Infant Behavior & Development 32 (2009) 59–71

Contents lists available at ScienceDirect

Infant Behavior and Development

Fetal sensitivity to properties of maternal speech and language

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ARTICLE INFO

Article history:
Received 14 May 2008
Received in revised form 18 August 2008
Accepted 17 October 2008

Keywords:
Fetus
Audition
Language
Speech
Voice
Learning

ABSTRACT

Fetal speech and language abilities were examined in 104 low-risk fetuses at 33–41 weeks gestational age using a familiarization/novelty paradigm. Fetuses were familiarized with a tape recording of either their mother or a female stranger reading the same passage and subsequently presented with a novel speaker or language: Studies (1) & (2) the alternate voice, (3) the father's voice, and (4) a female stranger speaking in native English or a foreign language (Mandarin); heart rate was recorded continuously. Data analyses revealed a novelty response to the mother's voice and a novel foreign language. An offset response was observed following termination of the father's and a female stranger's voice. These findings provide evidence of fetal attention, memory, and learning of voices and language, indicating that newborn speech/language abilities have their origins before birth. They suggest that neural networks sensitive to properties of the mother's voice and native-language speech are being formed.

1. Introduction

There is some evidence from newborn preference studies to support the hypothesis that fetuses recognize and remember human voices and language to which they are exposed. For example, newborns have been shown to prefer their mother's voice over that of a female stranger (DeCasper & Fifer, 1980), a story read by the mother during late gestation compared to a novel story (DeCasper & Spence, 1986), and their native language compared to a foreign language (Moon, Cooper, & Fifer, 1993). Nevertheless, except for demonstrating differential response to the mother's compared to a female stranger's voice (Kisilevsky et al., 2003), no studies have reported comparisons of fetal response to the mother's verses other voices or foreign languages. It is the focus of this study.

While newborn preference studies may suggest a sensitivity to the properties of voices, they also can be seen as examples of a more general ability to discriminate between two stimuli. More direct evidence that newborns are sensitive to language comes from studies such as that by Pena et al. (2003) using optical topography. These researchers showed that newborns respond specifically to language stimuli. They showed left hemisphere activation to forward speech when compared to backward speech or silence. Given that these abilities are evident shortly after birth, it is reasonable to postulate that fetuses should show some response to human voices and speech patterns when exposed in utero.

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0163-6383/$ – see front matter
doi:10.1016/j.infbeh.2008.10.002

However, there are a number of methodological issues which preclude exact replication of newborn studies with fetal populations because the fetus within the maternal abdomen is not directly accessible. Most notably, auditory information processing abilities (i.e., preference, discrimination) can be demonstrated in the newborn using a number of behavioural measures not available for use in the fetus such as non-nutritive sucking (e.g., DeCasper & Fifer, 1980), head-turning (e.g., Zelazo, Weiss, Papageorgiou, & Laplante, 1989), and looking time (e.g., Morrongiello, Fenwick, & Chance, 1998). Such measures are often employed in an infant habituation/familiarization-novelty paradigm and, although the procedures vary, they typically include a period of familiarization (either fixed time/trials or response decline criterion) followed by the presentation of a novel stimulus. Response to novelty is used to determine discrimination of two stimuli or preference for one of two stimuli (for a general discussion see Bahrick & Pickens, 1995; Hunter & Ames, 1988; Richard, Normandeau, Brun, & Maillet, 2004).

As well, electrophysiologic measures such as auditory brain stem responses (e.g., Ponton, Moore, & Eggermont, 1996) or event-related potentials (e.g., deRegnier, Nelson, Thomas, Wewerka, & Georgieff, 2000) have been used to examine newborn detection and discrimination of auditory stimuli. These measures are not possible with the fetus as brain-imaging measures have limited utility because the technology [e.g., functional magnetic resonance imaging, fMRI (Hykin et al., 1999; Moore, 2002) and magnetoencephalography, MEG (Draganova et al., 2005; Lengle, Chen, & Wakai, 2001; Zappasodi et al., 2001)] is not yet sufficiently developed for systematic fetal study.

Heart rate change is one of the few reliable methods available for use before and after birth. Even here, however, the techniques for measurement differ. While measures of newborn heart rate employ sophisticated technologies using an electrocardiogram, measures of fetal cardiac activity are crude by comparison. Because of difficulties inherent in reliably separating the maternal and fetal electrocardiogram and because the vernix caseosa on the fetal skin beginning about 25 weeks gestational age impedes conduction of fetal electric signals to the maternal surface, commercial fetal cardiotocographs measure muscular contraction of the fetal heart. Nevertheless, studies (e.g., Hepper, 1991; Kisilevsky & Muir, 1991) have shown a continuity between term fetal and newborn responses to similar kinds of stimulus materials.

Typically, fetal auditory abilities have been studied using immediate, brief cardiac and/or movement responses to short bursts (2.5 s duration) of relatively loud sound (105–110 dB; e.g., (Kisilevsky, Pang, & Hains, 2000). Joseph (2000) argues that these stimuli elicit components of a startle response, reflecting brain stem activities. Moreover, findings from such studies indicate that the auditory system is working (i.e., the fetus hears) by late gestation but tell us little about language processing.

Two early studies (DeCasper, Lecanuet, Busnel, Granier-Deferre, & Maugeais, 1994; Hepper, Scott, & Shahidullah, 1993) observed voice discrimination in fetuses. Measuring body movements, Hepper et al. (1993) found that fetuses discriminated between their own mother speaking and a tape recording of her voice but did not discriminate between the mother's and a female stranger's voice. Measuring fetal heart rate (FHR) changes, DeCasper et al. (1994) found that fetuses discriminated between a tape-recorded familiar rhyme (read daily by the mother from 33 to 37 weeks GA) and novel rhyme, both read by a female stranger. More recently, measuring both heart rate and body movements, Kisilevsky et al. (2003) observed that fetuses responded with an increase in heart rate to their mother's and a decrease in heart rate to a female stranger's voice reading the same passage. Taken together, these findings suggest attention and rudimentary memory and learning of voice/speech patterns by late gestation, analogous to what is reported in newborn studies.

