Brief Report

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Estimated Cardiac Vagal Tone Predicts Fetal Responses to Mother's and Stranger's Voices

ABSTRACT: *Heart rate responses of 84 near-term fetuses to recorded female voices were examined in 166 trials of auditory stimulation. Each fetus was presented with a 2-min recording of their mother's voice and a 2-min recording of a female stranger's voice, in counterbalanced order, with a 10-min rest period between trials. High frequency heart rate variability during a 2-min baseline period was used to estimate cardiac vagal tone for each trial. Differential heart rate responses to familiar and unfamiliar voice recordings were observed during a 2-min poststimulus period, only when estimated cardiac vagal tone was high. This finding suggests that vagal tone plays a moderating role in the cardiac responses of term fetuses to familiar and unfamiliar stimuli. © 2007 Wiley Periodicals, Inc.* Dev Psychobiol 49: 543–547, 2007.

Keywords: *human fetus; voice recognition; memory; vagal tone; high frequency heart rate variability*

INTRODUCTION

Term fetuses show different heart rate responses to a recording of their own mother's voice than to that of a female stranger (Kisilevsky et al., 2003; Kisilevsky & Hains, 2005). On average, prolonged heart rate increases are more likely to be elicited by the presentation of a recording of a mother's voice than by the presentation of a stranger's voice recording, though factors such as the fetus' prior exposure to the recorded passage may affect fetal responses (Smith, 2006). Individual differences in maturity and learning ability as well as behavioral state also would be expected to affect fetal responses to mother's and stranger's voices and were examined in this study.

Among infants, learning and attention have been correlated with estimates of heart rate and vagal tone. For example, Fox and Porges (1985) found that estimated vagal tone in newborns correlates positively with later developmental outcome assessed using the Bayley Mental Development Index. Indeed, no newborn with average or greater than average estimated vagal tone showed lower than average scores of mental functioning at 8 and 12 months of age. As well as reflecting individual differences, vagal tone also varies with behavioral state. For example, respiratory sinus arrhythmia, which provides an estimate of vagal tone, shows a higher amplitude during quiet than active sleep (Porges, Doussard-Roosevelt, Stifter, McClenny, & Riniolo, 1999).

Among 6-month-olds, vagal tone has been associated with recognition memory (Linnemeyer & Porges, 1986). Infants with higher vagal tone looked less at a familiar stimulus and more at a novel stimulus than did infants with lower vagal tone. Although it has been hypothesized that increases in parasympathetic influence, and thus vagal tone, affect fetal responses to recurring auditory stimuli (e.g., Krueger, Holditch-Davis, Quint, & DeCasper, 2004), to date, the effect of vagal tone on fetal learning has not been demonstrated. The purpose of this study was to test the utility of an estimate of cardiac vagal tone as a predictor of fetal responses to familiar and unfamiliar voices. Because vagal tone is associated with attention and learning capacity, we expected an interaction between estimated vagal tone and stimulus familiarity wherein

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fetuses having higher estimates would be more likely to exhibit differential responding to familiar and unfamiliar voices than would those showing lower estimates.

METHODS

Eighty-four near-term pregnant women ($M = 38.1$ weeks gestational age, $SD = .7$ weeks) were recruited for fetal testing from the antenatal clinics of a teaching hospital in Kingston, Ontario, Canada. Mothers were nonsmoking, English-speaking women ($M = 29.4$ years, $SD = 5.0$ years) experiencing uncomplicated, low-risk pregnancies. The 45 male and 39 female fetuses whose data were included in the present analyses were later born at term, with Apgar scores of at least 8 at 10 min after birth. An additional 14 fetuses were tested but not included due to experimenter error ($n = 9$), maternal risk factors ($n = 3$), incomplete heart rate data ($n = 1$), or low Apgar scores ($n = 1$). Mothers provided informed, written consent prior to participation. The study was conducted with ethical approval from the university and affiliated teaching hospital's research ethics board.

