The Relationship between Reduplicated Babble Onset and Laterality Biases in Infant Rhythmic Arm Movements

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Abstract

This study examined changes in rhythmic arm shaking and laterality biases in infants observed longitudinally at three points: just prior to, at, and just following reduplicated babble onset. Infants (ranging in age from 4 to 9 months at babble onset) were videotaped at home as they played with two visually identical audible and silent rattles presented at midline for 1.5 min each. Rate of rattle shaking increased sharply from the pre-babble to babble onset session; but there was no indication that this increase was specific to the right arm. This finding suggests that the link between babble onset and increased rhythmic arm activity may not be the product of language-specific mechanisms, but is rather part of a broader developmental process that is also perceptual and motor.

The onset of reduplicated babbling (vocalizations consisting of syllable repetition, e.g., [bababa]) has long been considered to be a major milestone in early language development. Although infants begin to produce single syllables (e.g., Oller, 2000; Fagan, 2005) and frequently repeat single sounds (e.g., vowels; Fagan, 2005) prior to babble onset, reduplicated babble is considered an important developmental advance because it marks the first appearance of repeated strings of well-formed syllables; and syllables are the fundamental organizational unit of adult language. The emergence of syllabically-organized vocalizations is therefore considered by many to be a crowning achievement of infant vocal development (see Oller, 2000, for extensive discussion).

While there is general agreement concerning the importance of reduplicated babble onset as a major developmental milestone, there is considerable controversy regarding the way in which it is conceptualized theoretically. Over the past 15 years, two contrasting views of reduplicated babble have emerged. These views – the motor stereotypy view and the linguistic view – differ sharply in their interpretation of the nature of reduplicated babble and its potential underlying mechanisms.

Babbling as a motor stereotypy

According to the motor stereotypy view, reduplicated babble is one among a family of rhythmically organized, stereotyped movements that are common in infant behavior (e.g., Kent, 1984). During the first year of life, infants frequently produce rhythmically-organized, repeated movements of the limbs and whole body (see Thelen, 1979). These movements typically exhibit clear developmental trajectories, with a distinct time of onset, peak, and decline. They are performed when infants have some control over their limbs and the desire to act but are still working out problems of adapting behaviors in a flexible and stable manner to achieve an intentional goal. As such, they are closely correlated with relevant motor milestones (Thelen, 1979). For example, infants wave their arms before they reach and rock on all fours before they crawl; and recent work suggests that there is developmental continuity between these early movements and later-emerging skilled behavior (e.g., see Bhat & Galloway, 2006; Bhat, Heathcock, & Galloway, 2005).

MacNeilage and Davis (1993) have argued that reduplicated babble shares properties of rhythmic motor stereotypies because it begins fundamentally as a mandibular oscillation. In their view, mandibular oscillations, in combination with phonation and limited tongue control, form the basis for the repetitive patterns typical of early reduplicated babbling. Specifically, the repeated lowering and raising of the mandible results in a perceived contrast between consonants produced when the vocal tract is closed and vowels that are produced when the vocal tract is open. As infants gain control of the tongue and its position during mandibular cycles, they begin to widen the repertoire of syllabic patterns that occur in their vocalizations (MacNeilage & Davis, 2000; MacNeilage, Davis, Kinney, & Matyear, 1999). In short, just as arm and leg rhythmicities are a product of the biomechanical properties of infant limbs under developing control, so too is reduplicated babble a product of the biomechanical properties of the mandible in combination with limited tongue control.

Evidence for the motor stereotypy view comes from studies indicating temporal coincidence between reduplicated babble onset and rhythmic motor activity, especially arm activity. Thus, for example, in longitudinal research, Thelen (1979) found a clear peak in frequency of rhythmic arm activity at around 28 weeks of age. This is the age at which many infants begin to produce reduplicated babble (e.g., Koopmans-van Beinum & van der Stelt, 1986; Oller & Eilers, 1988). More recent work has reported strong, positive correlations between ages of onset of reduplicated babble and rhythmic hand banging (e.g., Cobo-Lewis, Oller, Lynch, & Levine, 1996; Eilers, Oller, Levine, Basinger, Lynch, & Urbano, 1993).

Basing their interpretation on abundant evidence for the existence of a coupling of the vocal and motor systems[1] (particularly the manual system) from early in development, Iverson and Thelen (1999) have suggested that the close relationship between reduplicated babble onset and heightened upper limb rhythmicity is a product of the entrainment of coupled vocal-motor systems. According to their model, when a given behavior in one component of a coupled system is relatively stable and well-practiced, its activation naturally extends to the other component. When this happens, activity in the first system may "pull in" and entrain the activity of the complementary system. For example, when an infant is engaged in an intense bout of rhythmic limb activity, the level of activation in the motor system may "spill over" into the vocal system and entrain its activity, resulting in production of a co-occurring vocalization that may even be closely timed with the rhythmic limb movement (e.g., a string of reduplicated

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[1]The use of the terms "vocal" and "motor" in this paper reflects the fact that the two systems are anatomically distinct. This choice of terminology in no way implies that the systems are separate, as motor activity is clearly involved in the production of speech and vocalization.

syllables, each articulating with a movement cycle in a bout of rhythmic arm banging; see Iverson & Fagan, 2004).