Given the lack of an established methodology to determine fetal preference, we examined discrimination, modeling our study on the familiar-novelty paradigm used by Bahrick and Pickens (1995) in studying infant memory. Employing this paradigm, we present data from four studies designed to determine whether fetuses can distinguish between voices and languages using relatively lower intensity (95 dB A), longer duration (minutes rather than seconds) stimuli to avoid eliciting a startle response. The aim of the first and second studies was to examine fetal response to a novel voice following familiarization with the mother's or a female stranger's voice reading the same passage. The third study explored fetal response to the father's voice, following familiarization with the mother's voice, to examine the familiarity of the father's voice. The fourth study attempted to demonstrate fetal 'knowledge' of their native language by comparing response to English vs. Mandarin. Collectively, the studies examine fetal sensory capabilities, including attention (i.e., salience), memory for voices and language to which they are repeatedly exposed and learning of the mother's voice/language (mother's vs. stranger's voice; mother's vs. father's voice; mother's native language vs. foreign language). A demonstration of these abilities would provide evidence that the speech/language abilities observed in newborns have their origins before birth.

2. Study 1

Kisilevsky et al. (2003) argued that the differential fetal response observed to a mother's compared to a female stranger's voice reading the same passage (cross-sectional data) could be accounted for on the basis of recognition of the mother's voice. Here we attempted to obtain converging evidence for this hypothesis by using the familiar-novelty paradigm used by Bahrick and Pickens (1995). Following a familiarization phase, fetuses were presented with a novelty phase in which the speaker's voice was changed while the passage remained the same. Fetuses were familiarized with either their own mother's or a novel female's voice first; those fetuses who had heard their mother's voice subsequently received a stranger's voice and vice versa. Because the story being read in the first and second presentation of the voice was the same, any differences in response would be attributed to differences in voice recognition. If voice recognition was driving the response, fetuses in the stranger/mother group were expected to respond with an increase in heart rate to their own mother's voice and those in the mother/stranger group with a decrease in heart rate to a stranger's voice during novelty testing.

3. Methods

3.1. Participants

Twenty-four term fetuses (M = 38.4 weeks GA, S.D. = 1.1) of Chinese women receiving antenatal care at the Women's Hospital, Zhejiang University, Hangzhou, China were tested on one occasion. All pregnancies were singleton, considered low-risk, and healthy on newborn physical examination. Participants were a subset of the Chinese fetuses reported in Kisilevsky et al. (2003) who had previously heard either their mother's or a stranger's voice in the same study session. Testing was conducted in a laboratory near the out-patient fetal assessment unit. Gender was not determined at time of testing in any of the studies reported here. Women provided informed verbal consent prior to participation. A similar study received ethics approval from a University Ethics Review Board in Ontario, Canada.

3.2. Equipment

The 2 min speech stimuli were generated by tape-recording mothers reading an adult poem for children. Maternal speech was recorded and delivered using a Sanyo Cassette Recorder (Model M-1770K). A XingQui-ND2 Sound Pressure Level meter was used to measure sound intensity.

Continuous FHR was recorded in beats per minute (bpm) on a paper strip using a Sonicaid RS232 Cardiotocograph (Oxford Instruments). FHR strip recordings were scored in our Canadian laboratory with procedures and equipment used for previous fetal studies (Coleman, Kisilevsky, & Muir, 1993). A FHR for each second was obtained by tracing over the recording using a digitizer connected to a Macintosh computer.

3.3. Procedure

The design of the study is shown in Table 1. During the familiarization phase each fetus was presented with a 2-min tape recording of either their own mother or a female stranger (previous mother in the study) reading the same passage. Two minutes following the familiarization stimulus the novelty phase began. It included three sequential, 2 min periods. There was a 2-min no-sound pre-voice period, followed by a 2-min voice period (either the mother's or a female stranger's voice), followed by a 2-min no-sound post-voice period. Thus, the delay between the familiarization stimulus and the presentation of the novel stimulus was 4 min. Those fetuses who heard the mother's voice in the familiarization phase heard a stranger's voice and vice versa. For all four studies, the mother lay in a supine, wedged left position on a hospital bed during the familiar-novel procedure; the voice stimuli were delivered at an average of 95 dB SPL through a loud speaker held approximately 10 cm above the maternal abdomen; and, fetal heart rate was recorded continuously over the 6-min novelty phase.

For all four studies, SPSS version 16 was used for data analyses with significance set at α 0.05. Hynh-Feldt adjusted degrees of freedom were used for analyses including repeated measures.

Table 1
Design of studies.

	Familiarization phase	Delay	Novelty phase		
	Voice or language presentation (2 min)	Delay time	Pre-voice period 1 (2 min)	Voice or language period 2 (2 min)	Post-voice period 3 (2 min)
Study 1					
n = 12	Mother's voice	4 min	No-voice	Stranger's voice	No-voice
n = 12	Stranger's voice	4 min	No-voice	Mother's voice	No-voice
Study 2					
n = 21	Mother's voice	15 min	No-voice	Stranger's voice	No-voice
n = 19	Stranger's voice	15 min	No-voice	Mother's voice	No-voice
Study 3					
n = 20	Mother's voice	15 min	No-voice	Father's voice	No-voice
Study 4					
n = 5	Mother, English	15 min	No-voice	Stranger, English	No-voice
n = 5	Stranger, English	15 min	No-voice	Stranger, English	No-voice
n = 5	Mother, English	15 min	No-voice	Stranger, Mandarin	No-voice
n = 5	Stranger, English	15 min	No-voice	Stranger, Mandarin	No-voice

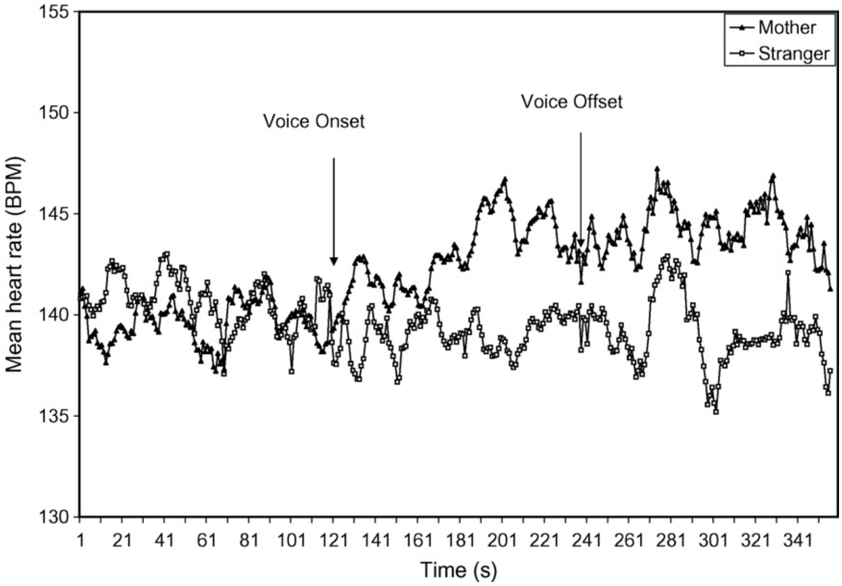

Fig. 1. Familiarization phase: mean fetal heart rate (bpm) as a function of time (s) to mother's and stranger's voices during familiarization pre-voice, voice and post-voice periods, for all four studies combined.

