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Depression Diagnoses and Fundamental Frequency-Based Acoustic Cues in Maternal Infant-Directed Speech

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Abstract

F_0-based acoustic measures were extracted from a brief, sentence-final target word spoken during structured play interactions between mothers and their 3- to 14-month-old infants, and were analyzed based on demographic variables and DSM-IV Axis-I clinical diagnoses and their common modifiers. F_0 range (ΔF_0) was negatively correlated with infant age and number of children. ΔF_0 was significantly smaller in clinically depressed mothers and mothers diagnosed with depression in partial remission, relative to non-depressed mothers, mothers diagnosed with depression in full remission, and those diagnosed with depressive disorder not otherwise specified. ΔF_0 was significantly lower in mothers experiencing their first major depressive episode relative to mothers with recurrent depression. Deficits in ΔF_0 were specific to diagnosed clinical depression, and were not well predicted by elevated self-report scores only, or by diagnosed anxiety disorders. Mothers with higher ΔF_0 had infants with reportedly larger productive vocabularies, but depression was unrelated to vocabulary development. Implications for cognitive-linguistic development are discussed.

Parents adopt a distinctive manner of speech when addressing young infants in which utterances are slowed, simplified, “stretched” temporally and spectrally, and exaggerated prosodically (Fernald, 1984; Snow, 1972). A number of studies have demonstrated that infants respond more strongly to parents' infant-directed speech (IDS) in comparison to adult-directed speech (ADS; Cooper & Aslin, 1990; Papoušek, Papoušek, & Symmes, 1991; Pegg, Werker, & McLeod, 1992), and IDS is more effective than ADS at modulating infant state and promoting rudimentary learning, memory, and speech processing (Kaplan, Jung, Ryther, & Zarlengo-Strouse, 1996; Singh, Nestor, Parikh, & Yull, 2009; Thiessen, Hill, & Saffran, 2005). Exaggerated pitch contours appear to be an important determinant of infant responding to IDS (Cooper & Aslin, 1994; Fernald & Kuhl, 1987), possibly because they signal greater positive affect (Kitamura & Burnham, 1998; Kitamura & Lam, 2009; Singh, Morgan, & Best, 2002; Trainor, Austin, & Desjardins, 2000). However, depressed mothers produce IDS with relatively flatter prosodic contours (Bettes, 1988; Kaplan, Bachorowski, Smoski, & Zinser, 2001), suggesting that any facilitative effects of IDS on infant behavior and language development may not accrue for infants of depressed caregivers.

The purpose of this study was to examine effects of maternal depression and related DSM-IV Axis-I diagnoses on F_0-based acoustic features in maternal IDS. An earlier study

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[3]Acoustic measures did not differ significantly between mothers diagnosed with Bipolar Disorder (BP I & BP II, n = 9) and those in the NDEP group (for ΔF_0, M_{BP} = 135 Hz, SD = 41.3; M_{NDEP} = 155 Hz, SD = 61.0, $F(1, 143)$ = 0.95; for mean F_0, M_{BP} = 275 Hz, SD = 42.8.4; M_{NDEP} = 286 Hz, SD = 57.4, $F(1, 143)$ = 0.58; for mean F_0 standard deviation, M_{BP} = 72.0, SD = 21.8; M_{NDEP} = 65.2, SD = 24.0, $F(1, 143)$ = 0.68, all p's > .32).

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suggested that even modestly elevated self-reported symptoms of depression, in the absence of clinical depression, were linked to lower pitch modulation and less contingent delivery in 3- to 4-month-olds (Bettes, 1988). Subsequent research using a relatively small sample of 4- to 13-month-old infants (*n* = 50) demonstrated that clinically depressed in comparison with non-depressed mothers produced IDS with significantly smaller extents of F_0 modulation (as measured by F_0 range or ΔF_0) in brief IDS samples recorded during a mother-infant structured play interaction (Kaplan et al., 2001). Mothers diagnosed with depression in remission (full remission, FR[1], and partial remission, PR, combined) had ΔF_0 values comparable to those of non-depressed mothers. Furthermore, older mothers produced IDS with significantly greater ΔF_0, and, although others had noted effects of infant age on F_0-based acoustic cues (Herrera, Reissland, & Shepherd, 2004; Kitamura & Burnham, 2003; Stern, Spieker, Barnett, & MacKain, 1983), infant age was unrelated to ΔF_0.

The current study took advantage of the greater statistical power afforded by a larger data set (*n* = 281) to not only attempt to replicate the effects of depression on maternal IDS, but also to reanalyze links between F_0-based acoustic features of IDS and key demographic variables. Three aspects of F_0 were examined, each averaged over three utterances: (1) mean F_0, which reflects lower vs. higher average pitch; mean F_0 is lower in the speech of depressed than non-depressed adults (Alpert, 1982; Sherer, 1986), but was uncorrelated with depression in an earlier study of maternal IDS (Kaplan et al., 2001); (2) mean F_0 range (ΔF_0; i.e., average of the range from lowest to highest pitch in each utterance), which has been linked to infant preference for IDS over ADS (Fernald & Kuhl, 1987; Katz, Cohn, & Moore, 1996), and which is significantly smaller in IDS produced by depressed than non-depressed mothers (Kaplan et al., 2001), and (3) mean F_0 standard deviation, a measure of the dispersion of F_0 in relation to the mean, and one that has received relatively little study in the IDS literature, but which is predicted to correlate with vocal expression of happiness and sadness in adults (Pittam & Sherer, 1993).

In addition to analyzing effects of depression diagnosis on these F_0-based acoustic cues, this study examined whether effects were present in mothers with elevated self-reported symptoms of depression in the absence of a depression diagnosis, and whether effects varied as a function of some of the more common DSM-IV Axis-I diagnoses, or as a function of common modifiers of the depression-related diagnosis (e.g., recurrent vs. single episode, prenatal vs. postpartum onset, etc.). We predicted that greater deficits in F_0-based acoustic cues, particularly in F_0 range, would be associated with more severe and chronic depression, and that these deficits would be specific to depression, as opposed to diagnostic categories involving anxiety disorders. Finally, relations between F_0-based acoustic cues, maternal depressive symptoms, and a preliminary assessment of infant vocabulary development were explored.