Each mother read from the story *Bambi* (Salton & Chambers, 1928) for approximately 2 min 10 s while her voice was digitally recorded. She then reread the same passage of text for the same duration, so that two recordings of her voice were obtained. A few of the mothers stumbled over some of the words in the story. Two recordings allowed for a smoother delivery of the text. The recording was edited so that it was of 2 min duration and the onset of the mother's vocalization of the word "Bambi" began within .5 s of the beginning of the sound file and amplitude was scaled so that it could be presented at the desired intensity. Sound files were played back at 88–95 dB A, measured at 10 cm from the speaker using a Bruel and Kjaer Sound Level Meter set to display the mean peak intensity obtained using a slow time weighting.

The present report includes data collected for two studies, one in which fetal testing began within an average of 15 min of the onset of the mother's first reading of the story ($n = 48$) and one in which fetal testing was delayed for at least a day after maternal voice recording ($n = 36$). In order to have the statistical power to see the expected effects of estimated vagal tone, data from the two studies were combined. In both studies, fetal heart rate was recorded, using a Hewlett–Packard Cardiotocograph Series 50A, while the fetus received two trials, each consisting of three periods: a prevoice no sound period (Control, 2 min), a voice period (Voice, 2 min), and a postvoice no sound period (Offset, 2 min). There was a 10 min delay between the end of the first trial and the beginning of the second trial to allow heart rate to return to baseline. Each fetus was presented with the mother's recording in one trial and a stranger's recording in the other trial, with the order of voice presentation counterbalanced over participants. Each mother served as the stranger for the next fetus tested, so that across participants the same set of recordings served as the mothers' voices and the strangers' voices.

Data were exported to a text file using a custom-designed software program that averages four heart rate readings per second to yield a record of heart rate at each second of monitoring. Complete data were available for 84 trials in which the mother's voice was presented, and 82 trials in which the stranger's voice was presented.

The fast Fourier transform (FFT) of the prestimulus data were obtained and frequencies over .33 Hz were isolated. Although frequencies between .33 and 1.3 Hz can be used in the analysis of respiratory sinus arrhythmia (e.g., Groome, Loizou, Holland, Smith, & Hoff, 1999; Groome et al., 1997; Richards, 1995), our sampling frequency of one observation/s limited our data to oscillation frequencies up to .5 Hz. Thus, our analyzed frequency range was .33–.5 Hz. For each trial, a series of numbers representing the amplitudes of the spectral components between .33 and .5 Hz were obtained from the FFT. The 75th percentile of those numbers was identified for each trial. The median of the 75th percentile values of all trials was identified and a median split was used to classify each trial as being one in which high or low vagal tone was shown. The third quartile was selected in favor of the mean as a method of summarizing the FFT values because the values were not normally distributed and included spikes at different points within the analyzed range.

Change in heart rate in response to stimulus presentation was assessed using heart rate difference scores, which were obtained by subtracting the median heart rate over the 10 s prior to stimulus onset from each prior and subsequent heart rate observation. A general linear model was tested in each of the three periods. The prestimulus period served as a control for spontaneous heart rate activity across high and low vagal tone trials. A general linear model was run on heart rate difference scores obtained in: (1) the prestimulus period, (2) the stimulus period, and (3) the poststimulus period separately. Factors were time (110 s), speaker (mother/stranger), and vagal tone (high/low).

RESULTS

As expected, there were no significant effects in the prestimulus period. During the stimulus period, however, the pattern of heart rate change over time differed across the high and low vagal tone trials, $F(8.30, 1344.56) = 2.866$, $p < .01$, $\eta^2_p = .017$. As shown in Figure 1, an initial deceleration to stimulus onset was observed on both high and low vagal tone trials. Subsequent to the deceleration, there was a prolonged heart rate increase on low vagal tone trials, whereas relatively lower heart rates were seen on high vagal tone trials.

In the poststimulus period, there was a Time X Speaker interaction, $F(8.313, 1346.78) = 2.025$, $p = .038$, $\eta^2_p = .012$, and a Time X Speaker X vagal tone interaction, $F(8.313, 1346.78) = 2.105$, $p = .031$, $\eta^2_p = .013$. The poststimulus effects were tested with two additional general linear models. When Time (110) and Speaker (mother/stranger) were entered as factors in a model predicting heart rate on low vagal tone trials, no significant effects were observed (Fig. 2A). In contrast, on high vagal tone trials, there was a significant Time X Speaker