4. Results

4.1. Familiarization phase

For display purposes, Fig. 1 demonstrates the mean heart rate response as a function of time (s) to the mother's and stranger's voices for the 104 fetuses in all four studies during the familiarization phase. The baseline FHR for the two groups was similar at the beginning of the familiarization phase prior to the onset of the first voice [M (±S.D.) = 141.9 (10.3) bpm and M (±S.D.) = 141.3 (6.4) bpm for those who were being familiarized with the mother's or stranger's voice, respectively]. There were no significant differences between the studies in the familiarization phase for the 2 min pre-voice period, $F(178, 4361) = 21.01$, $p = .43$, and for the 2 min post-voice period, $F(119, 2380) = 0.663$, $p = 1$. There was a difference between response to the mother's and stranger's voice in the voice period, $F(119, 2380) = 1298$, $p < .05$.

4.2. Novelty phase

Fig. 2 demonstrates the average fetal heart rate over time in response to a change to the mother's voice or to the stranger's voice. As can be seen, the FHR for the two groups of fetuses differed at the onset of the present 6 min novelty study [M (±S.D.) = 144.9 (7.7) bpm and M (±S.D.) = 139.0 (7.0) bpm for those who changed from mother to stranger and those who changed from stranger to mother, respectively] with those fetuses who had initially heard their own mother's voice having about a 6 bpm greater heart rate which continued throughout the recording period. Because previous studies have shown a change in heart rate within the first 30 s following stimulus onset, the data for the first 30 s following voice onset were analysed using a 1-between (Novelty Voice Group—mother, stranger), 1-within (time-30 s) ANOVA; no significant heart rate change was found. Next, the data for each period (pre-voice, voice, post-voice) were analysed separately using a 1-between (Novelty Voice Group—mother, stranger), 1-within (time-120 s) ANOVA. There were no heart rate differences between the voice groups in any period. Variability in heart rate at each second of recording averaged 8.9 bpm (range 6.1–10.6) in the pre-voice period, 9.8 bpm (range 8.3–11.7) for the voice period and 11.1 bpm (range 8.2–13.9) for the post-voice period.

5. Discussion

Following familiarization when the voice was changed from mother to stranger or stranger to mother, no effect of voice was found for either group of fetuses during the 2 min voice presentation. These results were unexpected given the literature. Although no similar fetal study looking at stimulation over an extended period had been reported previously, it was expected that the heart rate would return to baseline within a short period of time following sound offset in the familiarization phase. In all studies previously conducted in our laboratory on fetal hearing using relatively loud, short bursts of white noise, the fetal heart rate returned to baseline within 20–30 s (Kisilevsky et al., 2000). Even in discrimination studies carried out in 1F state, using short duration, repeated, relatively lower intensity airborne sound stimuli, the response has been reported to last a minute or less (DeCasper et al., 1994; Lecanuet, Granier-Deferre, Jacquet, Capponi, & Ledru, 1993). The same response

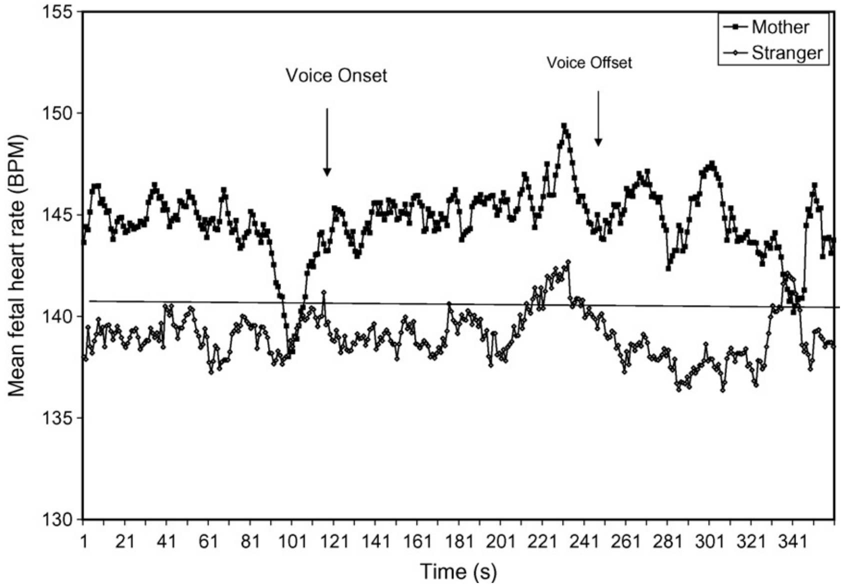

Fig. 2. Study 1, novelty phase: mean fetal heart rate (bpm) as a function of time (s) to the (1) mother's voice following familiarization with a stranger's voice and to a (2) stranger's voice following familiarization with the mother's voice during the novelty pre-voice, voice and post-voice periods.

duration was expected here given the lower stimulus intensity employed (95 dB) and the comparatively lower magnitude of heart rate acceleration anticipated (i.e., 5 bpm, Kisilevsky et al., 2003). In this study, although the difference in heart rate during the novelty period between those fetuses who were familiarized with their mother's voice and those with a stranger's voice was not significant, Fig. 2 shows that, with only two exceptions, the average heart rate for the mother to stranger group remained above baseline established prior to the presentation of the mother's voice (about 141 bpm) while that of the stranger to mother group remained below. This finding might represent a shift in baseline fetal heart rate. Alternatively, because the time between voice presentations was only 4 min, it may be that responding to the first voice was still in progress when the second voice was presented, preventing or interfering with the second voice's ability to capture fetal attention or its ability to respond to it.

6. Study 2

Study 2 was designed as a replication of Study 1. In the familiarization phase, the fetuses heard their mother's voice or a stranger's voice reading a story and the other voice in the novelty period. There were three procedural changes for this study. The story was changed from a Chinese adult poem to a children's story. The interval following the familiarization phase was extended to 15 min to allow fetal heart rate to return to baseline before the beginning of the novelty test. As well, mothers wore headphones during the familiarization and novelty phases through which they heard guitar music to mask the voices being played to the fetus.

