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# Frontal brain electrical activity (EEG) and heart rate in response to affective infant-directed (ID) speech in 9-month-old infants

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## Abstract

Many studies have shown that infants prefer infant-directed (ID) speech to adult-directed (AD) speech. ID speech functions to aid language learning, obtain and/or maintain an infant's attention, and create emotional communication between the infant and caregiver. We examined psychophysiological responses to ID speech that varied in affective content (i.e., love/comfort, surprise, fear) in a group of typically developing 9-month-old infants. Regional EEG and heart rate were collected continuously during stimulus presentation. We found the pattern of overall frontal EEG power was linearly related to affective intensity of the ID speech, such that EEG power was greatest in response to fear, than surprise than love/comfort; this linear pattern was specific to the frontal region. We also noted that heart rate decelerated to ID speech independent of affective content. As well, infants who were reported by their mothers as temperamentally distressed tended to exhibit greater relative right frontal EEG activity during baseline and in response to affective ID speech, consistent with previous work with visual stimuli and extending it to the auditory modality. Findings are discussed in terms of how increases in frontal EEG power in response to different affective intensity may reflect the cognitive aspects of emotional processing across sensory domains in infancy.

*Keywords:* Frontal EEG asymmetry; Infant-directed speech; Emotion; Temperament; Heart rate

## 1. Introduction

Parents, children, and individuals with no parenting experience have a natural tendency to produce infant-directed (ID) speech when communicating with infants (Dunn & Kendrick, 1982; Fernald, 1989; Jacobson, Boersma, Fields, & Olson, 1983). Since infants do not understand the content of speech, the utility of ID speech as a communication medium is of great interest to researchers. Infant-directed speech has a 'musical quality' (Fernald, 1989; Trainor, Austin, & Desjardins, 2000) and is characterized as having higher pitch, more exaggerated pitch contours, larger pitch range, slower tempo, and is more rhythmic than speech directed towards adults (e.g., Ferguson, 1964; Fernald, 1991; Katz, Cohen, & Moore, 1996; Papousek, 1992; Stern, Spieker, & McKain, 1982; Trehub, Trainor, & Unyk, 1993). Infants prefer and respond selectively to the prosodic features of ID speech compared with typical adult-directed (AD) speech (Fernald, 1991, 1993; Fernald & Kuhl, 1987; Werker & McLeod, 1989). Furthermore, ID speech appears to have a biological basis as it has been found across languages and cultures (Fernald, 1989; Greiser & Kuhl, 1988; Papousek & Hwang, 1991; Papousek, Papousek, & Symmes, 1991; Werker, Pegg, & McLeod, 1994).

ID speech may serve several functions. ID speech may (1) facilitate language learning by exaggerating lexical and grammatical structure (e.g., Fernald & Mazzie, 1991; Kemler Nelson, Hirsch-Paek, Jusczyk, & Wright-Cassidy, 1989; Shatz, 1982; Snow & Ferguson, 1977), (2) be used to obtain and/or maintain infants' attention (Fernald, 1991; Werker & McLeod, 1989), and (3) function to communicate affective and contextual information to infants

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(Fernald, 1991; Papousek, 1992; Singh, Morgan, & Best, 2002; Trainor et al., 2000). For example, ID speech expressing approval and eliciting attention is associated with large bell-shaped pitch contours; prohibiting a behavior is associated with short, low pitch, flat contours; and comfort and soothing are associated with lower pitch and falling contours (Fernald, 1989, 1991; Katz et al., 1996; Papousek et al., 1991). Adults and children can recognize the intended emotion in speech with ease even when the words are not informative (Leinonen, Hiltunen, Linnankoski, & Laakso, 1997; Scherer, Banse, & Wallbott, 2001), suggesting the listener is able to associate particular prosodic patterns of speech (i.e., pitch contours, pitch height) with certain emotions (Bachorowski, 1999; Bachorowski & Owen, 1995; Scherer et al., 2001). Trainor and her colleagues argued that the information in the prosody of ID speech is primarily emotional (Trainor et al., 2000) and that AD emotional speech is actually very similar in prosody to ID speech, but that emotional expression is typically constrained in AD speech.

Consistent with this explanation, Fernald (1989) showed that adults are better able to judge the context in which a phrase was uttered when it is in ID speech than when it is in AD speech. More recently, Further, Singh et al. (2002) have shown that when affect is held constant between ID and AD speech, infants do not prefer ID speech over AD speech, and that if the AD speech conveys more positive emotion than the ID speech, they will actually prefer the AD speech. Trainor et al. (2000) showed that similar prosodic features are used in ID and AD speech to portray emotion. Specifically, surprise is conveyed by high pitch, large bell-shaped pitch contours, moderate tempo, and exaggerated slowing at the beginning and ends of phrases. Love/comfort is conveyed by low pitch, falling pitch contours, and slow tempo. Fear is conveyed by flat pitch contours, fast tempo, and little slowing at the beginning and end of phrases. Together, these findings suggest that infants' early speech preferences are strongly influenced by the emotional expression in the speech.

