

# The Interplay Between Language, Gesture, and Affect During Communicative Transition: A Dynamic Systems Approach

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From a dynamic systems perspective, transition points in development are times of increased instability, during which behavioral patterns are susceptible to temporary decoupling. This study investigated the impact of the vocabulary spurt on existing patterns of communicative coordination. Eighteen typically developing infants were videotaped at home 1 month before, at, and after the vocabulary spurt. Infants were identified as spurters if they underwent a discrete phase transition in vocabulary development (marked by an inflection point), and compared with a group of nonspurters whose word-learning rates followed a trajectory of continuous change. Relative to surrounding sessions, there were significant reductions in overall coordination of communicative behaviors and in words produced in coordination at the vocabulary spurt session for infants who experienced more dramatic vocabulary growth. In contrast, nonspurters demonstrated little change across sessions. Findings underscore the importance of transitions as opportunities for observing processes of developmental change.

*Keywords:* communicative development, dynamic systems theory, vocabulary spurt, gesture, language development

Infant communicative expressions take multiple forms: smiles, frowns, vocalizations, gestures, and words. These expressive actions can occur in isolation or combine to deliver a communicative message. As communicative development unfolds over the first 2 years, children's ability to combine communicative behaviors from different modalities grows, even as the components of the communicative system—facial affect, vocalizations, gestures, and words—are themselves undergoing significant development.

A rich body of evidence has described the developing coproduction of communicative behaviors in infancy. Thus, for example, as early as 3 months of age, infants coordinate facial expressions (smiles and frowns) with vocalizations at greater than chance

levels (Yale, Messinger, Cobo-Lewis, & Delgado, 2003; Yale, Messinger, Cobo-Lewis, Oller, & Eilers, 1999). There is also substantial work supporting the existence of couplings between manual arm movements and vocalizations from 6 months of age (e.g., Iverson & Fagan, 2004; for a review, see Iverson, 2010). Around 12 months, positive facial expressions frequently accompany conventional gestures such as pointing and showing (Adamson & Bakeman, 1985; Kasari, Sigman, Mundy, & Yirmiya, 1990; Messinger & Fogel, 1998; Mundy, Kasari, & Sigman, 1992). By the second birthday, gestures and words are tightly coordinated; gestural and spoken elements in coordinated communications are both semantically coherent and temporally synchronous (Butcher & Goldin-Meadow, 2000; Pizzuto, Capobianco, & Devescovi, 2005).

Findings such as these point to close relationships between the facial, manual, and vocal modalities in the development of an integrated communicative system. What is not known, however, is whether and how these relationships may be altered during transition periods in development. The research presented here examines changes in infant coordination of facial affect expressions, gestures, vocalizations, and words during one such transition, the period of the vocabulary spurt.

## A Dynamic Systems Approach to Communicative Transitions

The conceptual framework employed in this research is based on dynamic systems theory (e.g., Thelen & Smith, 1994). The principles of dynamic systems theory are particularly useful for studying the communicative system during transition for two main reasons. First, a dynamic systems approach to studying development places a focus on the relationship among components as a source of change (Thelen & Smith, 1994). Complex organisms, including developing infants, are composed of multiple interacting

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parts that self-organize to operate collectively. A myriad of behavioral modes or cooperative coordinations are possible depending on the relative stability of each component of the system at a given time. Systems often move in and out of a state of flux, and as this happens, patterns dissolve and evolve, shifting from one preferred state to another (Smith & Thelen, 2003). An important implication of this view is that instability in one component (e.g., the introduction of a new skill or transformation of an existing skill) will engender changes in the way the system as a whole is organized.

Second, points at which new behavioral forms begin to emerge, or points of transition, serve as unique windows into the underlying process of change (Gershkoff-Stowe & Thelen, 2004; Iverson & Thelen, 1999; Thelen & Smith, 1994). During transitional periods, as new skills appear or undergo significant growth, the system loses its balance. In dynamic terms, the particular component that acts as the primary agent of change is known as the *control parameter* (Kelso, 1995; see Thelen & Smith, 1994, for additional discussion). Loss of stability in the system causes the parts to fall out of their previously stable patterns, temporarily dissolving their previous coordination. This highlights the dynamic systems notion of *soft assembly*: At any point in time, behaviors are loosely assembled so that many different coordinations are possible based on the influence and relative stability of the constituent parts (e.g., Iverson & Thelen, 1999; Thelen & Smith, 1994). The system then reorganizes while searching for new patterns of stability. Thus, because development is holistic, disruption in one component of the communicative system (during a period of transition) may profoundly alter the way in which all communicative behaviors work together.

In addition, when systems self-organize during a state of flux (initiated by the control parameter), they tend to seek, or settle into, certain preferred behavioral modes (Thelen & Smith, 1994). Some behavioral configurations, especially those involving newly emerging behaviors, may be more effortful and therefore less preferred. By contrast, patterns involving well-established behavioral forms are likely to be stronger, more stable, and therefore more preferred. The notion that stable and well-patterned coordinations are preferred over newer and less well-established ones appears often in studies of motor control (Zanone & Kelso, 1991; see also Iverson & Thelen, 1999). As children practice newly emerging skills, they become integrated with other well-established skills, and the system becomes increasingly stable and well defined.

### The Vocabulary Spurt as a Communicative Transition

Dynamic systems theory has provided a productive framework for studying transitional periods in domains such as motor development (e.g., Adolph, 2000; Corbetta & Bojczyk, 2002; Thelen & Ulrich, 1991) and word learning (e.g., Gershkoff-Stowe, 2002; Smith, 1995). To our knowledge, however, this approach has not yet been applied to empirical studies of multimodal communication in infants (but see Fogel, Garvey, Hsu, & West-Stroming, 2006, for an application to early communication within mother-infant dyads). During infancy, there are a number of developmental transitions characterized by rapid growth that provide an opportunity to observe reorganization within the communicative

system. One transition that represents a dramatic change in language development is the vocabulary spurt.

Infants typically utter their first words at around 8–12 months of age, and initially, words are acquired rather slowly. At about 16–18 months, however, children exhibit a sudden, rapid increase in vocabulary growth (e.g., L. Bloom, 1973; Dromi, 1987; Goldfield & Reznick, 1990), with vocabulary size often doubling within a month's time. Although the vocabulary spurt is considered a time of impressive growth in language, there is some indication that words are relatively fragile behaviors during this period. Gershkoff-Stowe (2001, 2002), for example, described the period surrounding the vocabulary spurt as a time when children are especially susceptible to naming errors. These errors, which tend to peak with the onset of accelerated vocabulary growth, may involve the overextension of a known word to a novel object similar in appearance to the referent of the known word (e.g., calling a sheep "doggie") or simple lexical retrieval errors (e.g., calling a stick "duck," even though the child regularly produces the word *stick*). Errors of this sort are considered to reflect momentary failures in accessing the correct word or heightened competition between newly acquired words and those more firmly established in the lexicon (Dapretto & Bjork, 2000; Gershkoff-Stowe, 2001; Gershkoff-Stowe & Smith, 1997). As words are practiced in production, they become stronger and more resistant to interference from lexical competitors (Gershkoff-Stowe, 2002).

Although there is widespread recognition of the vocabulary spurt as a milestone of linguistic development (e.g., L. Bloom & Capatides, 1987; Choi & Gopnik, 1995; Gershkoff-Stowe & Smith, 1997) and as a marker of developmental change (e.g., Fischer, Pipp, & Bullock, 1984; Lifter & Bloom, 1989), there is disagreement regarding its underlying mechanisms (e.g., McMurray, 2007) and possible universality (McCune, 2008). Indeed, some researchers have demonstrated that the vocabulary spurt is characterized by marked differences in the rate and shape of vocabulary development (e.g., Dale & Goodman, 2005; Gershkoff-Stowe, 2001, 2002; Goldfield & Reznick, 1990; Goodman et al., 1999). Thus, for example, data from the San Diego Longitudinal Study (Goodman et al., 1999) indicate that although infants as a group showed the typical pattern of slow initial vocabulary growth followed by a spurt in the rate of word learning, children varied widely in how early the spurt began and in the steepness of growth curve slopes. Indeed, multiple distinct types of vocabulary growth trajectories were observed, suggesting that although all children's vocabularies increased during the 2nd year, patterns of growth in children's vocabularies were highly variable. Recently, others have suggested that some children may not undergo a characteristic vocabulary spurt at all (i.e., a sudden explosion in the rate of word learning; e.g., Ganger & Brent, 2004).

