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Effects of Parental Interaction on Infant Vocalization Rate, Variability and Vocal Type

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Examination of infant vocalization patterns across interactive and noninteractive contexts may facilitate better understanding of early communication development. In the current study, with 24 infant-parent dyads, infant volubility increased significantly when parent interaction ceased (presenting a "still face," or SF) after a period of normal interaction ("face-to-face," or FF). Infant volubility continued at the higher rate than in FF when the parent re-engaged ("reunion," or RE). Additionally, during SF, the *variability* in volubility across infants decreased, suggesting the infants adopted relatively similar rates of vocalization to re-engage the parent. The pattern of increasing

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volubility in SF was seen across all of the most common speech-like vocal types of the first half-year of life (e.g., full vowels, quasivowels, squeals, growls). Parent and infant volubility levels were not significantly correlated. The findings suggest that by six months of age infants have learned that their vocalizations have social value and that changes in volubility can affect parental engagement.

INTRODUCTION

Prior to speaking in words, infants interact with caregivers, producing facial expressions and considerable amounts of vocalization (Locke, 1993). Volubility is the amount of speech-like vocalization produced by infants over a period of time, measured by either the number of vocalizations per minute or the percent of time spent vocalizing. Changes in infant volubility related to interactive circumstance are the focus of this study. In particular, we address changes in infant volubility within a longstanding paradigm of research in parent-infant interaction, the Face-to-Face/Still-Face paradigm (FFSF; Tronick, 1982).

Infant speech-like vocalizations appear to be salient signals to parents (Chisolm, 2003; Locke, 2006). Individual infant vocalizations tend to elicit immediate adult responses (Keller, Lohaus, Volker, Cappenberg, & Chasiotis, 1999; Goldstein, King, & West, 2003; Gros-Louis, West, Goldstein, & King, 2006; Symons & Moran, 1987; Warlaumont et al., 2010). Also, greater numbers of infant vocalizations are associated with greater numbers of adult responses (Gilkerson & Richards, 2009; Goldstein et al., 2003; Gros-Louis et al.). Prelinguistic vocalizations appear to provide a framework within which an interactive relationship can develop. Goldstein, Schwade, and Bornstein (2009) suggest that parental responses to infant vocalization likely assist in language acquisition. There is an extensive literature supporting this claim, invoking the idea that human infant emotions and intellect develop in substantial measure in the context of vocal and affective interaction (e.g., Anderson, Vietze, & Dokecki, 1977; Bakeman & Adamson, 1984; Beebe, Jaffe, Feldstein, Mays, & Alson, 1985; Bornstein & Tamis-LeMonda, 1989; Cohn & Tronick, 1987; Fogel & Garvey, 2007; Hsu & Fogel, 2003; Jaffe, Beebe, Feldstein, Crown, & Jasnow, 2001; Papoušek & Papoušek, 1979; Stern, 1974; Tronick, 1982; Weinberg & Tronick, 1996). In the first months of life, this interactive pattern is said to result in a capability for primary inter-subjectivity (dyadic interaction) and, later in the first year, secondary inter-subjectivity (triadic interaction incorporating joint attention; Trevarthen, 1977, 1979).

Socioeconomic status (SES) has been shown to be positively associated with infant volubility differences. Research by Oller, Eilers, Basinger, Steffens, & Urbano (1995) indicated lower volubility among infants from low to very low SES homes when compared with infants from mid SES homes. Additional research (Bornstein & Bradley, 2003; Craig & Washington, 2005; Farah et al., 2008; Hart & Risley, 1995, 1999; Hoff, 2003, 2006; Hoff & Tian, 2005; Kelly, 2011; Pungello, Iruka, Dotterer, Mills-Koonce, & Reznick, 2009) suggests that not only do infants vocalize less in low SES homes, but also that mothers talk less to their infants than in higher SES homes (Hoff, Laursen, &Tardiff, 2002; Rowe, 2008). Large-scale sampling of infant vocalizations in their homes has also indicated that infant volubility is correlated with parental input (Gilkerson & Richards, 2009; Hart & Risley, 1995, 1999).

Volubility appears to be undisturbed in the presence of certain disorders (Nathani, Oller, & Neal, 2007). Similar volubility levels have been reported when comparing infants with mild, moderate, severe, or profound hearing loss to infants with normal hearing (Clement, 2004; Davis, Morrison, von Hapsburg, & Warner-Czyz, 2005; Koopmans-van Beinum, Clement, & van den Dikkenberg-Pot, 1998; Iyer & Oller, 2008). One study even reported significantly higher volubility in deaf infants than in hearing infants up to 18 months of age (van den Dikkenburg-Pot, Koopmans-van Beinum, & Clement, 1998). Other factors that might be expected to affect volubility include premature birth and exposure to more than one language in the home, but previous work has found no significant differences in volubility among such groups (Oller et al., 1995; Oller, Eilers, Urbano, & Cobo-Lewis, 1997).