Do infants differentiate among the various emotions expressed in speech? While little work has examined this issue, there is evidence that infants discriminate at least positive from negative affect in speech. Infants have been shown to prefer to listen to ID speech expressing positive affect over ID speech expressing negative affect (Fernald, 1993; Papousek & Hwang, 1991), and they prefer speech with positive affect over speech with negative affect regardless of whether it is infant- or adult-directed (Singh et al., 2002). Here we used electrocortical and autonomic measures to examine infants' responses to different emotions in ID speech.

One model of brain activity suggests that the experience of positive affect (e.g., happiness, joy, interest) and approach-related behavior is associated with greater relative left frontal brain activity, whereas the experience of negative affect (e.g., fear, disgust, sadness) and avoidance-related behavior is associated with greater relative right frontal brain activity. These distinct patterns of frontal EEG asymmetry during the processing of positive and negative emotions have been noted in studies of adults, children, and infants across different sensory modalities (see Davidson, 2000; Fox, 1991, 1994 for a review). A second model suggests that the pattern of overall absolute activation in the frontal region may reflect the intensity of emotional experience (Dawson, 1994; Henriques & Davidson, 1991; Schmidt, 1999; Schmidt & Fox, 1999). For example, studies have shown that intense transient emotions are related to heightened overall activation in the frontal region of the brain (i.e., Dawson, 1994; Schmidt & Trainor, 2001).

We found support for both of these models in adults using affective musical excerpts (Schmidt & Trainor, 2001). Young adults exhibited greater relative left frontal EEG activity during the processing of musical excerpts eliciting positive emotions (e.g., joy and happiness) and greater relative right frontal EEG activity during the processing of musical excerpts eliciting negative emotion (e.g., fear and sadness), suggesting that the pattern of frontal EEG activity distinguishes emotional valence. Moreover, we found that the pattern of overall frontal activity was linearly related to the rated intensity of the emotion elicited by the musical excerpts, with the most overall frontal activity during the processing of fearful excerpts and the least during the processing of sad excerpts, suggesting that overall frontal activity may be linked to the intensity to which the emotion is experienced.

A second set of measures of particular interest was heart rate and heart rate variability. Heart rate has long been used as a measure of orienting reflexes and reactivity to sensory and affective stimuli in humans (see Bernston & Boysen, 1990). In infants, attention and orienting responses are accompanied by rapid heart rate deceleration that may facilitate further perceptual processing of information in the environment (Graham & Clifton, 1966; Lacey, 1967; Porges, 1995), while high reactivity and low levels of positive affect are associated with heart rate acceleration (Fox, 1989; Snidman, Kagan, Riordan, & Shannon, 1995).

Similar to the electrocortical/emotion studies reviewed above, some studies have found that autonomic measures distinguish among emotions (see e.g., Ekman, Levinson, & Friesen, 1983; Levenson, Ekman, & Friesen, 1990). Still others have used heart rate as a measure to distinguish among musical emotions, although the data here are not all that consistent perhaps due to conceptual and methodological problems (see, e.g., Dainow, 1977). However, more recent studies perhaps show greater promise than those in the past (Krumhansl, 1997; Nyklivcek, Thayer, & Van Dooren, 1997). Nyklicek and colleagues, for example, had participants listen to 2–4 min of musical segments and asked them to judge the strength of the emotion. They found that heart rate decelerated during all of the musical emotion conditions, but decelerated least during highly arousing, positively-valenced musical segments and most during negatively-valenced musical segments.

We (Schmidt, Trainor, & Santesso, 2003) recently examined regional EEG and heart rate patterning in response to affective musical stimuli in 3-, 6-, 9-, and 12-month-old infants. Three orchestral musical pieces that were known to vary in affective valence according to adult ratings (sad, fear, and joy) were presented. In this cross-sectional study, we found developmental changes in EEG responses to affective musical excerpts across age. Specifically, responses to the music showed up at more frontal scalp regions with increasing age, and affective musical excerpts produced an increase in overall cortical activity at 3-months and a reduction in overall cortical activity by 12-months, independent of valence. Although some previous studies have noted that by the first year of post-natal life the pattern of frontal EEG activity distinguished among different emotions (see Fox, 1991, for a review), we did not find this for these musical excerpts. Patterns of heart rate response to music also changed with age, but again we did not find that the pattern of heart rate distinguished among the valences of the musical excerpts. In response to all musical excerpts, there was a significant heart rate deceleration at 3- and 6-months of age, a significant heart rate acceleration at 9-months, and no change at 12-months. However, there were no relations between heart rate and the specific emotion being conveyed in the music. One possible reason for the lack of EEG and heart rate differentiation across valence is that the orchestral excerpts were too complex and unfamiliar to infants or the infants were not experiencing the intended emotion.