On this view, the onset of reduplicated babbling may be seen as a product of entrainment between the vocal and motor systems, specifically between rhythmically-organized motor activity and vocalization. Infants have a long history of producing rhythmic manual movements prior to the onset of reduplicated babbling. These repetitive, rhythmically-organized movements are very stable and well-practiced; and thus they should gradually entrain vocal activity, leading eventually to the production of the mandibular oscillations that comprise babbling. Thus, this behavioral coupling between vocalization and rhythmic arm activity that occurs in real time has implications for the emergence of reduplicated babble in developmental time; and this real time coupling may also have implications for the emergence of a linked gesture-speech system in developmental time. This is a topic to which we will return in the discussion.

Babbling as a linguistic behavior

Some investigators have taken issue with the notion that reduplicated babbling reflects the properties of a developing vocal-motor system, arguing instead that babbling is a systematic and fundamentally linguistic behavior (e.g., see Petitto et al., 2004, for a recent discussion). From this perspective, the mandibular cycles that comprise babbling reflect maximally contrasting syllabic units in the target language, and the production of babble reflects infants' *inherent* sensitivity to the rhythmic and temporal properties of natural language. In other words, the fact that reduplicated babble contains fundamentally linguistic units (i.e., syllables) indicates that it is controlled by a set of mechanisms dedicated uniquely to language. The onset of babbling is triggered by exposure over developmental time to a patterned input to which infants are sensitive. The subsequent production of babble provides infants with opportunities to discover the particular set of sounds that is employed in their language.

Evidence for the claim that babbling reflects an emerging linguistic capacity comes from three main sources. First, there is a high degree of continuity between the babbling patterns developed by an individual child and the early word forms produced by that child (see Vihman, 1996, for a review). Second, delayed babble onset and/or less voluble babble productions are reliable predictors of delayed or disordered language development (e.g., Oller, Eilers, Neal, & Cobo-Lewis, 1998; Oller, Eilers, Neal, & Schwartz, 1999). Thus, for example, infants with Down syndrome are delayed in both onset of reduplicated babble and language development (Lynch et al., 1995); and the babble production of late talkers is characterized by small phonetic repertoires and simple syllable shapes (Stoel-Gammon, 1989).

A third piece of evidence, and one that is at issue in the present paper, is that although infant hand preferences are generally unstable and fluctuate throughout the first year (Corbetta & Thelen. 1998), infants appear to demonstrate a temporary right hand preference in manual activity at reduplicated babble onset. One of the first to report this phenomenon was Ramsay (1984). Presenting infants with toys that contained a salient feature (e.g., a button) providing auditory and visual feedback, Ramsay examined unimanual hand preferences in infants followed weekly from 5 months of age to 8 weeks following the onset of reduplicated babble. Toys were presented at midline, and the proportion of right-handed toy contacts (defined as attempts to activate the movable portion of the toy) were coded at each session. Reporting that infants generally first produced a significantly higher proportion of right- than left-handed toy contacts during the week of reduplicated babble onset, Ramsay (1984) suggested that synchrony between babble onset and emerging right hand preference might be indicative of a change in hemispheric specialization accompanying the emergence of reduplicated babble.

On the basis of this work and other research pointing to behavioral associations between right-handed activity and speaking in older children (e.g., Hiscock & Kinsbourne, 1978; Kinsbourne & McMurray, 1975) and left hemisphere control of both segmental speech gestures and movements of the preferred hand (Fried et al., 1991; Ojemann, 1984), Locke, Bekken, McMinn-Larson, and Wein (1995) took this argument a step further. They suggested that the appearance of a right hand bias at reduplicated babble onset indexes increasing brain specialization for language functions. To test this claim, Locke et al. (1995) designed a cross-sectional study in which they placed audible and silent rattles in the left and right hands of infants of different ages presumed to vary in the amount of time they had been producing reduplicated babble. In light of the well-documented temporal link between enhanced arm rhythmicity and reduplicated babble onset, they reasoned that if the onset of reduplicated syllable production and repetitive manual activity are controlled by a common mechanism in the left hemisphere, then there should be a disproportionate increase in right-handed rhythmic activity with the onset of babbling. In addition, since babbling is an audible behavior, they hypothesized that auditory feedback (the sound made by an audible vs. a silent rattle) would enhance repetitive right-hand activity at babble onset.