Infant volubility levels have also been used in attempting to identify infants at risk for delays in expressive language acquisition. For example, 24-month-old toddlers identified with specific expressive language impairment have been found to vocalize less than typically developing infants at early ages (Rescorla & Ratner, 1996). Paul, Fuerst, Ramsay, Chawarska, and Klin (2010) compared infants with typically developing older siblings to those with older siblings diagnosed with autism, and although the study did not evaluate volubility overall in the way considered here, it did report significant differences in amounts of “transcribable” vocalization, such as canonical babbling (more in the low-risk group) and nontranscribable vocalization, such as squeals and growls (more in the infants at risk for autism). Other work has indicated that infants and toddlers with autism produce fewer speech-related vocalizations and engage in fewer vocal interactions with adults than typically developing children (Warren et al., 2010; Warlaumont et al., 2010). Thus, low levels of infant volubility may sometimes be an early indicator of a delay or disorder.

An important potential topic is variability of volubility *across* infants *within* differing circumstances, but this topic has not, to our knowledge, been a focus of any research. One reason attention to across-infant variability may be important is that we know volubility varies substantially both across studies and across infants within studies. For example the literature reports typically developing six-month-old infant groups with mean volubility ranging from 1.3 vocalizations per minute (Hsu, Fogel, & Messinger, 2001) to 11.3 per minute (Molemans, 2011). Differences in circumstances or measurement methods may be responsible for this wide disparity. Differences across infants *within* studies show an even larger range of differences. Our own longitudinal research often finds infants producing no speech-like vocalizations at all in a 20-minute sample, while other infants produce 20 utterances or more per minute in a sample of similar duration. Finally, as we will argue below, there may be considerable interest in effects of differing social circumstances for both volubility itself and for variability of volubility across infants. The evaluation of these factors may provide clues to infant learning and development of deliberate vocalization.

Prior research in infant vocal interaction has tended to categorize vocalizations in a very coarse way, usually distinguishing only cry and noncry or, at the most, further subdividing noncry vocalizations into two broad categories of syllabic and vocalic (Bornstein et al., 1992; Camp, Burgess, Morgan, & Zerbe, 1987; Hsu et al., 2001; van den Dikkenberg-Pot et al., 1998). Consequently, there has been little opportunity to determine if particular speech-like vocalization types are utilized to differential extents in different conditions of interaction. Does volubility across vocal types vary with circumstance, suggesting that different speech-like sounds may have consistently different functions? Until recently, research had provided a preliminary answer to this question, suggesting considerable flexibility of usage of sounds across circumstances (Papaeliou, Minadakis, & Cavouras, 2002; Hsu, Iyer, & Fogel, 2013; Scheiner & Fischer, 2011; Scheiner, Hammerschmidt, Jurgens, & Zwirner, 2006; Stark, Bernstein, & Demorest, 1993; Oller, 2000).

A recent study, however, illustrates more conclusively that the human infant shows extraordinary flexibility of usage of vocal types across different circumstances, apparently much greater flexibility than seen in any other primate at any age (Oller et al., 2013). How this functional flexibility manifests in drastically different interactive circumstances such as those described below is yet to be determined.

VOLUBILITY IN THE FACE-TO-FACE/STILL-FACE/REUNION PARADIGM

One of the most intriguing questions in the investigation of varying infant volubility concerns the social factors that may influence it. The FFSF paradigm may provide a useful setting to explore social influence on infant volubility. There are three episodes: 1) Face-to-Face (FF)—parent and infant sit across from each other and interact freely, 2) Still Face (SF)—the parent ceases interacting and does not respond to the infant, yet still looks directly at the baby, and 3) Reunion (RE)—the parent and infant interact spontaneously again. This longstanding paradigm for laboratory research has primarily been a vehicle for measuring affective interaction and communication between infant and parent (Cohn & Tronick, 1987, 1988; Tronick & Cohn, 1989; Tronick, 1982). This pattern of episodes offers the occasion to evaluate the infant's reaction to social influences and potentially to assess infant social motives.

Outside the laboratory, unconstrained parent-infant interactions suggest that increased parent responsivity is associated with increased infant volubility (Fogel & Garvey, 2007; Kaye & Fogel, 1980). Contingent responses to prelinguistic vocalizations are typical in mother-infant interactions (Goldstein & West, 1999; Gros-Louis et al., 2006; Hsu & Fogel, 2003). In SF interactions, there is a violation of the unconstrained pattern of parent-infant interaction (Braungart-Reiker, Garwood, Powers, & Wong, 2001), since the parent tries not to respond to infant vocalizations or affect in any way. It has been reported that infant volubility during SF increases (Delgado, Messinger, & Yale, 2002; Goldstein et al., 2009; Yale, Messinger, Cobo-Lewis, Oller, & Eilers, 1999) for infants at 6 months. The transition from an interactive episode (FF) to a noninteractive episode (SF) has been interpreted as providing the impetus for infants to attempt to reestablish interaction by increasing volubility. An increase in behavior during the SF episode has been observed in a number of different studies and appears to generalize across different durations of episodes, use of parent versus stranger as interactor, and differences in adult gaze direction during still-face (Delgado et al.; Goldstein et al., 2009; Delgado, Messinger, & Yale, 2002; Yale et al., 1999). According to the standard reasoning first suggested by Tronick, Als, Adamson, Wise, and Bolton (1978), it is the loss of the contingent response from the parent that appears to drive increased infant volubility. When interaction resumes between parent and infant in the RE episode, infant volubility has been reported to decrease slightly but not to the level of the FF episode (Delgado et al., 2002; Goldstein et al., 2009; Yale et al., 1999). It seems reasonable to interpret this higher level of volubility in RE as indicating that infants are motivated to maintain interaction with the parent after having just experienced the SF.