There were two goals of the present study. The primary goal was to examine infants' EEG and autonomic responses to emotion using a more meaningful set of stimuli, namely, affective ID speech, than the musical stimuli that had been used earlier (Schmidt et al., 2003). We used the ID speech samples from Trainor et al. (2000) expressing love/comfort, surprise, and fear.

A second goal was to examine the relation between infant temperament and the pattern of frontal EEG activity and heart rate during baseline conditions and in response to affective ID speech. There is a growing literature that suggests that the pattern of resting frontal EEG activity is related to individual differences in infant and child temperament (see Fox, 1991, 1994; Schmidt & Fox, 1999 for reviews) and adult affective style and personality (Davidson, 2000; Schmidt, 1999). Infants and children who exhibit greater relative resting right frontal EEG activation are known to be fearful, easily distressed, and behaviorally inhibited. Temperamentally socially anxious children exhibit greater relative right frontal EEG activation at rest and during the processing of negative-valenced stimuli (Schmidt, Fox, Schulkin, & Gold, 1999; Theall-Honey & Schmidt, 2006).

We predicted that (1) because ID speech would be salient and attract the infants' attention, infants would exhibit increased frontal EEG power and heart rate deceleration independent of valence as a function of stimulus intensity: fear, followed by surprise, followed by love/comfort; and (2) temperamentally distressed infants would exhibit greater relative right frontal EEG activity and a high heart rate during baseline and in response to negatively-valenced ID speech.

## 2. Method

### 2.1. Participants

Thirty-nine healthy infants (24 male, 15 female) were recruited from a large database that contained the birth records of children born within the McMaster University Medical Center and St. Joseph's Hospital (Hamilton, Ontario). All infants were tested within one week of their 9-month birth date (mean age = 9 months, 3 days). Infants were primarily Caucasian, and all were full-term, healthy, and experienced no pre- or post-natal health problems.

### 2.2. Affective stimuli

We used previously recorded speech samples (described in detail in Trainor et al., 2000) of mothers expressing either comfort, surprise, or fear as they said the phrase "Hey, honey, come over here" to their infants. In each case, the mothers acted out emotional scenarios intended to elicit each emotion. Trainor et al. (2000) showed that adult raters readily identified the intended emotion in these samples, and that the different emotions were clearly distinguished according to acoustic analyses. A group of adults also distinguished these stimuli in terms of affective valence and affective intensity: love/comfort and surprise were rated as more pleasant than fear; fear was rated as the most intense followed by surprise and love/comfort. In all, six samples of each of the three emotions were used and the recordings were normalized for sound intensity. Love/comfort, surprise, and fear conditions were constructed such that the samples expressing that emotion were played in random order for 60 s.

### 2.3. Procedure

All infants were tested in the Child Emotion Laboratory at McMaster University. Upon arrival at the laboratory, the mother and infant were ushered into the testing room. The mother was briefed about the procedures and consent was obtained. The mother was seated in a comfortable chair with her infant on her lap. A lycra EEG stretch cap was put on the infant's head and heart rate electrodes were attached to the infant's chest. Mothers were instructed to remain silent and give no emotional cues to the child during the psychophysiology recording. EEG and heart rate were collected for a one minute baseline condition, after which time the three affective ID speech conditions (love/comfort, surprise, fear) were each presented for 60 s, with a 30 s pause in between conditions. To control for order effects, different infants were tested on each of the six possible orders of the three emotion conditions. Following the psychophysiology testing, the EEG cap and heart rate electrodes were detached, and the mother was asked to complete ratings of her child's temperament. Each mother was then given a photograph of her child and the infant was given a small toy prize at the completion of the study as a token of appreciation for their participation.

### 2.4. Psychophysiology data collection

#### 2.4.1. EEG recording

The EEG was collected with SA Instrumentation Bioamplifiers and a lycra stretch cap (Electro-Cap, Inc.) from four scalp locations: left and right mid-frontal (F3, F4) and parietal (P3, P4) sites during baseline and each of the three affective ID speech conditions. The EEG sites represent the left and right hemispheres and anterior and posterior regions of the brain. The cap electrodes are positioned according to the 10/20 system of the International Federation (Jasper, 1958). All electrode impedances were maintained below 10 kΩ at each site and within 500 Ω between homologous sites, and all electrodes were referenced to the central vertex (Cz) during recording. The EEG data were recorded at a sampling rate of 512 Hz, and bandpass filtered between 1 Hz (high pass) and 100 Hz (low pass).

#### 2.4.2. Heart rate recording

Heart rate was recorded continuously during the baseline and each of the three affective ID speech conditions using two disposable pediatric electrodes attached to the infant's chest. The heart rate signal was collected and amplified by a separate SA Instrumentation Bioamplifier. The heart rate data were recorded at a sampling rate of 512 Hz, and bandpass filtered between 1 Hz (high pass) and 100 Hz (low pass).