Currently, it is difficult to determine the extent of these differences in vocabulary growth due to wide variation across studies in the nature of the data collected (i.e., parent report vs. spontaneous production), the data collection schedule, and sample size. An even more significant limitation, however, is that criteria for identifying the vocabulary spurt have differed substantially across studies. The most commonly used method is the "threshold approach" (Ganger & Brent, 2004, p. 622), in which a given number of words must be acquired during a specific period; but the numbers of new words required and the length of the period have varied across studies, ranging from 10 new words acquired over 2 weeks to 15 new

words acquired over 4 weeks (Goldfield & Reznick, 1990; Lifter & Bloom, 1989; Mervis & Bertrand, 1994; Poulin-Dubois, Graham, & Sippola, 1995). In addition, some, but not all, investigators have set a base criterion in which a minimum vocabulary size must be attained before crossing the specified threshold (e.g., L. Bloom & Capatides, 1987; Lifter & Bloom, 1989).

In an attempt to address the existing methodological issues in identifying the vocabulary spurt, Ganger and Brent (2004; see also van Geert, 1991) employed a mathematical approach by modeling a statistical representation of children's rates of early word learning. They argued that the vocabulary spurt as it is traditionally conceptualized should involve a discrete shift from an initial stage of slow vocabulary growth to a subsequent sustained stage of faster growth. Thus, if a child's learning rate undergoes a transition between a low stage and a high stage, it should be possible to identify a specific point in the learning rate curve where this transition occurs. Using longitudinal data, they modeled rate of word learning with two statistical functions: a logistic function, which involves an inflection point (i.e., a point where the rate of increase of a curve is greater than it is before or after), and a quadratic function without an inflection point. They found that data for only a minority of children showed a better fit for the logistic function, suggesting that most children experience a more gradual increase in word learning rather than a discrete transition between two stages.

### The Present Study

The present study is based on the assumption that transition points in development bring about instability through which change can be observed. Specifically, in line with the dynamic systems view outlined above, the study was designed to examine whether the closely linked relationship between language, gesture, and affect is altered as spoken language undergoes a period of significant growth and increased instability. We expected that only children who undergo a discrete phase transition in vocabulary development (marked by an inflection point; i.e., spurters) would show evidence of greater systemwide instability, as evidenced by alterations in relations between language, gesture, and affect.

Three specific predictions were addressed in this study. The first is that during the vocabulary spurt, systemwide instability brought about by rapid expansion in language (i.e., the control parameter) should lead to a temporary decoupling of behavioral components of the communicative system. If the sharp transition in the rate of word learning exhibited by spurters is indicative of greater instability in the communicative system, then these children should be less likely to coordinate communicative behaviors at the spurt session relative to nonspurters (i.e., children who exhibit a more gradual increase in vocabulary size). Thus, we expected coordinations of multiple communicative behaviors (i.e., combinations of gestures, facial affect, words, and/or nonword vocalizations overlapping in time) to be less frequent during the vocabulary spurt, relative to before and after the spurt.

Second, during the vocabulary spurt, words are acquired at a rapid pace, and their production appears to place high demands on children's resources (e.g., Gershkoff-Stowe, 2001, 2002). Because words are relatively effortful at this time, their co-occurrence with other communicative behaviors may be specifically impacted. In other words, if the relatively fragile status of language during the

spurt renders behavioral configurations involving words more sensitive to disruption, then we would expect words to appear in coordination with other communicative expressions (e.g., gesture, facial affect) less frequently at the spurt session relative to the prespurt and postsput sessions. Such a disruption should be apparent only among spurters, for whom vocabulary growth involves rapid expansion in a small window of time.

Third, older behavioral forms (i.e., those that are well practiced and more established) are, in dynamic terms, less susceptible to disruption. Thus, when the communicative system is unstable and infants combine behaviors to communicate, they should rely more extensively on those that are well established and highly practiced. Therefore, compared with nonspurters, when spurters coordinate communicative expressions at the vocabulary spurt, a greater proportion of those coordinations should consist entirely of developmentally prior forms of communication (i.e., affective expressions, gestures, nonword vocalizations) than at prespurt or postsput periods.

In summary, the overarching goal of the present study was to evaluate the three predictions outlined above having to do with whether instability generated by the vocabulary spurt influences coordination of communicative behaviors overall and the integration of newly emerging versus developmentally prior behaviors in coordinated bouts in particular. We did this by examining the production and coordination of communicative behaviors in a group of infants who demonstrated a clear point of transition in word-learning rate and a group of comparison infants who exhibited an increase in word learning that was more gradual and not characterized by an inflection point.

### Method

#### Participants

The initial sample consisted of 30 typically developing, healthy infants (14 boys) and their primary caregivers (mostly mothers). Infants and caregivers were observed at home twice a month from 2 to 19 months of age as part of a larger longitudinal study of infant vocal-motor coordination (e.g., Iverson, Hall, Nickel, & Wozniak, 2007). Observations were scheduled to occur within a week of each infant's birthday and at the midpoint between birthday anniversaries. Dyads were recruited from a small midwestern city and a large mid-Atlantic city through published birth announcements and word of mouth. Eligible families were contacted by letter and follow-up phone call. Informed consent was obtained from parents upon enrollment. All infant participants were from full-term, uncomplicated pregnancies with normal deliveries; had 5-min neonatal Apgar scores within the normal range (9 or better; Apgar, 1953); and came from monolingual, English-speaking homes. To be included in the final sample for the present study, infants must have had an observable vocabulary spurt prior to completion of the larger study (see below for details of the vocabulary spurt identification procedure).

Three infants met criteria for a vocabulary spurt less than 1 month prior to the end of data collection (ages 18.5, 18.5, and 19 months, respectively). Because postsput sessions were not available for these three infants, they were not included in the study. Data from an additional seven infants were examined for a vocabulary spurt but did not meet either the statistical or threshold

criteria (see below). Seventy-seven percent of the infants in our sample exhibited a spurt based on threshold criteria; this figure is comparable to those of other studies using similar methodology (e.g., Goldfield & Reznick, 1990). In addition, two infants were excluded from the initial sample due to sickness or malfunction in sound equipment.

The final sample of 18 infants (eight boys) was 44% male and 95% Caucasian. Seven infants were firstborn, and two were receiving child care at least 24 hr per week at the time of study enrollment. Fifty-five percent of mothers had some graduate or professional school experience, and 45% had some college or a college degree. For fathers, 39% had some graduate or professional school experience, 45% had some college or a college degree, and 11% had completed high school only. Information on the socioeconomic status of the families that participated in this study was not collected.

### Identifying the Vocabulary Spurt

Parents completed the MacArthur–Bates Communicative Development Inventories (CDI; Fenson et al., 1993), a widely used measure of early communicative development, at regular 2-week intervals from infant ages 8 to 19 months. Parent report is commonly used in studies of early language development, and data suggest that parents are fairly good informants of their children's language development (e.g., Bates, Bretherton, & Snyder, 1988; Fenson et al., 1994; Goldfield & Reznick, 1990). Indeed, the CDI has excellent internal consistency ( $rs = .95-.96$ ), test–retest reliability ( $rs = .80-.90$ ), and concurrent validity with tester-administered measures ( $r = .72$ ; Bates et al., 1988; Fenson et al., 1994). Between the 8- and 16-month sessions, the Words and Gestures form of the CDI (CDI–WG) was administered to parents. This form, standardized for use with children 8–16 months of age, consists of a 396-item vocabulary checklist on which parents check items that their child only understands or both understands and says.

Beginning at the 16-month observation, the Words and Sentences form of the CDI (CDI–WS) was employed. At the time of data collection, the CDI–WG form was standardized only to age 16 months, and so a switch to the CDI–WS was necessary at that point. However, there is no statistically significant difference in median scores between the CDI–WG and the CDI–WS at 16 months of age in a large sample of typically developing children (P. Dale, personal communication, September 26, 2009). The CDI–WS form, designed for use with children 16–30 months of age, consists of a 680-word vocabulary checklist organized into 22 semantic categories on which parents indicate words that the child says. The total CDI expressive language score (i.e., number of words that the child understood and said) was then computed for all sessions from 8 months forward.