Reported results were generally consistent with the first prediction: rate of rattle shaking was relatively low among the youngest, pre-babbling infants and increased substantially, especially for the right hand, among infants who were presumed to be new babblers. Following babble onset, rate of rattle shaking declined somewhat (but remained above that for prebabblers) and the right hand advantage disappeared. With regard to the second prediction, infants tended to shake the audible more than the silent rattle, but this effect was not specific to babble onset. On the basis of these findings, Locke et al. (1995) concluded that "...repetitive right-hand activity increased at about the same age as repetitive vocal-motor activity, suggesting that babbling onset may reflect the maturation of control mechanisms in the left hemisphere." (p. 505).

The present study

Although Locke et al.'s (1995) results are intriguing in light of recent interest in language-motor links (e.g., Rizzolatti & Arbib, 1998), they are limited in several significant ways. First, the Locke et al. design was cross-sectional. Infants were divided into groups of prebabblers, new babblers, and experienced babblers based on parent report of whether or not the infant produced reduplicated babble and infant age. Since no information was available regarding babble onset for individual infants, length of time since the emergence of reduplicated babble was estimated on the basis of infant age in relation to data from the largest parametric study of babble onset then available (van der Stelt & Koopmans-van Beinum, 1986). Unfortunately, this procedure results in a confound between infant age and babbling status; and it is therefore unclear whether the observed increase in rate of shaking (especially right hand shaking) is specifically related to babble onset or simply a function of infant age. Second, because Locke et al. used a cross-sectional design, no information is available with regard to change over time in proportion of right-handed grasping and shaking. Third, no data are reported regarding the hand preferences of individual infants. Therefore, it is impossible to know how many recent babblers show the reported right hand preference effect.

The present study was designed as a partial replication and extension of Locke et al. (1995). Our goal was to use a longitudinal approach to gather evidence on the hypothesized relationship between onset of reduplicated babble and increase in right-handed manual rhythmicity. Through longitudinal observation employing a task generally comparable to that of Locke et al., we wished to pinpoint the onset of reduplicated babble for each infant and examine changes over time in grasping and rhythmic arm activity prior to, at, and following babble onset. With longitudinal data from infants roughly comparable to Locke et al.'s three critical groups (oldest

prebabblers, recent babblers, and youngest experienced babblers), we could then track changes in proportions of right-handed grasping and shaking in individual infants. And because infants begin to babble at widely varying ages, we could disentangle the effects of infant age and babbling status.

Method

Participants

Participants for this study were 26 infants (10 males, 16 females) who were taking part, with their primary caregivers, in a larger study of vocal and motor development. All infants were born at term and had normal hearing. Twenty-four infants were Caucasian and two were Asian-American. All of the infants had at least one parent with more than a high-school education, and 12 infants had at least one parent who was educated beyond the collegiate level.

As participants in the larger study, infants were seen at home every two weeks for 45 minutes between the ages of 2 and 19 months. At each session they were audio- and video-taped during everyday activities (e.g., playing alone, locomoting around the home, eating), play with the caregiver, and play with rattles. Because the greatest change in rhythmic arm activity in Locke et al.'s (1995) study was apparent in the oldest prebabblers, the new babblers, and the youngest experienced babblers, and since infants in each group differed in age by approximately 4 weeks, the data presented here are taken from three sessions surrounding the onset of reduplicated babble that were spaced at intervals of approximately 4 weeks. These were the session that coincided with babble onset and those that took place one month prior to and one month following babble onset. Babble onset was defined by parent report of production of repeated strings of consonant-vowel syllables (e.g., [bababa]) <u>and</u> experimenter observation of at least two such utterances during a given observational session. Using these criteria, the mean age at babble onset for infants in this sample was 6.56 months ($SD = 1.18$ months), an age consistent with that reported in other recent longitudinal research (e.g., 28.5 weeks, $SD = 3.93$; Eilers et al., 1993).

Procedure

The results presented here are derived from a segment of the overall session designed to parallel the procedure employed by Locke et al. (1995). In this segment, infants were given the opportunity to play with each of a pair of visually identical standard infant rattles—one sounding and one with the noisemaker removed—in two trials lasting approximately 1.5 min each. The rattles consisted of a round plastic head attached to a hard plastic handle in the shape of ring, making it easy to grasp. Infants sat on the primary caregiver's lap and were supported around the abdomen with arms, legs, and feet free to move. At the beginning of each trial, a rattle (with the handle at center and perpendicular to the floor) was presented at midline, and the infant allowed to reach, grasp, and shake. If the infant dropped the rattle before a trial was completed, it was retrieved and presented again at midline. No other objects were available to the infant during this time. Order of trials was fixed, first the audible rattle, and then the silent rattle, and identical for all participants.

Coding

Using a computer program (The Observer, Noldus Information Technologies) all instances of rattle grasping and rattle shaking were identified and coded. The duration of each behavior was also noted.