### 2.5. Psychophysiology data reduction

#### 2.5.1. EEG data reduction and analysis

The EEG data were visually scored for artifact due to eyeblinks, eye movements, and other motor movements, using software developed by James Long Company (EEG Analysis Program, Caroga Lake, NY). This program removes data from all channels if artifact is present on any one channel.

All artifact-free EEG data were analyzed using a discrete Fourier transform (DFT), with a Hanning window of 1 s width and 50% overlap. Power (microvolts-squared) was derived from the DFT output in the 4–8 Hz frequency band for baseline and each of the three affective ID speech conditions. This frequency band was chosen because it contained a majority of the EEG power and is thought to represent the infant alpha band (see e.g., Calkins, Fox, & Marshall, 1996). A natural log (ln) transformation was performed on the EEG power data to reduce skewness.

#### 2.5.2. Heart rate data reduction and analysis

A file of inter-beat-intervals (IBI) was created on each infant for baseline and each of the three affective ID speech conditions. The IBI data were visually edited for artifact and analyzed using software developed by James Long Company (ECG Analysis Program, Caroga Lake, NY). This program calculates the mean heart period (expressed in ms) and the standard deviation of the mean heart period (i.e., heart period variability) measures.

### 2.6. Maternal report of infant temperament

Maternal perceptions of infant temperament were assessed using the Infant Behavior Questionnaire (IBQ; Rothbart, 1981). Of particular interest were subscales indexing fear (e.g., "cry after startling"), distress (e.g., "fuss or cry when washing baby's face"), and soothability (e.g., "smile or laugh when tossed around playfully").

## 3. Results

### 3.1. Patterns of regional EEG activity in response to affective infant-directed speech

We first performed an analysis of variance (ANOVA) with Condition (Baseline, Love/Comfort, Surprise, Fear), Region (Frontal, Parietal), Hemisphere (Left, Right), and Order (6) as within-subjects factors in order to ensure that there were no significant effects due to presentation order. The dependent measure was ln(4–8 Hz) EEG power. This analysis indicated that there were no main effects of, or interactions involving, order so the data were collapsed across order in subsequent analyses. We then performed an analysis of variance (ANOVA) with Condition (4), Region (2), and Hemisphere (2), as within-subjects factors. The dependent measure was ln(4–8 Hz) EEG power. The analysis revealed a significant main effect for Condition [$F(3, 105) = 5.29$, $p < .01$], a significant main effect for Region [$F(1, 35) = 18.82$, $p < .01$], and a trend for a significant Condition × Region × Hemisphere interaction [$F(3, 105) = 2.60$, $p = .056$].

In order to decompose these effects, a separate ANOVA with Condition and Hemisphere as within-subjects factors was performed for the frontal and parietal regions. Again, the dependent measure was ln(4–8 Hz) EEG power.

#### 3.1.1. Frontal EEG data

The analysis revealed a significant main effect only for Condition [$F(3, 105) = 6.82$, $p < .01$]. Accordingly, EEG power in the two frontal sites (F3 + F4) was collapsed and averaged (i.e., F3 power + F4 power/2), and a series of pairwise *t*-tests were performed. Fig. 1 presents the mean and standard errors for the overall frontal EEG power data collected during baseline and each of the three affective ID speech conditions.

As can be seen in Fig. 1, the pattern of overall frontal EEG power distinguished affective intensity of ID speech.

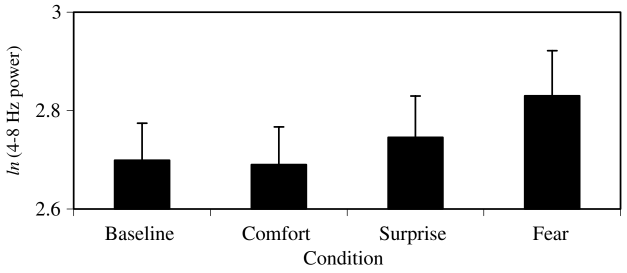

Fig. 1. Pattern of overall frontal EEG ln(4–8 Hz) power in distinguishing affective valence of ID speech in 9-month-old infants. (Note: EEG power is inversely related to activity, so high power is thought to reflect lower activity.)

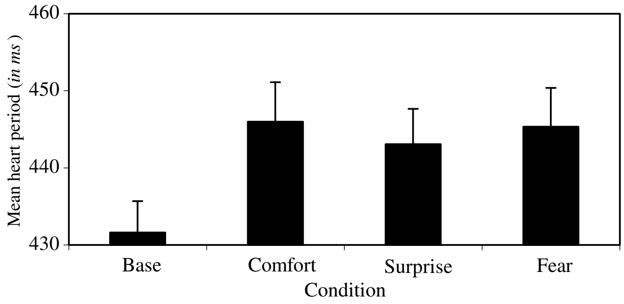

Fig. 2. Differences in mean heart period (in ms) during baseline and in response to affective ID speech in 9-month-old infants. (Note: mean heart period is inversely related to heart rate, so lower values reflect a faster heart rate.)