Method

Participants

Two-hundred and eighty-one mothers of 3- to 14-month-old infants (range: 76 to 433 days, *M* = 271 days, *SD* = 101.6; 156 girls and 125 boys) were recruited from birth notices, advertisements in a parenting magazine, and flyers distributed at Early Head Start Centers. The text of the recruiting advertisement stated that we were investigating how mothers talk to their infants and, although all mothers were invited to participate, we were particularly interested in mothers with a history of depression. Demographic data were obtained from

[1]Partial remission, PR, is defined as the presence of some symptoms associated with depression, but not enough to meet full criteria, or a period without significant symptoms that has lasted less than 2 months, with no previous dysthymic disorder. Full remission, FR, is defined as defined as the absence of significant symptoms for at least 2 months (APA, 2000).

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questionnaires. Self-reports of symptoms associated with depression were obtained using the Beck Depression Inventory (BDI; Beck, Ward, Mendelson, Mock, Erbaugh, 1961) and, for a subset of mothers (*n* = 114), the Postpartum Depression Screening Scale (PDSS; Beck & Gable, 2002). In addition, each mother was administered a Structured Clinical Interview for DSM-IV Axis-I diagnosis (SCID; First, Spitzer, Gibbon, & Williams, 1995), which provided the basis for clinical diagnoses. Clinical diagnoses were made by Ph.D.-supervised, masters-level clinical psychologists and clinical psychology graduate students, who had extensive training on the SCID and DSM-IV diagnosis. Training involved coursework, video demonstrations, observation of the trainer by the student, and practice interviews. Interviews lasted about 1 hr. Inter-rater reliability for diagnoses of Major Depression, calculated between the primary rater and a Ph.D.-level second rater yielded a kappa value of .82. Final diagnoses were based on the primary rater.

Table 1 presents key demographic variables as a function of maternal diagnosis. Current Axis-I depression-spectrum diagnoses (the DEP group, *n* = 52) included Major Depressive Disorder (MDD, *n* = 37), Dysthymia (DYS, *n* = 2), Double Depression (MDD+DYS = DBLD, *n* = 7), and Depressive Disorder Not Otherwise Specified[2] (DDNOS, *n* = 6). There were also 39 mothers diagnosed with depression in full remission (FR), and 32 mothers diagnosed with depression in partial remission (PR). Five mothers were diagnosed with Bipolar I disorder (including 2 with BP-I, FR), and 4 mothers were diagnosed with Bipolar II disorder (including 2 with BP-II, FR). An additional 20 mothers were diagnosed with an anxiety disorder (ANX) only, including 8 with Generalized Anxiety Disorder (GAD), 4 with Specific Phobias, 3 with Panic Disorder, 3 with Post-Traumatic Stress Disorder (PTSD), 1 with Anxiety Disorder Not Otherwise Specified, and 1 with Anorexia Nervosa. One hundred and twenty-nine mothers received no DSM-IV diagnosis and were classified as non-depressed (NDEP). DEP and PR mothers were significantly younger and had fewer years of formal education than NDEP and FR mothers. No other differences were significant. Some acoustic data from the initial 50 infants were published previously (Kaplan et al., 2001), but most mothers' data are presented here for the first time, including all data on F_0 standard deviations.

Speech Stimuli, Apparatus and Procedure

Two distinct strategies have been employed in obtaining speech samples from depressed mothers. Some studies have analyzed running samples of spontaneous speech (e.g., Bettes, 1988; Zlochower & Cohn, 1996), whereas others have focused on brief, structured samples in which each mother produces slight variation on a stock phrase during a semi-structured play interaction (Kaplan et al., 2001). In the present study, speech samples were obtained during a semi-structured play interaction (see below for details). The brief verbal sample has several advantages, including equating linguistic content across mothers, standardizing the behavioral interaction from which the utterances emerged, roughly equating the rate of speech across mothers, and reducing audio editing and analysis time. However, brief structured samples can have disadvantages as well, including smaller samples of maternal verbal behavior -- which may be less representative and less natural sounding -- and restricted variance relative to unconstrained samples (see Discussion section).

Following a 2-min free-play warm-up period, mothers were handed a stuffed toy gorilla and asked to interest their infant in it using the phrase “pet the gorilla.” Mothers were instructed to both “ask” and “tell” their infants to “pet the gorilla” to make sure that both declarative and interrogative utterances would be made. This phase of the recording lasted

[2]DDNOS involves disorders with depressive features that do not meet with full criteria for MDD or DYS. It includes Minor Depressive Disorder, in which an episode lasts at least 2 weeks but with fewer than the five items required for MDD, and Recurrent Brief Depressive Disorder, in which an episode lasts less than 2 weeks and occurs at least once per month for 12 months (APA, 2000).

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approximately 1 min. The first two interrogative and the first declarative “pet the gorilla” utterances were edited out of the speech stream, and formed the basis not only for the acoustic analyses reported here and previously (Kaplan et al., 2001), but also for infant perceptual/learning tests the results of which have been reported elsewhere (Kaplan et al., 1999; 2002; 2004). The “pet the gorilla” utterances for each mother contained three sentences with slight variations of the “pet the gorilla” theme spoken in succession (e.g., Will you pet the gorilla? Can you pet the gorilla? Pet the gorilla.”). Such a sequence of partially overlapping sentences with the name of a novel object located in the sentence-final position is similar to a “variation set” (see Goldstein et al., 2010, see Discussion), and is typical of maternal verbal behavior during joint attentional states with infants. We choose the mother's first two interrogative and first declarative sentences because it was assumed these would be the strongest or “freshest” exemplars. The stimulus structure of two interrogatives followed by a declarative was selected because prior research indicated that interrogatives are relatively more likely to have rising pitch contours, which are particularly effective at attracting an infant's attention, and declaratives are likely to have bell-shaped pitch contours, which have been shown to be effective at maintaining infant attention (Stern, Spieker, & MacKain, 1982).

F_0–based acoustic measures (see above) were calculated for the three distinct utterances, and the grand mean was used in the analyses reported below. The data presented below focus on the sentence ending “gorilla” utterances in part because mothers tend to position target words on pitch peaks in sentence-final positions (Fernald & Mazzie, 1991; Fisher & Tokura, 1996). The “gorilla” portion of the utterances accounted for approximately three fourths of the total amount of voiced speech (Kaplan et al., 2001).

