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Developing language in a developing body: the relationship between motor development and language development*

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ABSTRACT

During the first eighteen months of life, infants acquire and refine a whole set of new motor skills that significantly change the ways in which the body moves in and interacts with the environment. In this review article, I argue that motor acquisitions provide infants with an opportunity to practice skills relevant to language acquisition before they are needed for that purpose; and that the emergence of new motor skills changes infants' experience with objects and people in ways that are relevant for both general communicative development and the acquisition of language. Implications of this perspective for current views of co-occurring language and motor impairments and for methodology in the field of child language research are also considered.

The emergence of language is one of the crowning achievements of the first two years of life. We now know a great deal about developmental precursors to language and its timetable of emergence in both typically and atypically developing children; and it is widely acknowledged that there are links between achievements in the cognitive and social communication domains and the emerging language system.

During the first eighteen months of life, however, infants also acquire and refine a whole set of new motor skills that fundamentally transform their experiences with objects and people. Indeed, independent locomotion is one of, if not the developmental event most eagerly anticipated by proud

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parents; and, along with the acquisition of language, it is one with the greatest impact on the infant's world.

Despite widespread interest in describing ways in which the emergence of behaviors in the cognitive and social communication domains are related to and may even predict advances in language, little attention has been devoted to exploring the relationship between motor development and language development (but see Darrah, Hodge, Magill-Evans & Kembhavi, 2003; Le Normand, Vaivre-Douret & Delfosse, 1995; Molfese & Betz, 1987). This is particularly surprising given the long-standing, widespread but empirically unverified belief among parents, pediatricians and even some developmentalists that when children are in the process of acquiring new motor skills, progress in language comes to a halt (see Tipps, Mira & Cairns, 1981).

One reason for the lack of attention to the relationship between motor development and language development may be the general neglect within psychology of 'movement' as a topic of study. It is a paradox, indeed, that in a science of behavior, research on movement and motor control has little more than 'Cinderella' status within the field (see Rosenbaum (2005) for a lovely discussion of this issue).

A second reason may have to do with the fact that older views seen as ascribing parallels in motor and language milestone achievement to neuromotor maturation (e.g. Gesell, 1929; McGraw, 1943) are also thought to have been largely discredited. Indeed, it was in response to maturationism of this sort that early child-language researchers set out to characterize language development as a different kind of developmental task, arguing that because language requires abilities that are domain-specific, the process of language learning was fundamentally different from that of motor development (e.g. Lenneberg, 1967).

One premise of this article is that the development of language should be viewed in the context of the body in which the developing language system is embedded. In infancy, there are significant changes in the ways in which the body moves in and interacts with the environment; and these may in turn impact the development of skills and experiences that play a role in the emergence of communication and language. In the sections that follow, I review literature and reinterpret published findings related to the development and refinement of motor skills in infancy and their potential impact on the developing language system. The central claim is that changes in motor skills (i.e. achievements and advances in posture, independent locomotion and object manipulation) provide infants with a broader and more diverse set of opportunities for acting in the world. These opportunities provide contexts for acquiring, practicing and refining skills that contribute, both directly and indirectly, to the development of communication and language.

Before proceeding to this review, however, it is necessary to offer five caveats. First, for purposes of this article, 'motor development' is defined in terms of the larger motor system, exclusive of the movements involved in speech articulation. It is indisputable that speech production is a motor act, and links between oral-motor physiology, skill acquisition and oral language have been described elsewhere (e.g. Green & Wilson, 2006; Nip, Green & Marx, 2009; Thelen, 1991). While learning to coordinate and control the speech articulators is a core component of oral language development, it falls beyond the scope of this paper except insofar as it reflects developments in other motor systems (e.g. rhythmic arm movement), a topic to which I will return.

Second, for children learning signed languages, the primary articulators are, of course, the hands and arms, and there is evidence that motoric factors constrain children's early sign production (e.g. Meier, Mauk, Cheek & Moreland, 2008). Although spoken and signed language acquisition involves different articulators, a number of the issues to be discussed below are equally relevant to language development in both modalities.

Third, while there is a rich and rapidly growing literature detailing neurophysiological links between language and motor functions in adults (for an excellent recent review, see Willems & Hagoort, 2007), comparable data are not yet available for very young children. Thus, the focus of this article will be on behavioral rather than neurophysiological studies that speak to the relationship between motor and language development.

Fourth, the discussion that follows will be restricted to addressing evidence concerning the relationship between motor and language development in typically developing children. Questions concerning the relationship between risk status and motor development, the nature of motor delay and the effect of motor delay on language development in atypical populations are of great theoretical and practical interest; but they are, unfortunately, also beyond the scope of this discussion, albeit I will return to this topic very briefly in the 'Conclusion', when I discuss the implications of points made here for future research.

Finally, the link between language and gesture is, of course, an instantiation of the relationship between the language and motor systems. A substantial body of literature focusing on the nature and development of this link has been reviewed in detail elsewhere (e.g. Goldin-Meadow & Iverson, in press; McNeill, 2006); and it will therefore not be a focus of this review. Instead I will focus on other examples of the broader interface between the language and motor systems in development.

The body of this paper is organized in three major sections. The first addresses the issue of parallels that exist in the average ages of motor and language milestone achievement during the first year and reviews correlational analyses of individual differences in ages of milestone

achievement. These data are consistent with the view that developments in these areas are not a simple function of underlying neuromotor maturation.

Next, I discuss evidence concerning the relationship between rhythmic arm movement and the onset of reduplicated babble, changes in infants' skill in object displacement in relation to first words and the vocabulary spurt, and the emergence of naming in action and in words. These findings are used to support the claim that motor acquisitions provide infants with an opportunity to practice skills relevant to language acquisition before they are needed for that purpose.

Finally, I review data on the impact of the emergence of crawling and walking on communicative development and of unsupported sitting, object mouthing and object manipulation on prelinguistic vocalization. The interpretation of the data presented here is that the emergence of new motor skills changes infants' experience with objects and people in ways that are relevant for both general communicative development and the acquisition of language.

LANGUAGE DEVELOPMENT IS NOT A SIMPLE CONSEQUENCE OF NEUROMOTOR MATURATION

More than sixty years after the fact, and in an era in which the syntactic, semantic, lexical and phonological complexity of language is taken for granted, it may be difficult to appreciate the force of one of the very first questions to be raised about the relation of language to motor development. This was the question of the extent to which the emergence of language is dependent on neuromotor maturational processes. The maturationist view derived in part from the work of Gesell (1929), who claimed that '[t]he developmental complex as a whole, in spite of its manifoldness, tends to proceed as a whole … When the complex is divided into motor, language, adaptive, and personal-social behavior aspects, these factors prove to cohere to a considerable degree' (p. 126). But, as Lenneberg (1967) pointed out in a classic work, it was also seemingly suggested by the fact that major speech milestones are reached in a fixed sequence and at relatively constant chronological ages and by the fact that there is 'a remarkable synchronization of speech milestones with motor-developmental milestones' (p. 127). Indeed, and paradoxically, since it was his goal to argue strongly against the maturationist view, Lenneberg even provided a table (Table 4.1, pp. 128–30) with illustrative examples of concurrent developments in language and motor abilities. During the first year, for example:

(1) At twenty weeks, infants begin to sit with support. Vocalizations, which previously consisted of vowel-like cooing sounds, are now interspersed with consonant-like sounds.

(2) At 0;6, infants begin to sit independently and are able to lean forward and reach unilaterally while sitting. Cooing changes into babbling that resembles single-syllable utterances; but neither vowels nor consonants have fixed recurrences.
(3) At 0;12, children can walk when held by one hand and mouthing of objects has almost ceased. Vocalizations contain an increased frequency of occurrence of identical sound sequences; and words (e.g. *mamma* or *dadda*) begin to emerge.