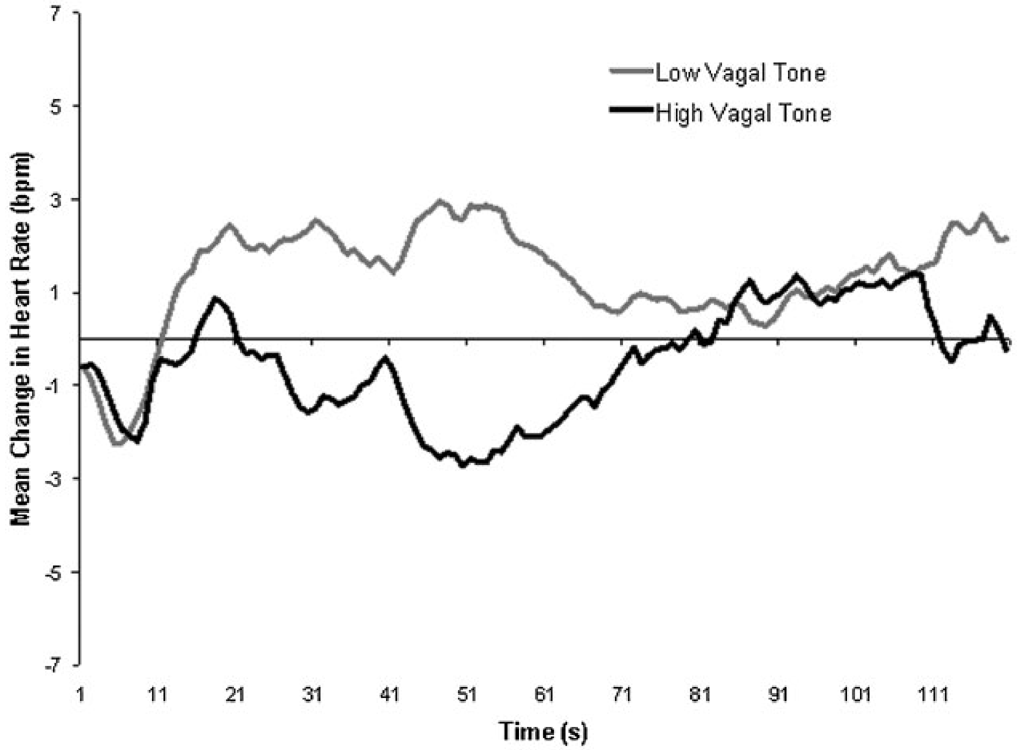

FIGURE 1 Average fetal heart rate change over time (bpm) during the 2 min stimulus period in response to mother's and stranger's voice.

interaction, $F(7.953,\ 644.177) = 2.574,\ p = .009,\ \eta_p^2 = .031$. As shown in Figure 2B, on high vagal tone trials in which mother's voice was presented, but not on those in which stranger's voice was presented, there was a sustained decrease in heart rate beginning approximately 40 s after voice offset.

DISCUSSION

Consistent with our hypothesis, differential responding to familiar and unfamiliar auditory stimuli was seen on trials in which estimated vagal tone was high but not on those in which it was low, even though our sampling frequency prevented the observation of very high frequencies. Our estimate of vagal tone was based on the power of the high frequency component of the fetal heart rate, recorded at 1 s intervals, during a no-sound control period. Although the observed effect size is small, the low sampling frequency did not preclude the finding of differential responding, perhaps because the responses are robust.

Porges (1995) makes a distinction in his polyvagal theory between the ‘‘vegetative vagus’’ which originates in the dorsal motor nucleus and effects reflexive orienting responses and the ‘‘smart vagus’’ which originates in the nucleus ambiguus and is involved with higher level attentional and defensive responses. Here, we saw brief decelerative responses consistent with an auditory orienting response (Groome et al., 1997) at stimulus onset on both high and low vagal tone trials. Subsequent to the initial decelerative response, there was a divergence of heart rate patterns seen, with heart rate being lower on trials on which vagal tone was estimated to be high.

Lower heart rate during stimulus presentation has been associated with high vagal tone in previous studies of learning. Linnemeyer and Porges (1986) report that only infants with high vagal tone showed heart rate decelerations during stimulus presentation in a visual memory task and that recognition memory was associated with heart rate decelerations. It was during the period after stimulus offset that a differentiation between responses to mother's and stranger's voices was evident here using an estimate of vagal tone. On trials in which estimated vagal tone was high, fetal heart rate decreased relative to prestimulus periods by approximately 4 bpm, a decrease that persisted across the last minute of observation.