7. Methods

7.1. Participants

Forty mother-fetal pairs at 33–41 weeks GA (M = 35.7, S.D. = 1.1) were recruited from the antenatal clinics at a community teaching hospital in Southern Ontario. Gestational age was calculated from the first day of the last menstrual period if periods were reliable or from early ultrasound scan for dating. Only non-smoking women at least 18 years-of-age (M = 28.6, S.D. = 4.8) experiencing an uneventful, singleton pregnancy with delivery of a healthy full-term infant [GA at birth, M (±S.D.) = 40.1 (0.94) weeks GA; birthweight, M (±S.D.) = 3458 (484) g; Apgar 5 min, M (±S.D.) = 9.0 (0.85); cord artery base excess, M (±S.D.) = −6.46 (2.9)] were included. Studies 2–4 were carried out according to ethics approval obtained from the University and Affiliated Teaching Hospitals Health Sciences Research Ethics Board with informed, written consent obtained from the pregnant women prior to testing.

7.2. Equipment

A 2-min Canadian English speech stimulus was generated by each study mother reading the story of Bambi (Salten & Chamber, 1928). The readings were computer recorded and played using Praat (version 4.1.15) software and delivered via a

Sony speaker (average 95 dB SPL) held 10 cm above the maternal abdomen. For Studies 2–4, the ambient noise level with all equipment running was 47 dB SPL. Sound levels were measured in air at a distance of 10 cm using the A scale of a Bruel & Kjaer Sound Pressure Level (SPL) meter (Model 2235).

Continuous fetal heart rate was obtained using a Hewlett Packard cardiotocograph (Model 1351A). Using purpose written software, the digital record of instantaneous heart rate in bpm was sampled four times per second and the average for each second was stored in a computer text file.

7.3. Procedure

Each mother read the story of Bambi for 2 min while her voice was recorded. Following a standardized fetal observation of spontaneous behaviour lasting approximately 50 min, the familiarization procedure occurred. As in Study 1, it consisted of a 2-min recorded passage read by their mother or the mother of the previous participating mother (i.e., female stranger). Following a 15 min interval, the 6 min auditory procedure was repeated with the novel voice (either the mother's or that of the mother of the previous fetus). For Studies 2–4, during the auditory procedure, mothers wore headphones through which they heard guitar music as a mask.

8. Results

Extending the time interval between the presentation of the first and second voice to ensure that the fetal heart rate had returned to baseline was successful. The heart rate at the outset of this study [M (±S.D.) = 140.7 (11.5) bpm] was similar to that prior to the familiarization period [M (±S.D.) = 140.7 (11.4) bpm].

The data for each novelty period (pre-voice, voice and post-voice) were analysed separately using a 1-within (time) ANOVA. There was no significant change in fetal heart rate over time in the pre-voice baseline period, $F(119, 2380) = 0.426$, $p > 0.05$, or the post-voice period, $F(119, 2380) = 0.515$, $p > 0.05$, for either group of fetuses. However, in the voice period, there was a significant Time effect for the mother's voice, $F(119, 2380) = 2.149$, $p < 0.001$, that had a significant linear component, $F(1, 20) = 6.21$, $p = 0.02$. As can be seen from Fig. 3A, following an initial (non-significant) decrease, fetal heart rate increased linearly over the voice period. The fetuses who received the stranger's voice, shown in Fig. 3B, had no significant change in heart rate across the voice period. Variability in heart rate at each second of recording averaged 7.8 bpm in the pre-voice period, 7.7 bpm for the voice period and 8.1 bpm for the post-voice period.

9. Discussion

Extending the interval between the familiarization and novelty phases allowed the fetal heart rate to return to baseline. The results from this study showed a novelty response which was limited to the mother's voice. The average magnitude of the heart rate increase was about 3 bpm, similar to an earlier report (Kisilevsky et al., 2003).

10. Study 3

The purpose of Study 3 was to explore fetal response to the father's voice. While newborns also attend to (Brown, 1979) and discriminate between the father's voice and that of other males (DeCasper & Prescott, 1984), they show no preference for the father's voice as late as 4 months-of-age (Ward & Cooper, 1999). The absence of a preference for the father's voice does not preclude it being recognized. Thus, if the father's voice is familiar, the fetuses should respond with an increase in heart rate to his voice similar to that seen to the mother (Kisilevsky et al., 2003). Alternatively, it is possible that they respond on the basis of a simple discrimination as demonstrated by Lecanuet et al. (1993).

The results of Study 2 demonstrated that extending the time delay between presentation of the familiarization and novelty phases allowed fetal heart rate to return to baseline prior to the presentation of a novel voice. The change in methodology was continued in this study and the following one.

11. Methods

Subject recruitment, equipment, and procedure were the same as those for Study 2 with the following exceptions noted below.

11.1. Participants

Twenty pregnant women and their male partners were recruited at 34–40 weeks GA (M = 36.9, S.D. = 1.4) as the comparison group for a study examining the effects of maternal smoking on fetal behaviour. (Cowperthwaite, Hains, & Kisilevsky, 2007). 'Father' was defined for this study as a male partner residing with the pregnant woman during the pregnancy. Only non-smoking women of at least 18 years-of-age (M = 27.7, S.D. = 4) experiencing an uneventful, singleton pregnancy with delivery