As predicted, infants exhibited significantly more overall frontal EEG power during the fear condition compared with the surprise [$t(35) = 2.26$, $p < .03$], comfort [$t(35) = 4.10$, $p < .01$], and baseline [$t(35) = 3.49$, $p < .01$] conditions; the surprise versus comfort comparison approached significance [$t(35) = 1.86$, $p < .071$]. The main effect of hemisphere and the interaction between hemisphere and condition were not significant.

### *3.1.2. Parietal EEG data*

The analysis failed to reveal any significant main or interaction effects for Condition and Hemisphere for the parietal region, suggesting that the infants did not exhibit distinct patterns of EEG activity in the parietal region in response to the affective ID speech.

## *3.2. Patterns of autonomic activity in response to affective infant-directed speech*

We first performed separate ANOVAs with Condition (4) and Order (6) on each dependent measure to ensure that there were no significant effects of Order. The dependent measures were mean heart period and mean heart period variability. These analyses indicated that there were no significant main or interaction effects for Order, so all subsequent analyses were collapsed across order.

We then performed a separate ANOVA with Condition (Baseline, Love/Comfort, Surprise, Fear) as a within-subjects factor for each dependent measure: mean heart period and mean heart period variability.

### *3.2.1. Mean heart period data*

The analyses revealed a significant main effect for Condition on mean heart period [$F(3, 99) = 5.06$, $p < .03$]. Fig. 2 presents the means and standard errors for the mean heart period data collected during baseline and each of the three affective ID speech conditions.

As can be seen in Fig. 2, infants exhibited a significantly lower mean heart period (i.e., higher heart rate) at Baseline than during Love/Comfort, Surprise, and Fear. In order to decompose the main effect for Condition, we then performed a series of pairwise *t*-tests. These analyses revealed that Baseline differed significantly from each affective condition: Comfort [$t(33) = 4.27$, $p < .005$]; Surprise [$t(33) = 3.89$, $p < .05$]; and Fear [$t(33) = 3.04$, $p < .005$]. However, there were no differences in mean heart period among the affective conditions, suggesting that the emotions elicited by the ID speech were not distinguishable by heart rate.

### *3.2.2. Mean heart period variability data*

The analyses failed to reveal a significant main effect for Condition on the mean heart period variability measure, suggesting that the emotions elicited by ID speech were not distinguishable on this measure.

## *3.3. Relations between infant temperament and psychophysiological responses to affective ID speech*

A series of Pearson correlations were computed to examine the relations between maternal report infant temperament and the pattern of frontal EEG activity and heart rate during baseline and the affective ID speech conditions. We first computed a frontal EEG asymmetry measure using ln(F4 power) – ln(F3 power) for baseline and each affective condition. Because EEG power is thought to be inversely related to activity in studies of emotion (Davidson & Tomarken, 1989), negative scores on this metric reflect greater relative right frontal EEG activity. Table 1 presents the inter-correlations between the IBQ subscales and (A) frontal EEG asymmetry and (B) heart rate measures during baseline and each of the affective ID speech conditions.

### *3.3.1. Relations between infant distress and frontal EEG activation*

As can be seen in Table 1(A), maternal report of infant distress was consistently related to greater relative right frontal EEG activity. Infants who were reported by their mothers as easily distressed by novel stimuli were likely to exhibit greater relative right frontal EEG activity at baseline and across all of the affective ID speech conditions; with the exception of Surprise, all were significant

Table 1
Correlations between maternal report of temperament and (A) frontal EEG asymmetry and (B) mean heart period measures during baseline and each affective ID speech condition in 9-month-old infants

| Measure | Infant behavior questionnaire subscale | | |
|---|---|---|---|
| | Fear | Distress | Soothability |
| (A) Frontal EEG laterality | | | |
| Baseline | .02 | −.42* | .07 |
| Comfort | .05 | −.35* | .08 |
| Surprise | −.19 | −.17 | −.09 |
| Fear | −.18 | −.34* | −.10 |
| (B) Mean HP | | | |
| Baseline | −.20 | −.03 | −.07 |
| Comfort | .20 | .21 | −.03 |
| Surprise | −.20 | .13 | −.10 |
| Fear | −.38* | −.05 | −.28 |

*Note.* Frontal EEG laterality is computed right (F4) power minus left (F3) power. Because EEG power is inversely related to activity, negative scores on the laterality metric reflect greater relative right frontal activity (Davidson & Tomarken, 1989); mean heart period is inversely related to heart rate, so lower values reflect a faster heart rate; $*p < .05$; $N = 32$.

at $p < .05$. The other temperamental subscales were not related to the pattern of frontal EEG asymmetry.

### 3.3.2. Relations between infant fear and heart rate

As can be seen in Table 1(B), maternal report of infant fear was related to the mean heart period only during the fear condition. Infants who were rated by their mothers as temperamentally fearful exhibited a high heart rate only during the fear condition ($p < .05$), but not during the other conditions. As well, there were no significant relations between the other maternal report of infant temperament subscales and the heart period measures collected during baseline and the affective ID speech conditions.

