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REPORT

Maturation of fetal responses to music

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Abstract

Maturation of fetal response to music was characterized over the last trimester of pregnancy using a 5-minute piano recording of Brahms' Lullaby, played at an average of 95, 100, 105 or 110 dB (A). Within 30 seconds of the onset of the music, the youngest fetuses (28–32 weeks GA) showed a heart rate increase limited to the two highest dB levels; over gestation, the threshold level decreased and a response shift from acceleration to deceleration was observed for the lower dB levels, indicating attention to the stimulus. Over 5 minutes of music, fetuses older than 33 weeks GA showed a sustained increase in heart rate; body movement changes occurred at 35 weeks GA. These findings suggest a change in processing of complex sounds at around 33 weeks GA, with responding limited to the acoustic properties of the signal in younger fetuses but attention playing a role in older fetuses.

Introduction

In recent years, parents as well as scientists have become increasingly interested in fetal perception and cognition. In a cross-cultural survey of maternal knowledge and beliefs concerning fetal development conducted in France and Canada, investigators (Kisilevsky, Beti, Hains & Lecanuet, 2001) found that many mothers-to-be believe that all perceptual systems are developed by about 25 weeks gestational age (GA). The majority of the respondents also believe that fetuses react to music about 1 week later and about half believe that fetuses have emotions and thoughts. Moreover, there is a common belief that playing music to fetuses and infants increases intelligence. The evidence for a positive effect of music on infant development is mostly anecdotal and is perhaps reinforced by a plethora of commercial audio-recordings (e.g. music, heart sounds) and devices purported to enrich the fetal environment and increase infant IQ.

Although it is difficult to find any scientific evidence for the 'music for a better brain' claim, Gray *et al.* (2001) argue that there is a biological and evolutionary origin of musical ability, and according to Tramo (2001), all of us are born with the capacity to apprehend emotion and meaning in music. If so, then this capacity should be present in near-term fetuses. We know that fetuses can hear by the last trimester of pregnancy (e.g. Kisilevsky, Pang & Hains, 2000) and that music played in the external environment is recognizable in utero (Querleu, Renard, Boutteville & Crepin, 1989). There is some evidence that term fetuses can distinguish between voices (mother versus stranger, Kisilevsky *et al.*, 2003; male versus female, Lecanuet *et al.*, 1993) and musical notes (piano D4 versus C5, Lecanuet, Granier-Deferre, Jacquet & DeCasper, 2000) as well as habituate to a brief piano sequence with changing melodic contour (Granier-Deferre, Bassereau, Jacquet & Lecanuet, 1998).

While there has been very little work in the area of fetal perception of music *per se*, fetal auditory perception is well described. By about 30 weeks GA, fetuses begin to respond to brief episodes (2–3 seconds) of relatively loud (110 dB sound pressure level [SPL]) airborne sounds with heart rate acceleration and body movement responses (Kisilevsky *et al.*, 2000). As gestation advances, the frequency and magnitude of responses increases and the threshold for a response decreases. At term, the complexity of the stimulus (pure tone, white noise, speech) as well as its intensity and frequency regulate the threshold and magnitude of a response (see Lecanuet, Granier-Deferre & Busnel, 1995 and reviews by Lecanuet & Schaal, 1996 and Kisilevsky & Low, 1998). Clearly, by late gestation the fetus can hear, and fetal auditory perceptual abilities become more sensitive with the maturation of the auditory system.

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The studies on the development of fetal hearing have used brief bursts of noise emitted over seconds rather than prolonged noise over a period of time as would be more typical of environmental sounds such as music. However, some previous studies have examined the effects of music on fetal behaviour using longer episodes of stimulation. Sontag, Steele & Lewis (1969) played a 10-minute tape-recorded passage of the mother's favourite piece of music through two floor speakers placed at the foot of a bed; intensity averaged 75 dB (range 65 dB to 100 dB) measured at the mother's head. In fetuses from 28 weeks GA to term ($n = 11$), they found that a significant cardiac acceleration (about 5 beats per minute) occurred 90 seconds after music onset. There were no changes in fetal body movements and no change in maternal heart rate. Fetal heart rate returned to baseline within 2 minutes of music onset. Because the onset of the response was delayed and there was no change in activity, the authors speculated that fetal response was mediated through the emotional reaction of the mother. Similarly, Zimmer *et al.* (1982) posited that changes in fetal behaviour were mediated by maternal hormonal changes when they played music via headphones to pregnant women at 34–40 weeks gestation (i.e. masked to the fetus). They found that fetuses showed decreased breathing activity and increased body movements if the mother listened to a preferred type of music (classical versus rock).

Other early attempts to characterize the effects of music on fetal behaviour were unsuccessful. Olds (1985a, 1985b) played various classical music pieces to fetuses from 30 weeks GA via headphones placed on the maternal abdomen. He noted that variability in fetal heart rate occurred during the music. However, fetal responses were not uniform, with heart rate increasing for some and decreasing for others, and statistical tests were not reported. It may be that Olds' fetal results were confounded by maternal responses, for Olds did not mask the music to the mother so that fetal behaviour could have been influenced by maternal emotional response.