Having experienced an episode of contingent responses, which is typical in parent-infant interactions (Bloom, Russell, & Wasseberg, 1987; Pelaez, Virues-Ortega, & Gewirtz, 2011; Tamis-LeMonda, Bornstein, & Baumwell, 2001), typically developing infants by 5 months appear to have learned that their vocalizations may elicit interaction from unfamiliar adults (Goldstein et al., 2009). Goldstein et al. (2009) found that within the SF episode, 5-month-old infants exhibited an increase in volubility followed by an extinction burst during the SF, as if giving up, since no contingent response was being made by the interactor, who was a stranger rather than a parent. In contrast, Ekas, Haltigan, and Messinger (2012) found that infant-cry-face expressions increased over the course of SF. This pattern of cry-faces in SF appears to show a different temporal trajectory than that reported by Goldstein et al. (2009) for vocalization, perhaps because parents were the interaction partners or perhaps because of the difference in behavioral channel (Ekas et al. did not report on infant vocalizations). It is possible that a different pattern of volubility within SF would be observed than that observed by Goldstein et al. if parents were the interaction partners, given the much longer history infants have with their parents compared to strangers.

As far as we know, there has as yet been no systematic evaluation of *variability* in volubility across infants who react to SF by increasing volubility. Assessment of variability may yield new perspectives on the nature and course of social influence during infant vocal interactions. Further research on infant volubility may be of additional benefit for both clinical and scientific reasons. As reviewed above, vocalization has been thought to be instrumental in establishing the parent-infant bond during the first year. Volubility levels appear to be strongly related to rate of language development and to exhibit important group differences, particularly with respect to SES. By monitoring volubility, we may be able to identify patterns of parent-infant interaction that are most effective in supporting the acquisition of language.

RATIONALE AND OBJECTIVES OF THIS STUDY

The volubility of infants in response to changes in circumstance is a key matter related to the degree to which infant vocalizations are endogenously produced as opposed to being influenced by social interaction or other environmental factors (Locke, 1993). Of particular interest is volubility among the speech-like vocalizations, or protophones, of the first months of life including: quasi or fully resonant vowel-like sounds, squeals (high pitched sounds), growls (sounds having low pitched or harsh vocal quality), and canonical babbling (Oller, 1980; Koopmans-van Beinum & van der Stelt, 1986; Stark, 1978, 1983). An infant's ability to respond systematically with speech-like sounds to vocalizations from caregivers has been documented (Farah et al., 2008; Goldstein et al., 2009; Tamis-LeMonda et al., 2001). The fact that younger infants (at 3 months) have *not* been shown to increase their vocalization rates in SF (Yale et al., 1999) while older infants (by 5 months) *do* show such an increase has been interpreted as follows: Younger infants (3 months of age) do not appear to recognize that vocal responses from the parent are systematically related to their own vocalizations, but by 5 months infants do appear to have developed an expectation that their own vocalization will elicit a response (Goldstein et al., 2009).

The rise-fall pattern in infant volubility during SF as reported in the Goldstein et al. study was interpreted as indicating infants may have given up in attempting to elicit a response from adults. Additional probes about this pattern would seem to be in order. For example, by using a parent rather than a stranger as the interactor, it may be possible to determine if the rise-fall in volubility during SF is affected by familiarity of the adult.

Also we note that prior research has not assessed variability of volubility across infants within the FFSF paradigm. It seems possible that changes in variability of volubility across infants over different episodes could reveal variations in the degree to which the infants react similarly to the social manipulations of the paradigm.

Additionally, prior research has not reported possible differences in the types of speech-like vocalizations occurring during the episodes. An analysis of the different protophone types (e.g., quasivowels, full vowels, squeals, growls) across episodes may illuminate the nature of the infant's adjustment to the changing conditions of the paradigm and indicate whether particular vocalization types may have particular functions revealed by differential usage in the different episodes. Finally, analysis of possible relations between parent volubility and infant volubility within the FFSF paradigm may assist in determining the role of parents in infant vocal communication—to our knowledge no prior evaluation of the correlation of parent and infant volubility within the paradigm has been reported.

Inspired in part by the results and interpretation of Goldstein et al. (2009), we propose to evaluate and expand on the issues raised in their study, which differed from the one to be presented here in several ways. For example, our work draws data from an existing longitudinal study, where the interactor was a parent rather than a stranger, where the infants were 6 months old rather than 5, where the FF-SR-RE durations were 3-2-3 rather than 1-2-1 minutes, and where the families were often Hispanic. These differences were dictated by the data we had available. The analyses we conducted included several new features not present in any of the prior studies. The goals of the present study were thus to:

- reevaluate findings from prior studies (Delgado et al., 2002; Goldstein et al., 2009; Yale et al., 1999), which indicated that infant volubility increased significantly in the SF episode and decreased slightly in the RE episode;
- evaluate the time course of volubility change within episodes and especially during SF, with special attention to the extinction burst that has so far has only been reported in Goldstein et al. (2009);
- assess for the first time the variability across infants in volubility during the three episodes of the FFSF paradigm;
- analyze for the first time the pattern of volubility change for different infant vocal types across episodes; and
- analyze for the first time the possible relation between parent volubility and infant volubility in the FF and RE episodes.