Although examples such as these might appear to provide evidence of links between motor and language development (an issue to which I will return below), Lenneberg (1967) used them as a means for making a strong argument against this view, claiming not only that 'the onset of language is not simply the consequence of motor control' (p. 127) but that there is 'independence of language development from motor coordination' (p. 131). His claim was based on two principles: (a) that the development of language is independent of articulatory skills; and (b) that mastery of articulation patterns cannot be predicted on the basis of general motor development.

With regard to the first, Lenneberg (1967) cites the common observation that most children produce a word or two before they begin to walk, suggesting that even before the end of the first year they possess some of the articulatory skill necessary for speech production; and yet subsequent vocabulary growth occurs in an exceedingly slow manner, indicating its dependence on factors other than articulatory skill. Along similar lines, children who produce single words cannot be trained to combine two words into a single utterance, even though they babble for periods longer than the duration of sentences and often with adult-like intonation. In Lenneberg's view, phenomena such as these indicate that the availability of articulatory abilities is not sufficient for language development; there must be other psychological factors that are responsible for its slow pace.

With regard to the second principle, Lenneberg (1967) noted that while manual skills in early childhood show improved coordination relative to those in infancy, manual dexterity is still quite immature on an absolute scale, falling far below future levels of accomplishment. By contrast, speech articulation, which requires extremely precise and rapid movements of the lips and tongue in finely tuned coordination with activity in the laryngeal and respiratory systems, is all but fully developed by age 3;0. Lenneberg interpreted this difference between manual and speech articulatory skills as an indication that the development of speech control is independent of the development of hand and finger control.

While Lenneberg's (1967) analysis was based on general patterns in the average age of motor and language milestone achievement, his argument gained further support from longitudinal studies of individual differences in early language and motor development carried out by Bates, Benigni, Bretherton, Camaioni & Volterra (1979) and Bloom (1993). In both studies, measures of motor development were included as proxy variables for physical and neural maturation with a view to demonstrating that observed relationships between aspects of cognitive, communicative and language development were not simply a product of global maturation.

Thus, for example, Bates *et al.* (1979: Ch. 2) included an eleven-item locomotor development scale in a longitudinal study of twenty-five infants followed from 0;9 to 0;12. Ages of onset for major locomotor milestones spanning the first three years (e.g. sitting without support, pulling to a stand, walking independently, jumping) were reported by mothers and verified by experimenter observation at monthly home visits. A single score was derived from both the maternal report and the observations and included in correlational analyses with maternal report and observational measures of gestural communication and language.

Although Bates *et al.* (1979) did not provide specific values for correlational analyses carried out between gestural communication and locomotor development, they note that:

> Correlations among communicative variables would be of relatively little interest if they were simple epiphenomena of general physical and neural maturation. Insofar as the locomotor development scale is an adequate measure of physical maturation, we can conclude that the pattern of results for gestural communication is not an artifact of very general developmental factors. Locomotion correlated positively and significantly with the gestural measures in only 4 out of 200 possible relationships, or 2% of the matrix. (p. 94)

A comparable result was obtained with the various language measures (e.g. comprehension, babble, word production). Although, again, no specific correlation values are reported, the authors state that only 15 out of 120 possible correlations were significant, and that the correlations between language and locomotor development were much lower than those for the language measures with one another. Based on these findings, they concluded that 'it is, then, extremely unlikely that the relationships among various aspects of early language development are artifacts of general maturation' (p. 102).

A similar approach was taken by Bloom and colleagues in a longitudinal study of the relation between object play and language (Lifter & Bloom, 1989; see Bloom, 1993). The fourteen infants who participated in the study visited the laboratory for monthly play sessions between the ages of

0;8 and 2;2. While the study was designed to focus on developmental changes in infants' object play and vocabulary acquisition (see additional discussion below), the investigators also included two measures of motor development: age of walk onset (defined as the ability to take two independent steps without support or assistance) and performance on a block building task, in which infants were given a set of 1-inch wooden cubes and encouraged to build a tower. The criterion for passing the task was independent construction (i.e. with no direct adult assistance) of a tower of six cubes.

In line with Bates *et al.* (1979), Bloom (1993) noted that the walk onset and block building measures were intended to provide a means for determining whether any observed relationships between variables of interest (i.e. play and language development) were independent of age, and not a product of 'simple maturation'. Along these lines, she reports that age at walk onset was not systematically related to the age at which the first word was produced, and that although the mean age for walk onset for the group of children was one month prior to that for first words, earlier and later word learners did not differ in average age of walking. Thus, all of the later word learners (but only two of the early word learners) walked before they said their first words.

Progress in block building was also generally independent of developments in play and language. All of the children, regardless of the timing of achievements in play and language, were similar in age when they first passed the block building task. Bloom (1993) cites the examples of Shirley, who reached first words and the vocabulary spurt at 0;10 and 1;1, respectively, and Jessica, who reached these milestones at 1;2 and 1;10; but despite this variation in language abilities, both succeeded at constructing a tower of six blocks at 1;9 but not at 1;6. Based on these results, Bloom concluded that 'block building is a motor skill that is age related and determined by maturation. In contrast, developments in play and language … were not simply a function of age and general maturation' (p. 239).

In sum, the view of motor development and its potential relationship to language development described above makes a clear distinction between achievements in the two domains. The general theoretical goal of this research, broadly speaking, was to demonstrate that the development of language involves a unique constellation of interrelated cognitive and symbolic abilities (many of which are not language-specific) that come together at a particular point in time. Because motor development was conceptualized as a proxy variable for general maturation, it needed to be explicitly ruled out in order to make the argument for direct, specific relations between language and other cognitive and symbolic abilities.

In an era in which the relationship between language and other cognitive and symbolic abilities is no longer controversial and in which few (if any) would argue that language development is a simple product of neuromotor maturation, these results are not unexpected. Unfortunately, however, they can be easily misinterpreted as suggesting that infant motor skills and motor development during the first eighteen months are irrelevant to the development of language. That this IS a misinterpretation is perhaps the major point of this article. My defense of this proposal proceeds in the following way. In the next section, I argue from developmental evidence that the acquisition of motor skills provides infants with an opportunity to practice skills relevant to language acquisition before they are needed for that purpose. I then show that the emergence of new motor skills changes infants' experience with objects and people in ways that are relevant for both general communicative development and the acquisition of language.

SPECIFIC MOTOR BEHAVIORS PROVIDE THE OPPORTUNITY TO ACQUIRE AND PRACTICE SKILLS CRITICAL FOR THE DEVELOPMENT OF LANGUAGE

Interest in examining relationships between developments in language and other non-linguistic domains (e.g. play, symbolic abilities) grew rapidly in the 1970s, and a number of researchers began to document correspondences between milestones in the development of non-linguistic skills and achievements in language (e.g. Corrigan, 1979; Nicolich, 1977; Snyder, 1978). This work was part of a broader theoretical effort to demonstrate that language is not solely a product of domain-specific, dedicated processes and abilities, but rather draws on skills from other domains. Thus, for example, Bates *et al.* (1979) argued that the links observed between achievements in non-linguistic cognition (e.g. symbolic play) and early developments in language were indicative of the emergence between 0;9 and 1;0 of a general symbolic function manifested not only in language behaviors but also in behaviors outside the realm of language (e.g. in play-related actions).

A key characteristic of the non-linguistic behaviors explored in relation to language during this period was that they were classic sensorimotor behaviors of the sort described by Piaget (1952). Studies in this tradition focused primarily on describing these behaviors in terms of the underlying cognitive abilities that they revealed and the relevance of those abilities for language development (e.g. Bates *et al.*, 1979). In the context of the current discussion, however, it is important to emphasize that although these sensorimotor behaviors are undoubtedly indices of underlying cognitive change, they are also MOTOR behaviors, behaviors that represent

advances in the infant's capacity for action. In this section, I consider three sensorimotor behaviors – rhythmic arm movement, object construction, and recognitory gestures – from an action perspective and explore ways in which the emergence and development of these actions provide infants with opportunities to practice skills that are ultimately shared with language. Practicing these skills in the context of concrete action provides infants with immediate and salient visual, auditory and kinesthetic feedback, the opportunity to observe the result of the action in relation to this feedback, and a means for beginning to notice and attend to the relationship between their own motor action and its effects.