Grasping was coded when infants held the rattle in such a way that they could manipulate or control the rattle without dropping it. Grasping was only coded when the infant was independently holding the rattle; instances in which the parent or caregiver was assisting the

infant in either grasping or shaking were not included. All grasps were further coded for laterality (right, left, or both). Because infants sometimes transferred the rattle back and forth between the left and the right hands, we excluded instances of grasping with both hands that lasted for less than 1 sec.

A *shake* was defined as an excursion of the arm(s) in the lateral (forward-backward), frontal (right-left), or vertical (up-down) plane that included movement at the elbow and shoulder. To be coded as a shake, the arm(s) had to make a complete excursion in the plane of movement, returning to at least half the distance from the original starting point. Shakes also included arm movements in which the rattle came into contact with other surfaces (including the infant's own body). Shakes were then further coded for laterality. A *shake right* was coded when the infant shook the rattle unimanually with the right hand, a *shake left* was coded when the infant shook the rattle unimanually with the left hand, and a *shake both* was coded when the rattle was held in both hands while the infant was performing a shake.

Reliability

Three trained observers coded infant shaking and grasping from the videotapes. Intercoder reliability was assessed by independent double coding of 15% of the videotapes. Mean agreement was .89 (range 0.83-0.93) for identifying shaking and grasping and .99 for coding laterality (range 0.97-1.0).

Results

This study employed the rattle shaking paradigm utilized by Locke et al. (1995) in a longitudinal data collection designed to evaluate whether grasping and/or rattle shaking increase in relation to the onset of reduplicated babble, whether any grasping/shaking changes prior to, at, and/or following babble onset vary as a function of rattle audibility (audible vs. silent), and whether the proportion of right-handed grasping and shaking increases from pre-babble to babble onset. Following presentation of preliminary analyses focusing on infant age at babble onset, we present data on grasping and rattle shaking in turn.

Preliminary analyses

The age of onset of reduplicated babble among infants in this sample varied widely (range 4-9 months), and preliminary visual inspection of data on grasping and shaking indicated potential effects of infant age at babble onset on these behaviors. In order to remove variance due to age from subsequent analyses and increase power, a post-hoc blocking procedure was employed in which infants were divided into two groups based on mean normative age of babble onset (approximately 7 months; e.g., Eilers et al., 1993): a) those who began to babble before 7 months of age (Younger Babblers); and b) those who began to babble at or after 7 months (Older Babblers). The 15 Younger Babblers (5 males, 10 females) achieved babble onset at an average age of 5.70 months (*SD* = .774); and the 11 Older Babblers (5 males, 6 females) began to babble at an average age of 7.68 months (*SD* = .750).

Grasping

Our measure of grasping was the total time (in sec) that infants held the rattles. These times were calculated separately for the audible vs. silent rattles and the right vs. left hands at each session; and a 3 (Session) × 2 (Audibility) × 2 (Age) repeated measures ANOVA was carried out on these data. Results of this analysis yielded only a single significant effect. Infants were found to grasp the audible rattle significantly longer than they did the silent rattle, $F(1, 24) = 469.56$, $p = .000$ ($M_{audible} = 115.338$, $SD = 22.629$; $M_{silent} = 56.216$, $SD = 15.195$). No other main effects or interactions were reliable. Indeed, mean grasp times for the three sessions were

virtually identical (M_{pre} = 83.923, SD = 29.77; M_{babble} = 83.867, SD = 22.277; M_{post} = 89.541, SD = 27.004) as was the audibility effect at each session.

To examine any laterality effect that might be present in the data, we calculated the proportion of overall grasping time that involved the right hand (i.e., right hand grasping time/total grasping time, a number which is, of course, the reciprocal of the proportion of left-hand grasping). We did this separately for the audible and silent rattles for each infant at each session. These data were arcsine transformed and subjected to a 3 (Session) × 2 (Audibility) × 2 (Age) repeated measures ANOVA. Although there was a slightly greater proportion of right-handed grasping at the Babble Onset (M = .57, SD = .232) and Post-Babble (M = .57, SD = .225) sessions relative to Prebabble (M = .49, SD = .274), this difference failed even to approach significance, F (2, 48) < 1, p = .435, as did all other main effects and interactions. Furthermore, inspection of these data on an infant-by-infant basis revealed that while 15 of 26 infants exhibited a proportionate increase in right-handed grasping from Prebabble to Babble Onset, 11 exhibited a proportionate decrease. This distribution is close to that which would be expected on the basis of chance (Binomial test, p = .69). In short, there was no reliable evidence in these data for a proportionate increase in right-handed grasping at babble onset.

Rattle Shaking

To control for variation in opportunity to shake as a function of varying grasp times, a rate of shaking variable similar to that reported by Locke et al. (1995) was created. This was done by dividing the total number of shakes by the total grasping time separately for each hand and for audible and silent rattles at each of the three sessions. Two 3 (Session) × 2 (Audibility) × 2 (Age) repeated measures ANOVAs were carried out on these data, one on the data from right-hand shaking, a second on the data from left-hand shaking. Results from the two analyses were highly parallel.