## 4. Discussion

### 4.1. Does the pattern of frontal EEG activity distinguish affective valence and intensity of ID speech?

We found that the pattern of overall frontal EEG absolute power distinguished among the intensity of emotions elicited by infant-directed speech, with highest frontal EEG power associated with fear followed by surprise than comfort. Similar to our previous findings using musical excerpts (Schmidt et al., 2003), we did not find that the pattern of frontal EEG asymmetry distinguished among the emotions elicited by ID speech stimuli. Although these findings may seem at odds with the frontal activation emotion models articulated by others (Davidson, 2000; Dawson, 1994; Fox, 1991, 1994), they are consistent with recent findings in which increases in EEG power are thought to reflect increased cognitive demands at this age (Bell, 2002). Bell argued that increases in EEG power during infancy are related to cognitive/attentional properties of stimuli. It is likely that infants oriented toward the ID speech, and this was reflected cortically with increases in EEG power. We speculate that the salient and highly engaging affective ID speech stimuli used in the present study were recruiting the cognitive aspects of affect and perhaps resources for additional processing as reflected in the pattern of overall frontal power.

### 4.2. Does the pattern of autonomic activity distinguish affective valence and intensity of ID speech?

We found that relative to baseline, infants exhibited a significant heart rate deceleration across all of the affective ID speech conditions. Infant heart rate became slower to the presentation of the affective ID speech conditions compared with baseline. This result is consistent with our recent findings (Schmidt et al., 2003) in which we note a similar pattern of heart rate response to affective musical excerpts in infants across the first year of life. The present results are inconsistent with studies of adults in which it has been noted that heart rate distinguishes among different affects (Ekman et al., 1983) and musical emotions (Krumhansl, 1997). The pattern of heart rate response that we noted in relation to affective ID speech conditions is consistent with the pattern of frontal EEG response. That is, heart rate is known to decelerate in response to attentional load (Lacey, 1967). We speculate that ID speech, irrespective of valence, was emotionally and attentionally engaging. This autonomic finding, then, lends support to the notion that the EEG findings described above may have reflected the attentional qualities of the stimuli given the concordance of autonomic patterning noted with the central measures.

### 4.3. Does infant temperament relate to the pattern of infant psychophysiology during affective ID speech?

We found that maternal report of infant temperamental distress was consistently related to greater relative right frontal EEG activity in response to affective ID speech conditions. Infants who were reported by their mothers as easily distressed to novel stimuli were likely to exhibit greater relative right frontal EEG activity at baseline and across all of the affective ID speech conditions. This pattern of finding is consistent with work by Fox and his colleagues (Fox, Henderson, Rubin, Calkins, & Schmidt, 2001) who have noted relations between individual differences in temperament and frontal EEG asymmetry. For example, infants and children who are easily distressed, fearful, and wary of novel stimuli are known to exhibit greater relatively right frontal EEG activity at rest. The findings from the present study suggest that some infants who are easily distressed process emotions elicited by ID speech in a distinct manner as evidenced by their pattern of frontal EEG asymmetry. These findings also are consistent with the notion that infants and children who are fearful have problems regulating the processing of emotion (Theall-Honey & Schmidt, 2006). The pattern of greater relative right frontal

EEG activity noted here during the processing of emotion in some temperamentally distressed infants supports this idea. This notion is also supported by the findings that there were significant relations between infant temperament and emotion processing on an autonomic level. For example, we noted that maternal report of infant temperamental fear was related to the mean heart period measure during the fear condition. There was a match between infant temperamental style and the processing of negative emotion. Infants who were rated by their mothers as temperamentally fearful exhibited a high heart rate during the fear condition.

### *4.4. Conclusions and implications*

The present study suggests that there are distinct patterns of EEG and heart rate activity during the processing of emotions elicited by ID speech in typically developing 9-month-old infants and that these patterns vary with the temperament of the infant. Specifically, heart rate and the pattern of anterior, but not posterior, EEG activity distinguishes affective intensity consistent with cognitive aspects of emotional processing in infants. Furthermore, infants who are temperamentally fearful exhibit greater right frontal activation in general, and high heart rate during ID speech expressing fear.

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## References

Bachorowski, J. (1999). Vocal expression and perception of emotion. *Current Directions in Psychological Science, 8*, 54–57.

Bachorowski, J., & Owen, M. J. (1995). Vocal expression of emotion: Acoustic properties of speech are associated with emotional intensity and context. *Psychological Science, 6*, 219–224.

Bell, M. A. (2002). Power changes in infant EEG frequency bands during a spatial working memory task. *Psychophysiology, 39*, 450–458.