Tape-recorded speech stimuli were digitized at 44 kHz with 16-bit resolution, and were analyzed using Speech Station 2 (Senimetrics Corp., Somerville, MA) and Praat Acoustical Analysis (Boersma & Weenink, 2009) software packages. Three dependent variables tapping different aspects of prosodic contours were derived from the taped IDS: mean fundamental frequency (F_0), mean F_0 range (ΔF_0), and mean F_0 standard deviation (variability), as defined above.

Data were available for a subset of the infants (*n* = 138) from the parental-report MacArthur Communicative Development Inventory (MCDI), Short Infant Form (Fenson, Pethick, Renda, Cox, Dale, & Reznick, 2000). The MCDI is a norm-referenced parental report of a child's lexical growth in 8- to 18-month-old children, in which parents identify from a standardized questionnaire of 89 words those that the infant understands but does not yet say (comprehension), and those that the infant both understands and says (production). The MCDI short form was developed from the long-form. Items were selected that were both early- and late-appearing within this age range, and were balanced among the various semantic and structural linguistic categories (62% nouns, 15 % verbs, 12% adjectives and adverbs, and 11% pronouns, sound effects, and other parts of speech). The scores on the two forms are highly correlated (Fenson et al., 2000). Mothers filled out the MCDI when the infants were 12-13 months old. For some infants, this was concurrently with their visit to the lab, but for others the form was mailed out and returned up to 8 months after the visit to the lab. There were no significant differences in MCDI scores based on when in relation to the lab visit the form was completed.

Results

Table 2 shows correlations between demographic, speech acoustic, and maternal self-report of depression symptoms. Infant gender was unrelated to any of the F_0-based measures, and so is not discussed further in reference to speech acoustics. Mean F_0 (overall vocal pitch)

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averaged across the 3 “gorilla” utterances was negatively correlated with two demographic variables: age of the mother and age of the infant. Older mothers had lower mean F_0 in their ID vocalizations, possibly reflecting maturational effects within the 20- to 40-year-old age range. Mothers used higher pitch (mean F_0) with the youngest infants (3-6 months) relative to all other age groups. An ANOVA on mean F_0 data, in which infants were categorized into 4 age groups [i.e., 3-6 months (up to 183 days; $n = 82$), 6-9 months, (184-275 days; $n = 51$), 9-12 months (276-365 days; $n = 82$), and 12-14 months (above 365 days; $n = 66$)], yielded a significant effect of age, $F(3, 277) = 3.79$, $p = .01$, $\eta^2 = .040$, and a significant linearly decreasing trend, $F(1, 277) = 8.30$, $p = .01$. LSD post-hoc tests revealed only significantly higher mean F_0 between the 3-6-month-olds and each of the other age groups ($p = .05$). However, in contrast to some findings with depressed adults (Alpert, 1982), but consistent with prior findings with maternal IDS (Kaplan et al., 2001), mean F_0 was unrelated to maternal depression. Mean F_0 did not correlate with maternal BDI scores, $r = -.05$, $p = .41$, and, as shown in Table 3, did not vary significantly as a function of maternal depression diagnosis (4 levels: NDEP, FR, PR, and DEP), $F(3, 252) = 0.89$. Thus, depressed mothers were as likely as non-depressed mothers to use elevated overall pitch.

Mean ΔF_0, the difference between the highest and lowest pitch averaged across the 3 “gorilla” utterances (i.e., the mean pitch range), was also related to two demographic variables: infant age and number of children in the family. Although an ANOVA on mean ΔF_0 showed no significant overall effect of infant age, $F(3, 277) = 1.78$, $p = .15$, there was a significant linearly decreasing trend of infant age, $F(1, 277) = 4.72$, $p = .05$. LSD post-hoc tests showed a significant difference between the 3-6-month-olds and the 9-12-month-olds ($p = .05$), but no significant difference between the 3-6-month-olds and the 12-to-14-month-olds group ($p = .06$). There was a significant negative correlation between number of children in the family and mean ΔF_0; number of children was positively correlated with maternal age, and negatively correlated with maternal education.

Most importantly for current purposes, IDS produced by depressed mothers had a relatively restricted pitch range. Consistent with prior work (Kaplan et al., 1999; Kaplan et al., 2001), mean ΔF_0 was significantly negatively correlated with maternal BDI scores, $r = -.17$, $p = .05$ (Table 2). As shown in Table 3 and Figure 1, mean ΔF_0 also differed as a function of diagnostic category: An ANOVA comparing ΔF_0 in IDS samples recorded from mothers in the NDEP, FR, PR, and DEP groups yielded a significant effect, $F(3, 252) = 5.08$, $p = .01$, $\eta^2 = .056$.[1] ΔF_0 in IDS samples produced by NDEP mothers did not differ from that produced by FR mothers, but ΔF_0 in each of these groups differed significantly from that produced by DEP mothers and PR mothers (LSD post-hoc tests, $p = .05$). PR and DEP groups did not differ significantly from each other.

Mean F_0 standard deviation (F_0 variability) was unrelated to maternal age, infant age, and number of children, but was significantly positively correlated with maternal education. F_0 standard deviation did not correlate significantly with BDI scores. However, an ANOVA showed a significant effect of the 4 diagnostic groups on mean F_0 standard deviation, $F(3, 252) = 2.66$, $p = .05$, $\eta^2 = .031$, but LSD post-hoc tests demonstrated significantly higher mean F_0 standard deviation only in the FR group relative to the DEP group ($p = .01$), and a non-significant difference for this same measure between the FR and PR groups ($p = .06$).

To further explore the significant effect of maternal depression diagnosis on ΔF_0, two additional analyses were done. First, to examine effects of antidepressant medication on ΔF_0, a 4 (diagnostic group) × 2 (antidepressant medication or not) ANOVA replicated the effect of diagnosis on ΔF_0, $F(3, 249) = 3.03$, $p = .05$, but found no effect of antidepressant medication, $F(1, 249) = 0.18$, and no significant group × medication interaction, $F(3, 249) =$

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1.20, p = .31. Antidepressant medication was also unrelated to mean F_0 and F_0 standard deviation.

Second, to rule out important roles for demographic correlates of the depression diagnosis, a hierarchical linear regression was performed on the ΔF_0 data. Contrast-coded minority status was entered in step 1, followed by maternal education, number of children, infant age, BDI score, and diagnostic category in steps 2-6, respectively. Table 4 shows that, after demographic variables had been accounted for, BDI score was not significantly associated with ΔF_0. However, after all demographic variables and BDI score had been accounted for, diagnostic category predicted a small but significant increment in R^2, $\Delta R^2 = .017$, $F(1, 249) = 4.67$, $p = .05$.