With regard to right-hand shaking, analyses revealed a significant main effect of Session, F (2, 48) = 7.192, p = .002, and a trend toward main effects of Audibility, F (1, 24) = 3.272, p = .083, and Age, F (1, 24) = 3.299, p = .082; but no significant interactions. Overall older infants tended to have a higher shaking rate (M = .37, SD = .153) than younger infants (M = .16, SD = .12), infants tended to produce higher rates of shaking with the audible (M_{aud} = .406, SD = .438) than with the silent rattle (M_{sil} = .279, SD = .219); and there was a striking increase in rate of shaking from Pre-Babble to Babble Onset. The right hand means by session are presented below in Figure 1. As is evident in the figure, rate of rattle shaking with the right arm increased almost fourfold from Prebabble (M = .09, SD = .131) to Babble Onset (M = .40, SD = .285). Pairwise comparisons revealed that this difference was highly significant (p = .004). Rate of right arm shaking declined somewhat from the Babble Onset to the Postbabble session (M = .32, SD = .277), but the difference was not statistically reliable.

With regard to left-hand shaking, analyses revealed significant main effects of Age, F (1, 24) = 6.335, p = .019, and Session, F (2, 48) = 8.893, p = .001, and a trend toward a main effect of Audibility, F (1, 24) = 2.756, p = .110; but no significant interactions. Overall older infants had a significantly higher shaking rate (M = .281, SD = .235) than younger infants (M = .127, SD = .203), infants tended to produce higher rates of shaking with the audible (M = .228, SD = .199) than with the silent rattle (M = .180, SD = .138); and again there was a striking increase in rate of shaking from Pre-Babble to Babble Onset. The left hand means by session are also presented in Figure 1. As is evident, rate of left-arm shaking increased sharply from Pre-Babble (M = .05, SD = .101) to Babble Onset (M = .33, SD = .361), a difference that was highly reliable (p = .001), and there was a significant decline from Babble Onset to Postbabble (p = .025). In short, the data for right- and left-hand shaking are strikingly parallel. As with grasping times, in other words, there is no evidence for a right-hand advantage from pre-babble to babble onset.

Examination of data from individual infants also confirmed the absence of an increase in right arm activity at babble onset. For this analysis, we examined the magnitude of change in rate of shaking from Prebabble to Babble Onset in the right vs. left arms by computing the difference between rates of right arm shaking and rates of left arm shaking separately for each infant. We then classified infants into two groups on the basis of whether they exhibited greater change in shaking rate in the right or the left arm. Of the 25 infants for whom data were available[2], 14 demonstrated greater change in the right arm and 11 greater change in the left arm, a distribution quite close to that expected by chance (Binomial test, p = .69).

Lastly, because it is theoretically possible that change in right arm activity at babble onset, even if not evident in grasp times or shaking rates, might be manifest in production of temporally more extended bouts of activity with the right than the left arm at Babble Onset, we performed two final analyses. First we calculated the average shaking bout duration (i.e., number of shakes/total shake duration) at Babble Onset separately for the right and left arms and compared them. Results indicated that at the Babble Onset session, shaking bouts produced with the left arm ($M = 2.03$, $SD = .723$) were almost identical in duration to those produced with the right arm ($M = 1.99$, $SD = .558$); the slight difference was not statistically significant, $t(19) = -.724$, ns. In addition, we examined the magnitude of change in the duration of right vs. left arm shaking bouts from the Prebabble to the Babble Onset session on an infant-by-infant basis. Results of this analysis indicated that 15 infants exhibited greater change in the right arm and the remaining 10 greater change in the left arm, a distribution once again not reliably different from that expected on the basis of chance (Binomial test, p = .42).

Discussion

This research used a longitudinal design to gather data relevant to the hypothesized relationship between reduplicated babble onset, rhythmic arm activity, and the emergence of a temporary right hand preference in infants. Only two studies have previously addressed aspects of this topic. One of these studies (Ramsay, 1984) followed infants longitudinally so that age of babble onset could be specified, but examined hand preference in the context of a single behavior (i.e., toy contacts) that is not known to be systematically related to the onset of reduplicated babble. The other study (Locke et al., 1995) focused on a behavior known to increase substantially at babble onset (i.e., rhythmic arm activity), but employed a cross-sectional analysis that precluded exact specification of the babble onset period. In the Locke et al. study, infant age was employed as a proxy variable for time since babble onset.

The present study was designed to overcome the limitations inherent in both of these approaches by examining laterality biases in rhythmic arm activity in infants followed longitudinally and for whom data were therefore available regarding both the timing of reduplicated babble onset and possible shifts over time in the frequency of rhythmic arm activity. We found no evidence for the appearance of a right hand bias in manual activity or any interaction between hand preference and the increase in rhythmic arm activity at this point in development. Following a discussion of this result in the context of the controversy surrounding the nature of babbling, we consider the implications of increased rhythmic arm activity at babble onset for the development of the link between gesture and speech.