Example 1: increased rhythmic arm movement coincides with the onset of reduplicated babble

In a longitudinal study of rhythmic motor stereotypies in typically developing infants during the first year of life, Thelen (1979) reported a striking peak in frequency of rhythmic arm movements (e.g. shaking, swinging, banging) at around twenty-eight weeks of age. This is also the age at which many infants begin to produce reduplicated babble, vocalizations in which well-formed syllables are organized into a regularly timed, rhythmically organized sequence (e.g. [bababa]; Koopmans-van Beinum & van der Stelt, 1986; Oller & Eilers, 1988).

Several longitudinal studies have explored the nature of the relationship between rhythmic arm activity and onset of reduplicated babble by following infants from the pre-babble period through the onset of reduplicated babble. In the first of these, Eilers, Oller, Levine, Basinger, Lynch & Urbano (1993) followed infants from the second month of life, with regular laboratory observations occurring every two to four weeks. Parents reported the onset of rhythmic hand banging and reduplicated babble, and behavior onset was credited when an experimenter confirmed the parent's report via observation during a subsequent lab visit.

Results indicated that the mean age of onset of rhythmic hand banging preceded that for reduplicated babble by two to three weeks. Although no correlational analyses are presented and the extent to which this pattern was apparent in individual infants within the sample is not described, these data suggest the possibility that hand banging may present an opportunity for practicing the production of rhythmically organized, tightly timed actions of the sort required for babbling. Specifically, hand banging produces highly redundant, multimodal feedback that facilitates infants' growing awareness of correlations between their own movements and resultant sound patterns. When infants engage in rhythmic banging, they feel themselves move, they see the movement of their arms, and they hear the resultant sound, all occurring in synchrony. The extensive

literature on multimodal perception in young infants (see Lewkowicz (2000) for a review) suggests that infants are highly sensitive to this type of synchrony, and that the presence of such redundant cues facilitates recognition of contingencies (e.g. Gogate & Bahrick, 1998; Gogate, Bolzani & Betancourt, 2006). When infants subsequently begin to babble, they may very well be better prepared to recognize the contingent auditory feedback from their own sound production, feedback that allows them to monitor and adjust the state of the vocal tract as they vary their sound production.

Support for this view comes from three longitudinal studies that have taken a milestone-based approach to the relationship between rhythmic arm movement and reduplicated babble (Ejiri, 1998; Iverson, Hall, Nickel & Wozniak, 2007; Locke, Bekken, McMinn-Larson & Wein, 1995). In all of these studies, infants were given rattles to shake, their rattle-shaking was observed in sessions prior to, at and following the onset of reduplicated babble, and changes in rhythmic arm activity were examined as a function of time relative to babble onset (i.e. without regard to infant chronological age). The consistent finding was that rhythmic arm shaking was lowest in pre-babbling infants, increased sharply in infants who had just begun to babble, and then began to decline as infants became experienced babblers. This pattern (distinct time of onset, peak and decline) parallels that of developmental trajectories observed for other rhythmic stereotypies (Thelen, 1979). Thus, for example, infants rock on all fours before they crawl and wave their arms before they reach; and once these milestones have been attained, rocking and arm waving become less frequent. On this view, once infants have begin to babble, rhythmic arm activity may have accomplished at least part of its developmental task – providing infants with a rich sensorimotor context for practicing skills that underlie (at least in part) the production of reduplicated babble.

The close temporal relationship between reduplicated babble and rhythmic arm activity is often interpreted as indicating that babble is one of a family of rhythmically organized motor stereotypies that emerge and are commonly produced by infants during the first year of life (e.g. MacNeilage & Davis, 2000; Kent, 1984; Iverson *et al.*, 2007; Meier, McGarvin, Zakia & Willerman, 1997) and as evidence of a tight, specific link between the manual system and the oral–vocal system (e.g. Iverson & Thelen, 1999). The data reviewed above suggest a third, complementary interpretation of this relationship, namely that skills observed in rhythmic arm activity are shared by reduplicated babble. As infants perform rhythmic arm movements, they have the opportunity to practice a skill – production of rhythmically organized, tightly timed actions – that is a central characteristic of reduplicated babble. Hand banging provides a supportive context for the development of this skill because it provides multimodal feedback that

allows the infant to observe (and vary) the relationship between a concrete action and its auditory and visual properties.

Example 2: developments in object displacements in play are related to first words and the vocabulary spurt

Lifter & Bloom (1989; see also Bloom, 1993) conducted a longitudinal study of the relationship between language and object knowledge, as indexed by object displacements in spontaneous play. They focused specifically on identifying developments in play and their relationship to the emergence of specific object knowledge, i.e. of the perceptual and functional attributes that differentiate objects from one another. They reasoned that the extent to which children's actions with objects took account of specific properties of those objects provided a source of information for inferring the object-specific knowledge that underlies the formation of the object concepts necessary for talking about objects and events. Once again, however, it is important to note here that the development of action on objects depends not only on cognitive gains but also on gains in motor skills such as unilateral reaching, use of a pincer grip, finer eye-hand coordination, and independent use of the hands and arms in relation to one another.

In their longitudinal study of infants seen monthly between the ages of 0;8 and 2;2, Lifter & Bloom (1989) examined object displacement activities, defined as actions in which infants moved one toy in relation to another (e.g. dropping a bead into a container, putting one nesting cup into another, feeding a doll with a spoon) 'with deliberate volition to achieve the action' (p. 399). The primary criterion for 'volition' was that the infant had to orient to the object first and then act on it; success in achieving the target action was not considered in this coding decision, but random encounters with objects (e.g. accidentally dropping a bead into a box) were ignored.

Once object displacements had been identified, an initial distinction was made between those that were SEPARATIONS, involving DISASSEMBLY of a complex object into components (e.g. taking a peg person out of a seesaw), and those that were CONSTRUCTIONS, involving ASSEMBLY of a more complex object out of components (e.g. putting a peg person into a seesaw). Constructions were then subclassified according to whether or not they: (a) were imposed by the child and differed from those originally presented by the researchers (e.g. putting a peg person into a nesting cup); and (b) made use of particular properties of objects in relation to one another (e.g. stringing beads; feeding a doll with a spoon).

Developments in language were tracked by transcribing word use at each session and identifying the ages of onset of first words (i.e. the session at

which one conventional word was used at least twice) and the vocabulary spurt (i.e. the session at which twelve new words had been added since the previous visit, after reaching a baseline of twenty words) for each child. This permitted the examination of developmental changes in action on objects in relation to both chronological age and language level.

There was a clear developmental progression in infants' action that was closely linked to achievements in language. During the prespeech period, the vast majority of infants' object displacements involved taking things apart. With the advent of first words, however, putting things together not only became progressively more frequent, but children also began to put objects together in ways that they had not previously seen them combined (e.g. putting a bead inside a nesting cup rather than putting one nesting cup inside another). During the vocabulary spurt, constructions began to make use of specific features rather than generic characteristics of objects (e.g. putting a bead on a string rather than simply placing the bead inside a nesting cup). This developmental progression in action on objects and its association with achievements in language was observed in all of the children despite substantial individual differences in rate of language acquisition. Bloom (1993) has argued that this parallelism reflects common developments in underlying cognition, specifically changes in object concepts and advances in the ability to access this knowledge for actions with both objects and words.