As described above, a true vocabulary spurt requires a sharp and sustained change in the rate of word learning following a period of slow vocabulary growth, rather than a large number of new words acquired within a specific and limited period (P. Bloom, 2000; Ganger & Brent, 2004). Identification of the occurrence and nature of the vocabulary spurt was achieved via a two-step process (see below for further details). Following Ganger and Brent (2004), we modeled longitudinal word production data from all 18 infants (gathered using the CDI) to determine whether the growth trajec-

tory had an inflection point, the statistical definition of a shift in rate of development. After identifying a subset of children who met statistical criteria for a vocabulary spurt, we analyzed the word production data again, this time using the traditional threshold approach. This was done in an effort to identify a group of infants who had also experienced a marked change in word learning (but not a true phase transition) with which to compare data on communicative coordination gathered with the observational methods described below.

**Statistical approach.** First, we considered mathematical representations of vocabulary growth for the 18 participants. Specifically, we examined whether infants' rates of new word acquisition were better modeled by a logistic or quadratic function. The logistic function includes an inflection point (i.e., a specific point of rapid change surrounded by points of slower change) and is proposed to be a more accurate representation of a discrete transition between a slow learning stage and a faster learning stage (Ganger & Brent, 2004). The quadratic function is the traditional choice for representing the course of early word learning by depicting a period of slow word learning followed by steady and continued acceleration in vocabulary growth, but it does not involve an inflection point (Ganger & Brent, 2004; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991).

A logistic function takes the general form  $y = a/[1 + e^{-bx - c}]$  and involves three parameters,  $a$ ,  $b$ , and  $c$ . Parameter  $a$  corresponds to the rate of learning after the transition, or the asymptote. Parameter  $b$  corresponds to the length of time over which the transition occurs, or the slope of the function at the transition point; and parameter  $c$  corresponds to the point at which the transition occurs, also known as the inflection point. A quadratic function has the general form  $y = ax^2 + bx + c$  and also involves three parameters (but not an inflection point). Here  $b$  corresponds to the steady increase in word-learning rate,  $a$  corresponds to the steady acceleration in word-learning rate, and  $c$  is a constant defining where the function crosses the vertical axis.

Both the logistic and the more traditional quadratic models were fitted to each child's data independently with SPSS for Windows. Children's data were represented as rate of new word acquisition (new words per 2 weeks) versus cumulative vocabulary (see Ganger & Brent, 2004, for a detailed rationale for variable choice). A logistic model was fitted to each child's data by using the nonlinear regression function in SPSS for Windows and entering the model asymptote/ $\{1 + e^{[-\text{slope}(\text{words} - \text{inflection point})]}\}$  by hand. Words, the child's cumulative vocabulary level, was the independent variable. Asymptote, inflection point, and slope are parameters that are fit to the child's data. Initial values of the parameters were set as follows: asymptote = 3.0, inflection point = -0.1, and slope = 0.1. These values were chosen to be consistent with Ganger and Brent's (2004) method. We then tested the fit of a quadratic model by using the curve-fitting function in SPSS for Windows and selecting the quadratic option. Three criteria were used to determine which model was the better fit for the data.

The first criterion involved an initial comparison for goodness of fit with  $R^2$  values: The model with the higher  $R^2$  was considered to be the potentially better fit. However, to make the comparison more rigorous, we also computed log-likelihood ratios (LLRs) for the two models, or the ratio of the probability of the observed data points under one model (the logistic) to their probability under an alternative model (the quadratic). LLRs, computed with the for-

mula [(Quadratic root-mean-square residuals)/(Logistic root-mean-square residuals)]<sup>number of observations</sup>, are typically given in (Base 10) logarithms. Thus, a ratio of 100:1 is a log of 2, and 10:1 yields a log of 1. According to Ganger and Brent (2004), “by convention, a ratio of 100:1 is required to be very confident of the result, a ratio of 10:1 is worth a second glance, and anything smaller is not acceptable” (p. 627). Our second criterion was therefore that the LLR had to be 1 or larger to indicate that the logistic model fit better than the quadratic model. All prediction-driven analyses were rerun without the two participants with an LLR between 1 and 2, and the results remained in the same direction as those for the larger group.

The final criterion for determining better fit was whether the model computed a reasonable inflection point. For this analysis, any inflection point greater than 20 and fewer than 90 words was considered acceptable (e.g., Ganger & Brent, 2004; Lifter & Bloom, 1989). A minimum of 20 words was chosen based on the widespread opinion that it represents a time in lexical development that is too early for a true spurt (e.g., Lifter & Bloom, 1989). A maximum of 90 words was selected to be consistent with the original criterion proposed by Ganger and Brent (2004).

Children had to meet all three criteria to be considered spurters, and this resulted in nine of the 18 participants being classified as spurters. Table 1 displays the inflection points,  $R^2$  values, LLRs, and spurter status for each of the 18 children. With regard to the nine participants in the spurter group, 56% were male and 56% were later-born; their mean age at the vocabulary spurt was 15.67 months ( $SD = 1.00$ ).

**Threshold approach.** To allow a direct comparison of communicative abilities during the time surrounding the spurt, we then tested word production data from the remaining nine participants to determine whether they exhibited some demonstrable change in

word learning (albeit did not meet statistical criteria). We used the traditional threshold approach for this purpose. As previously discussed, historically the most common method for identifying the point at which a child has undergone a vocabulary spurt is the threshold approach, in which a given number of new words is acquired over a given period (e.g., Goldfield & Reznick, 1990). Although recent arguments suggest that this method cannot capture a true shift in the rate of vocabulary learning (Ganger & Brent, 2004; McCune, 2008), most would agree that it represents a sudden and marked growth in the number of new words in children’s productive vocabularies (e.g., L. Bloom, 1993; Goldfield & Reznick, 1990; Nelson, 1973). Following the most conservative criteria in the literature, we defined this sudden vocabulary growth as the first observation at which the number of words produced increased by at least 10 in a given 2-week period and after the infant had acquired a minimum of 20 words (Lifter & Bloom, 1989; Mervis & Bertrand, 1994).

Under this procedure, all nine nonspurters demonstrated marked growth in word learning. Of the nine participants in this group, 33% were male and 67% were later-born; their mean age at the time of growth was 16.78 months ( $SD = 1.18$ ). Although a minimum cumulative vocabulary of 20 words was required, none of the infants demonstrated an increase of 10 words in 2 weeks prior to achieving the base criterion. As stated above, spurters were matched with nonspurters on vocabulary size at the spurt within an average of three words (range: 0–7). Further, it was determined that all nine spurters also met threshold criteria. The mean age at vocabulary spurt (as identified via the statistical or threshold approach) for all infants in this study, regardless of group, was 16.22 months (range: 14–18). Consistent with previous investigations (e.g., L. Bloom, 1973; Dromi, 1987; Goldfield & Reznick, 1990), the average size of infants’ vocabularies at spurt onset was about 50 words ( $M = 48.89$ ; range: 37–69).

It is unlikely that the mean age at vocabulary spurt is a product of the transition from the CDI–WG to the CDI–WS at the 16-month observation. However, to assess this possibility, we recomputed the acquisition of new words for each participant based only on those items that appeared on both measures and found that for all but one participant the age at vocabulary spurt remained the same. To address the possibility that parents may have been tempted to endorse a larger number of words on the CDI–WS because it is longer than the CDI–WG, we calculated the percentage of words selected on each form as a reliability check. In fact, the percentage of words selected shows a similar increase over time ( $M_{\text{prespurt}} = 5.22$ ,  $SD = 1.67$ ;  $M_{\text{spurt}} = 8.84$ ,  $SD = 3.08$ ;  $M_{\text{postspurt}} = 13.04$ ,  $SD = 6.00$ ). In addition, this pattern was observed in every participant. Further, only three of the 18 children reached threshold criteria at 16 months of age based on the CDI; and all three children also exhibited a marked increase in the number of words produced spontaneously during the videotaped observation session from the prespurt session to the spurt session (i.e., an average increase of 43 words).