Is Babbling a Motor Skill, a Language Skill, or Both?

Contrary to prior report, we found no indication of a shift to a right hand preference at reduplicated babble, neither at the group level nor among individual infants. In other words, our data do not support the supposed shift to left-lateralized motor activity at babble onset that

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[2]Data from one infant were excluded from this analysis due to failure to shake the rattle at either session.

is sometimes cited as evidence that babble onset is controlled by mechanisms uniquely specialized for language. While this is only one of several findings used as support for the linguistic view of babbling and our data do not speak to the other sources of evidence, our results do suggest at minimum that the previously reported temporary shift to right-hand preference at babble onset should not be cited as support for the linguistic view.

At issue in the controversy surrounding the motor and linguistic views of babbling is the extent to which the onset of babbling *necessarily* reflects the operation of mechanisms *unique* to language and language development. Thus, for example, Petitto et al. (2004) have claimed that when infants babble, their production reflects the syllabic units of their language from the very start. Implicit in this claim is that because there is an isomorphism between the sound patterns present in infant babble and the syllable as the fundamental unit of human language, babble must therefore reflect the operation of language-specific mechanisms.

Reasoning such as this is analogous to arguing that since the leg movements involved in the kicking of very young infants reflect the later leg movements involved in walking, kicking must therefore necessarily reflect the operation of walking-specific mechanisms. However, recent work suggests that assumptions based on logic of this sort may be mistaken. Galloway and Thelen (2004), for example, demonstrated that when a toy is presented near the feet, infants can adapt their leg movements online to reach for the object, suggesting that leg movements are not necessarily predestined uniquely for walking. It is not, in other words, logically necessary to conclude that infant babbling must be a uniquely linguistic behavior simply because it involves the presence of syllable-like units.

In our view, asking whether babbling is *either* a motor skill *or* a language skill obscures its complexity and richness as a behavioral and developmental phenomenon. The view of babbling as a motor stereotypy is by no means incompatible with evidence for its demonstrated relationship to the developing language system and its potential role in language development (see also Oller, 2000, for a similar argument). Babbling could, in principle, *begin* as an oscillatory behavior that is a product of the developing speech motor system; but its emergence could then initiate a cascade of new opportunities for learning and environmental changes that have major implications for the developing language system.

Consider again the case of infant leg kicking. Kicking may *begin* as an oscillatory behavior that is a product of the developing motor system; but then become adapted to meet specific task demands (e.g., Angulo-Kinzler & Horn, 2001; Angulo-Kinzler, Ulrich, & Thelen, 2002; Thelen, 1994) and lead infants to learn about the consequences of self-produced movement (e.g., Rovee-Collier, 1991). In other words, kicking provides infants with opportunities to gain control over the limbs and patterns of limb coordination and to learn about properties of the effectors (the legs) and relationships between self-produced movements and features of the environment that will be required for the acquisition of controlled behavior in later walking (Ulrich & Ulrich, 1995).

We see strong parallels between the relationship of leg kicking to walking just described and the relationship of reduplicated babble to language. The onset of reduplicated babble is a marker of infants' progress in the development of speech motor control: it is fundamentally an oscillatory behavior, reflecting developing control over the speech articulators. Early on, the product of this activity is a sound pattern that may be perceived by mature speakers as strikingly speech-like because, for biomechanical reasons, it is organized into units that correspond to syllables in adult language.

However, once achieved, the simple motor rhythmicity underlying reduplicated babble production introduces a major qualitative change in infants' vocalizations, and this in turn has at least two significant consequences for the developing language system. First, reduplicated

babble provides new opportunities for infants to learn about language-specific sounds. Babble is a means for infants to practice increasingly complex articulatory movements (e.g., varying tongue position during mandibular movement), and, as they work on this skill, to amass information about the auditory and proprioceptive consequences of their own articulatory movements and relate them to the phonetic properties of the ambient language. The effects of this process are evident in the phenomenon of "babbling drift," in which the vocalizations of infants toward the end of the first year increasingly reflect the sound inventory specific to the target language (e.g., de Boysson-Bardies, Sagart, & Durand, 1984; de Boysson-Bardies & Vihman, 1991).

Second, infants' production of more speech-like vocalizations may induce changes in the nature of the input they receive. Work by Goldstein and West (1999) suggests that parents are sensitive to differences in the complexity of infants' vocalizations, shifting their interpretations of infants' behavior (e.g., whether the baby wants something, is distressed, or attempting to communicate) in response to change in the acoustic properties of infants' vocalizations (e.g.. marginal syllables vs. canonical babble). In further experimental work, Goldstein and colleagues (2003) demonstrated that parents' nonimitative, contingent responses to their infants' vocalizations relate to increased vocalization overall and to increased rates of infants vocalizations with more mature voicing and syllabic structure. Thus, infants' production of more developmentally advanced vocalizations, in conjunction with caregivers' responses to those vocalizations, may provide additional sources of information that set the stage for further refinement in infant vocal production.