While Bloom's (1993) interpretation makes excellent sense, it is important to reiterate that these common developments in underlying cognition themselves depend on advances in infant capacity for action. Infants in this study began by engaging primarily, if not exclusively, in separating objects. Separating is a relatively simple motor task: it only requires the infant to grasp one object and pull at it to make the configuration come apart. Although objects can, in principle, be immediately put back together once they are separated, Lifter & Bloom (1989) note that at this early object separation stage infants generally did not do so; rather, it was mothers who often reconstructed the configurations so that the infants could separate them again. They also point out that as infants repeatedly take constructions apart, they learn about the separateness of objects and that objects can be joined together; in other words, that '[l]earning how to construct a relation begins with learning how to take it apart' (p. 414).

In short, the emergence of constructions indexes two closely related progressions in infant action. The first is the recognition that things go together, indicated in the context of action by placing them in physical relationship to one another (e.g. a bead can be put in a nesting cup). The second, and perhaps even more fundamental recognition, however, is that actions are reversible; in other words, that the bead that can be dumped out of the nesting cup can also be put back in it. Armed with these two new

possibilities for action, infants can not only construct relations; they can also experiment with creating varying and novel combinations of constructions. Such an infant can now not only put a bead in a nesting cup and take it out, but then put it into a toy car, pick up a peg person and put the peg person in the now-empty nesting cup.

In the context of these play actions, the child has the opportunity to notice, attend more specifically to, and learn about progressively more specific properties of objects. Thus, in creating different constructions involving nesting cups and beads, the child might notice the fact that the nesting cup can serve as a container for many different toys and that the bead has a small hole in it. In other words, in the course of putting toys together and observing the consequences of these actions, children begin to link objects with meanings created in the context of their actions, i.e. the nesting cup is a container. The ability to connect meaning with a referent is, of course, fundamental for word learning.

Finally, as children notice progressively more specific characteristics of objects – that, for example, the bead has a small hole in it – opportunities for more refined actions on those objects are created. When the child notices that the hole in the bead is similar in diameter to the string, she might attempt to put the bead on the string. Even if this action is unsuccessful and the bead falls off the string, the physical attempt to create this highly specific construction provides an opportunity to give additional meaning to the bead: where it was previously something to be put in a container, it is now something that can also be strung. As Bloom (1993) suggests, the increasing specificity observed in children's object constructions over time provides evidence of development in the ability to attribute mental meanings that are increasingly varied and elaborated. The critical point here, however, is that these mental meanings – and their links with objects – are given in the context of developing physical action: playing with, manipulating and acting on toys in new and progressively more specific ways. These new forms of action depend in turn on developing motor skills.

To summarize, developmental progression in action on objects and achievements in early language development are closely associated, and intersections between these domains are traditionally interpreted as reflecting advances in common underlying cognition. A complementary perspective is that physical action on objects sets a context for attributing meaning to those objects via action. As infants act on objects in increasingly sophisticated ways dependent on increasingly sophisticated motor skills, they are presented with the opportunity to notice more specific object features. As they refine their actions further in order to make use of these features, they are able to attribute increasingly specific meanings to objects. This latter development is of particular importance inasmuch as learning

words requires, among other things, the mapping of specific meanings to specific referents.

Example 3: the emergence of naming in action and language

A final example of correspondence between milestones in motor action and language is evident in work begun in the Piagetian tradition, pursued by Bates and colleagues (e.g. Bates *et al.*, 1979) during the 1970s and 1980s, and revisited most recently by Volterra and colleagues (e.g. Capirci, Contaldo, Caselli & Volterra, 2005; Volterra, Caselli, Capirci & Pizzuto, 2005). At issue in this work is a behavioral phenomenon frequently termed 'recognitory gesture'.[1] Recognitory gestures are actions that are brief, stylized versions of the actions typically produced on associated objects. For instance, when an infant between the ages of 0;9 and 1;0 first catches sight of a toy telephone among her play objects, she may pick up the receiver, touch it momentarily to her ear and then immediately set it down. Through this gesture, the child is, in effect, indicating recognition that she knows what the object is. Additional examples might include making a brief stirring motion with a toy spoon or touching a hairbrush briefly to the hair.

There are two indications that recognitory gestures are not simply a product of the infant's attempt to imitate the prototypical actions that adults produce with objects. The first is that, unlike adult models for these actions (e.g. holding up the telephone receiver to the ear and talking), the infant version is, as indicated above, generally very brief and incomplete, lasting only two to three seconds. The second is that the recognitory gesture does not appear to be an attempt to satisfy a need; for example, an infant might pick up an empty cup and touch it briefly to the lips, not in an attempt to drink from a cup that contains no liquid but rather to show by means of the gesture that the cup is used for 'drinking'.

The appearance of recognitory gestures marks an important transition in infant action. Prior to the emergence of these gestures, infants act on objects for the purpose of manipulating them. When an infant aged 0;7 plays with a toy telephone, he may shake the cord, bang on the base, mouth the receiver or run an exploratory finger over the buttons. Although these actions reflect growing sophistication in object manipulation, they are relatively generic and could, in principle, be applied to any number of different objects. With the appearance of recognitory gestures, however, comes evidence of an emerging ability to use action for the purpose of assigning specific meanings to objects. At 0;10, when an infant picks up the phone receiver and briefly touches it to her ear, she is not merely manipulating the receiver; she is

[1] Recognitory gestures have also been termed 'symbolic play schemes' (e.g. Inhelder *et al.*, 1971) and 'gestural depiction' (Werner & Kaplan, 1963).

reflecting her awareness that the object has a specific meaning, that it is, in other words, a telephone.

Recognitory gestures of this sort not only indicate the emergence of the infant's ability to assign meaning intentionally, they also provide infants with a way of practicing meaning-making at a point in development at which they are just beginning to face the problem of using words to convey meaning. Furthermore, this practice takes place in a concrete context. Unlike word–referent links, which are generally highly abstract and require the child to pair arbitrary sound productions with meaning, the link between a recognitory gesture and its referent is relatively concrete. Meaning is assigned through a non-arbitrary action that produces immediate perceptual and proprioceptive feedback. Thus, for example, unlike the word *phone*, which bears no physical resemblance to its referent, the recognitory gesture 'phone' incorporates elements of the action (albeit in stylized form) that is typically associated with and conforms to the physical characteristics (size, shape, etc.) of the telephone. Furthermore, as the infant brings the telephone receiver to her ear, she feels the movement of her arm, the object in her hand, and ultimately the contact between the receiver and the side of her head. If a helpful adult is nearby, she may even receive some timely linguistic input: 'That's right, that's a phone. Are you calling someone? Is that Daddy?' At such moments, infants learn not only about action–referent mappings, but that they themselves are capable of making meaning, meaning that is appreciated by others in their environment.

In line with this view, Capirci *et al.* (2005) recently observed that meanings that infants initially 'practiced' in recognitory gestures were highly likely to enter their communicative repertoires as representational (i.e. empty-handed) gestures and/or words. In a longitudinal study of three children, these investigators found that the percentage of semantic overlap (i.e. the percentage of items in the repertoire that conveyed the same meaning) between recognitory gestures and representational gestures and/or words ranged from 88% to 97·5% and that recognitory gestures corresponding in meaning with a representational gesture and/or a word generally appeared before the emergence of the corresponding representational gesture/word. In addition, as the authors note: 'Almost all actions were produced by the three children in a situation in which the caregiver was present and was making comments and attributing meaning to the action performed by the child' (p. 173).

The role of recognitory gesture in early symbolic development has been extensively discussed in the theoretical literature (Inhelder, Lézine, Sinclair & Stambak, 1971; Piaget, 1952; Werner & Kaplan, 1963). A common theme in these discussions is that recognitory gestures are yet another manifestation of the emergence of a general symbolic capacity

toward the end of the first year. Indeed, Escalona (1973) has even argued that infants use recognitory gestures in much the same ways as they do first words: to identify, recognize, categorize or 'name' an object, event, or class of objects and events. For this reason, she refers to recognitory gestures as 'enactive naming' because, as Bates, Bretherton, Snyder, Shore & Volterra (1980) have suggested, 'infants seem to be using these schemes for a very different function than the one originally intended by the culture: to label a known object by carrying out an activity typically associated with that object' (p. 408).