### Observational Data

As described above, all participants were observed every 2 weeks from 2 to 19 months of age. For the present study, we focused on three observations from the period in which infants achieved the vocabulary spurt: (a) that occurring 1 month prior to

Table 1  
Model Fit Statistics From Word Production Analyses Using a Statistical Approach

| Subject number | Logistic $R^2$ | Quadratic $R^2$ | Log-likelihood ratio | Inflection point <sup>a</sup> | Spurter? |
|----------------|----------------|-----------------|----------------------|-------------------------------|----------|
| 1              | .682           | .687            | 0.852                | 11                            | No       |
| 2              | .963           | .979            | 0.002                | 33                            | No       |
| 3              | .950           | .975            | 0.001                | 104                           | No       |
| 4              | .646           | .613            | 2.228                | 40                            | Yes      |
| 5              | .357           | .349            | 1.122                | 9                             | No       |
| 6              | .673           | .655            | 1.686                | 153                           | No       |
| 7              | .958           | .944            | 13.818               | 311                           | No       |
| 8              | .838           | .708            | 360.816              | 29                            | Yes      |
| 9              | .964           | .962            | 1.970                | 24                            | Yes      |
| 10             | .807           | .821            | 0.963                | 57                            | No       |
| 11             | .923           | .857            | 146.884              | 31                            | Yes      |
| 12             | .905           | .842            | 322.193              | 35                            | Yes      |
| 13             | .822           | .767            | 7.569                | 53                            | Yes      |
| 14             | .476           | .360            | 9.946                | 24                            | Yes      |
| 15             | .945           | .982            | 0.000                | 49                            | No       |
| 16             | .542           | .521            | 1.671                | 23                            | Yes      |
| 17             | .794           | .824            | 0.207                | 41                            | No       |
| 18             | .919           | .874            | 85.149               | 33                            | Yes      |

<sup>a</sup> Inflection points less than 20 were not considered acceptable (e.g., Lifter & Bloom, 1989), and those greater than 90 were not possible given the range of data; in such cases, the program could not find a reasonable fit within the range of actual data (Ganger & Brent, 2004).

the onset of the vocabulary spurt (prespurt session), (b) that coinciding with the onset of the vocabulary spurt (spurt session), and (c) that occurring 1 month following the onset of the vocabulary spurt (postspurt session). Observation time points were determined for each participant according to milestone onset (i.e., the vocabulary spurt) and were chosen based on inflection points for spurters and threshold criteria for nonspurters; however, the age at spurt onset was the same for all the spurters regardless of whether the threshold approach or inflection point approach was used. This type of longitudinal approach (i.e., milestone-based approach) was chosen because it avoids the potential confound between infant age and milestone onset and allows us to determine that any observed changes in communicative behaviors are specifically related to infants' achievement of the vocabulary spurt and not simply a function of age.

Infants were videotaped at home with the same primary caregiver for approximately 45 min. For all infants, the first and final 15 min of the session consisted of unstructured, naturalistic observation. Caregivers were asked to continue their normal activities during this time; no attempt was made to structure this portion of the session. These activities may have included play with their infant, cleaning or other homemaking activities, feeding, or conversation with the experimenter. During the middle 15 min, caregivers were seated on the floor with the infant, and infants were videotaped interacting with the caregiver and playing with favorite toys. To enhance the audio component of the recordings, infants wore a small wireless microphone clipped to a cloth vest worn over their clothing during the session. To allow for warm-up, the initial 15-min naturalistic segment was not coded; the data reported here were obtained from the middle semistructured play and final naturalistic play periods.

## Coding

Coding was completed by one primary observer (the first author) and three secondary observers blind to the study's hypotheses. All spontaneous (i.e., not explicitly elicited by an adult) and communicative utterances produced by infants during the 30-min session were coded continuously from the videotape, with onset and offset times identified for each behavior. Utterances consisted of gestures alone, facial affective expressions alone, words alone, nonword vocalizations alone, or any combination of these behaviors produced together (i.e., in coordination). Coding criteria, adapted for words, nonword vocalizations, and gestures from Iverson and Goldin-Meadow (2005) and for infant facial expressions from babyFACS (Oster, 2000), are described below. To facilitate analysis of the relative timing of communicative behaviors, video coding was completed with a time-linked, computer-based video interface system (Observer Video-Pro, Noldus Information Technology, Leesburg, VA).

**Gestures.** In keeping with traditional criteria, all communicative gestures were coded. The infant had to make a clear effort to direct the caregiver's attention (e.g., through use of eye contact, vocalization, postural shift, or repetition) for a gesture to be considered communicative (e.g., Iverson, Capirci, Volterra, & Goldin-Meadow, 2008; Iverson & Goldin-Meadow, 2005; Thal & Tobias, 1992). Gestures were of two types. Deictic gestures (e.g., pointing, reaching, giving, and showing) express intent to request or declare (e.g., Bates, 1979). These gestures indicate referents

(i.e., object, location, event) in the immediate environment, and their meanings are thus context bound. Representational gestures (e.g., nodding the head "yes," raising the arms high for "tall") refer to an object, person, location, or event through hand movement, body movement, or facial expression. These gestures differ from deictic gestures in that they represent specific referents and their basic semantic content does not vary with the context (e.g., Iverson, Capirci, & Caselli, 1994).

**Vocal utterances.** All words and nonword vocalizations were coded in a manner consistent with previous work examining the gesture-speech relationship in infants and young children (see Butcher, Mylander, & Goldin-Meadow, 1991; Goldin-Meadow & Mylander, 1984). Words involved use of the same sound pattern to refer to a specific referent on multiple occasions or in different contexts. They were either actual English words (e.g., *cat*, *duck*, *hot*) or sound patterns that were consistently used by a particular child to refer to a specific object or event (e.g., using "bah" to refer to a bottle in a variety of different contexts). Words that were purely imitative (i.e., words repeated immediately after being spoken by another person) were not coded.

All uninterpretable strings of speech sounds were coded as nonword vocalizations. Nonword vocalizations included vowel strings (e.g., "eaa"), reduplicated babbling (e.g., "gaga"), or variegated babbling (e.g., "bama").

**Facial affect expressions.** Facial expressions were coded as affect expressions if they reflected positive emotionality-joy, negative emotionality-distress, or surprise-interest. Positive emotionality-joy was defined as the presence of upward lip corner pull (AU12) and/or cheek raising (AU26c-e/27). Negative emotionality-distress was defined by the presence of downward lip corner pull (AU12) and brows lowered or furrowed and/or mouth opening and/or cheek raising. Surprise-interest was defined as the presence of one or any combination of the following three action units: raised brows, raised eyelids, and mouth opening (Facial Action Coding System [FACS], Ekman & Friesen, 1978; babyFACS, Oster, 2000). Facial affect was coded as neutral when none of these expressions was active.

**Coordinated bouts.** In addition to coding vocal, gestural, and affective behaviors (i.e., those produced in isolation), a second-order variable (i.e., coordinated bouts) was derived by examining instances in which communicative behaviors co-occurred in time. Co-occurrence was defined when the duration of two (or more) events had some overlap in time course. Similar definitions have been used in descriptions of speech and gesture combinations (e.g., "gestural and/or vocal units that were produced simultaneously, with some extent of overlap, or in immediate succession, were classified as combinations"; Capirci, Iverson, Pizzuto, & Volterra, 1996, p. 655) and in nonrandom patterns of infant vocalizations and facial expressions (Yale et al., 2003, 1999). We did not consider nonoverlapping behaviors as co-occurring in an effort to be conservative.

Coordinated bouts were classified into one of four main categories: gesture plus facial affect expression plus vocal utterance, vocal utterance plus gesture, vocal utterance plus facial affect expression, and facial affect expression plus gesture. Figure 1 presents a schematic of communicative behaviors produced by a single infant during a 30-s portion of the session. As is apparent in the figure, the infant produced three coordinated bouts during this time. The first involved the co-occurrence of a facial affect ex-

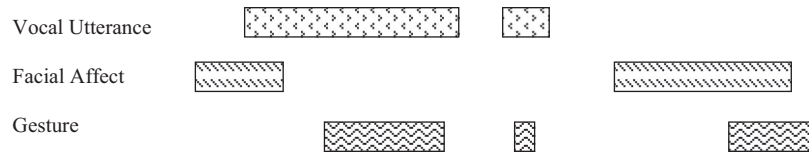


Figure 1. Schematic of communicative behaviors produced by a single infant during a small sample of time in one session, depicting temporal overlap between behaviors in three communicative modalities.

pression, a vocal utterance, and a gesture; it was initiated by a facial affect expression and ended with a vocal utterance. The second involved a gesture that began and ended within a vocal utterance; and the third consisted of a facial affect expression and a gesture, with the facial affect expression beginning before and extending into the gesture.