Several group comparisons (besides FR vs. PR vs. DEP) related to the question of the effects of depression severity and duration on acoustic measures. Among currently depressed mothers, those diagnosed with DDNOS (i.e., minor depression plus Recurrent Brief Depressive Disorder) produced IDS that had significantly larger ΔF_0 relative to mothers diagnosed with MDD, DYS, and DBLD (MDD+DYS) combined, $F(1, 50) = 5.42$, $p = .03$, $\eta^2 = .098$. Their IDS did not differ from that of other depressed mothers in mean F_0 or F_0 standard deviation. (p's > .25). However, among mothers with current MDD, there was no significant difference in any of the 3 acoustic measures attributable to interviewer-rated severity of depression (defined by the number of criterial symptoms of depression, where 5/9 = mild, 7/9 = moderate, 9/9 = severe, and the degree of interference with social and occupational functioning; American Psychiatric Association, 2000). In addition, mothers diagnosed with DBLD had slightly but not significantly smaller ΔF_0 than mothers diagnosed only with MDD, $M_{DBLD} = 93.7$ Hz, $SD = 28.3$ vs. $M_{MDD} = 122.0$ Hz, $SD = 56.4$, $F(1, 42) = 1.66$, $p = .21$.

None of the F_0-based acoustic measures correlated with either the post-partum duration of the mother's depressive episode (all p's > .28), or, as shown in Table 5, with prenatal vs. postpartum depression onset. Interestingly, mothers diagnosed with single episode MDD had significantly smaller ΔF_0 than mothers diagnosed with recurrent MDD.

BDI scores were significantly higher in mothers diagnosed with an Axis-I Anxiety Disorder (ANX) only, in comparison with currently non-depressed mothers (NDEP plus FR, minus those with BDI-II scores > 13), $F(1, 157) = 66.05$, $p = .001$, $\eta^2 = .296$. This result suggested that some of the effects attributed to depression might be due to anxiety instead, or to comorbid anxiety and depression. However, several lines of evidence indicated that deficits in ΔF_0 were specific to a diagnosis of depression. First, mean ΔF_0 in IDS samples produced by mothers diagnosed with only an Axis-I anxiety disorder (n = 20) did not differ significantly from that produced by currently non-depressed mothers (NDEP + FR; and BDI-II scores < 13), $M_{ANX} = 128.9$ Hz, $SD = 54.3$ vs. $M_{NDEP} = 151.4$ Hz, $SD = 49.5$, $F(1, 158) = 2.59$, $p = .11$. Similarly, ΔF_0 did not differ between IDS samples produced by mothers diagnosed with the most often-diagnosed anxiety disorder, GAD (n = 8), in comparison to non-depressed mothers, $F(1, 146) = 0.94$. Second, IDS samples produced by mothers diagnosed with an Axis-I depression-spectrum disorder only (n = 33) did not differ in ΔF_0 (or other F_0 measures) from those diagnosed with comorbid depression plus anxiety diagnoses (n = 19), $F(1, 50) = 0.66$. Finally, self-reports of symptoms of anxiety obtained from a subset of non-depressed (64 NDEP and 19 FR), depressed (13 PR and 13 DEP), and anxious (5 ANX) mothers using the Anxiety subscale of the PDSS did not correlate with mean F_0, $r = -.09$, $p = .37$, mean ΔF_0, $r = .05$, or F_0 standard deviation, $r = .02$.

Mothers of 138 infants also filled out the maternal-report MCDI to assess vocabulary comprehension and production when the child was 12-14 months old. Receptive vocabulary

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age- and gender-normed percentile scores were significantly higher for boys than girls, and were negatively correlated with maternal education (*r* = -.24, *p* = .01), and positively correlated with number of children (*r* = .21, *p* = .01) and ethnic minority status (where 1 = minority and -1 = non-minority, *r* = .19, *p* = .05), but were unrelated to BDI scores or depression diagnosis. These results were surprising, and possibly anomalous, because prior research had shown higher receptive vocabulary in girls than boys, and in higher vs. lower SES samples (Fenson et al., 1994). However, for productive vocabulary, neither the raw scores nor the age- and gender-normed percentile scores correlated with any of the diagnostic or demographic variables. For this measure, infants with vocabulary production percentile scores above the median had mothers with significantly higher mean ΔF_0, *M*s = 145 Hz, *SD* = 55.3, vs. 126 Hz, *SD* = 51.9, respectively, $F(1, 136) = 4.53$, $p = .05$, $\eta^2 = .032$. This effect remained significant when maternal education was used as a covariate, $F(1, 135) = 4.77$, $p = .05$, $\eta^2 = .034$. MCDI percentiles did not correlate with mean F_0 or F_0 standard deviation.

Discussion

F_0-based acoustic measures were extracted from a brief, sentence-final target word spoken during structured play interactions between mothers and their 3- to 14-month-old infants, and were analyzed based on DSM-IV Axis-I clinical diagnoses and their common modifiers. Although the mean F_0 or average vocal pitch in the IDS of clinically depressed mothers was comparable to that of non-depressed mothers, depressed mothers' utterances exhibited a significantly smaller F_0 or vocal pitch range (ΔF_0). ΔF_0 in IDS produced by mothers diagnosed with clinical depression in partial remission (PR) resembled that of currently depressed mothers, whereas ΔF_0 for mothers diagnosed with clinical depression in full remission (FR) resembled that of non-depressed mothers. Mean values for F_0 variability (i.e., standard deviation), which has received scant prior attention in studies of maternal IDS, showed a similar trend to those for ΔF_0, but differences were significant only between depressed mothers and FR mothers. Several demographic variables were correlated with effects on pitch modulation. For example, higher maternal education correlated with higher F_0 variability, whereas greater infant age and greater number of children in the family were linked with a relatively restricted F_0 range. In fact, regression analyses revealed that after demographic variables had been taken into account, maternal self-report scores on the BDI – often the only measure of symptoms of depression used in studies of depressed mothers' IDS (Bettes, 1988) – did not account for unique variance in ΔF_0. However, after demographic variables and BDI scores had been accounted for, clinical depression still predicted a small but significant amount of unique variance in ΔF_0. Further evidence for unique effects of clinical depression on extent of pitch modulation was obtained from analysis of the effects of anxiety on IDS: neither anxiety disorder diagnoses, co-morbid depression plus anxiety, nor self-report measures of anxiety correlated with any of the F_0-related acoustic measures.

