this is a common occurrence in descriptive studies (see Fagen & Young, 1978; Lemon &Chatfield, 1971). Often, behavioral acts are collapsed to avoid violating this assumption. However, in this study, since issues of laterality were of interest, acts could not be collapsed across handedness group or age. In order to reduce over-exaggerated significance, any significant contingency with an observed frequency of less than 10was not included in subsequent analyses. Additionally, it should be noted that the majority of the observed frequencies were much greater than the expected frequencies.

Although 1st order sequences of act s were examined, apart from object acquisitions (coded as “touch-hold”) they provided little information on the ability to manage multiple objects. Therefore, the following sequences of acts are either 2nd- or 3rd-orde r contingencies. That is, the acts examined are those that are assumed to have a probability of occurrence which depends jointly on the identities of the two acts immediately preceding the act or the three acts immediately preceding the act. It is in these contingency levels that “storage” can be identified. Subsequent chi-square analyses were conducted to examine the differences in frequencies of the types of significant non-random patter ns that infants performed according to age, handedness group, and sex. Of the significantly contingent patterns (sequences of acts), there were very few types of patterns that differed among groups. However the frequencies of these shared sequences of acts did vary among groups.

Across Age

The relationship between age and transfer pattern (see Tab. 5) was analyzed at the 2nd-order level of nonrandom contingencies of acts. Transferring objects represents a sequence of acts that depends on the sequential and temporal ordering of acts between both of the hands—that is, bimanual coordination. A potential transfer (i.e., unsuccessful transfer) was comprised of a sequence in which one hand acquired, then both hands held an object, and finally, the original hand retained control of the object. Successful transfer, compared to potential transfer, was significantly related to age $X^2(3, 829) = 8.30$, $p < .05$. Post-hoc analysis revealed that the only significant difference was a decrease in frequency of potential transfer between 7 (193) and 13 months of age (80).

Instances of sequences that represented successive acquisitions were analyzed across age. There were two patterns of acquisition with one having a “drop” between successive acquisitions and the other having a “place” between successive acquisitions (see Tab . 5). Their relation to age was statistically significant, $X^2(3, 916) = 25.18$, $p < .01$. Infants at 7 months of age exhibited less place-successive acquisitions (32), and less drop-successive acquisitions (66), than at 13 months (180 and 137respectively), Infants at 9 months showed less place-successive acquisitions (69) compared to infants at13 months (180). That is, older infants were more likely to place an object down prior to acquiring a subsequent object.

Between Handedness Groups

The sequences of successive acquisitions (see Tab. 6) were significantly different between hand-use preference (stable and non-stable) groups, $X^2(1, 896) = 18.93$, $p < .01$. Infants with stable hand-use preferences performed more place-successive acquisition sequences (161) than infants without a stable hand-use preference (153).

Between Infant Sex

Sequences of successive acquisition were related to the infant's sex, $x^2(1, 899) = 5.51$, $p < .05$. Males performed less place-successive acquisition sequences (175) than did females (242). An analysis of age by sex revealed that females were more likely to perform this sequence of acts at both 11 and 13 months of age whereas males were more likely to perform this sequence at 13 months of age.

Discussion

The results of this study confirm Bruner's (1973) observation that the ability to acquire and store objects improves with age. By the end of their first year, infants can effectively manage multiple objects. This ability is achieved by employing one or both of two strategies: (1) a currently acquired object is transferred to the opposite hand so that additional objects may be acquired; or (2) previously acquired objects are placed (not dropped) near the body making them available for future use.

The second strategy, especially when combined with the first, provides opportunity for the infant to experience the simultaneous comparison of the properties of more than two objects. The second strategy alone allows successive manipulation of more than two objects, via subsequent retrieval of the stored object, for intra-manual comparisons. It is likely that such comparison enhances the saliency of the relative nature of the object properties (e.g., smoother than, heavier than, softer than, more easily grasped) and perhaps some transitive relations. Also, both intermanual and intra-manual manipulation with stored objects allows the infant to discover that objects can have effects on one another (e.g., pounding, inserting, and stacking). Thus, the motor skills for multiple object management may provide important experiences for the development of haptic perception (Bushnell & Boudreau,1993) and those cognitive abilities employed in the comprehension of physical properties.