Bernston, G. G., & Boysen, S. T. (1990). Cardiac indices of cognition in infants, children, and chimpanzees. In C. Rovee-Collier & L. P. Lipsitt (Eds.). *Advances in infancy research* (Vol. 6, pp. 187–220). Norwood, NJ: Albex.

Calkins, S. D., Fox, N. A., & Marshall, T. R. (1996). Behavioral and physiological antecedents of inhibited and uninhibited behavior. *Child Development, 67*, 523–540.

Dainow, E. (1977). Physical and motor responses to music. *Journal of Research in Music Education, 25*, 211–221.

Davidson, R. J. (2000). Affective style, psychopathology, and resilience: Brain mechanisms and plasticity. *American Psychologist, 55*, 1196–1214.

Davidson, R. J., & Tomarken, A. J. (1989). Laterality and emotion: An electrophysiological approach. In F. Boller & J. Grafman (Eds.), *Handbook of neuropsychology* (pp. 419–441). New York: Elsevier.

Dawson, G. (1994). Frontal electroencephalographic correlates of individual differences in emotional expression in infants. In N.A. Fox (Ed.), The development of emotion regulation: Behavioral and biological considerations. *Monographs of the Society for Research in Child Development* (pp. 135–151). 59(2–3, Serial No. 240).

Dunn, J., & Kendrick, C. (1982). The speech of two- and three-year-olds to infant siblings: "Baby talk" and the context of communication. *Journal of Child Language, 9*, 579–595.

Ekman, P., Levinson, R. W., & Friesen, W. V. (1983). Autonomic nervous system activity distinguishes among emotions. *Science, 221*, 1208–1210.

Ferguson, C. (1964). Baby talk in six languages. *American Anthropologist, 66*, 103–114.

Fernald, A. (1989). Intonation and communicative intent in mothers' speech to infants: Is melody the message? *Child Development, 60*, 1497–1510.

Fernald, A. (1991). Prosody in speech to children: Prelinguistic and linguistic functions. *Annals of Child Development, 8*, 43–80.

Fernald, A. (1993). Approval and disapproval: Infant responsiveness to vocal affect in familiar and unfamiliar languages. *Child Development, 64*, 657–674.

Fernald, A., & Kuhl, P. K. (1987). Acoustic determinants of infant preference for motherese speech. *Infant Behavior & Development, 10*, 279–293.

Fernald, A., & Mazzie, C. (1991). Prosody and focus in speech to infants and adults. *Developmental Psychology, 27*, 209–221.

Fox (1989). Infant response to frustrating and mildly stressful events: A positive look at anger in the first year. *New Directions in Child Development, 45*, 47–64.

Fox, N. A. (1991). If it's not left, it's right: Electroencephalogram asymmetry and the development of emotion. *American Psychologist, 46*, 863–872.

Fox, N.A. (1994). Dynamic cerebral processes underlying emotion regulation. In N.A. Fox (Ed.), The development of emotion regulation: Behavioral and biological considerations. *Monographs of the Society for Research in Child Development*, *59*(2–3, Serial No. 240), 152–166.

Fox, N. A., Henderson, H. A., Rubin, K. H., Calkins, S. D., & Schmidt, L. A. (2001). Continuity and discontinuity of behavioral inhibition and exuberance: Psychophysiological and behavioral influences across the first four years of life. *Child Development, 72*, 1–21.

Graham, F. K., & Clifton, R. K. (1966). Heart rate change as a component of the orienting response. *Psychological Bulletin, 65*, 305–320.

Greiser, D. L., & Kuhl, P. K. (1988). Maternal speech to infants in a tonal language: Support for universal prosodic features in motherese. *Developmental Psychology, 24*, 14–20.

Henriques, J. B., & Davidson, R. J. (1991). Left frontal hypoactivation in depression. *Journal of Abnormal Psychology, 100*, 535–545.

Jacobson, J. L., Boersma, D. C., Fields, R. B., & Olson, K. L. (1983). Paralinguistic features of adult speech to infants and small children. *Child Development, 54*, 436–442.

Jasper, H. H. (1958). The ten–twenty electrode system of the International Federation. *Electroencephalography and Clinical Neurophysiology, 10*, 371–375.

Katz, G. S., Cohen, J. F., & Moore, C. A. (1996). A combination of vocal f0 dynamic and summary features discriminates between three pragmatic categories of infant-directed speech. *Child Development, 67*, 205–217.

Kemler Nelson, D. G., Hirsch-Paek, K., Jusczyk, P. W., & Wright-Cassidy, K. (1989). How the prosodic cues of motherese might assist language learning? *Journal of Child Language, 16*, 55–68.

Krumhansl, C. L. (1997). An exploratory study of musical emotions and psychophysiology. *Canadian Journal of Experimental Psychology, 51*, 336–352.

Lacey, J. I. (1967). Somatic response patterning and stress: Some revisions of activation theory. In M. H. Appley & R. Trumbull (Eds.), *Psychological stress: Issues in research* (pp. 14–37). New York, NY: Appleton-Century-Crofts.