METHOD

Participants

Twenty-four (15 male and 9 female) 6-month-old infants participated in the study along with 24 parents, primarily mothers. The families of all of the infants were categorized as mid-SES (Hollingshead, 1975, 1978). Nine of the infants were White Non-Hispanic, 14 were White Hispanic, one was African-American Non-Hispanic, and all had an older sibling. All 24 infants had been recruited as part of a larger longitudinal study of social and emotional development of infants. The infants were recruited primarily from Miami-Dade County, Florida, birth records. In addition to the 24 infants whose data were analyzed here, there were three infants for whom data on all three episodes were not available due to technical errors or fussing; the data from these three were not included in the analysis.

Procedure

Audio-video recordings were made during the FFSF paradigm. Episodes were 3, 2, and 3 minutes in length, respectively. Infants were placed in an elevated car seat, and the parent sat directly opposite in the en face position. Parents were first asked to play with their infant without toys for three minutes (FF episode), then to stop playing and maintain a still face with a neutral expression for two minutes (SF episode), and then to resume play for another three minutes (RE episode). A two-second tone sounded at the beginning of each episode to inform parents when a new episode should begin. The interaction was recorded using a lavalier microphone placed in a pocket on the infant's chest, within six inches of the infant's mouth for coding infant vocalizations, and a second lavalier microphone was worn by the parent.

Coding

Coding was conducted off-line using the audio recordings only. The following categories were coded for both parent and infant: speech-like vocalization (or protophones, the presumed precursors to speech), vegetative sound, laugh, cry, fuss, and other. Speech-like vocalizations were the primary focus in measuring infant and parent volubility. The speech-like vocalizations were coded as: 1) full vowels (fully resonant vowel-like sounds where the supraglottal vocal tract is open), 2) quasivowels (quasi resonant vowel-like sounds where the supraglottal vocal tract is at rest or closed), 3) squeals (sounds of higher pitch than expected for the infant voice in question), and 4) growls (sounds of lower than normal pitch or having a harsh or raucous vocal quality) (for details of the definitions, see Buder, Warlaumont, & Oller, 2013; Oller, 2000).

Coding was performed using the Action Analysis Coding and Training software (Delgado, 1996). The AACT system was used to review spectrographic displays of the audio recordings, to mark onset and offset of each utterance produced by both the infants and parents during the episodes, and to code each infant utterance by protophone type.

The Hispanic parents spoke a mixture of both English and Spanish during the interactions, and the non-Hispanic parents spoke English. The primary coder, who was trained in identifying and classifying early infant vocalizations, listened to utterances as many times as necessary to make judgments and categorization decisions. In addition to listening to the recordings, spectrographic displays were visually evaluated. Infant and parent utterances were identified using a breath-group criterion (Oller & Lynch, 1992), which is to say that utterances were defined as periods of vocalization separated from other vocalizations by either an ingressive breath or a period of time consistent with a possible breath *and* no perceived consonant-like closure that would prevent breathing.

The total duration of infant speech-like vocalizations as a proportion of the total duration of the recording session and the number of infant vocalizations per minute occurring within the FF, SF, and RE episodes were measures of interest. The total duration of parent vocalizations as a proportion of the total duration of the recording session as well as the number of parent vocalizations per minute occurring in the FF and RE episodes were measured and used to assess correlations during those episodes with infant volubility. Additionally, both infant and parent vocalizations were analyzed within episodes by dividing the episodes into 15-second intervals in order to make a specific comparison with prior research (Goldstein et al., 2009), which had suggested systematic changes in volubility within the SF episode.

Interrater Agreement

To assess observer agreement, the primary coder (whose data were used in all the analyses in Results) and a second coder (who was also highly trained in identifying and classifying infant vocalizations) categorized utterances for 15 episodes from 5 infant participants and 10 episodes from the mothers of the participants in order to assess intercoder agreement on overall volubility. These reliability samples were randomly selected from a larger sample in the longitudinal study. Point-to-point agreement was measured by first dividing each recording into 11-millisecond time bins (n = 218,728 bins across 15 episodes totaling 40 minutes). For each coder, a time series was created assigning a 1 to each bin including a segment of vocalization and a 0 otherwise. For the infant vocalizations the coders showed an overall agreement of 99% and kappa of .72. There was 88% overall agreement and a kappa of .74 for maternal vocalizations. The pattern of increased infant vocalizations from FF to SF with a slight subsequent decline in RE was evident for both coders.