In short, it appears to us that babbling can be conceptualized as *both* a motor and a language skill. Babbling may have its origins in the oscillatory properties of the developing speech motor system, but its emergence and continued production has far-reaching consequences that extend to other developing systems, providing opportunities for increasingly complex learning about correspondences between articulatory movements, their auditory consequences, and mappings between productions and target sounds in the language, and inducing change in patterns of input (see also Thelen, 1991). In that sense, it may be thought of as "linguistic," but it may not be uniquely so.

Rhythmic Arm Activity and Reduplicated Babble: Implications for the Development of the Gesture-Speech Link

Consistent with previous reports (e.g., Ejiri, 1998; Locke et al., 1995), we found a sharp increase in rhythmic arm activity at the onset of reduplicated babble. In addition, however, because our longitudinal data collection allowed us to specify age of babble onset with some precision and because infants vary widely in age of babble onset (4-9 months in this sample), we were able to disentangle the effects of age from the effects of babble onset on this increase. Specifically, our data indicate that an increase in rhythmic arm activity occurs at babble onset regardless of the age at which it occurs. Although younger babblers produced fewer shakes overall than did older babblers, younger and older babblers alike exhibited increased rhythmic arm shaking at babble onset. Furthermore, this increase was evident in shaking rates for both arms and for both the audible and silent rattles. Thus, the consistency with which arm rhythmicity changed at babble onset across infants, arms, and rattles suggests that it is a developmentally robust phenomenon (see also Cobo-Lewis et al., 1996; Eilers et al., 1993; Lynch et al., 1995; Masataka, 2001).

What are the implications of this developmental event for the emergence of the link between gesture and speech? Iverson & Thelen (1999) have proposed that the tight linkage between gesture and speech is likely a manifestation of more general links between language and movement systems observed in adults and in infants. In adults, there is ample evidence for neural connections between language and movement systems in the brain. Thus, for example,

regions typically implicated in motor functions (e.g., inferior lateral cerebellum) are active in language tasks (e.g., Petersen et al., 1989), and there is evidence for the existence of anatomical pathways connecting the cerebellum to other classical 'language areas' (e.g., Leiner, Leiner, & Dow, 1989, 1993). Conversely, areas of the brain implicated in language functions (e.g., Broca's area) are also involved in motor tasks. Much of this research has focused specifically on Broca's area (Brodmann's area 44, 45, and 46); the general finding is that activation occurs in portions of Broca's area during motor tasks, particularly tasks involving hand movement (e.g., Erhard et al., 1996; Iacoboni, Woods, Brass, Bekkering, Mazziotta, & Rizzolatti, 1999). This result is of particular importance because it points to a possible neural substrate for the link between gesture and speech. Broca's area appears to play a critical role in the generation of coherent sequences of action. Such a mechanism may well be involved in the co-production of speech and gesture, which requires the generation of sequential movements that are precisely timed with one another.

While there is currently no comparable neurophysiological evidence available for infants, a number of behavioral studies have provided evidence consistent with the existence of such links. Thus, for example, coordination between oral and manual actions is relatively common in young infants' spontaneous movements. When newborns bring their hands to the facial area to introduce the fingers for sucking, they open their mouths as the hand is moving toward the facial area, in anticipation of its arrival (Butterworth & Hopkins, 1988; Lew & Butterworth, 1997). Similar movements have also been observed during ultrasonic scans of fetuses beginning at 12 to 15 weeks gestational age, occurring as frequently as 50-100 times per hour (de Vries, Visser, & Prechtl, 1984).

Assuming an initial linkage of the mouth and hand subserved by the same brain systems, it is plausible that rhythmicity in the two effector systems is mutually influential. This combination of initial vocal-motor couplings and mutual influence may provide a developmental pathway to the gesture-speech link, and the onset of reduplicated babble may mark an important milestone along this pathway. Whereas infants may initially coordinate vocalizations with rhythmic activity in other limbs and body segments (e.g., legs, torso), the increase in rhythmic arm activity at reduplicated babble onset presumably creates more opportunities for *specific* entrainment of the vocal and manual systems to occur. Thus, the tendency to coordinate vocalizations with *manual* activity may be differentially strengthened relative to that for vocalizations with other limb movements. This claim is supported by the finding that among 6 month-old infants, the proportion of rhythmic manual movements produced in coordination with vocalization was almost twice as high for babblers as that for prebabblers (Iverson & Fagan, 2004).