Our results suggest that vagal tone plays a moderating role in the cardiac responses of term fetuses to familiar and unfamiliar stimuli, extending the work of Linnemeyer and Porges (1986) to an earlier age. Of course, the generality

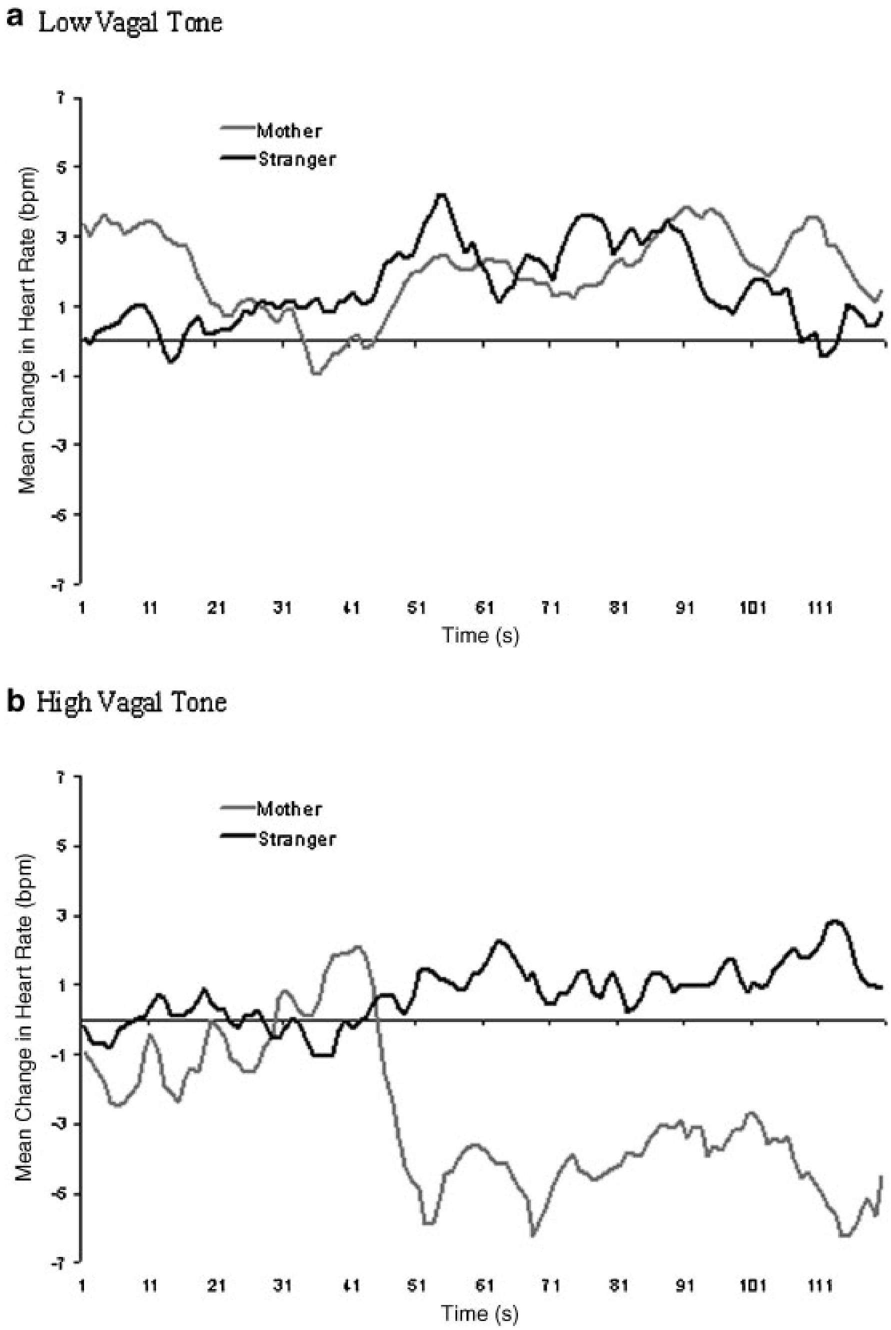

FIGURE 2 Average fetal heart rate (bpm) change over time during the 2 min following offset of the mother's and stranger's voice when estimated vagal tone is (a) low and (b) high.