At the episode level, agreement between the two coders in terms of number of vocalizations and total duration of vocalization was determined first using the interclass (Pearson) correlation coefficient. Across the 15 episodes, the two coders' total number of infant vocalizations divided by episode length correlated at 0.82. For parents, the correlation was 0.72 (n = 10 episodes, parents were silent in SF). Correlations for total duration of infant speech-like sounds across episodes was 0.97 (n =15 episodes) and for duration of parental vocalizations was 0.75 (n =10 episodes).

We also calculated intraclass correlations (ICC). For infant vocalizations per minute, the ICC was 0.67, for parent vocalizations per minute, the ICC was 0.84, for total duration of infant vocalizations, 0.93, and for total duration of parent vocalizations, also 0.84.

A third coder, also trained in identifying and classifying early infant vocalizations, coded 50% (75 episodes) of the infants' data to determine agreement on infant vocalization type (full vowel, quasivowel, squeal, growl). The primary coder and the third coders' overall agreement was 83% (Cohen's kappa = 0.53, $p < .05$). Both of these coders showed a strong increase in infant speech-like vocalizations from FF to SF for all four vocal types (> 36% increase in all four cases). These two coders showed the same patterns of increases and decreases from FF to SF and from SF to RE for each of the vocal types. The primary coder's results are reported throughout the Results.

RESULTS

Goal 1: Volubility

The data did not significantly violate normality, Kolmogorov-Smirnov $z = .159$, $p = .12$. A one-way within-subjects analysis of variance on the mean number of infant vocalizations per minute across the three episodes (FF, SF, RE) revealed a significant main effect of episode, $F(2, 46) = 11.32$, $p < .001$, $\eta_p^2 = .33$.

Volubility across the episodes in protophone utterances per minute is displayed in Figure 1, which shows more than a doubling of volubility from FF to SF (4.45 to 10.18). Pairwise t-tests with a Bonferroni adjustment (*p*s = .02) were conducted to compare number of vocalizations across the episodes. There was a significant increase from FF to SF ($t(23) = -4.73$, $p < 0.001$) and a decrease from SF to RE ($t(23) = 2.859$, $p = 0.009$) with large effects between

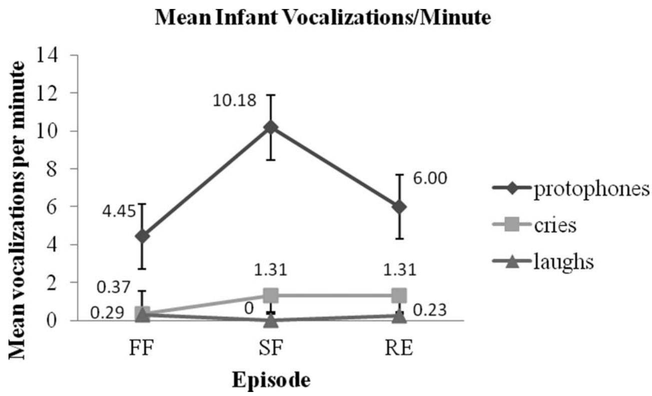

FIGURE 1 Mean number of infant protophones, cries, and laughs per minute.

SF and FF ($d = 0.98$) and SF and RE ($d = 0.51$). The increase from FF to RE ($t(23) = -1.516$, $p = 0.07$) approached significance. The pattern of highest volubility in the SF period compared with the FF and RE is similar to the pattern seen in prior research (Delgado et al., 2002; Goldstein et al., 2009; Yale et al., 1999).

The percentage of time occupied by protophones within each episode followed the same pattern as the number of vocalizations per minute, rising from FF to SF ($t(23) = -4.265$, $p < .001$), falling from SF to RE ($t(23) = 2.47$, $p = 0.01$), and with marginally significant values for RE vs. FF ($t(23) = -1.57$, $p = 0.06$) (Figure 2). Again, this pattern of increasing volubility in SF from FF with a decrease in RE is similar to the results reported in the above cited research. There was a large effect size between SF and FF ($d = 1.01$) and a medium effect for SF to RE ($d = 0.36$).

Cries and laughs did not occur often in these samples; 17% of the total vocalizations were cries or laughs, and 29% of the infants produced cries or laughs. There were no significant differences in the frequency of cries and laughs per minute across episodes (Cry: FF to SF, $t(23) = -1.49$, $p = .15$, SF to RE, $t(23) = .001$, $p = 1.00$, FF to RE, $t(23) = -1.32$, $p = .19$. Laugh: FF to SF,

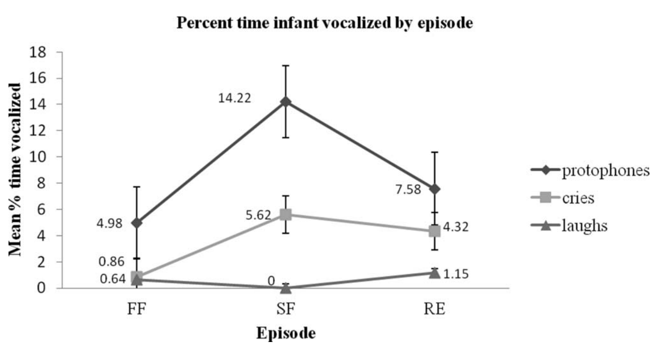

FIGURE 2 Mean percent of time infant spent producing protophones, cries, or laughs.