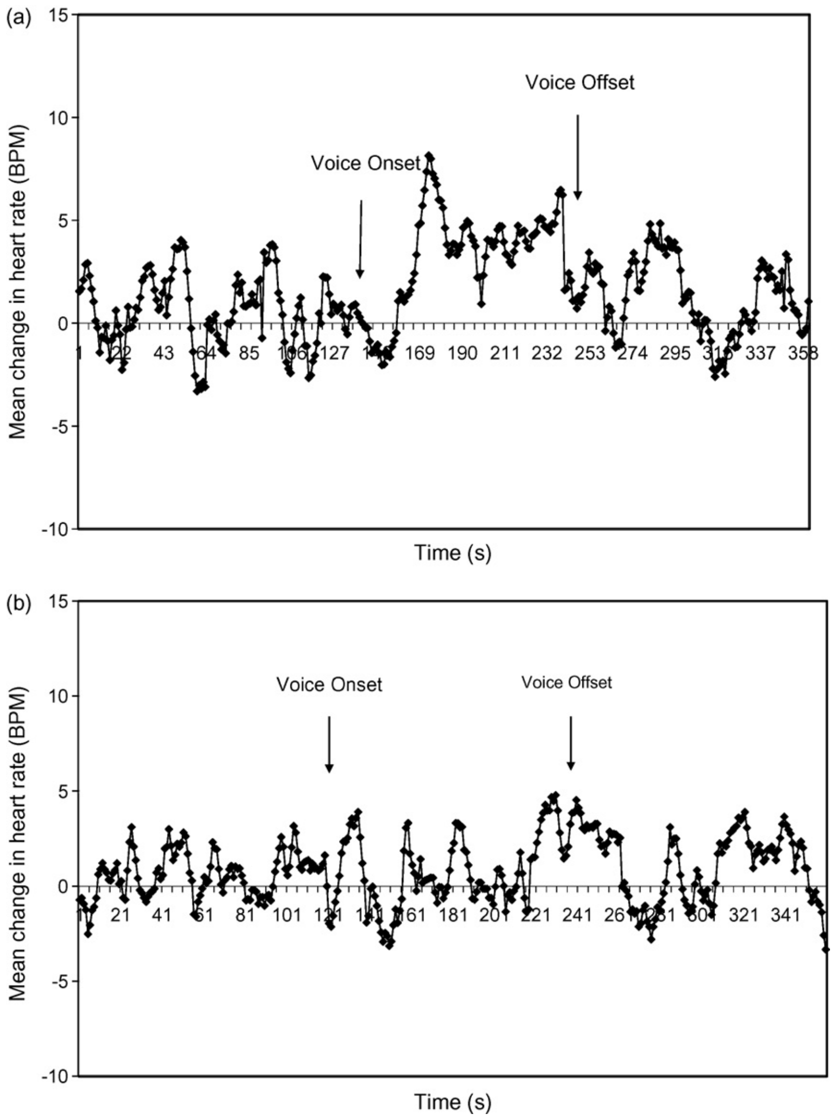

Fig. 3. Study 2, novelty phase: mean fetal heart rate (bpm) change as a function of time (s) to the (A) mother's voice following familiarization with a stranger's voice and to a (B) stranger's voice following familiarization with the mother's voice during the novelty pre-voice, voice and post-voice periods.

of a healthy full-term infant [GA at birth, *M* (±S.D.) = 39.9 (0.9) weeks GA; Birthweight, *M* (±S.D.) = 3554 (351) g; Apgar 5 min, *M* (±S.D.) = 9 (0.6); cord artery base excess, *M* (±S.D.) = −6.43 (2.8)] were included in this study.

11.2. Equipment

The readings of the story of Bambi by the mother and father were tape-recorded (Sony Cassette-Corder TCM-20DV), played on a cassette-tape player (Yamaha Natural Sound Double Deck Cassette Box KX-W952) and delivered via a loud speaker (Auratone 5C Super-Sound-Cube) at an average intensity of 95 dB SPL.

11.3. Procedure

First the mother and then the father read the story for 2 min and their voices were tape-recorded. Subsequently, each mother had a standardized observation of spontaneous fetal behaviour lasting approximately 50 min which was followed by the familiarization phase of this study, 2 min of the tape-recorded mother's voice. After a 15 min interval, the 6 min novelty phase for the present study was presented using the father's voice: 2 min no-sound, 2 min father's voice, 2 min no-sound. The study design is shown in Table 1.

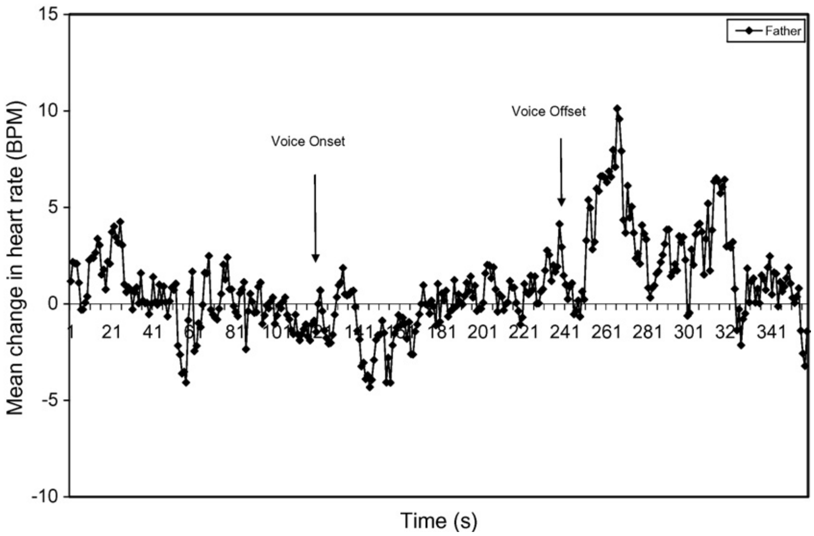

Fig. 4. Study 3, novelty phase: mean fetal heart rate (bpm) change as a function of time (s) to the father's voice during the novelty pre-voice, voice and post-voice periods.

12. Results

The mean fetal heart rate at the outset of this study [M (±S.D.) = 136.8 (7.6) bpm] was similar to that prior to the presentation of the familiarization period with the mother's voice [M (±S.D.) = 137.1 (10.2) bpm], to which fetuses had responded with a heart rate increase. Variability in heart rate at each second of recording averaged 11.9 bpm in the pre-voice period, 12.4 bpm for the voice period and 11.8 bpm for the post-voice period.

The data for this study are shown in Fig. 4. The data for each novelty period (pre-voice, father's voice and post-voice) were analysed separately using a 1-within (time) ANOVA. There was no significant change in fetal heart rate over time in the pre-voice baseline period, $F(117, 4797) = 0.97$, $p > 0.05$, or the voice period, $F(117, 4797) = 1.08$, $p > 0.05$. However, in the post-voice period, there was a significant Time effect following the offset of the father's voice. As can be seen in Fig. 4, it had a significant quadratic component, $F(1, 47) = 11.23$, $p < 0.01$; fetal heart rate increased linearly over the first 30 s following voice offset, $F(29, 551) = 7.26$, $p < 0.01$, followed by a decline back to baseline.