These results replicated prior findings of a link between maternal clinical depression and F_0 range in brief IDS samples, using the largest data set currently available in the literature. They also extend previous work in several important ways. First, in contrast to earlier research suggesting that ΔF_0 in IDS produced by mothers with depression-in-remission (FR + PR) was not significantly different from that in IDS produced by NDEP mothers (Kaplan et al., 2001), the present study revealed that degree of remission affected ΔF_0 in IDS. This discrepancy is likely attributable to the greater statistical power afforded by the larger numbers here relative to the earlier study. It is important to note that this between-groups difference cannot be taken as evidence for within-subject changes in ΔF_0 over the full course of a depressive episode, in part because PR mothers differed from FR mothers in a number of demographic variables that may have contributed to the differences between the two diagnostic conditions. Clearly, multiple within-subject acoustic measurements will be

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needed to document changes in ΔF_0 as a mother transitions from DEP through PR to FR. But past depression (i.e., FR) was not linked to any speech acoustic effects here. Second, as mentioned above, obtained effects were specific to clinical depression, not fully explained by various demographic factors or anxiety disorders, and unaffected by mothers' use of antidepressant medication.

Third, deficits in ΔF_0 were more pronounced in the IDS of mothers diagnosed with major depression vs. conditions is which the number of symptoms of depression or their duration was reduced, including not only FR but also DDNOS, which encompasses minor depression and Brief Recurrent Depressive Disorder. However, teasing apart effects attributable to severity vs. chronicity in these cases is difficult because number of symptoms and their duration can each factor into the diagnosis (see Footnotes 1 and [2]). In cases of current major depression specifically, rated severity of depression, or an additional diagnosis of dysthymia, did not significantly affect ΔF_0, although the trends were in the predicted direction. Larger sample sizes may yet reveal effects of severity within the major depression diagnostic category, but effect sizes are likely to be very small. Also within this diagnostic category, there was no evidence that greater chronicity, either in the sense of greater duration of the current depressive episode, or via the occurrence of multiple episodes, was linked to deficits in pitch modulation. In fact, pitch range was smaller for mothers diagnosed with single-episode than recurrent depression, an effect that may reflect some degree of adaptation across episodes to the adverse effects of depression on mother-infant interactions.

Although there were *statistically* significant effects of clinical depression on pitch range, can we conclude that these are *clinically* significant effects? Less that 6% of the variance in ΔF_0 was attributable to clinical diagnosis, and regression analyses revealed that clinical diagnosis accounted for less than 2% of the variance in ΔF_0 after relevant demographic variables and BDI scores had been taken into account. The effect size for comparable analyses in prior work was larger ($\Delta R^2 = .13$ in Kaplan et al., 2001, but BDI scores were not controlled for prior to entering clinical diagnosis in that analysis). The present small effect sizes could be interpreted to indicate that the contribution of clinical depression to speech acoustics in IDS is trivial in comparison to other factors (although not including the above demographic risk factors). Indeed, clinical depression was unrelated to maternal reports of infant productive vocabulary, which were related to ΔF_0.

However, there are a number of reasons to hypothesize that our regression analysis underestimated the true effect size for the link between depression and extent of pitch modulation in IDS. First, because the BDI gets at many of the same symptoms used by trained clinical interviewers to assign DSM-IV Axis-I depression-spectrum diagnoses (although assigning a clinical diagnosis of major depression also requires a minimum of 2 weeks of continuous presence of the symptoms, plus significant interference with social and/or occupational functioning), the effect size for clinical diagnosis obtained from the regression analysis should be viewed as a conservative estimate of the effect of depression on pitch range. Second, the brief, structured nature of these speech samples may have minimized differences in acoustic cues to emotionality in maternal speech between depressed and non-depressed mothers. The observed differences likely will be amplified in the course of more spontaneous, longer, and more varied verbal interactions, as well as over the course of repeated mother-infant interactions. Indeed, Bettes (1988), who studied spontaneous samples of running speech, found differences in extent of pitch modulation between mothers with very modestly elevated vs. non-elevated BDI scores.

In addition, acoustic differences in maternal IDS may have been minimized by the “spotlight” provided by the structured play interaction (i.e., situational response characteristics), in which mothers were given specific instructions about what to say.

Besides limiting variation in the content of maternal speech, this procedure may have differentially affected depressed mothers' arousal or desire to appear “normal,” resulting in increased motivation to engage with the infant and an artifactual increase in ΔF_0. In the end, however, we cannot conclude with certainty that the small proportion of the variance in ΔF_0 that was uniquely attributable to clinical depression accounts for decreased infant responding, poorer learning, or problems in cognitive or linguistic development (but see below for a discussion of links between ΔF_0 and infant learning).

Mothers of relatively younger infants (3- to 6-month-olds) were found to have higher vocal pitch and greater pitch range than mothers of older infants. These effects were not consistent with our initial findings (Kaplan et al., 2001), but were more in line with what has been reported by investigators from other laboratories. However, prior significant effects have been linearly increasing and/or inverted-U shaped functions, with mean F_0 peaking between 4 and 6 months, and F_0 range peaking at about 9 months (Kitamura & Burnham, 2003; Stern et al., 1983). We found linear declines from the youngest age grouping. Discrepancies may be due to the brief, sentence-final nature of the present samples, in comparison to longer running samples in some other studies. Variations in F_0-based cues in IDS with infant age may be attributable to a developmental shift in caregivers' emphasis from perceptual/affective cues in the IDS of mothers of young infants, to linguistic cues in the IDS of mothers of older infants (Herrera et al., 2004; Kitamura & Burnham, 1998; Ma et al., 2011; Song, DeMuth, & Morgan, 2010).

The effect of number of children on ΔF_0 was not observed in the earlier study. It cannot be attributed to one correlate of number of children, maternal education. Effects of number of siblings on pitch range in maternal IDS is intriguing, suggesting perhaps that mothers with multiple children do not provide the same quality of vocal stimulation to their infants as mothers with fewer children. Additional work will be needed to rule out influences of other variables correlated with number of children. Another important question is whether IDS directed toward the youngest child in the family by older siblings, grandparents, and other caregivers compensates for diminished prosodic cues in maternal IDS (Weppelman, Bostow, Schiffer, Elbert-Perez, & Newman, 1993; Shute & Wheldall, 2001).