$t(23) = -1.22$, $p = .23$, SF to RE, $t(23) = -1.73$, $p = .10$, FF to RE, $t(23) = .24$, $p = .81$). The pattern for percentage of time spent in cry and laugh also did not show any significant differences, although there was a marginally significant difference in Cry from FF to SF (Cry: FF to SF, $t(23) = 1.75$, $p = .09$, SF to RE, $t(23) = .47$, $p = .64$, FF to RE, $t(23) = -1.61$, $p = .12$. Laugh: FF to SF, $t(23) = -1.11$, $p = .28$, SF to RE, $t(23) = 1.48$, $p = .15$, FF to RE, $t(23) = -.57$, $p = .57$). However, cries tended to be longer than protophones, and consequently the percentage of time occupied by cries appears higher on the graph for percent time vocalizing (Figure 2) than in the case of utterances per minute (Figure 1).

Goal 2: Variability in Volubility within Episodes

In order to compare our results with those of Goldstein et al. (2009) regarding the pattern of change in volubility within episodes, we broke the volubility data down into 15-second intervals. Figure 3 displays the mean number of vocalizations for the 24 infants within each episode in these 15-second intervals.

The 15-second interval data show that most of the individual intervals were consistent with the overall volubility patterns across episodes, that is, highest values during SF and second highest during RE. Correlations between volubility and the order of 15-second intervals (i.e., first through twelfth for the FF and RE and first through eighth for the SF) indicate that volubility rose within two of the three episodes, and nearly significantly so within the last episode (in FF, $r(11) = -.21$, $p = .57$, in SF, $r(7) = .49$, $p = .14$, and in RE, $r(11) = .44$, $p = .09$). This pattern contrasts with that reported by Goldstein et al. (2009), who found a rise-fall pattern within the SF episode, and where the first 75 seconds showed a significant increase. For the present work there was a large rise in five of the eight intervals in the SF episode and no fall at the end (see Figure 3). This is in sharp contrast with the findings of Goldstein et al. (2009).

Goal 3: Variability across Infants

The infants within this study demonstrated substantial individual variation. One indicator of this pattern is that within each episode there was at least one infant who did not vocalize at all (see Table 1). While the infants were highly variable, 18 (75%) followed the pattern of increasing

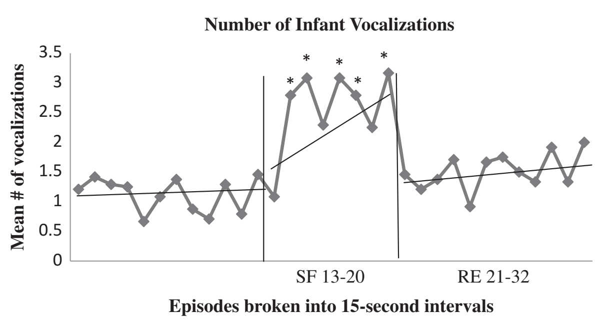

FIGURE 3 The mean number of infant protophones broken down into 15-second time intervals. $^{*}p < .05$, indicating significantly higher volubility in SF intervals with respect to that of the final FF interval.

TABLE 1
Mean Number of Infant Vocalizations per Minute and Percent Time Vocalizing

	Episodes					
	FF		*SF*		*RE*	
Vocalization values	*n*	*percent*	*n*	*percent*	*n*	*Percent*
Minimum	0	0	0	0	0	0
Maximum	12.7	19.4	31	42.9	17.6	29.2
Mean (SD)	4.4 (3.6)	4.6 (0.8)	10.2 (7.0)	14.2 (11.9)	6.0 (5.0)	8.2 (1.7)

Note. N is the number of infant vocalizations per minute and percent is the percent of time infants vocalized per minute. Minimum is the least number or lowest percent time of infant vocalizations across all infants. Maximum is the greatest number or percent time of infant vocalizations across all infants. SD is standard deviation.

volubility in SF when compared with FF and a decline from SF to RE. Four (17%) of the infants showed an increase in volubility from FF to SF to RE, and two (8%) showed a high FF with declining SF and further declining RE volubility. A chi-square test of independence was performed to determine whether the bias toward more frequent occurrence of the rise-fall pattern of infant volubility from the FF episode to the SF and RE episodes was statistically significant. The test showed that despite the variability among infants, there was a reliable tendency for most infants to exhibit the rise-fall pattern (X^2 (2, $N = 24$) = 19.00, $p < .001$, with an adjusted residual of 10.0 for rise-fall).

Figure 4 displays the coefficient of variability (COV), which is the standard deviation (SD) of volubility (vocalizations per minute) for all 24 infants divided by the mean for the 24 infants, for each 15-second interval. The COV corrects for changes in the mean across intervals. Because of the large changes in means, we deemed the use of the COV (rather than the uncorrected standard deviation) appropriate.