The most widely cited evidence for the view that recognitory gestures are a type of naming comes from longitudinal work carried out by Bates *et al.* (1979) and Volterra, Bates, Benigni, Bretherton & Camaioni (1979). This research gathered detailed information about the vocal and gestural repertoires of twnety-five Italian and American infants between the ages of 0;9 and 1;1 and involved a combination of observational data and maternal report measures. They documented a series of close parallels in the development of recognitory gestures and first words. Two of these are of particular importance for the present discussion.

First, recognitory gestures and first words appeared in individual children's repertoires at around the same time, though there was considerable variability in the ages at which they were first observed and the rate at which they emerged. In addition, they tended to refer to a common set of meanings: eating, dressing, playing with vehicles, telephones, games of exchange and peekaboo, bathing, and doll play. Indeed, there was considerable overlap in the content of the vocal and gestural repertoires when they were compiled across children. Interestingly, however, this redundancy was uncommon among individual children: it was not the case that each child who had a recognitory gesture for a given object also produced the corresponding word.

Second, over the course of the period from 0;9 to 1;1, both recognitory gestures and words underwent a similar process of decontextualization, progressing from initially highly context-bound productions to application across a broader set of contexts. Thus, for recognitory gestures, the following developmental progression was noted (see also Nicolich, 1977):

(1) Briefly carrying out an object-related activity to recognize appropriate object use (e.g. briefly bringing a telephone receiver to the ear).
(2) Carrying out a familiar activity that is within the child's existing repertoire, but outside of its usual context (e.g. 'sleeping' with head on the table).
(3) Carrying out actions with others in which child's role is reversed (e.g. rather than feeding himself, the child feeds mommy or a doll) or

that are typically associated with others (taking on an adult role; e.g. vacuuming, wiping the highchair tray with a cloth).

(4) Carrying out an action with a substitute object (e.g. using a spoon as a telephone).

In the course of this decontextualization process, infants apply action schemes across a widening range of contexts, to progressively more abstract objects, and to different recipients. This is suggestive of two major developments. First, production of recognitory gestures (and of meanings in general) becomes less reliant on contextual support. Thus, where the 'phone' recognitory gesture was once produced only in the presence of the toy telephone and was only self-directed, it eventually begins to be applied to other objects (e.g. using a spoon as a telephone) and to other individuals (e.g. holding the receiver to the doll's ear). In other words, production of the 'phone' gesture no longer requires a precise replica of the conditions under which the action first emerged (i.e. during spontaneous play with the toy telephone).

The second development is that as infants gradually extend action schemes outside the original context of production, they begin to appreciate the fact that a common action and therefore a common meaning can be applied to a variety of different objects. An infant might, for example, assign 'phone' meaning by making the 'phone' gesture not only with the toy telephone, but also with a spoon, a rattle and a plastic banana.

Thus, production of recognitory gestures provides infants with opportunities to learn: (a) that meanings are context-independent; and therefore (b) that the same meaning can be assigned to different objects in different contexts. While objects and contexts may vary, a particular and specific meaning can remain invariant. This sets the stage for one of the most important advances in early language development, namely the recognition that because a given word can be used to refer to a range of referents (e.g. *dog* can refer to the family Saint Bernard, a pictured story-book chihuahua, and a Great Dane seen in the park), word meanings are both general and relatively specific. As infants begin to use first words, this is something that they must come to understand.

Understanding of this sort, however, develops only gradually. As Volterra *et al.* (1979) have observed, first words, like recognitory gestures, also undergo a process of decontextualization. Infants' initial word productions are highly context-bound and, more specifically, bound to particular actions and procedures with which they have been associated. In the Volterra *et al.* data, most instances of early word use occurred as the child executed a specific action in a specific context. Thus, for example, *bye-bye* was initially produced only when the child was putting down the phone receiver. At this point in development, the meaning of *bye-bye* was

something like 'breaking contact while putting down a phone receiver', a meaning both limited to a single context and given by reference to the entire context of action and object rather than to a specific referent.

As development proceeds, the infant extends *bye-bye* to contexts beyond that of hanging up the phone. With extension, meaning becomes not only increasingly context-flexible (e.g. *bye-bye* is now produced not only when putting down the phone receiver, but also when people are departing, when a toy disappears from sight and when someone is preparing to leave the house) but specific (*bye-bye* now represents breaking contact, regardless of the immediate context). Decontextualization of recognitory gesture, in which the child practices assigning common meaning in multiple and varying contexts, helps set the stage for this advance.

In short, during the period between 0;9 and 1;0, recognitory gestures and first words develop in both content and gradual decontextualization. Not only does this reflect the emergence of a general ability to symbolize (e.g. Bates *et al.*, 1979), it suggests that naming (both gestural and verbal) is born in motor action. Recognitory gestures provide children with the opportunity to practice 'naming', first by assigning meaning to an individual referent and then by extending a common meaning across a variety of different referents. Furthermore, and importantly, this prelinguistic 'naming' occurs in the domain of action in which the relationship between the action component of the gesture and the referent is both non-arbitrary and concrete. When children then begin to assign meaning using the arbitrary sound productions that constitute words, they can draw upon their experience with recognitory gestural naming to facilitate the acquisition of this new skill. It is therefore not surprising that first words are tightly bound to action and that children are highly likely to name objects as they act on them (Rodgon, Jankowski & Alenskas, 1977; Volterra *et al.*, 1979) or that children's early words tend to refer to small, easily manipulated objects (Nelson, 1973; Bates *et al.*, 1979).

MOTOR DEVELOPMENT IS AN ORGANIZER FOR COMMUNICATIVE AND LANGUAGE DEVELOPMENT

The achievement of motor milestones such as unsupported sitting, reaching, crawling and walking radically alters the infant's relation to the objects and people in his immediate environment. Infants who can sit without support can freely rotate head and trunk with consequent improvement in visual observation of the surrounding world. An infant who has begun to reach encounters a new set of opportunities with regard to object manipulation and, as any parent knows full well, when infants become mobile, first by crawling and then by walking, they not only greatly extend the range of accessible objects, they alter the possibilities of social interaction in myriad

ways. Motor development over the first eighteen months, in other words, radically alters the child's experience with the world; and this has significant implications for the development of communication in general and language in particular.

Only recently have studies been specifically designed to examine the impact of motor advances on infant communication, and to date they have been relatively few in number. These studies are reviewed in the following two sections of this paper, along with data from other investigations that have explored concurrent relationships between infant motor activity and vocal production. The broad theme to be developed here is that motor abilities, and the advances that occur in these abilities during the first two years of life, organize a whole series of experiences that expand infants' interactions with their environments and the objects and individuals in it and thereby create altered possibilities for communicative and language development.

Motor development and communication

Two studies to date have examined the influence of experience with new forms of locomotion on communicative development. One focused on crawling experience in relation to the ability to follow referential signals, and the second explored ways in which the transition to walking impacts infants' production of communicative bids related to objects.

In a line of research designed to examine the consequences of the onset of crawling, Campos, Anderson, Barbu-Roth, Hubbard, Hertenstein & Witherington (2000) proposed that the emergence of ability to follow eye gaze and pointing directed toward distal objects – a major milestone in the development of joint attention – may be related to crawling experience. The joint attention literature suggests a clear developmental sequence in the emergence of the ability to follow referential gestural communication (i.e. eye gaze with pointing gesture; see Moore, 1999). Thus, infants as young as 0;3 can follow an adult's eye gaze and head turn as long as the adult's head and the target are in same visual field (e.g. D'Entremont, Hains & Muir, 1997). Between 0;8 and 0;10, infants become able to follow a pointing gesture accompanied by eye gaze shift and head turn when the gesturer and the target are in different visual fields. During the second year, this skill is further refined, such that infants become able to localize a target correctly, even when it is located behind them (e.g. Butterworth & Grover, 1990).