A past finding that was not replicated here was the significant positive correlation between maternal age and ΔF_0. Instead, maternal age was unrelated to ΔF_0, but significantly negatively correlated with mean F_0, possibly reflecting maturational/aging effects in women in the age range studied. Mothers in this study were on average slightly older and better educated than in the initial sample.

Beyond small effect sizes, there were some other limitations to the present study that may affect its generalizability. First, our acoustic analyses focused on the mean values of 3 repetitions of a brief sentence-final utterance obtained from a structured play interaction, rather than on spontaneous, running speech. The construction of our “pet the gorilla” stimuli may seem arbitrary, unnatural, or contrived. However, it is also possible to overstate how unnatural these IDS samples were. Frequent repetition is a defining quality of maternal IDS. In fact, during joint attentional states, mothers often label novel objects using “variation sets,” in which a sequence of partially overlapping sentences directs the infant's attention to an object and provides clues to its name (see Goldstein et al., 2010, pp. 250-252; e.g., “Look at the nice kitty. What a nice kitty. What a pretty kitty. See the kitty?”). Mothers in our samples also produced varying stems that ended in “pet the gorilla,” at least for the two interrogative utterances. In this sense, our experimental stimuli were obtained from a typical kind of novel object-centered dyadic interaction, and their overall structure was similar in form to that of “natural” variation sets.

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Second, two characteristics of our sample deserve discussion. On the one hand, the depressed mothers in our study came from a community sample; clinical samples may yield different, perhaps more pronounced, results. This is perhaps another reason to hypothesize that our findings may underestimate speech acoustic effects of depression in IDS. On the other hand, through the wording of our recruitment advertisement, we attempted to over-sample mothers in the community who had a history of depression, which resulted in a proportion of mothers with DSM-IV Axis-I diagnoses that was higher than one would expect in the general population of mothers of young infants. But this should not have affected the differences we observed between non-depressed and depressed mothers in ΔF_0.

Third, with only slightly more than 50 clinically depressed mothers, our ability to detect effects of different Axis-I depression-spectrum diagnoses and their modifiers was limited. With larger samples, significant effects of Bipolar Disorder, Anxiety Disorder, pre-natal vs. post-partum depression, etc., yet may be detectable. Fourth, this study leaves open the question of whether other speech acoustic cues in IDS, such as spectral cues, are affected by maternal depression. Spectral cues are known acoustic correlates of positive (and negative) affect in adult speech (Sherer, 1986; Tartter, 1980).

The implications of these findings for infant learning and language development remain to be determined, especially in the light of the small amount of unique variance in ΔF_0 explained by clinical diagnosis. The multiple effects of IDS on infant state, attention, and learning have already been mentioned. Extent of pitch modulation is an important predictor of young infants' greater preference IDS over ADS (Fernald & Kuhl, 1987), suggesting that depressed mothers' IDS may not be preferred over ADS, or may sound like ADS to infants. However, pitch modulation may only be important to the extent that it signals positive affect (Kitamura & Burnham, 1998; Kitamura & Lam, 2009; Singh et al., 2002; Trainor et al., 2000), and multiple stimulus dimensions, including “source-based” (e.g., F_0-related) and “filter-based” (e.g., resonant or spectral) cues figure into adult judgments of emotional valence in speech stimuli (Bachorowski, 1999; Pittman & Sherer, 1993).

Research in a non-language-learning paradigm has demonstrated a significant negative correlation between mean ΔF_0 in IDS speech samples and group mean associative learning scores obtained from 4-month-old infants in conditioned-attention tests, in which an IDS segment was followed immediately by an image of a smiling adult female face (Kaplan et al., 1999), and evidence for the acquisition of voice-face associations was studied. However, in this paradigm, variations in ΔF_0 across IDS samples did not correlate with variations in *individual* 5- to 13-month-old infants' associative learning scores in response either to the infant's own mother's IDS or an unfamiliar mother's IDS (Kaplan, Dungan, & Zinser, 2004; Kaplan, Danko, Diaz, & Kalinka, 2011). Instead, the best predictor of 6- to 13-month-old infants' learning was neither ΔF_0 nor maternal depression but rather the mother's rated sensitivity coded from a separate play interaction (Kaplan, Burgess, Sliter, & Moreno, 2009), suggesting that the acquired significance of IDS for infants in this age range is more important than F_0-based acoustic features in predicting this kind of learning.

Still, evidence indicates that pitch range and the shapes of the pitch contours are among the important cues that increase the salience of IDS -- resulting in more robust learning and memory (Kuhl, 2007). Despite the fact that IDS does not appear to “induce” the development of speech perception or rudimentary language skills (Pinker, 1994, pp . 283-284), there is considerable evidence that it can facilitate these processes. At the correlational level, a mother's use of IDS during infancy predicts a child's later language development (Liu & Tsao, 2008). Furthermore, laboratory studies on infants have demonstrated that, in comparison to ADS, IDS generates greater neural activity (Zangl & Mills, 2007), and better facilitates phoneme discrimination (Liu, Kuhl, & Tsao, 2003;

Trainor, Austin, & Desjardins, 2002), word segmentation (Thiessen et al., 2005), word learning and memory (Ma et al., 2011; Singh et al., 2009), and the detection of phrase boundaries (Jusczyk et al., 1992). Pitch cues likely play a more pronounced role with relatively younger infants, with other stimulus dimensions assuming more prominent roles with relatively older infants (Herrera et al., 2004; Kitamura & Burnham, 1998; Ma et al., 2011). For example, IDS facilitates word recognition in 19-month-olds, but this effect appears to be mediated by vowel hyper-articulation and slowed speech rate, rather than increased pitch range (Song et al., 2010).