The present study added the dimension of infant hand-use preference status to the development of multiple object management skill. Infants with stable hand-use preferences exhibited more object storage acts, and a faster rate of development, than infants without a stable hand-use preference. Infants with stable hand-use preferences are better able to "manage" multiple objects either by placing them within reach (for future use) and/or transferring objects to the opposite hand. Contingency analyses revealed that the infants with stable hand-use preferences more readily acquired another object after storing an object ("object place") than did infants without stable hand-use preferences. Thus, infants with stable hand-use preferences may experience more instances of object contrast and comparison than infants without stable hand-use preferences. These skills, in turn, may promote further development of other motor skills and/or cognitive abilities. Moreover, since the development of multiple object storage skills are likely related to the development of intermanual coordination (e.g., transferring objects between the two hands) and certain perceptual/cognitive skills (active comparison and contrast of object properties), infants without stable hand-use preferences may differ from those with stable hand-use preferences in more subtle forms of cognitive abilities rather than those typically assessed with standardized tests. The present results call for further systematic investigation of the neuromotor and cognitive develop-mental consequences of infant hand-use preferences.

Hand-Use Preference	Place-Pick-Up	Drop-Pick-Up
Stable	261	234
Nonstable	153	248
Sex		
Female	242	242
Male	175	240

Table 6. Frequency of Place-Pick-Up and Drop-Pick-Up Sequences of Acts According to the Hand-Use Preference or Sex of the Infant

Unlike other storage acts, transferring objects between hands reflects a skill that involves bimanual, and perhaps interhemispheric (Diamond, 1991), coordination. The ability to transfer objects depends on the ability for each hand to take on a separate functional role (Fagard, 1991). That is, each hand successively ‘‘takes turns’’ holding and releasing the object. The capacity to “de-couple” the motor control of the hands allows greater potential for adaptations to the manipulative demands of variable environmental circumstances such as those represented by multiple objects that vary in their properties. Perhaps infants’ hand-use preferences contribute to the development of both inter-manual coordination and inter-hemispheric coordination. Infants with stable hand-use preferences exhibited more right-to-left hand transfers than infants without stable hand-use preferences perhaps because most of the infants were right-handed.

Although frequency of object transfers did not change with the age, the type of transfer pattern differed as a function of infant age. The frequency of “potential” transfer sequences declined between 7 and 13 months of age whereas the frequency of successful transfers did not change with age. The high number of potential transfer sequences at 7 months may mark the inability of the infant to “release” an object to the opposite hand (a decoupling ability). Studies of the development of the corpus callosum (c.f. Michel, 1988) suggest that not until approximately 10 months of age are the two sides of the brain in sufficient functional communication via the corpus callosum, to enable one hand to ‘‘know’’ what the other is doing. Therefore, it may be that for the younger infant both hands make contact with the object and “struggle” for sole possession with the hand that had original possession having an advantage. When a successful transfer occurred at the younger ages, it often appeared as a jerky snap as the object was released from being held by both hands to being held by the hand opposite from the original holding hand.

The increase with age of the sequence of acts where by an object was acquired immediately after an object was placed nearby may represent improved ability to “remember” such placement for easy retrieval. Although both Bruner and we found that the frequency of storing objects increases with age, the contingency analyses reveal that even when multiple objects are managed at different ages, the skill is organized quite differently. Development may occur separately in the execution and in the achievement of a skill. In our results, differences in the development of execution provide insights into potential differences in cognitive abilities among groups.

In conclusion, the results demonstrate that during the last half of their year infants actively change the manner in which they manage the objects in the world. This change may contribute to the development of the cognitive skills underlying knowledge and understanding of physical objects. What may underlie this change (e.g., whether there are changes in "attention span," finer motor skills, spatial abilities, memory retention or "internal representation," etc.) is unknown. Our results also show that differences in handedness status are associated with differences in multiple object management. It is conceivable that the differences in object management skill might contribute to the development of subtle differences in the cognitive skills between those infants with and without stable handedness although this remains to be tested. A stable hand-use preference could facilitate the expression, if not the development, of object management skill by altering the information processing decisions involved in the engagement of unimanual prehension. For example, infants with stable handedness may be more susceptible to using the preferred hand, even if it is not the nearest hand, thereby reducing decision time for which hand should be used, or lead, in any manual skill.

Acquiring and storing objects creates the conditions in which the infant comes to achieve control over the kinds of exploratory and manipulation experiences needed to manage an environment comprised of multiple objects with physical and functional similarities and differences. That the infant's own handedness status is related to the development of these multiple object management skills demonstrates that the infant's actions can generate self-educational experiences that may contribute to the reciprocal relationship shared during development between sensorimotor skill and intelligence.

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