**Reliability.** We assessed intercoder reliability by having all coders independently code sixteen 10-min segments randomly chosen from observations of different infants at different ages (four from the prespurt session, eight from the spurt session, and four from the postspurt session). Under this procedure, mean intercoder agreement was 92% (range: 83%–98%) for identifying vocal utterances, 89% (range: 82%–100%) for identifying gestures, 79% (range: 74%–100%) for identifying facial affect, and 82% (range: 67%–100%) for identifying coordinated bouts. Mean intercoder agreement was 87% ( $\kappa = .78$ ; range: .58–.96; Cohen, 1960) for classifying vocal utterances as words or nonword vocalizations, 95% ( $\kappa = .94$ ; range: .86–1.0) for classifying gesture type, and 98% ( $\kappa = .98$ ; range: .86–1.0) for classifying affect type. Disagreements were resolved by joint viewing of the clips and discussion, and if a resolution was not reached, the first author decided on the appropriate code. All reliability statistics reflect scores prior to discussion.

## Results

The overarching goal of this study was to examine the production and coordination of affect, gestures, words, and nonword vocalizations at the vocabulary spurt, a time of significant growth in language and presumably of increased instability and reorganization within the communicative system. We begin by presenting analyses confirming the presence of a vocabulary spurt (initially identified by parent report data) in infants' spontaneous word production during the three observations. We then present descriptive data on production of coordinated bouts, our main variable of interest, for the entire sample. Finally, we focus on a set of predictions derived from dynamic systems theory regarding ways in which the co-occurrence of communicative behaviors may be disrupted at the vocabulary spurt by comparing data from spurters and nonspurters. We expected that a destabilization of existing communication patterns would be most apparent among spurters, who more clearly undergo a phase transition in vocabulary development.

Prior to conducting statistical analyses, data were inspected for gender, birth order, and age differences. Preliminary analyses revealed no effects of gender,  $t(16) = -0.307$ , *ns*, or birth order,  $t(16) = 0.242$ , *ns*, on overall infant communicativeness (i.e., the mean number of communicative acts produced across all three sessions). In addition, there was no significant positive relationship

between age and infant communicativeness ( $r = .365$ , *ns*). Thus, all subsequent analyses were carried out without regard to these variables. Data were subjected to 2 (group: spurters, nonspurters)  $\times$  3 (observation: prespurt, spurt, postspurt) repeated measures analyses of variance with follow-up simple-effects analyses where appropriate. All proportional variables were arcsine-transformed prior to conducting statistical analyses.

## Confirmation of the Vocabulary Spurt Using Observational Data

An initial set of analyses was conducted on the observational data obtained at the three home visits to corroborate the validity of the vocabulary spurt identification procedure (conducted on the basis of the CDI data). These analyses focused on the overall spontaneous production of words.

With regard to the mean number of words produced at each session, only the main effect of observation was significant,  $F(2, 32) = 13.40$ ,  $p < .001$ ,  $\eta^2 = .456$ , indicating that children in both groups showed an increase in word production at the spurt session (spurters:  $M_{\text{prespurt}} = 14.22$ ,  $SD = 11.39$ ;  $M_{\text{spurt}} = 41.22$ ,  $SD = 28.28$ ;  $M_{\text{postspurt}} = 37.67$ ,  $SD = 15.95$ ; nonspurters:  $M_{\text{prespurt}} = 16.33$ ,  $SD = 12.63$ ;  $M_{\text{spurt}} = 32.56$ ,  $SD = 15.28$ ;  $M_{\text{postspurt}} = 51.89$ ,  $SD = 26.93$ ). All but two infants exhibited this pattern. However, simple-effects analyses indicated that spurters demonstrated a significant increase in observed word production from the prespurt to spurt sessions ( $p = .011$ ) and no significant difference between spurt and postspurt sessions ( $p = .968$ ); whereas nonspurters did not demonstrate an increase in observed word production from the prespurt to the spurt session ( $p = .163$ ), but a statistically significant increase was detected between the spurt and postspurt sessions ( $p = .002$ ; see Figure 2).

## Coordination of Communicative Behaviors: Descriptive Analyses

Descriptive statistics for coordinated bouts are presented in Table 2. All the infants produced multiple coordinated bouts at each session, at a rate of almost one per minute. With respect to developmental change in the production of coordinated bouts across the vocabulary spurt period, a repeated measures analysis of variance revealed significant increase in the total number of coordinated bouts over the three sessions ( $M_{\text{prespurt}} = 19.44$ ,  $SD = 11.17$ ;  $M_{\text{spurt}} = 19.22$ ,  $SD = 9.55$ ;  $M_{\text{postspurt}} = 29.22$ ,  $SD = 14.12$ ),  $F(2, 34) = 5.94$ ,  $p = .006$ ,  $\eta^2 = .259$ . Planned contrasts indicated no significant difference in number of communicative coordinations between the prespurt and spurt sessions,  $F(1, 17) = 0.01$ ,  $p = .946$ ; however, coordinations increased significantly

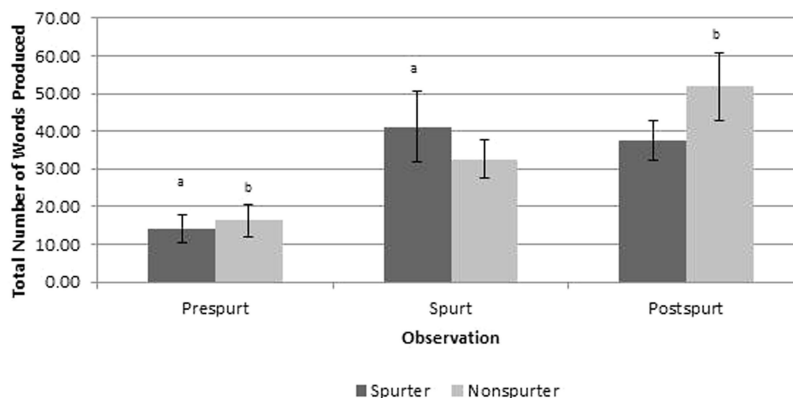


Figure 2. Total number of words produced in 30-min prespurt, spurt, and postspurt observation sessions. Error bars indicate standard errors. Subscripts reflect statistical differences at  $p < .05$ .

from the spurt to the postspurt session,  $F(1, 17) = 11.91, p = .003, \eta^2 = .412$ .

However, because it is possible, at least in principle, that infants who frequently produce gestures, vocalizations, and affect will show some coordination between these behaviors simply due to chance, we also assessed the likelihood that the duration of coordination is greater than that predicted by the base rates of occurrence of the three behaviors. This was done in the following way. The total duration of all vocalizations, gestures, and affective expressions was calculated separately, and the probability of occurrence for each type of behavior in a given session was estimated by dividing these numbers by the total length of the session. The joint probability of a vocal, gestural, and affective behavior co-occurring by chance (i.e., if these behaviors are independent) was then estimated based on the product of these probabilities and compared with the probability of occurrence of a coordinated bout (estimated by dividing the total duration of all temporally overlapping behaviors by the total length of the session) via two-tailed one-sample  $t$  tests. Results revealed that the obtained probability of a coordinated bout was significantly greater than expected by chance at the prespurt,  $t(17) = 6.36, p < .001$ ; spurt,  $t(17) = 6.32, p < .001$ ; and postspurt sessions,  $t(17) = 8.54, p < .001$ .

**Coordination of Communicative Behaviors: Developmental Predictions**

The main goal of the study was to test predictions derived from dynamic systems theory that had to do with the relationship

between the vocabulary spurt and the co-occurrence of communicative behaviors from three modalities. In particular, we investigated whether disruption in the organization of the communicative system was evident during a phase transition in language development. It was generally expected that relative to nonspurters, spurters would show evidence of greater systemwide instability due to a clear and marked transition in the rate of word learning.