That these bouts of coordination between rhythmic upper limb activity and vocalization may be a developmental precursor to the patterns of coordination observed in mature speakers is suggested by three additional findings (Iverson & Fagan, 2004). First, a majority of vocal-manual coordinations involved one arm rather than both arms. Second, right-arm movements were more likely to be coordinated with vocalization than left arm movements. This preference for coordinating vocalization with right-arm movements is parallel to patterns observed in the gesture-speech co-productions of adults: in right-handed speakers, most gestures are executed with a single arm, and most often with the right arm (Kimura, 1973a, 1973b). Finally, the vast majority of infant coordinations displayed the pattern of temporal organization evident in adult gesture-speech co-productions, with motor activity either slightly anticipating or synchronous with vocalization onset (e.g., Nobe, 2000; McNeill, 2005).

Thus, once infants have begun to babble, the vocal-manual link is progressively strengthened. At the same time, the tendency to coordinate vocalization with rhythmic nonmanual behaviors begins to decline (Iverson & Fagan, 2004). By the time infants reach the ages of 9-12 months,

the time of first gesture and first word onset (e.g., Bates et al., 1979), the link between vocalization and manual activity is strong, specific, stable, and potentially available to be utilized for purposes of communication.

In sum, the findings reported here provide no indication of a shift to a temporary preference for right-hand activity at reduplicated babble onset. There was, however, a sharp increase in production of rhythmic arm activity that is apparent in babblers varying widely in age, in both arms, and with both audible and silent rattles. While the appearance of babbling can be construed as both a motor and a language milestone, we propose that it is also a milestone in the development of the gesture-speech system. With the emergence of babble, there are increased opportunities for mutual vocal-manual entrainment that may lead to the increased likelihood of coordination between bouts of vocal and manual activity. In addition to providing a means for infants to work out the problem of coordinating vocal with manual activity (a foundational ability in mature gesture-speech production), production of such coordinations may in turn serve to strengthen the vocal-manual link. Thus, the link between gesture and speech may be constructed in the course of everyday activity, as infants vocalize and move their bodies. The coupling between vocal and manual activity and the ability to coordinate behaviors in the two systems may then be co-opted for communication when children begin to talk and to use gestures. We believe that this perspective is consistent with the beautifully articulated view of Bates (2004) that language is "a new machine that nature has constructed out of old parts" (p. 250). Rhythmic motor activity and reduplicated babble may be among the old parts from which the gesture-speech link is eventually constructed.

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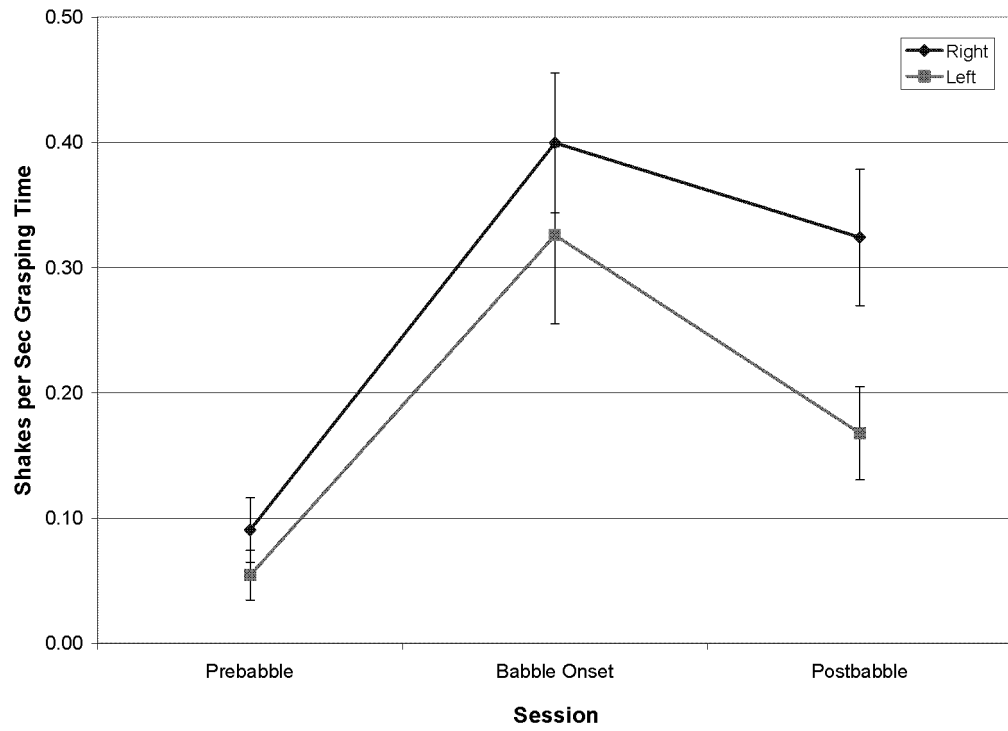Vihman, MM. Phonological development. Blackwell; Cambridge, MA: 1996.

Figure 1.
Mean rate of right- and left-arm shaking as a function of babble onset status.