There was a significant drop from FF to SF ($t(7) = 3.34$, $p = .0002$) in the COV and an increase from SF to RE ($t(7) = -3.63$, $p = .0009$), and the great majority of 15-second interval comparisons conformed to the observed pattern. The COV was nearly significantly larger in FF

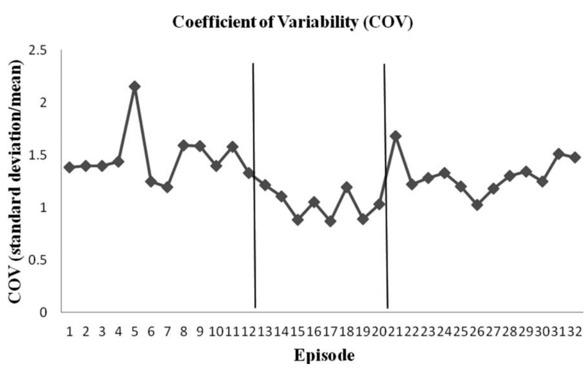

FIGURE 4 Coefficient of variability (COV), the standard deviation/mean of volubility across the 15-second intervals.

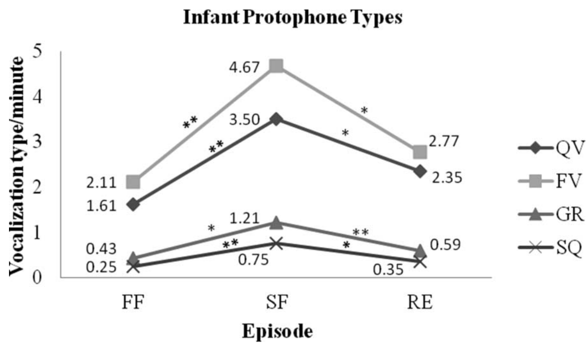

FIGURE 5 Infant protophone types across episodes, average vocal types per minute.QV = quasivowel, FV = full vowel, GR = growl, SQ = squeal. * $p < .05$. ** $p < .001$.

than RE ($t(11) = 1.81$, $p = .099$). Across all 32 intervals we found a strong negative correlation of COV with utterances per minute ($r(31) = -.70$, $p = .006$). This correlation indicates that, overall for the 15-second intervals, as volubility increased, variability among infants on volubility, corrected for differences in the mean, decreased.

Goal 4: Protophone Types across Episodes

There were 1,276 protophones identified in total across the sample. An analysis of different vocal types demonstrated increases in volubility from FF to SF for each of the protophones (see Figure 5).

There were significant increases from FF to SF for all the protophones: quasivowels ($t(23) = -3.39$, $p = .002$), full vowels ($t(23) = -2.618$, $p = .008$), growls ($t(23) = -2.43$, $p = .014$), and squeals ($t(23) = -3.13$, $p = .003$). There were significant decreases across the protophones seen from SF to RE: quasivowels ($t(23) = 3.27$, $p = .001$), full vowels ($t(23) = 1.823$, $p = .04$), growls ($t(23) = 3.49$, $p = .001$), and squeals ($t(23) = 1.86$, $p = .04$). There were no significant differences for any of the protophones between FF and RE. A within-subjects analysis of variance on infant production of full vowels and quasivowels per minute across the three episodes (FF, SF, RE) was conducted to assess the possibility that different protophones might show different patterns of volubility across episodes. Squeals and growls were not included because of their low N. The analysis revealed a significant main effect of vocal type for full vowels and quasivowels, (F (5, 138) = 3.51, $p < .005$, $\eta_p^2 = .11$), but no significant interaction between vocal type and episode (F (2, 138) = .21 $p = .814$).

Goal 5: Parent Volubility as a Potential Predictor of Infant Volubility

Pearson correlations between parent and infant vocalization rates were computed (comparing all six possible combinations: FF infant to FF parent, FF infant to RE parent, SF infant to FF parent, SF infant to RE parent, RE infant to FF parent, and RE infant to RE parent). Parent volubility was consistently high across both FF and RE, with parents vocalizing close to 50% of the time in both episodes. There was no significant change or difference between the two episodes in volubility of the parents. Parent volubility was not significantly correlated with infant volubility; Pearson *r* ranged between −.29 and .05 across the six possibilities.

DISCUSSION

Sometime between 3 and 5 months of age, infants appear to learn that their vocalizations elicit social responses (Goldstein et al., 2009; Yale et al., 1999). Infants appear to have learned by 5 months that they can re-engage their parents through speech-like vocalizations when the parent withdraws. This interpretation, first proposed by Tronick et al. (1978) and re-emphasized by Goldstein et al. (2009), is compatible with the results in the present study.

Infant recognition of the contingency between their vocalizations and those of their parents may be the reason behind infants' higher volubility rates in SF. Since this higher volubility rate occurred when interacting with either the parent, as in our study, or with a stranger (Goldstein et al., 2009), it appears that infants have learned by 6 months of age that their vocalizations can influence a variety of adult interactors.

While volubility did decline in RE compared to SF, it remained higher than in the initial interactive FF episode. The higher volubility in RE than FF may have been a preventive measure on the part of the infants, who after experiencing a lack of responsivity in the SF episode were inclined to maintain a higher than usual rate of vocalization to maintain parental engagement. Alternatively, increased volubility during RE compared to FF could also have reflected infants' passive continuation of the higher rate of volubility during the SF situation.