**Prediction 1: Instability and uncoupling in the communicative system.** From a dynamic systems perspective, instability in one component of a developing system may engender changes in the overall organization of the system. Specifically, because behavioral patterns are softly assembled and flexible, the multiple interacting components in a system are particularly susceptible to decoupling during times of transition. Therefore, it was generally expected that relative to nonspurters, fewer instances of coordination of communicative behaviors would be evident among spurters during the vocabulary spurt session in comparison to the prespurt and postspurt sessions. We addressed this prediction by examining the frequency of communicative coordinations relative to overall production of communicative expressions (i.e., the number of coordinated bouts divided by the total number of communicative acts). The mean proportions of communicative acts consisting of coordinated bouts are presented separately for spurters and nonspurters in Figure 3.

As is evident in the figure, spurters exhibited a clear drop and subsequent rebound in production of coordinated bouts at the vocabulary spurt, whereas nonspurters appeared less affected by

Table 2

*Descriptive Information for Coordinated Bouts: Mean Number of Coordinated Bouts, Mean Proportion of Communicative Attempts That Were Coordinated Bouts, Mean Duration and Number of Behaviors Involved in Coordinated Bouts, and Mean Proportion of Coordinated Bouts Composed of Developmentally Prior Communicative Behaviors*

| Behavior            | Prespurt |           |       | Spurt    |           |       | Postspurt |           |       |
|---------------------|----------|-----------|-------|----------|-----------|-------|-----------|-----------|-------|
|                     | <i>M</i> | <i>SD</i> | Range | <i>M</i> | <i>SD</i> | Range | <i>M</i>  | <i>SD</i> | Range |
| Number of bouts     | 19.67    | 11.50     | 42.00 | 19.22    | 9.55      | 28.00 | 29.22     | 14.11     | 58.00 |
| Proportion of bouts | 0.14     | 0.07      | 0.25  | 0.11     | 0.06      | 0.19  | 0.15      | 0.06      | 0.22  |
| Duration of bouts   | 3.24     | 0.96      | 3.29  | 2.69     | 0.54      | 1.66  | 2.37      | 0.48      | 1.57  |
| Number of behaviors | 2.04     | 0.08      | 0.24  | 2.04     | 0.06      | 0.18  | 2.07      | 0.09      | 0.31  |

Note.  $n = 18$ . Data were collected from 30-min observation sessions.

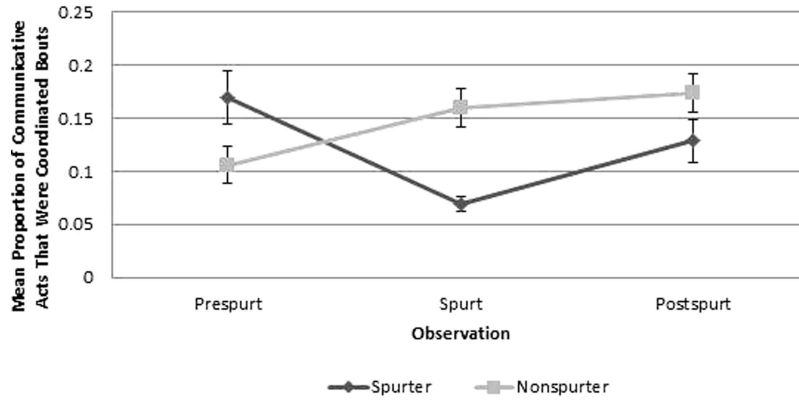


Figure 3. Mean proportion of communicative attempts that were coordinated bouts.

this transition. The main effects of observation,  $F(2, 32) = 2.96$ ,  $ns$ , and group,  $F(1, 16) = 1.03$ ,  $ns$ , were not statistically reliable, but the Group  $\times$  Observation interaction was highly significant,  $F(2, 32) = 13.10$ ,  $p < .001$ ,  $\eta^2 = .450$ . Simple-effects analyses indicated that the source of the effect was in the significant decrease in relative frequency of coordination between the prespurt and spurt sessions in the spurter group ( $p = .001$ ). There were no significant differences across sessions for the nonspurter group. Moreover, there was no significant change in the total number of gestures ( $M_{\text{prespurt}} = 35.22$ ,  $SD = 21.78$ ;  $M_{\text{spurt}} = 22.67$ ,  $SD = 11.46$ ), vocalizations ( $M_{\text{prespurt}} = 107.67$ ,  $SD = 47.99$ ;  $M_{\text{spurt}} = 162.00$ ,  $SD = 73.91$ ), or affective expressions ( $M_{\text{prespurt}} = 13.00$ ,  $SD = 8.03$ ;  $M_{\text{spurt}} = 16.78$ ,  $SD = 8.97$ ) from the prespurt to spurt sessions ( $ps > .05$ ), indicating that the disruption in the production of coordinated bouts among spurters is not an artifact of a reduction in the base rates of communicative behaviors.

**Prediction 2: Newly emerging behaviors.** Our second prediction was that the rapid expansion of the lexicon during the vocabulary spurt confers a fragile status on words (e.g., Gershkoff-Stowe, 2001, 2002), and this would in turn reduce the likelihood that words would enter into coordination with other communicative behaviors. Therefore, it was expected that relative to nonspurters, spurters would produce fewer coordinated bouts involving words during the vocabulary spurt session.

Data on the overall production of words in coordinated bouts are presented in Figure 4. As is evident, spurters showed a strong decline and subsequent increase in words produced in coordination, whereas there was relatively little change across sessions for nonspurters. Analyses revealed a reliable main effect of observation,  $F(2, 32) = 4.57$ ,  $p = .018$ , but no statistically reliable main effect of group,  $F(1, 16) = 0.39$ ,  $ns$ . However, the Group  $\times$  Observation interaction was significant,  $F(2, 34) = 4.29$ ,  $p = .022$ ,  $\eta^2 = .211$ . Follow-up simple-effects analyses indicated that for spurters, there was a marked decrease in words produced in coordination from the prespurt session to the spurt session ( $p = .001$ ). The nonspurter group did not differ across sessions.

**Prediction 3: Developmentally prior behaviors.** The final prediction was that older, well-practiced behavioral patterns are preferred at times when the system is disrupted by rapidly changing skills. One might therefore expect coordinations produced by spurters during times of transition to be composed of well-

practiced, developmentally prior forms of communication (i.e., gestures, nonword vocalizations, facial affect). To address this prediction, we examined the composition of coordinated bouts produced by spurters and nonspurters across sessions to identify those that were composed entirely of developmentally prior communicative expressions (i.e., gesture plus affect, gesture plus nonword vocalization, and affect plus nonword vocalization).

Separate repeated measures analyses of variance conducted for each coordination type revealed significant main effects of observation. Specifically, for both spurters and nonspurters, the mean proportion of coordinated bouts consisting of gesture plus affect was higher at the vocabulary spurt than at adjacent sessions,  $F(2, 32) = 5.00$ ,  $p = .013$ ,  $\eta^2 = .238$  (spurters:  $M_{\text{prespurt}} = 0.04$ ,  $SD = 0.07$ ;  $M_{\text{spurt}} = 0.10$ ,  $SD = 0.09$ ;  $M_{\text{postspurt}} = 0.03$ ,  $SD = 0.05$ ; nonspurters:  $M_{\text{prespurt}} = 0.03$ ,  $SD = 0.04$ ;  $M_{\text{spurt}} = 0.09$ ,  $SD = 0.09$ ;  $M_{\text{postspurt}} = 0.02$ ,  $SD = 0.03$ ). Gesture plus nonword vocalizations were by far the most common type of bout produced at the spurt session, but they decreased significantly from the prespurt to the spurt session in both groups,  $F(2, 32) = 4.85$ ,  $p = .015$ ,  $\eta^2 = .232$  (spurters:  $M_{\text{prespurt}} = 0.82$ ,  $SD = 0.34$ ;  $M_{\text{spurt}} = 0.52$ ,  $SD = 0.27$ ;  $M_{\text{postspurt}} = 0.61$ ,  $SD = 0.20$ ; nonspurters:  $M_{\text{prespurt}} = 0.75$ ,  $SD = 0.23$ ;  $M_{\text{spurt}} = 0.60$ ,  $SD = 0.26$ ;  $M_{\text{postspurt}} = 0.63$ ,  $SD = 0.15$ ). Although spurters on average produced a higher proportion of affect plus nonword vocalization bouts at the spurt session than did nonspurters, the Group  $\times$  Observation interaction just missed conventional levels of significance,  $F(2, 32) = 3.02$ ,  $p = .063$ . No other differences were statistically reliable.