13. Discussion

We hypothesized that if the father's voice was familiar, then fetuses should respond with a heart rate increase when it was played, a response similar to that seen to the mother's voice. This was not the case. Fetuses showed no change during the playing of the father's voice but rather an increase in heart rate at the offset of the voice that peaked at about 30 s before returning to baseline. There are several possible explanations of this effect. It may be that fetuses took longer to process the father's voice possibly because attention to and memory of his voice was not as well developed compared to that of the mother so that processing of a relatively less familiar voice was slower. Alternatively, it may be that the father's voice is unfamiliar and, while noticed, it was not salient enough to capture attention.

14. Study 4

Moon et al. (1993) demonstrated that newborns can discriminate between their native language and a foreign language. Thus, the present study was conducted to explore the ability of near-term fetuses to discriminate between their familiar (i.e., language spoken by the mother) native English language and a novel foreign language. Mandarin was chosen because it differs radically from English on a number of dimensions (e.g., pitch, stress and tone). Following familiarization with either their own mother's or a female stranger's voice, half of the fetuses were presented with a female stranger's voice as had been done in Studies 1 and 2. The other fetuses received the voice of a female stranger reading the same story in the foreign language. It was expected that fetuses, similar to newborns, would show discrimination of the two languages.

15. Methods

Subject recruitment, equipment, and procedure were the same as those for Study 3 with the exceptions noted below.

15.1. Participants

Twenty mother–fetal pairs at 33–41 weeks GA ($M = 36.1$, S.D. = 0.5) were recruited from the antenatal clinics at a community teaching hospital in Southern Ontario as a comparison group for a study examining fetal behaviour in hypertensive pregnancies (Lee, Hains, Brown, & Kisilevsky, 2007). Only non-smoking women at least 18 years-of-age ($M = 27.8$, S.D. = 4.0) experiencing an uneventful, singleton pregnancy with delivery of a healthy full-term infant [GA at birth, M (±S.D.) = 39.7 (1.4) weeks GA; birthweight, M (±S.D.) = 3564 (470)g; Apgar 5 min, M (±S.D.) = 8.75 (0.9); cord artery base excess, M (±S.D.) = −6.14 (3.2)] were included.

15.2. Equipment

A 2-min Canadian English speech stimulus was generated by each study mother reading the story of Bambi. A 2-min Chinese (Mandarin) speech stimulus was generated by Chinese researchers in Study 1 also reading the story of Bambi.

15.3. Procedure

Each mother read the story of Bambi for 2 min while her voice was tape-recorded. Subsequently, there was a standardized observation of spontaneous fetal behaviour lasting approximately 50 min and then presentation of the familiarization procedure, a 2-min tape-recorded passage read by the mother or a female stranger. Following a 15-min interval, the novelty phase of the present study was conducted. The 6 min auditory procedure was repeated with a novel voice (a female stranger) speaking in the native, English language for half of the fetuses and a novel voice (a female stranger) speaking in a novel language (Mandarin) for the other half. The study design is shown in Table 1.

16. Results

The heart rate data for this study are shown in Fig. 5A (Mandarin language) and 5B (English language). There was no significant change in heart rate across the pre-voice period. As in previous studies, the data for the first 30 s following voice onset in the novelty phase were analysed using a 2-between (voice, language), 1-within (time, 30 s) ANOVA. This analysis showed a Time effect, $F(29, 464) = 1.57$, $p < 0.05$, and a time × language interaction $F(29, 464) = 2.37$, $p < 0.01$. Simple effects analyses on the data for each language separately showed no significant heart rate change to the English speaking stranger. The data for the Mandarin speaking stranger showed a Time effect, $F(29, 232) = 2.73$, $p < 0.01$, that had a significant linear component.

The data for the complete 2 min, voice (English or Mandarin language) period were analysed using a 2-between (voice previously heard, language), 1-within (time, 120 s) ANOVA for each period separately. Across the voice period, there was a time × language interaction, $F(117, 1872) = 2.202$, $p < .01$, and a time × language × voice interaction, $F(117, 1872) = 1.59$, $p < 0.01$. Simple effects analyses on each language separately showed no change in heart rate for the English voice but an increase in heart rate to the Mandarin language, $F(117, 936) = 1.71$, $p < 0.01$, that differed according to whether the fetuses had been familiarized with their mother's or a stranger's voice, $F(117, 936) = 1.60$, $p < 0.01$. For those who had experienced their own mother's voice first, the latency to response was shorter (within the first 20 s) compared to those who had experienced the stranger's voice first.

The analyses for the first 30 s of the post-voice period, when the voices were turned off, showed an immediate 4 bpm increase in heart rate over the first 15 s for those fetuses who received their native English language, $F(14, 126) = 2.02$, $p < 0.05$. The fetuses responded to the offset of the Mandarin language with a slow but non-significant reduction in heart rate towards baseline. The analysis of the data for the complete 120 s post-voice period showed no significant change in heart rate to either the Chinese Mandarin or Canadian English speaker. Variability in heart rate at each second of recording averaged 11.9 bpm in the pre-voice period, 11.3 bpm for the voice period and 12.9 bpm for the post-voice period.

17. Discussion

The results of this study demonstrate that a change in language was necessary to capture fetal attention and elicit renewed responding to a voice during novelty testing. Even after a 15 min delay, fetuses did not show renewed responding to a novel female's voice speaking in the same language (English) whether it was preceded by the mother's voice or another female stranger's voice. Renewed responding was limited to a female voice speaking a novel language. These data extend the newborn work of Moon et al. (1993), demonstrating that the ability to discriminate between a native language (familiar) and a foreign language (novel) begins prior to birth. However, the basis for the discrimination is yet to be determined. While fetuses did not respond to their native English language during its presentation, they showed a brief, offset response within the first 30 s following stimulus termination. This result suggests that, while the fetuses might have noticed the stimulus, similar to the father's voice, it was not salient enough to capture attention.