Consistent with facilitative effects of IDS on rudimentary language acquisition, by 12-14 months of age, infants of mothers in the present sample with larger ΔF_0 in their IDS were reported to have larger productive vocabularies. Still, this finding must be interpreted with caution for a number of reasons. First, we also found a downward trend in extent of pitch modulation in the IDS of mothers of relatively older infants. These infants are arguably more deeply engaged in language-acquisition processes such as speech stream segmentation and word learning than are 3- to- 6 month-olds, who, at least in this study, heard speech with the largest ΔF_0. Second, despite the obtained acoustic differences in IDS, there was no effect of maternal mood on 1-year-olds' developing vocabulary, although maternal depression has been linked to differences in child language in older children (Cicchetti, Rogosch, & Toth, 2000; NICHD Early Childhood Research Network, 1999). Follow-up assessments with the current sample could reveal later effects of depression on vocabulary development. Third, some of our MCDI findings were anomalous, possibly calling into question all of our MCDI data. Mothers' reports that boys had larger receptive vocabularies than girls, and that children of younger and less well educated mothers had larger receptive vocabulary sizes than older and better-educated mothers were not consistent with past findings (Fenson et al., 1994) and may reflect biased reporting. And yet there was no evidence of biased reporting about infants' *productive* vocabulary, and the correlation between MCDI productive vocabulary percentile scores and ΔF_0 in maternal speech was not confounded with maternal demographic variables.

However, much work remains to show that this correlation in indicative of a causal mechanism, and the role of depression must still be elucidated. It is unclear whether the speech acoustic characteristics of maternal IDS promote vocabulary development, or whether other variables, related to a different aspect of the quality of the caregiver-child interaction, might account for this correlation. For instance, prior research in our laboratory showed that mothers' rated covert hostility (e.g., irritability, impatience), coded from a separate play interaction, was significantly negatively correlated with ΔF_0 in IDS produced by mothers of 6- to 13-month-olds (Kaplan et al., 2009). Other studies have shown that depressed mothers differ from non-depressed controls not only in speech acoustic measures but also in the content, degree of contingent delivery, and degree of infant focus of their speech (Bettes, 1988; Breznitz & Sherman, 1987; Herrera et al., 2004; Murray, Kempton, Woolgar, & Hooper, 1993; Zlochower & Cohn, 1996). A mother's rated verbal focus on her 2-month-old predicts the infant's object concept score at 18 months (Murray et al., 1993). Similarly, the number of parents' comments contingent on an infant's object of attention at 9 months predicts the child's later language comprehension and production (Rollins, 2003).

Whether or not parents' use of IDS can be shown to have independent effects on aspects of language development, it is likely an important part of a complex of cues that, taken together, link maternal clinical depression with increased risk for delays in cognitive-linguistic development (Murray et al., 1993). Interventions that target clinically depressed mothers and their infants, whether they address maternal depression generally, mother-infant interactions, or maternal production of IDS specifically, may effectively prevent or reduce these developmental delays.

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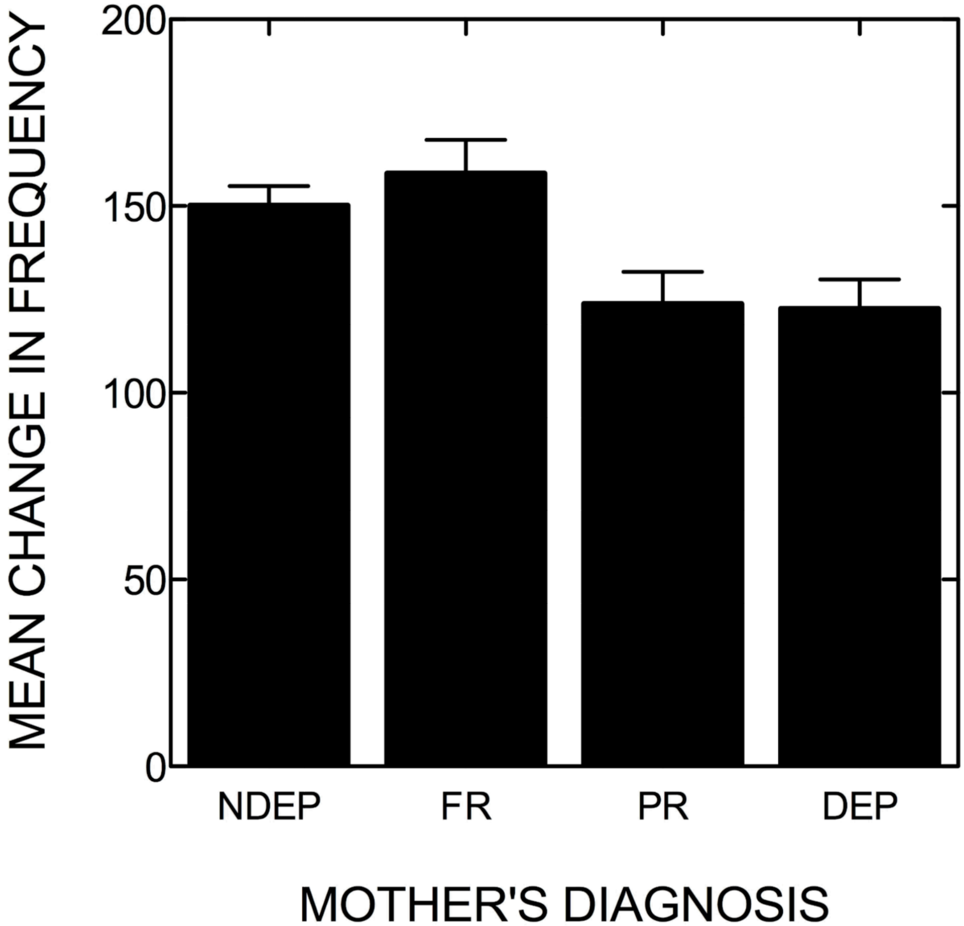

Figure 1.
Mean change in fundamental frequency or F_0 range (F_{0max} - F_{0min} = ΔF_0) in infant-directed utterances of non-depressed mothers (NDEP), depressed mothers (DEP), and those diagnosed with depression in full remission (FR), or partial remission (PR). Error bars are standard errors of the mean.