## Discussion

This study extends prior work demonstrating that temporally linked production of communicative behaviors is a robust feature of infant behavior (e.g., Butcher & Goldin-Meadow, 2000; D'Odorico, Cassibba, & Salerni, 1997; Yale et al., 2003). All the infants in this study combined behaviors from multiple modalities to deliver a communicative message, and they did so frequently, at levels greater than expected by chance. This is consistent with earlier work demonstrating that children coordinate communicative behaviors at greater than chance levels from early infancy (Yale et al., 2003, 1999). The rate of about one coordinated bout per minute found in this study is comparable to those reported by

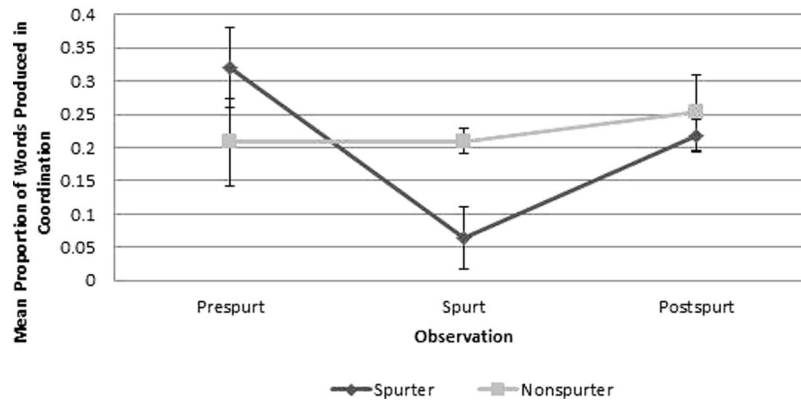


Figure 4. Mean proportion of words that were produced in coordination.

Wetherby, Cain, Yonclas, and Walker (1988) and Wetherby and Rodriguez (1992) for their samples of typically developing children communicating at the one-word stage.

At issue in this research was whether the tight links between language, gesture, and affect are temporarily loosened during a major communicative transition, the vocabulary spurt. From a dynamic systems point of view, developmental transitions present ideal opportunities for observing underlying processes of change (Thelen & Smith, 1994). It was expected that the instability produced by the vocabulary spurt would alter existing patterns of behavior and that this would be reflected in a reorganization of communicative behaviors. In light of widely varying definitions of the vocabulary spurt (see Ganger & Brent, 2004; McCune, 2008), a more stringent assessment of the rate of word acquisition was required in order to be more confident in our ability to capture a true developmental transition. Thus, we also used a new, statistical approach to identify the vocabulary spurt and asked whether instability in the communicative system was more pronounced for infants who experienced a more marked phase shift in word learning (i.e., spurters).

### What Is the Impact of the Vocabulary Spurt on the Communicative System?

The present study tested three predictions regarding the impact of the vocabulary spurt on the communicative system. These predictions had to do with effects of instability introduced by the vocabulary spurt on the patterning and frequency of coordination of communicative behaviors, including the heightened vulnerability of co-occurrences involving words, and differences between newly emerging and well-established communicative behaviors. It was expected that spurters—children demonstrating a clear transition in language development—would show more evidence of disruption in the communicative system during this transition period than nonspurters.

Findings were generally consistent with these predictions. A general decoupling of communicative behaviors was observed for spurters at the vocabulary spurt session, a time when increased effort was presumably dedicated to word learning. Prior to the vocabulary spurt, communicative behaviors such as gesture, affect, nonword vocalizations, and words were produced in coordinated patterns of communication; however, when children began to

acquire words rapidly, these patterns were disrupted. This is consistent with previous work documenting U-shaped changes in development, in which behaviors apparently disappear or regress, only to resurface later (Gershkoff-Stowe, 2001, 2002; Gershkoff-Stowe & Thelen, 2004; Strauss, 1982; Strauss & Stavy, 1982). U-shaped developmental phenomena are considered particularly valuable because they direct one's attention to places where reorganization might be taking place (Goldin-Meadow, 2004).

In addition, during the vocabulary spurt, not only are words being acquired at a rapid pace, they appear to have a particularly fragile status. On average, spurters produced 3 times as many words in general at the vocabulary spurt session than the prespurt session. However, words were more likely to be used alone when recruited for communication at the vocabulary spurt session. In contrast, prior to the vocabulary spurt, when words were being acquired at a slower pace, they often appeared in coordination with gestures and affect. Following the vocabulary spurt, as spurters gained experience with word learning and the system regained stability, words appeared in coordinated bouts with increased frequency. This pattern of failing to use existing skills during a time of instability or increased difficulty is consistent with the finding that novice word learners can detect fine phonetic detail in a syllable discrimination task but fail to do so in a word-learning task, presumably because it requires mapping sound to meaning, an ability that is newly emerging (Stager & Werker, 1997).

The difference between the prespurt and spurt sessions in the coordination of words may also reflect the relative degree of practice both with word learning in general and with specific word forms. Initially, word learning is a relatively slow process, with acquisition of the first 10 words often taking place over the course of several months (Dapretto & Bjork, 2000). Thus, prior to the vocabulary spurt, children are relatively less experienced word learners. Presumably, learning new words places high demands on children's cognitive resources, making those words particularly fragile and thus less likely to be coordinated with other behaviors. During the spurt, children gain extensive experience learning words as their vocabularies increase rapidly; and as they become more experienced word learners with larger lexicons, newly acquired words may be relatively less effortful. The implication of this is that during the postspurt period, words are more readily available for coordination with other behaviors. In fact, previous

work has demonstrated that as words are practiced in production, they become stronger and more resistant to naming errors (Gershkoff-Stowe, 2001, 2002).

One explanation for this finding may be that during a time of accelerated vocabulary growth, infants also rely less on nonspeech communicative behaviors (e.g., gestures) to supplement words. Thus, the observed decrease in the overlap between words and other communicative behaviors may not necessarily be an indicator of instability but rather a measure of increasing lexical skill. This seems unlikely, however, because words were again integrated with gestures and affect in coordinated bouts in the month after the vocabulary spurt, suggesting that the temporary reduction in the frequency with which infants coordinated words with other behaviors is directly related to systemic changes brought about by the vocabulary spurt. Moreover, although spoken language is ultimately the primary mode of communication, children continue to produce gestures with speech frequently well beyond the 2nd year (e.g., Church & Goldin-Meadow, 1986; Pine, Lufkin, & Messer, 2004), and the two modalities remain integrated in adulthood (e.g., McNeill, 1992).

The effects of increased efforts devoted to word learning are also evident in findings from studies of speech perception; infants with larger expressive vocabularies are better able to discriminate word-object pairs relative to infants with smaller vocabularies (Werker, Fennell, Corcoran, & Stager, 2002; see also Storkel, 2001). Thus, as words become more well established in infants' vocabularies, and they develop a larger lexical repertoire, newer words become more accessible, less effortful, and thus more likely to be integrated with other components of the system (Thelen & Smith, 1994).

Finally, the prediction that there would be group differences in the coordination of well-established behaviors was not supported. Both spurters and nonspurters relied on developmentally prior behaviors in the construction of coordinated bouts (e.g., configurations involving gestures, affect, and nonword vocalizations, behaviors that have been in infants' communicative repertoires since before the onset of the first word) at the spurt session. This suggests that reliance on well-established behaviors when faced with the task of learning a new skill, regardless of the rate at which this new skill is acquired, may be a more general developmental phenomenon; and it may indicate a more widespread pattern of temporary regression to more primitive forms at a time of disruption (e.g., Thelen & Smith, 1994).