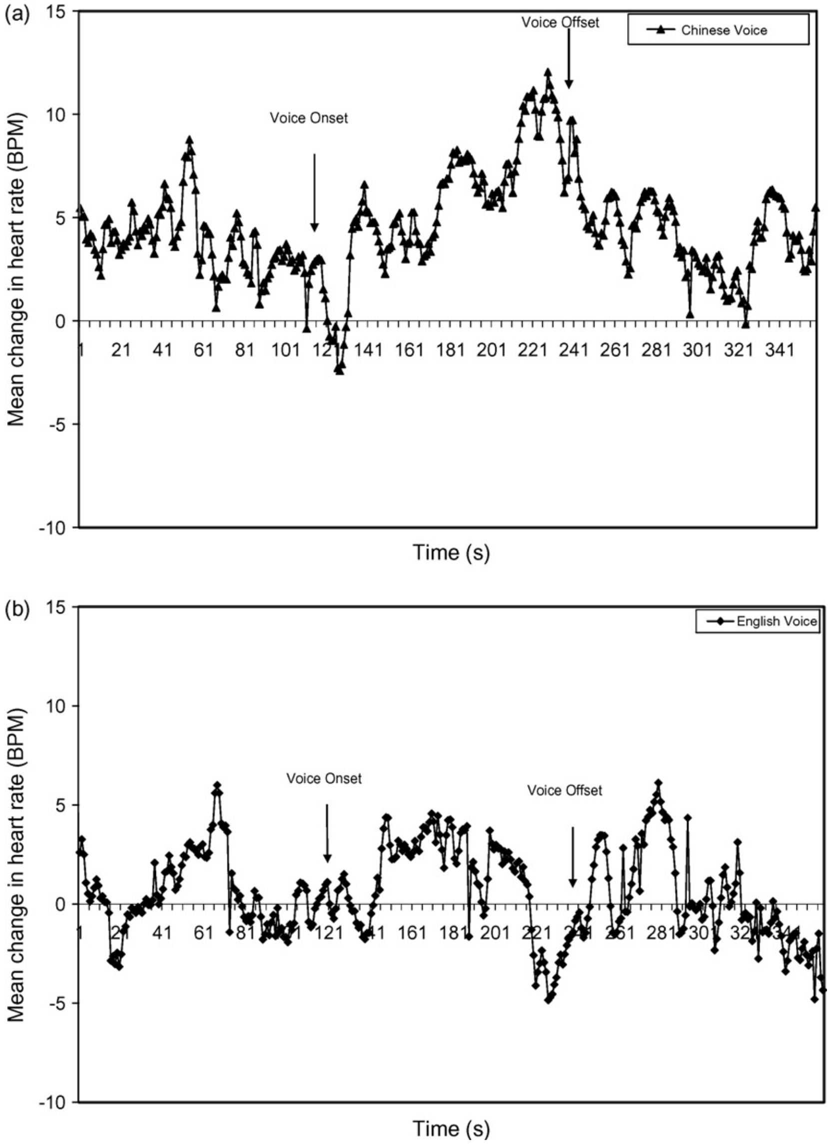

Fig. 5. Study 4, novelty phase: mean fetal heart rate (bpm) change as a function of time (s) to (A) a Mandarin speaker following familiarization with the mother's or a stranger's voice combined and (B) an English speaker following familiarization with the mother's or a stranger's voice combined during the novelty pre-voice, voice and post-voice periods.

18. General discussion

The purpose of the present set of studies was to demonstrate that fetuses recognize and remember voices and language to which they are repeatedly exposed, to determine whether speech/language abilities observed in newborns have their origins before birth and to examine the effect on fetal auditory processing of the mother's voice and language. Overall, our findings provide evidence of fetal attention to and rudimentary memory and learning of voices and language, indicating that newborn speech/language abilities have their origins before birth. As well, they demonstrate that fetuses respond differently to their mother's voice than to any other voice, and respond differently to their native and a foreign language, suggesting that fetuses are sensitive to the properties of the mother's voice and native language.

The results of Study 2 demonstrated a novelty response; fetuses showed an increase in heart rate to their mother's voice but showed no response to a female stranger (previous mother) reading the same passage. In Kisilevsky et al. (2003), it was suggested that differential fetal response to mother's vs. female stranger's voice might be a familiarity effect. However, it would seem unlikely that a fetus would show a fairly long-lasting heart rate increase every time it heard its mother's voice. An alternate explanation could be that the fetus is not responding to the voice per se but to the quality of the mother's voice presented less directly via a loudspeaker through her abdominal wall and the amniotic fluid than from the mother's internal organs. Thus, it may be that rather than responding to the familiarity of the mother's voice, fetuses are responding to the novelty of the presentation (loud speaker) of her voice or the novelty of the location. There is some evidence (Hepper et al., 1993) to support this explanation in that fetuses have been shown to discriminate between their own mother speaking and a tape recording of her voice. These new data suggest that fetal heart rate changes may be a very indirect measure of fetal neural activity and similar changes can have a variety of causes/meanings.

Although the differential response to the mother's and stranger's voices in the familiarization phase replicated Kisilevsky et al. (2003) in regards to a heart rate increase to the mother's voice, a heart rate decrease to a stranger's voice found by Kisilevsky et al. (average of about 2 bpm, S.D. = 6.6) was not found. However, the subset of those fetuses that were included in Study 1 of this paper had an average decrease of only 1.5 bpm (S.D. = 6.6) while those fetuses used in Study 2 had an increase of .98 bpm (S.D. = 8.8). Thus, the response to the stranger's voice can be seen as minimal and the difference between the studies is probably due to random variability in the data. Alternatively, methodological differences might account for the findings. For example, for Studies 2–4, the first presentation of the tape-recorded stranger's voice occurred about 50 min (rather than 15 min) following the maternal reading. Firm conclusions await systematic examination of the effect of delay between maternal reading and tape-recorded voice presentation (i.e., the length of time fetuses hold auditory information in memory).

In Study 4, we found that fetuses responded to a novel language (Mandarin) with a heart rate increase similar to that shown to their mother's voice. The language discrimination observed here is probably not an ability to distinguish language per se. While Werker and Tees (1984) demonstrated that newborns can discriminate native and non-native phonetic contrasts, Nazzi, Bertoncini, and Mehler (1998) found that French newborns could discriminate the English from the Japanese language but not the more rhythmically similar German language. Given these newborn findings, the more likely explanation for the observed discrimination is that the fetuses were responding to the different prosodic qualities of English and Mandarin. Many aspects of the Mandarin voice were novel to the Canadian fetuses (e.g., pitch, stress and tone) in contrast to an English speaking stranger's voice which shares most attributes with the maternal voice. Thus, the increase in fetal heart rate to the Mandarin voice can only be ascribed to novelty. Taken together, these findings lead to the conclusion that fetuses are sensitive to acoustic properties of their mother's voice and the prosodic properties of their native language.