The rationale for the Campos *et al.* (2000) proposal is grounded in the observation that when infants begin to crawl, there is a concurrent and dramatic change in the type and source of social signals that they receive. Crawling infants typically encounter risky objects and contexts as they explore their surroundings, and caregivers naturally respond to this by increasing their affective and vocal communication in order to regulate this exploration

(e.g. Zumbahlen, 1997). Importantly, however, this communication is likely to have a clear distal referent and to come from a communicator who is located at a distance from the infant.

Because there is presumably little need for this type of distal caregiver communication prior to the onset of independent locomotion, it represents a substantial shift in the nature of the social signals directed toward the infant. In other words, as infants locomote and explore their environments, they gain experience attending to and interacting with distally located objects and people; this is a skill that is implicated in the second phase of the developmental sequence for following referential gestural communication described above, i.e. the ability to follow pointing with eye gaze and head turn when the communicator and the referent are in different visual fields. Thus, infants with crawling experience should be more likely to follow such cues than prelocomotor infants.

In support of this notion, Campos *et al*. (2000) cite an earlier study (Campos, Kermoian, Witherington, Chen & Dong, 1997) that tested this prediction using an age-held-constant design. Participants consisted of three groups of infants all of whom were 0;8·5: prelocomotor infants (i.e. infants who had not yet begun to crawl) with little or no experience in a walker, prelocomotor infants with at least forty hours of experience in a walker, and infants with up to six weeks of hands and knees crawling experience. The testing situation involved eight toys arranged in four pairs and positioned on the left and right sides of a square curtained area. On each trial, the experimenter looked at one of the eight toys and drew the infant's attention to it, saying 'Look over there' while turning her head and eyes and pointing across the body in the direction of the target toy (without extending the arm beyond the body periphery).

Crawling infants and infants with walker experience looked at the correct side (i.e. in the direction that the experimenter looked) on significantly more trials than did prelocomotor infants. In addition, whereas prelocomotor infants looked at the correct and incorrect sides on roughly equal proportions of trials, crawling infants and infants with walker experience looked to the correct side significantly more often than to the incorrect side.

Campos *et al*. (2000) interpret these results in the context of the following developmental scenario. When a crawling infant encounters a prohibited object, caregivers typically respond with distal communication (often with high affect) to distract or inhibit the infant. When infants are initially exposed to this type of communication, they respond by orienting to the caregiver; and this marks an initial phase in the development of the infant's attention to the caregiver's message. Subsequently, and with repeated orienting to the caregiver, the infant is motivated to discover the object of the caregiver's communication, a process that may be facilitated by enhanced infant attention to distal events and advances in spatial understanding (both of which are

related to the onset of crawling; see Campos *et al.*, 2000). As infants both attend to the caregiver and seek to discover the referent of the caregiver's communication, they gradually come to appreciate the general direction of the caregiver's head turn, gaze or pointing gesture; and it is this initial general appreciation that has been described as a step in the gradual development of the ability to localize the target of a pointing gesture smoothly and accurately (see Moore, 1999).

In the second study, focused on the transition to walking, Karasik, Tamis-LeMonda and Adolph (under review) observed fifty infants at 0;11 and 1;1. At 0;11, all of the infants were crawling; but by 1;1, half were walking, thereby allowing an examination of whether infants' communicative object sharing (i.e. showing or offering an object to another person) changed with the onset of walking.

At both ages, infants were observed during everyday activities in the home with a primary caregiver. All episodes involving manual object contact were identified, and the overall duration of each episode was divided into time spent carrying an object (i.e. infant engaged in forward movement while grasping an object) versus grasping an object while remaining stationary. In addition, all instances in which an infant showed or offered a toy to the adult by extending the arm were coded as object-related social bids; these were classified according to whether they were stationary (i.e. infants remained in their position and extended an object toward the person to 'show' or 'offer') or moving bids (i.e. infants 'brought' an object to a person by crawling, cruising or walking).

The onset of walking was related to qualitative changes in the way in which infants engaged with objects and in their object-related social bids. Thus, at 1;1, walkers carried objects more frequently and spent more time traveling with objects overall than did their crawling age-mates. A parallel difference was apparent in infants' object sharing with their mothers. Specifically, despite the fact that both crawlers and walkers at 1;1 produced object-related social bids and did so with comparable frequency, walkers were more likely than crawlers to share objects by moving to their mothers. Indeed, 44% of walkers' (but only 3% of crawlers') bids were characterized as moving bids. Walkers, in other words, were more likely to locomote toward their mothers and then hold out the object for her inspection; but crawlers continued to bid from stationary positions by extending their arms with the object in hand in the mothers' general direction.

Although crawlers demonstrated the skills necessary for moving bids – they carried objects and they also engaged in object-related bids – they only infrequently brought these skills together in the context of bidding to their mothers. As Karasik *et al.* (under review) note, there are at least three reasons why the transition from crawling to walking may facilitate the translation of these abilities into moving object bids. First, walking may provide infants

with enhanced opportunity to access distally located objects because it is more efficient and less taxing than crawling. Second, the hands are no longer involved in supporting the infant's weight and can now be used to carry objects. Finally, the upright position of the head afforded by walking provides an elevated vantage point, which may make it easier for infants to see and locate objects and people in their surroundings.

Thus, the transition to walking brings about a change in infant experience: infants are now able to bring an object of interest to an adult in order to share interest and attention to it. This is, of course, the essence of joint attention. Because the object-related social bids of crawling infants are generally limited to nearby objects, bid success requires a fairly attentive adult. Walking infants, on the other hand, are free to travel to an object of interest and then transport it directly to the adult. In other words, with the transition to walking comes a natural broadening of the range of communicative referents available to the infant (i.e. communication can now be about both proximal and distal objects); and the infant can now play a more active role in establishing interaction (see Clearfield, Osborne & Mullen (2008) for a similar argument), selecting precisely those objects that are of interest. Moving bids may also be more salient to caregivers; even if the caregiver is distracted or in the next room, the arrival of an infant whose arm is extended to show an object is a clear social signal that is likely to elicit the caregiver's attention and result in both the establishment of joint attention to and communication about the object. And because infants are especially likely to learn words when their attention is already focused on the referent (e.g. Tomasello & Farrar, 1986), these moving bids, in combination with timely caregiver input, may provide rich opportunities for language learning.

Motor development and language

Three studies to date have provided data consistent with the notion that motor development also provides altered opportunities for infants to explore and expand skills more specifically relevant to the acquisition of oral language. All of these studies focused on prespeech vocalizations in the first year, presumably because of the rapidly changing landscape of motor skills that is evident during this time. Collectively, they suggest that progressions in motor abilities orchestrate opportunities for infants to explore and vary their existing sound production capacities, with consequences that may contribute to developmental change in vocalization characteristics and the speech sound repertoire.

In an unpublished dissertation, Yingling (1981) approached this issue by exploring the possibility that the achievement of unsupported sitting (which results in substantial changes in respiration and the position of the speech

articulators) is accompanied by changes in the characteristics of infant vocalizations. Because the rib cage is freed, sitting infants can breathe more deeply and maintain subglottal pressure more consistently than is possible in a supine position. This should, in principle, permit the production of longer strings of utterances in a single breath. In addition, the new upright head position alters the position of the spine and the vocal tract curve; and the tongue falls to a more forward position in the oral cavity. This in turn should enhance the production of consonant–vowel (CV) segments.