Analysis of volubility in 15-second intervals revealed a notable difference from the effect reported in Goldstein et al. (2009), who saw a rise then fall in the SF episode. We, on the other hand, observed a rise but no fall. This may indicate that infants in the present study increasingly attempted to re-engage the unresponsive parents, but infants with strangers (Goldstein et al., 2009) tended to more quickly give up.

A second possible interpretation of the differences across the studies in the pattern of volubility in SF is that the short one-minute FF period in Goldstein et al.'s (2009) study may not have primed the infant for vocal engagement as much as the longer three-minute FF episode used in our study. The infants in our study may have been more fully engaged during FF and therefore more inclined to persevere in attempting to re-engage. A third possibility is that the 5-month-old infants in Goldstein et al. (2009) may have been less experienced and less able to exploit a possible contingency than the 6-month-old infants in the present study, who may have been more inclined, due to their greater experience with vocal contingencies, to continue vocalizing in an attempt at re-engagement.

Additional analyses revealed that volubility was less variable across infants in SF than in either FF or RE episodes. It appeared the infants as a group tended to use more similar strategies to re-engage the parent in SF and more variable interaction strategies when the parent was engaged. This is the first report of a tendency for individual infants to vocalize with more similar levels of volubility when under the stress of SF. One might ask whether there is a general tendency in vocalization for variability as measured by COV to decrease as mean rate increases, given that we found a strong correlation between variability and volubility in the present study. A comparison of infant and child volubility data obtained during other circumstances not involving SF (Shriberg, Green, Campbell, McSweeny, & Scheer, 2003; Smith, Hellenbrand, Wasowicz, & Preston, 1986) as well as unpublished data from our own laboratory allowed computation of the relation between COV and mean volubility. The analyses revealed that COV in these studies did not typically decline when mean volubility increased, as it did in the present study, but in fact usually increased.

Another new finding from the present study is that infants used all the vocal types studied at significantly higher rates during the SF episode, including quasivowels, full vowels, squeals, and growls. Thus these infants appeared to be using all their vocal tools in order to reengage the parent. During RE, the volubility of all the protophones fell back significantly though not to the level of FF. The results did not show a differential use of full vowels and quasivowels across social contexts. Because squeals and growls occurred at low rates, no statistical test of possible differences in their patterns across episodes was conducted.

The fact that all the protophones seemed to participate in the cross-episode pattern offers support for the idea that human infants are able to use their speech-like vocalizations flexibly (Oller et al., 2013), not being constrained to use any particular protophone for a particular function (such as re-engaging a withdrawn parent). Instead the human infant appears to have the capacity to freely associate any speech-like vocalization with any function, a pattern that is required in all aspects of mature human language, which requires speakers to learn arbitrary associations among sound, meaning, and function (Austin, 1962; de Saussure, 1968).

It was surprising to find that parent volubility showed little if any correlation with infant volubility. Prior research has suggested that parent interactive behavior elicits infant vocalizations (Kaye & Fogel, 1980) and that there is significant bidirectional coupling found between infants and parents in the affective domain (Chow, Haltigan, & Messinger, 2010). Perhaps the reason for lack of notable correlation here is that all of the parents tended to adopt a similar very high level of vocalization during the brief intervals of the FFSF paradigm. Parents were encouraged to interact and play freely with their infants and encourage them to interact. Parents tended to vocalize close to or more than 50% of the time. In the FF episode, 14 of the 24 (58%) parents vocalized more than 50% of the time, and 17 of the 24 (71%) parents in RE vocalized more than 50% of the time. The average number of words spoken by parents over the course of the day has been reported to be more than five words per minute based on automated analysis of all-day recordings (Gilkerson & Richards, 2009); the average number of utterances (which typically consisted of multiple words) per minute in this study was more than 11. Thus, it appears that parents vocalized a great deal more during the FFSF paradigm than during a randomly selected period of a normal day. Further research into the impact of very high levels of parent volubility may be warranted, as other studies (e.g., Hart & Risley, 1999) have posited a positive correlation between parent and infant volubility over long developmental periods.

In conclusion, infants by 6 months of age appear to have learned that their vocalizations have social value and may be used to elicit interactive responses. In the SF episode, infants appeared to attempt to re-engage the parents, and across infants the strategy seemed similar in that inter-infant variability in volubility decreased notably during SF. Additionally, the increase across all vocal types during SF and the decline in RE indicates that all the protophones were used by the infants when attempting to engage adults. Such flexibility of infant protophones has been noted as a potentially key development that is foundational for language (Oller et al., 2013). While the present work showed no correlation between parental and infant volubility, this result may have been a result of the very high rates of vocalization produced by the parents in this paradigm.

Given that the increase in volubility from FF to SF was large (more than a factor of two) and that more than 90% of infants showed an increase, it seems reasonable to consider possible clinical implications as a logical next step. It could be that infants who either demonstrate no increase in volubility during SF or no increase in a particular vocal type are either delayed or disordered. Further research with a high-risk or disordered comparison group would be useful. For example, research involving infants at familial risk for either autism spectrum disorder or specific expressive language impairment may reveal differences in volubility across interactive circumstances at six months and suggest a potential component for a screening and assessment tool, or even indicate the need for increased input or therapeutic intervention.

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