There are several examples of this temporary regression to old behavioral forms at times of transition in the motor development literature (Adolph, 1997, 2000; Corbetta & Bojczyk, 2002; Corbetta & Thelen, 1996; Thelen & Ulrich, 1991). For example, Corbetta and Bojczyk (2002) demonstrated that infants temporarily reverted to two-handed reaching when they were learning to walk. Prior to the onset of walking, most infants were able to produce well-coordinated movement patterns that involved the extension of one arm when reaching for objects. When they began to walk, however, those infants increased their rate of two-handed reaching; and as they gained better balance control, they returned to unimanual reaching.

In sum, developing systems, such as the communicative system, are composed of many interacting parts that disassemble and reassemble during periods of transition. Spurters (i.e., children whose vocabulary growth consisted of a discrete transition from a

slow learning stage to a faster learning stage) showed greater evidence of systemwide instability specifically at the vocabulary spurt session, as indicated by (a) a drop in overall coordination of communicative behaviors and (b) a decreased likelihood that words would be produced in coordination. In contrast, nonspurters (i.e., children whose vocabulary growth was best described as continuous incremental improvement) did not demonstrate as dramatic a change in these behaviors across the three sessions. Our findings suggest that instability in the linguistic component has far-reaching effects on the entire communicative system that are manifested in multiple and varying ways. Newly emerging forms (i.e., words) are initially unstable but are gradually integrated with practice and support from well-established patterns of behaviors. Future work examining temporal patterns of multiple, diverse behaviors at other linguistic milestones (e.g., onset of the first word, the transition into two-word speech) will shed further light on the relevance of systemic disruption for engendering changes in communication and on general processes underlying development.

### Is the Vocabulary Spurt a Universal Phenomenon?

In this study, we also attempted to address some existing methodological issues inherent in measuring the vocabulary spurt. This developmental milestone has not been clearly defined in the literature to date, with studies differing somewhat arbitrarily in their definitions as to what constitutes a spurt. Further, the majority of prior identification efforts require that children's rate of word learning cross a previously specified threshold, and not necessarily that they experience a sustained change in learning rate, which encapsulates the traditional conceptualization of a spurt (P. Bloom, 2000; Dapretto & Bjork, 2000). Because our interest in the vocabulary spurt was dependent on its representation as a transition period in language development, we adopted a more rigorous identification procedure first proposed and implemented by Ganger and Brent (2004). Our results suggest that the vocabulary spurt, as it has traditionally been conceptualized, is indeed a real developmental phenomenon; however, there is evidence to suggest that it may not necessarily be a single, unified phenomenon.

All the infants in the current study gave evidence of an increase in word acquisition under the commonly employed threshold approach, which requires that a threshold of a specific number of words per unit of time must be crossed (Choi & Gopnik, 1995; Goldfield & Reznick, 1990; Gopnik & Meltzoff, 1987; Lifter & Bloom, 1989; Mervis & Bertrand, 1994; Poulin-Dubois et al., 1995; see Method for specific criteria). However, within the larger group, two patterns of vocabulary growth were identified through statistical modeling techniques, with only one providing evidence of a true phase shift in the rate of word learning via an inflection point (Ganger & Brent, 2004). It is interesting that the percentage of children who qualified as spurters in this sample was 50%, which is more than twice as high as the 20% reported in Ganger and Brent (2004). Although we adopted a slightly less conservative approach by not requiring an LLR greater than 2 when identifying spurters, only two participants were affected by this criterion. Even if they were reassigned to the nonspurter group, the percentage of spurters would equal 39%, remaining just under twice as high as that reported by Ganger and Brent. The reason for this difference is unclear, but it may be that the children who participated in the Ganger and Brent study were all twins, and there are notable

differences in language development between twins and singletons (e.g., Mogford, 1993). Further work with larger samples is needed to examine relations between differences in vocabulary growth and communicative development more generally.

Previous accounts of the vocabulary spurt propose that it is driven by major cognitive change such as the “naming insight” (e.g., Dore, 1978; Reznick & Goldfield, 1992), or dramatic advances in object concepts (Gopnik & Meltzoff, 1987; Lifter & Bloom, 1989; Mervis & Bertrand, 1994; Poulin-Dubois et al., 1995). However, the fact that approximately half the children in our sample experienced a spurt under our more stringent statistical criteria whereas the remaining children did not suggests at the very least that the vocabulary spurt may not reflect a universal cognitive transformation. Any theory that attempts to explain the vocabulary spurt must account for this variation in spurt patterns. Further, the mechanism underlying the spurt may itself be dynamic and fluid, determined by a collection of influences that vary with experience and from child to child, rather than a universal, specialized learning mechanism (see also McMurray, 2007). This is consistent with the dynamic systems emphasis on relationships among behaviors as a source of change with no single component claiming causal priority (e.g., Smith & Thelen, 2003), a view that is gaining broader acceptance among developmentalists (e.g., Ganger & Brent, 2004; McMurray, 2007; Vihman, DePaolis, & Keren-Portnoy, 2009).

Although variability in vocabulary growth is increasingly emphasized, relatively little work has examined this variability in specific ways. The role of variability in shaping processes by which developmental change is created is of critical importance in dynamic systems theory (Smith & Thelen, 2003). Although the general organization of the system is highly variable at developmental transitions, and change in one component of the system may have far-reaching effects on the composition of the entire system, even small differences in beginning states and in developmental histories can amplify and lead to large differences.

Prior evidence indicates that there are indeed differences in the age of onset of the vocabulary spurt, as well as in the rate and shape of vocabulary development (e.g., Dale & Goodman, 2005; Goodman et al., 1999). For example, L. Bloom (1993) reported that of 14 children followed in her study, nine exhibited a spurt prior to producing 50 words, with the remaining five showing a spurt after 50 words, all ranging in age from 18 to 26 months at spurt onset. Likewise, in Goldfield and Reznick’s (1990) classic study, the base vocabulary for spurters ranged from zero to 60 words at spurt onset and age at the spurt ranged from 15 to 22 months (see also Lifter & Bloom, 1989; Nelson, 1973). Our data suggest that an examination of differences in word acquisition is an important endeavor for future research. One approach could entail the investigation of correlates of more unusual growth trajectories, such as those of children who demonstrate a late-onset vocabulary spurt (late spurters; e.g., D’Odorico, Carubbi, Salerni, & Calvo, 2001; Mervis & Bertrand, 1995), children who appear to undergo two spurts (Dale & Goodman, 2005; Goodman et al., 1999), and children who do not exhibit any vocabulary spurt at all. In addition, although the vocabulary spurt is typically measured in terms of number of words acquired, alternative measures of the vocabulary spurt may be more apt to reveal the impact of differences in word learning. Measuring growth in the diversity and structure of vocabulary, a method suggested by Pan, Rowe, Singer,

and Snow (2005) and investigated by McCune (2008), is one promising approach.

Moreover, the vocabulary spurt is a phenomenon that has typically been studied at the level of the individual. However, it is difficult to provide a complete picture of the course of communicative development outside the social framework in which communicative acts occur. The broader environment of the child, together with within-person constraints and possibilities, operates to determine developmental outcomes (e.g., Fogel & Thelen, 1987). A central component of infants’ social context is, of course, the caregiver. Fogel and colleagues (e.g., Fogel et al., 2006; Hsu & Fogel, 2001) described the communicative system as an interpersonal relationship between the caregiver and the child within which early expressive and communicative behaviors develop dynamically. Indeed, parents respond differentially to infants’ vocalizations (e.g., Goldstein & West, 1999; Gros-Louis, West, Goldstein, & King, 2006) and are sensitive to changes in their infant’s communicative acts (Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007). Individual differences in the history and immediate state of the caregiver–child relationship and in caregiver responsiveness to changes in children’s communication may well relate to the variability observed in patterns of communicative behaviors described here.

Taken together, the data from the present study demonstrate that the vocabulary spurt is a time of considerable change that alters existing communication patterns. The findings presented are consistent with the notion that during a transition in communicative development, previously stable and cohesive behaviors are disrupted. With practice and experience, however, new behaviors are increasingly strengthened and integrated. The results also suggest that differences in the shape of the word-learning curve influence the relationships between various communicative behaviors. Thus, children who showed a more prominent transition in word learning were more likely to show a disruption in the communicative system. The milestone-based design employed here permits the examination of changes in behavior as they specifically relate to the emergence of a new communicative skill and underscores the fruitfulness of examining developmental transitions as a window into the process of developmental change.

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