Based on these considerations, Yingling (1981) hypothesized that the achievement of independent, unsupported sitting would initiate a transitional period in which vocalizations progress from being highly variable to more closely resembling well-timed, patterned speech. To test this prediction, she followed a group of infants aged 0;5·5 longitudinally through the transition to unsupported sitting, with observations prior to and following attainment of independent sitting.

Spectrographic analyses revealed that vocalizations changed in three major ways after infants began to sit on their own. First, infants began to demonstrate greater control over utterance production, as exemplified in decreased length of individual utterances, greater uniformity in duration, and increased variation in the number of utterances produced in a single breath. Second, there was an overall increase in the frequency of CV units and a corresponding decrease in simple vowel production. Vowel duration also decreased, with production of single, elongated vowels held over the entire length of an expiration becoming much less frequent. And as infants began to produce vowels that were relatively short and clipped, instances of two or more vowels per breath group became more common.

Finally, the number of CV syllables per breath group increased and CVs became shorter and more consistent in duration just before the onset of unsupported sitting. As CV units became more punctate and less variable, there was a corresponding decline in CV repetitions across the post-sitting observations. Thus, as infants became more skilled at maintaining an upright posture, CV production became more consistent; and relative consistency in production is, of course, a hallmark of skilled, controlled behavior.

Taken together, these findings suggest that the onset of unsupported sitting initiates a period of exploration and change in infant vocalization. When infants are first able to maintain an upright sitting position, they 'discover' new possibilities for vocal production in the very act of vocalizing. The proprioceptive and auditory feedback generated by these initial experiences then leads to continued exploration of the vocal possibilities generated by enhanced lung capacity and repositioned speech articulators (perhaps most especially the mandible and tongue, which are highly relevant for CV production; e.g. MacNeilage & Davis, 2000). In the course of this

exploration, as Yingling (1981) put it, 'the infant's ''practice-play'' with speech patterns … become[s] more complex, specifically involving series of sound variations' (p. 97). In addition, as infants attempt to match target sounds from their ambient language in their own production, they begin to hone in on timing parameters that are present in that language. Indeed, data from Yingling's final post-sitting session indicated that, in a number of important respects, infant vocalizations were coming to resemble those of adult speech (e.g. embedding of multiple utterances within a breath group, more punctate and word-like utterances).

Two additional studies have explored the relationship between motor activity and vocalization qualities by analyzing vocalizations produced during bouts of object manipulation. In a cross-sectional study of infants between the ages of 0;6 and 0;9, Fagan & Iverson (2007) examined vocalizations produced as infants mouthed objects and compared them to vocalizations produced without co-occurring mouthing. While mouthing has received considerable attention in work on infant object exploration (e.g. Fenson, Kagan, Kearsley & Zelazo, 1976; Ruff, 1984; Ruff, Saltarelli, Capazzoli & Dubiner, 1992), its possible role in infant vocalization and vocal development has been largely ignored (but see Elbers, 1982; Ejiri & Masataka, 2001). This is so despite the fact that: (a) the peak period of mouthing as a means of exploring objects, which occurs between ages 0;6 and 0;9, coincides with that for the emergence of consonants; and (b) mouthing of objects can be a means for introducing vocal tract closure, a key feature of supraglottal consonants (consonants formed by the tongue or lips, e.g. [d]). Because infants often explore the sound-related consequences of their actions (e.g. preferring to shake sounding rather than soundless toys), they may appreciate the potential for object mouthing to influence vocalization. As a result, when infants vocalize during mouthing, they may benefit both from proprioceptive feedback regarding oral postures associated with object mouthing and auditory feedback about the consonant sounds associated with these oral postures.

In light of these observations, Fagan & Iverson (2007) reasoned that relative to vocalizations unaccompanied by object mouthing, vocalizations that co-occur with mouthing should be more likely to contain a supraglottal consonant and to contain a greater variety of consonant sounds. To address this prediction, they coded vocalizations for presence of at least one consonant and vowel. Consonants were further categorized as glottal (e.g. [h]) or supraglottal (e.g. [k], [d], [b]), and a supraglottal consonant inventory was compiled for each infant. Finally, vocalizations were classified on the basis of whether or not they were produced during mouthing of objects, hands or fingers.

Infants regularly vocalized while mouthing objects. On average, 28% of vocalizations produced during the observations occurred during instances of

mouthing, and thirty-nine of the forty infants vocalized while mouthing. Thus, the co-occurrence of object mouthing and vocalization is a robust developmental phenomenon. And although the proportions of vocalizations containing a CV were similar for mouthing and non-mouthing vocalizations, vocalizations co-occurring with mouthing were significantly more likely to contain a supraglottal consonant and to include a greater variety of supraglottal consonants than those co-occurring with non-mouthing (though all were among those typically produced by young infants).

This pattern of results suggests that not only is object mouthing an effective mechanism of object exploration for infants aged 0;6 to 0;9, it may also play a role in infants' exploration of their own vocalizations. Although infants undoubtedly explore vocalizations produced both with and without mouthing, mouthing may uniquely influence co-occurring vocalizations in a way that facilitates consonant exploration. Specifically, mouthing may bring about vocal tract closure and affect change in articulatory postures in association with object position, shape and movement. Moreover, the availability of multimodal feedback in mouthing vocalizations may encourage consonant exploration as infants vary routinely produced features of consonant articulation (i.e. place, manner and voicing).

Finally, there are data indicating links between characteristics of vocalizations and features of objects that are being concurrently manipulated. Bernardis, Bello, Pettenati, Stefanini and Gentilucci (2008) presented infants between the ages of 0;9 and 0;11 with small (2 cm) or large (4 cm) wooden objects one at a time. On each trial, an experimenter drew attention to the object, manipulated it and then placed it on the table in front of the infant. All vocalizations produced during object manipulation were recorded and spectrograms of these vocalizations were analyzed.

Findings indicated that when infants vocalized while manually manipulating objects, characteristics of those vocalizations tended to vary as a function of object size. Specifically, the first formant in the voice spectra (F1) was significantly higher for large relative to small objects. F1 is related to internal mouth aperture, with a higher value indicating a larger opening. In light of evidence indicating the existence from birth of a tight link between the manual and oral/vocal systems (see Bates & Dick, 2002; Iverson & Thelen, 1999), the authors interpreted these data as suggesting that when an infant prepares to manipulate a large object, the motor command to increase the opening of the fingers for large object manipulation is also sent to the mouth, resulting in a larger aperture that gives rise to the higher F1 values observed in co-occurring vocalizations. It is noteworthy that this effect is not limited to infants: a study of adults and older children revealed that execution of grasping influences the simultaneous pronunciation of syllables, such that when large objects are grasped, lip opening and F1 increased in a fashion that corresponded to changes in finger shaping during

grasp movements (Gentilucci, Santunione, Roy & Stefanini, 2004; Gentilucci, Stefanini, Roy & Santunione, 2004).

To summarize, developmental advances in motor skill in infancy create a broad range of novel experiences and opportunities for exploration that may have implications for language development. With the attainment of new postural and locomotor skills come opportunities for infants to experiment with vocal production in a different biomechanical configuration, gain experience with distal communication, and play an increasingly active role in the communicative process. All of these are relevant to the development of language. Furthermore, infants' propensity to engage with and actively explore objects in the environment using hands and mouths may provide information not only about those objects, but about the infants' own vocalizations. In short, as infants move through and engage with their surroundings (behaviors that are traditionally situated in the domain of motor development), these everyday activities and experiences have effects that extend beyond the motor domain to the developing communicative and language systems.

SUMMARY AND CONCLUSIONS

I began this review by noting that striking parallels exist in average ages of motor and language milestone achievement during the first year, but that correlational analyses of individual differences in ages of milestone achievement provide evidence against the notion that developments in these areas are simply a function of underlying neuromotor maturation. While this has sometimes been taken to imply that the development of motor skill is irrelevant to the emergence of language, I have argued against this view and for the claim that the developing motor system contributes to the development of language in at least two significant ways.