Leinonen, L., Hiltunen, T., Linnankoski, I., & Laakso, M. L. (1997). Expression of emotional–motivational connotations with a one-word utterance. *Journal of the Acoustical Society of America, 102*, 1853–1863.

Levenson, R. W., Ekman, P., & Friesen, W. V. (1990). Voluntary facial action generates emotion-specific autonomic nervous system activity. *Psychophysiology, 27*, 363–384.

Nyklivcek, I., Thayer, J. F., & Van Dooren, L. J. P. (1997). Cardiorespiratory differentiation of musically-induced emotions. *Journal of Psychophysiology, 11*, 304–321.

Papousek, M. (1992). Early ontongeny of vocal communication in parent-infant interactions. In H. Papousek, U. Jurgens, & M. Papousek (Eds.), *Nonverbal vocal communication* (pp. 230–282). New York: Cambridge University Press.

Papousek, M., & Hwang, S. F. C. (1991). Tone and intonation in Mandarin babytalk to presyllabic infants: Comparison with registers of adult conversation and foreign language instruction. *Applied Psycholinguistics, 12*, 481–504.

Papousek, M., Papousek, H., & Symmes, D. (1991). The meanings of melodies in motherese in tone and stress languages. *Infant Behavior and Development, 14*, 415–440.

Porges, S. W. (1995). Orienting in a defensive world: Mammalian modifications of our evolutionary heritage, A Polyvagal Theory. *Psychophysiology, 32*, 301–318.

Rothbart, M. K. (1981). Measurement of temperament in infancy. *Child Development, 52*, 569–578.

Scherer, K. R., Banse, R., & Wallbott, H. G. (2001). Emotion inferences from vocal expression correlate across languages and cultures. *Journal of Cross-Cultural Psychology, 32*, 76–92.

Schmidt (1999). Frontal brain electrical activity in shyness and sociability. *Psychological Science, 10*, 316–320.

Schmidt, L. A., & Fox, N. A. (1999). Conceptual, biological, and behavioral distinctions among different categories of shy children. In L. A. Schmidt & J. Schulkin (Eds.), *Extreme fear, shyness, and social phobia: Origins, biological mechanisms, and clinical outcomes* (pp. 47–66). New York: Oxford University Press.

Schmidt, L. A., Fox, N. A., Schulkin, J., & Gold, P. W. (1999). Behavioral and psychophysiological correlates of self-presentation in temperamentally shy children. *Developmental Psychobiology, 35*, 119–135.

Schmidt, L. A., & Trainor, L. J. (2001). Frontal brain electrical activity (EEG) distinguishes valence and intensity of musical emotions. *Cognition and Emotion, 15*, 487–500.

Schmidt, L. A., Trainor, L. J., & Santesso, D. L. (2003). Development of frontal electroencephalogram (EEG) and heart rate (ECG) responses to affective musical stimuli during the first 12 months of post-natal life. *Brain and Cognition, 52*, 27–32.

Shatz, M. (1982). On the mechanisms of language acquisition: Can features of the communicative environment account for development? In E. Werner & L. R. Gleitman (Eds.), *Language acquisition: The state of the art* (pp. 102–127). New York: Cambridge University Press.

Singh, L., Morgan, J. L., & Best, C. T. (2002). Infants' listening preferences: Baby talk or happy talk? *Infancy, 3*, 365–394.

Snidman, N., Kagan, J., Riordan, L., & Shannon, D. (1995). Cardiac function and behavioral reactivity in infancy. *Psychophysiology, 32*, 199–207.

Snow, C. E., & Ferguson, C. A. (Eds.). (1977). *Talking to children*. Cambridge, England: Cambridge University Press.

Stern, D. N., Spieker, S., & McKain, K. (1982). Intonation contours as signals in maternal speech to prelinguistic infants. *Developmental Psychology, 18*, 727–735.

Theall-Honey, L. A., & Schmidt, L. A. (2006). Do temperamentally shy children process emotion differently than non-shy children? Behavioral, psychophysiological, and gender differences in reticent preschoolers. *Developmental Psychobiology, 48*, 187–196.

Trainor, L. J., Austin, C. M., & Desjardins, R. N. (2000). Is infant-directed speech prosody a result of the vocal expression of emotion? *Psychological Science, 11*, 188–195.

Trehub, S. E., Trainor, L. J., & Unyk, A. M. (1993). Music and speech processing in the first year of life. In H. W. Reese (Ed.). *Advances in child development and behavior* (Vol. 24, pp. 1–35). New York, NY: Academic Press.

Werker, J. F., & McLeod, P. J. (1989). Infant preferences for both male and female infant- directed talk: A developmental study of attentional and affective responsiveness. *Canadian Journal of Psychology, 43*, 230–246.

Werker, J. F., Pegg, J. E., & McLeod, P. J. (1994). A cross-language investigation of infant preference for infant-directed communication. *Infant Behavior and Development, 17*, 321–331.