of our results is limited because we used a single, static estimate of vagal tone and categorized trials as reflecting high or low vagal tone. Our observations also were limited to the frequency range of .33–.5 Hz. For firm conclusions regarding the influence of vagal tone on fetal recognition memory to be drawn, replication using a continuous measure of vagal tone to compare the pattern of changes in vagal tone at stimulus onset and offset is needed. Also, the meaning of differences in spectral power within the frequency range affected by vagal tone, including frequencies above .5 Hz, should be explored. Subsequently, we could have an efficient means to study the effect of individual differences in vagal tone on learning and memory in the fetus.

The finding of differential heart rate changes to mother's and female stranger's voices replicates that of

Kisilevsky et al. (2003). However, the nature of our results is quite different. The previous article reported sustained heart rate acceleration to the mother's voice and deceleration to a stranger's voice. In contrast, here, the finding of differential responding was limited to the period following voice offset. There are at least three methodological differences between the studies that could account for the observed differences in results. The languages spoken by the mothers differed in the two studies, nontonal English in this study compared to tonal Mandarin in the previous study. Thus, whereas the mother's voice in each study would still constitute a ubiquitous familiar sound, the passage may not represent a similar stimulus across languages. As well, in this study, the mother read the story aloud twice during the recording session, compared to once in the previous study. Greater exposure to the story could facilitate greater recognition (i.e., the stranger/passage in this study being more familiar). Finally, the intensity level of the stimulus was lower in the present study than in the previous one. Whereas the earlier study used average SPL, this study used an average of the peak SPL. The higher stimulus intensity most likely accounts for the more rapid and sustained response observed in the earlier study. However, additional studies are required in order to fully untangle these issues.

REFERENCES

Fox, N., & Porges, S. (1985). The relation between neonatal heart period patterns and developmental outcome. Child Development, 56, 28–37.

Groome, L., Loizou, P., Holland, S., Smith, L., & Hoff, C. (1999). High vagal tone is associated with more efficient regulation of homeostasis in low-risk human fetuses. Developmental Psychobiology, 35, 25–34.

Groome, L., Mooney, D., Holland, S., Bentz, L., Atterbury, J., & Dykman, R. (1997). The heart rate deceleratory response in low-risk human fetuses: Effect of stimulus intensity on response topography. Developmental Psychobiology, 30, 103–113.

Kisilevsky, B., Hains, S., Lee, K., Xie, X., Huang, H., Ye, H., Zhang, K., & Wang, Z. (2003). Effects of experience on fetal voice recognition. Psychological Science, 14, 220–224.

Kisilevsky, B. S., & Hains, S. M. J. (2005). Comparison of fetal behavior in low- and high-risk pregnancies. Fetal and Pediatric Pathology, 24, 1–20.

Krueger, C., Holditch-Davis, D., Quint, S., & DeCasper, A. (2004). Recurring auditory experience in the 28- to 34-week-old fetus. Infant Behavior and Development, 27, 537–543.

Linnemeyer, S., & Porges, S. (1986). Recognition memory and cardiac vagal tone in 6-month-old infants. Infant Behavior and Development, 9, 43–56.

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

Porges, S., Doussard-Roosevelt, J., Stifter, C., McClenny, B., & Riniolo, T. (1999). Sleep state and vagal regulation of heart period patterns in the human newborn: An extension of the polyvagal theory. Psychophysiology, 36, 14–21.

Richards, J. (1995). Reliability of respiratory sinus arrhythmia in R-R intervals, in 14-, 20-, and 26-week-old infants. Infant Behavior and Development, 18, 155–161.

Salton, F., & Chambers, W. (1928) Bambi, a life in the woods. (W. Chambers, Trans.). New York: Simon and Schuster. (Original work published in 1923).

Smith, L. (2006). Determinants of term fetal cardiac responses to voice: Stimulus familiarity, orienting response, and vagal tone. Unpublished doctoral dissertation, Queen's University, Kingston, Ontario, Canada.