First, the acquisition of motor skills provides infants with opportunities to practice skills relevant to language acquisition before they are recruited for that purpose. The rhythmic hand and arm movements that emerge prior to reduplicated babble onset allow infants to practice rhythmically organized, tightly timed actions of the sort required for babbling. And prior to and during the period of first word onset, infants practice meaning making in action: they play with, manipulate and act on toys in progressively more specific ways; and, via gestural 'naming', they assign progressively more specific meanings to referents and extend common meanings across a variety of referents. All of these new forms of action – which are closely related to the emergence of early language milestones – are dependent on advances in motor skill.

Second, the emergence of new motor skills changes infants' experiences with objects, people and their own bodies in ways that are relevant for both

general communicative development and the acquisition of language. Unsupported sitting is related to changes in vocalization characteristics that appear to reflect exploration of the newly reconfigured vocal tract, expanded lung capacity and advances in speech timing; and the onset of independent locomotion provides infants with greater exposure to the problem of communicating about a distal referent with a distally located interlocutor. In addition, infants' oral and manual manipulation of objects can shape co-occurring vocalizations, both by introducing variation into routinely produced features of vocalizations (e.g. through vocal tract closure and change in articulatory postures that occur during object mouthing) and through receipt of information about object size from the hands and fingers.

That motor development is not irrelevant to the acquisition of language, however, leads naturally and immediately to an important question and to two significant implications. The question is an obvious one: Are motor advances of the sort described here either necessary or sufficient for language development? The answer to this question, in my view, is an unqualified 'no' (see Campos *et al*. (2000) for a similar argument). The evidence reviewed here supports a role for motor development in language acquisition that might be best labeled 'normally participatory'. All other things being equal, and given a typically developing child in a typical environment, motor development is a key participant in the process of language acquisition. That motor development is normally participatory, however, does not imply that it is necessary for language development. Nor does slow progress in motor achievement necessarily imply that language will develop at a similarly slow pace; there is undoubtedly a wide variety of alternative means for accessing the kinds of language-learning contexts that, in normative development, are provided by gains in motor skill.

Nor, obviously, is motor development sufficient for the emergence of language. If there is a single conclusion from the past fifty years of research on language development on which most everyone can agree, it is that the acquisition of language involves the coming together of a very broad array of abilities and skills. While motor development can be an agent of change for the developing language system, it should be obvious that the acquisition of language requires far more than simple growth in motor abilities.

That motor development is neither necessary nor sufficient for language development in the logical sense by no means minimizes its role in relation to the emerging language system. Indeed, lack of necessity and sufficiency is a central tenet of a systems approach to development, which explicitly rejects simple cause and effect models in favor of the notion that multiple and varying factors contribute to the emergence and development of a given behavior. Behavior and development, in other words, represent the confluence of multiple skills that are softly assembled as the child acts and interacts in a particular environment at a given moment in time (e.g. Thelen & Smith,

1993). On this view, motor skills are one among several sets of abilities that are involved in language; and although they are normally participatory in language development, should any given pathway be blocked, there is sufficient flexibility in the organization of the system to yield a myriad of possible (yet still normative) developmental trajectories leading to the emergence of language.

As to the implications of the view that motor development is normally participatory in the emergence of language, the first has to do with our thinking about the developmental origins of the now well-replicated finding that children with language impairments often exhibit motor difficulties (e.g. Bishop & Edmundson, 1987; see Hill (2001) for a review). This relationship has been interpreted as reflecting the fact that speech production and the kind of motor tasks that are typically employed in these studies (e.g. finger tapping) both involve precise timing of motor movements, and that the observed motor difficulties are more a reflection of difficulties with precise timing rather than problems with the motor system per se.

However, Bishop (2002) has pointed out that comparable difficulties are also apparent on other tasks that do not specifically require precise timing of movements (e.g. peg moving and gesture imitation tasks); instead, she has argued that co-occurring motor and language difficulties may have an underlying genetic basis, with the genes that put a child at risk for communicative impairment also affecting motor development. This view is supported by data from prospective studies of infants at risk for a variety of communication disorders, including autism spectrum disorders (Iverson & Wozniak, 2007) and dyslexia (Viholainen, Ahonen, Cantell, Lyytinen & Lyytinen, 2002; Viholainen, Ahonen, Lyytinen, Cantell, Tolvanen, & Lyytinen, 2006), for whom attainment of early motor milestones (e.g. independent sitting) lags behind that of no-risk comparison infants.

Delays in motor development have been traditionally conceptualized as indices of 'delayed maturation' or 'neurological soft signs', particularly when they co-occur with language difficulties; and indeed, motor difficulties are among the exclusionary criteria in widely used research definitions of specific language impairment (SLI; Leonard, 2000). The fact remains, however, that a substantial proportion of children with SLI exhibit co-occurring motor difficulties (e.g. Hill, 1998). The literature reviewed here suggests a possible developmental mechanism for this relationship.

Consider, for example, an infant aged 0;6, who has difficulty reaching for and grasping objects. As described above, object mouthing provides infants with information not only about objects, but also about their own vocalizations. An infant with limited ability to grasp objects and bring them to the mouth may therefore have more limited means (but certainly does not entirely lack the means) for exploring and learning about vocalizations,

particularly those that involve vocal tract closure; and this might in turn influence that infant's production and acquisition of supraglottal consonants. In other words, even a small distortion in a very basic and early emerging developmental skill – reaching and grasping – can have cascading effects in development that lead to disturbances extending beyond the motor domain (see Thelen (2004) for additional discussion). Since much of what infants do during the first two years of life involves moving through and acting on the environment, delays or deficits in motor skills may constrain the learning that takes place during these everyday activities.

The second implication of the argument developed here is methodological in nature. It is common in research on spoken language development for investigators to work with audiotaped language samples and/or language transcripts. For many purposes, this may be adequate; but I would like to encourage the field to make much greater use of video-recording. Videotaped data can be a source of important information not only about qualitative aspects of communication and language but about the movement context in which that language is produced, about what infants are doing while they are vocalizing, communicating or speaking.

Coding the movement context for language production allows for the observation of patterns not otherwise accessible. Thus, for example, although crawlers and walkers in the Karasik *et al*. (under review) study produced comparable numbers of social object-related bids at age 1;1, walkers produced significantly more moving bids than did their crawling age-mates. Since moving bids may elicit different patterns of response from parents, which could in turn impact infants' language experiences, this is important information. Unfortunately, however, it is information that is lost unless attention is paid to what the child is doing at the time of the bid. Similarly, students of infant vocalization, who often audio-record infants as they play with soft, quiet toys chosen to reduce interference with the quality of the recording, would be advised to video-record as well and code the infant's movements at the time of vocalization. Even soft, quiet toys are likely to be mouthed by infants. And because mouthing appears to influence consonant production, video-recording would provide additional, fine-grained information about the status of specific consonant sounds in the infant's repertoire, i.e. whether they only appear in a more supportive context (when the vocal tract is blocked with a toy) or whether (and when) they emerge outside the context of mouthing. In short, whenever possible, language researchers should record and analyze the movement context of a child's language production. This will not only reveal more about the relationship between motor development and language, it will provide critical information on the context in which changes in language come about.

In conclusion, I have suggested here that there is a relationship between motor development and language development, but it is complex and multi-faceted rather than simple and directional. The emergence and continued development of new motor abilities during the first eighteen months has far-reaching consequences that extend to other developing systems, including language. The developing motor system provides opportunities for practicing and refining skills that are crucial for language and for increasingly complex learning about speech sounds and meaning making. Studying the ways in which motor achievements contribute to the development of language may not only yield a more comprehensive picture of the emerging language system; it may also provide fundamental insights into the processes underlying this emergence.

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