Our findings indicate that near term fetuses discriminate their mother's voice from other voices and their native English language compared to a foreign language (Mandarin). While fetal methodologies preclude determining preferences at this time, differential responding to the mother's voice and the native language could predispose the infant to orienting to the mother and the native language following birth which would facilitate both attachment and language learning. There is some evidence to support this notion in that Sai (2005) showed that early recognition of the mother's face seems to depend on prenatal exposure to her voice. Further, these findings indicate very early learning of the elementary components of language in general and perhaps prosody more specifically, suggesting higher level (i.e., in terms of cognitive sophistication) brain processing.

The observations in this study fit well with what is known of brain development and postulates of perinatal brain function. The perinatal period is the time of the most rapid accumulation of synapses in the sensory, motor, and associational cortical areas (e.g., macaque; Bourgeois, Goldman-Rakic, & Rakic, 1994; Bourgeois & Rakic, 1993; Hepper & Shahidullah, 1994). Werker and Tees (1999) propose an epigenetic model of language development which presumes an interaction between genetic expression of neural development and species-specific experience. Their model fits the emerging picture of mammalian brain development in general (Bourgeois, 1997) and the relation of synaptogenesis and functional maturation specifically. (Bourgeois & Rakic, 1993; Bourgeois et al., 1994). Moreover, Greenough and colleagues (Black & Greenough, 1998; Bruer & Greenough, 2001; Greenough, Black, & Wallace, 1987) propose that the mechanisms of maturation in the perinatal period include transition from gene expression to 'experience-expectant' and 'experience-dependent' phases of development. The 'experience-expectant' phase is thought to underlie the critical period phenomena when ubiquitous stimuli (e.g., speech) from the external world are necessary for the adjustment of the neural circuits. Excess neurons are pruned and through dendritic attrition specific neural networks are sculpted and formed (Joseph, 1999), resulting in changes that are relatively permanent and can serve as the basis for subsequent building. 'Experience-dependent' processes refer to storage of environmental information that is idiosyncratic to the individual; new synaptic connections are formed in response to the events providing the information to be stored. This latter type of learning is open to subsequent change. Balaban (2006) argues that development processes inseparably fuse these two phases and Graybiel (2004) has suggested that one function of cortico-basal ganglia loops is to build experience-dependent representations of actions. Our results indicate that neural networks sensitive to the properties of the mother's voice and native-language speech are being formed before birth. Whether they are relatively permanent or modifiable is unknown. We speculate that the foundation for language acquisition is laid during this period through experience with sounds from within, primarily the mother's voice, and outside of the uterus shaping neural networks.

Given a paucity of information regarding fetal voice processing, the identification of these networks is a matter of speculation at this time. Although Joseph (2000) attributes a fetal heart rate acceleration response such as that elicited by short duration, relatively loud sounds to brain stem reflex (i.e., a startle response), response to human speech/voices using longer duration (2 min), lower intensity (85–95 dB) stimuli is more complicated than a startle response. It is well known that language processing is associated with Broca's and Wernike's areas of the cortex, however, control of cognitive processes resides in lower areas. Recent work on adult language perception has shown that language processing involves the basal ganglia and cerebellar pathways (Blank, Scott, Murphy, Warburton, & Wise, 2002). Indeed, Graybiel (2005) characterizes the basal ganglia of the human brain as part of a set of adaptive neural systems promoting cognitive and motor activity. Moore's (2002) and other's (e.g., Chugani, Phelps, & Mazziotta, 1987) work demonstrating a mature cochlea and brain stem but mature axons present only in the most superficial layer of the human auditory cortex at term suggest limited cortical processing. Although, preliminary results of studies using new imaging technologies (e.g., fMRI, (Hykin et al., 1999; Moore et al., 2001) and MEG, Lengle et al., 2001; Zappasodi et al., 2001; Draganova et al., 2005) indicate some cortical functioning, it may be that language processing in the fetus occurs at the level of the colliculus where temporal and spectral aspects of sound are both topographically, but mutually orthogonally, mapped (e.g., see review by Eggermont, 2001). Clearly, multiple areas of the brain are involved in auditory processing of speech and language stimuli and the structures operational in late gestation are yet to be understood.

The results of this study showed some unexpected outcomes which may relate to the effect of timing and/or amount of exposure of auditory information on fetal memory. In Study 1 there was no response during the novelty voice period to either the mother's voice following a stranger's voice or a stranger's voice following the mother's voice when the voice was presented three times for a total of 6 min in a 15–20 min time frame. In contrast, in Study 2, the mother read a story for 2 min and then there was a 50–60 min interval before the familiarization phase. The third presentation of the story, the novelty phase, occurred at least 15 min following the second exposure. Thus, in Study 2, the fetus heard the same story three times, also for a total of 6 min, but over a period of 80–90 min. There is some support for the notion that the amount of exposure to a voice and/or the timing of the exposure influences subsequent response. For example, Floccia, Nazzi, and Bertoncini (2000) demonstrated that newborns can discriminate novel voices when multiple tokens of a single, disyllabic word are used and Swain, Zelazo, and Clifton (1993) showed that newborns can hold novel words in memory for at least 24 h when the words have been repeatedly presented in an habituation paradigm. As term fetuses and newborns are essentially the same gestational age, these data suggest that a term fetus has the cognitive capacity to 'remember' a 2-min voice stimulus presented 4–15 min previously and that repeatedly presenting the voice will lead to habituation of responding to voice onset.

The second unexpected effect was that shown in Studies 3 and 4 where fetuses showed no significant change in heart rate during the novel voice presentation of either the father's voice or a female stranger speaking in the native language. The fetuses showed a response to the offset of both the father's and stranger's voice. Similar responding to the father's voice which is on average of lower frequency and female strangers' voices which are on average of higher frequency suggests that the fetal response is not driven by average frequency. As noted by others (e.g., Cohen, 2004; Houston-Price & Nakai, 2004a,b; Slater, 2004), interpretation is problematic in the absence of a novelty response. However, because the lack of response to these voices during the novelty voice period and the offset response were similar for both the father's and the female stranger's voice, it may be reasonable to conclude that neither are salient stimuli to the fetus. This conclusion agrees with the findings of DeCasper and Prescott (1984) who found that newborn's showed no preference for the father's voice over that of another male although they could discriminate between two male voices.

In summary, this series of four studies have demonstrated that near-term fetuses have some appreciation for the properties of their mother's voice as well as their native language. These cognitive abilities are similar to those demonstrated by newborns using a wider range of behavioural measures. They provide evidence of fetal attention to and rudimentary memory and learning of voices and language, suggesting that neural networks sensitive to the properties of the ubiquitous mother's voice and native-language speech are being formed before birth.

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