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Table 1

Maternal and Infant Demographic Data as a Function of Diagnostic Categories

Variable	NDEP	FR	PR	DEP	BP	ANX
N	129	39	32	52	9	20
Mother's Age	$32.0 (4.7)_a$	$32.2 (5.1)_a$	$28.5 (6.3)_b$	$29.6 (4.9)_b$	$31.8 (5.5)_a$	$31.0 (4.2)_a$
Infant's age	274.0 (105.6)	286.2 (99.8)	273.0 (102.8)	264.6 (95.3)	276.0 (94.5)	231.5 (91.4)
Ethnicity						
White	92 (71.3%)	33 (84.6%)	21 (65.6%)	32 (61.5%)	7 (77.8%)	16 (80.0%)
Latina	21 (16.3%)	3 (7.7%)	7 (21.9%)	14 (26.9%)	0 (0.0%)	2 (10.0%)
Black	10 (7.8%)	2 (5.1%)	3 (9.4%)	2 (3.8%)	2 (22.2%)	1 (5.0%)
Asian	5 (3.9%)	1 (2.6%)	0 (0.0%)	1 (1.9%)	0 (0.0%)	1 (5.0%)
Native Am	1 (0.7%)	0 (0.0%)	1 (3.1%)	3 (5.8%)	0 (0.0%)	0 (0.0%)
Mother's edu	$6.0 (1.5)_a$	$5.7 (1.4)_a$	$4.8 (1.3)_b$	$4.8 (1.5)_b$	$5.3 (1.6)_a$	$6.0 (1.6)_a$
# of Children	1.6 (0.8)	1.7 (0.8)	1.7 (1.0)	1.7 (0.8)	1.9 (0.9)	1.7 (0.9)
BDI score	$8.3 (6.7)_a$	$9.7 (5.9)_a$	$17.5 (9.4)_b$	$23.5 (6.6)_c$	$18.4 (13.9)_b$	$15.3 (8.9)_b$

Means with different subscripts differ significantly from one another ($p = .05$).

NDEP = non-depressed, FR = clinical depression in full remission, PR = clinical depression in partial remission, DEP = currently diagnosed clinical depression, BP = bipolar disorder (I & II combined, including those in remission), and ANX = anxiety disorder diagnosis (see text for sub-categories).

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Table 2

Correlation Matrix Relating Demographic and Speech Acoustic Variables

	1	2	3	4	5	6	7	8	9	10
1. Mean F_0	--									
2. Mean ΔF_0	.27**	--								
3. Mean $F_0 SD$	.32**	.57**	--							
4. Infant age	-.20**	-.12*	.07	--						
5. Gender	.05	.07	.02	.01	--					
6. Mother's age	-.12*	.04	-.04	-.03	.03	--				
7. Education	.01	.11	.18**	-.03	.01	.32**	--			
8. # Children	-.05	-.16**	-.06	.10	.01	.18**	-.18**	--		
9. Minority	-.03	-.11	-.08	.14*	.01	-.27**	-.28**	.06	--	
10. BDI score	-.05	-.17**	-.05	-.01	-.03	-.13*	-.32**	.15*	.06	--

"minority" was contrast coded, where 1 = ethnic minority, -1 = white, non-Hispanic.

* signifies $p = .05$;

** signifies $p = .01$. Mean F_0 refers to the average pitch across all 3 distinct "gorilla" utterances; mean ΔF_0 refers to the average pitch range, a gross measure of change in pitch; mean F_0 SD refers to the standard deviation of the pitch in "gorilla" utterances, a measure of the dispersion of F_0 in relation to the mean.

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Table 3
Acoustic Findings as a Function of Depression and Remission Classification

Variable	NDEP	FR	PR	DEP
Mean F_0	284.1 (58.3)	285.5 (50.9)	285.3 (62.2)	278.2 (55.7)
Mean ΔF_0	150.1 $(59.3)_a$	158.7 $(56.6)_a$	123.8 $(53.5)_b$	122.5 $(56.4)_b$
Mean F_0 *SD*	65.0 $(23.4)_{a/b}$	72.4 $(26.6)_b$	61.5 $(24.6)_{a/b}$	58.8 $(22.7)_{a/c}$

Means that do not share a subscript differ significantly from one another (p = .05). NDEP = non-depressed, FR = depression in full remission, PR = depression in partial remission, DEP = current clinical depression. Mean F_0 refers to the average pitch across all 3 distinct “gorilla” utterances; mean ΔF_0 refers to the average pitch range, a gross measure of change in pitch; mean F_0 SD refers to the standard deviation of the pitch in “gorilla” utterances, a measure of the dispersion of F_0 in relation to the mean.

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Table 4

Hierarchical Linear Regression of Demographic and Diagnostic Variables on Mean Fundamental Frequency Range (ΔF_0)

Model	Variable	ΔR^2	Total R^2	B	SE B	β
Step 1	Minority status	.009	.009	-2.98	4.12	-.046
Step 2	Education	.013	.022	1.53	2.65	.039
Step 3	# children	.017	.040	-8.98	4.48	-.124*
Step 4	Infant age	.011	.050	-.063	-.036	-.109
Step 5	BDI score	.012	.063	.001	0.55	.000
Step 6	Diagnosis	.017	.080	-9.00	4.16	-.183*

* $p = .05$.

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Table 5

Effects of Depression Diagnosis Modifiers on F_0-Based Acoustic Cues

Modifier	Levels	Mean F_0 (Hz)	Mean ΔF_0 (Hz)	Mean F_0 S.D.
Recurrent/Single	recurrent (*n*=41)	280.5 (53.9)	131.5 $(59.0)_a$	59.0 (25.3)
	single (*n*=9)	263.5 (71.8)	88.4 $(35.7)_b$	56.4 (9.2)
Timing of Onset	postpartum (*n*=20)	269.9 (67.2)	137.0 (72.9)	63.0 (25.4)
	prenatal (*n*=24)	278.2 (39.9)	106.0 (34.6)	53.0 (18.4)
Severity (MDD)	mild (*n*=21)	266.9 (50.9)	133.5 (62.4)	55.2 (23.8)
	moderate (*n*=19)	273.9 (61.4)	121.0 (60.3)	60.1 (23.9)
	severe (*n*=4)	294.1 (68.1)	98.3 (51.4)	54.6 (19.1)

Number in parentheses are standard deviations. Means with different subscripts (across rows) differ significantly ($p = .05$). Ratings of severity of depression apply only to mothers diagnosed with Major Depressive Disorder (MDD). Mean F_0 refers to the average pitch across all 3 distinct "gorilla" utterances; mean ΔF_0 refers to the average pitch range, a gross measure of change in pitch; mean F_0 SD refers to the standard deviation of the pitch in "gorilla" utterances, a measure of the dispersion of F_0 in relation to the mean.