While the results of Olds' work are equivocal, Hepper (1991) demonstrated limited fetal and newborn response to music in a series of studies examining learning before and after birth. For fetuses and newborns the procedure was similar: a no-music baseline period followed by a 3-minute music period with statistical comparisons between either a 30-second baseline and the last 30 seconds of the music period (newborns) or a 1-minute baseline and the last minute of the music period (fetuses). An increase in body movements was elicited by the theme song of a television soap opera in a group of 36–37 weeks GA fetuses whose mothers had watched the programme throughout their pregnancies, but not in a group of younger fetuses, 29–30 weeks GA, or a group whose mothers had not watched the programme. Two- to 4-day-old newborns showed the opposite response, a decrease in movement and heart rate and the adoption of an alert state. However, they showed no change in behaviour when the theme song was played backwards or when a theme song of a programme their mother had not watched during pregnancy was played. At 21 days of age, infants whose mothers had not watched the programme since delivery showed no response to the theme tune. Taken together, these findings indicate that fetal response to a particular piece of music is experience-dependent, and experience with the music must be continued after birth for the response to continue.

The results of studies examining the effects of music on newborns and premature infants could indicate the capabilities of fetuses of equivalent GA. Findings from studies of the development of active cochlear mechanisms in premature infants demonstrate that otoacoustic emissions (OAE) indicating outer hair cell activity begin at about 30 weeks conceptual age (Morlet *et al.*, 1995) with functional maturation nearly complete by 33 weeks (Morlet, Collet, Salle & Morgon, 1993). A lack of activity in the medial olivocochlear system indicates functional immaturity in the auditory pathway relaying information to the cortex (Morlet *et al.*, 1993). Thus, it is unlikely that fetuses of less than 33 weeks GA are capable of the higher order processing necessary for complex auditory stimuli and music in particular. Nevertheless, music has been shown to have positive effects on premature infant behaviour. From 31 weeks GA, premature infant behaviours (i.e. heart rate, state-of-arousal, facial expressions of pain) returned to baseline more rapidly when Brahms' Lullaby (vocal or piano) was played immediately following heel lance (Butt & Kisilevsky, 2000) than in a no-music comparison condition. The results of non-contingent music in the premature nursery environment are equivocal. Playing 10 minutes of non-contingent music in the isolette, Lorch, Lorch, Diefendorf and Earl (1994) found that premature infants were excited (increased heart rate) or quieted (decreased heart rate) by different music pieces. In contrast, when female vocalist recordings of lullabies were delivered via headphones for 20 minutes over three consecutive days, Standley and Moore (1995) found that oxygen saturation increased during music on day 1 only and decreased in the post-music period on days 2 and 3. While the outcome of playing non-contingent music in the premature nursery is equivocal, Kaminski and Hall (1996) suggest that it is beneficial in the normal newborn nursery (i.e. full-term infants). During a 6-hour observation, including both a no-music and a music period, they found fewer high arousal states and fewer state changes during music compared to no-music.

Kaminski and Hall chose Brahms' Lullaby for their study because the tempo approximated the rate of the maternal heartbeat, 65–80 beats per minute, which DeCasper and Sigafoos (1983) had shown to be an effective reinforcer for infants in an operant learning task, presumably because of their previous experience. DeCasper and Carstens (1981) also found that newborns modulate their sucking to elicit music if they have had prior contingent experience with it (i.e. previous experience with producing vocal music by increasing the inter-burst interval of non-nutritive sucking) but not if the experience was non-contingent.

Although music has a number of characteristics that affect adult response (e.g. pitch, rhythm, tempo; Parsons, 2001), little is known about how they affect fetal responses. Lecanuet and colleagues have demonstrated that fetuses can discriminate two low-pitched musical notes (Lecanuet *et al.*, 2000) and two different tempi (Lecanuet, unpublished data). In older infants, a higher pitch is more effective in capturing and holding attention (Trainor & Zacharias, 1998) while variations in tempo can excite (fast) or soothe (slow) (Trehub, Hill & Kamenetsky, 1997).

In summary, while it appears that near-term fetuses respond to a music stimulus which has been repeatedly presented in the environment and that fetuses can discriminate some characteristics of music (e.g. notes, tempi) that affect adult responses, no studies have systematically examined fetal perception of a music stimulus over gestational age. Thus, third trimester development of auditory perception using a music stimulus will be examined in the present study as well as the effects of variations in tempo on fetal behaviour. For this first step in characterizing the maturation of fetal perception of a music stimulus, we chose to use Brahms' Lullaby because of its successful use with premature and full-term infants as noted above.

Method

Participants

A total of 122 fetuses of women experiencing a low-risk, uneventful pregnancy were tested on one occasion. Gestational age was determined from last menstrual period if periods were reliable (accuracy rate 75–85%) and/or from early ultrasound scan (SD = ±1 week). Forty-seven 28–38 weeks GA fetuses were recruited from antenatal clinics at a teaching hospital in southern Ontario, Canada. The data from two fetuses were eliminated because of preterm birth. The remaining 45 fetuses were born healthy at term (i.e. 5-minute Apgar score of 8–10, birthweight > 10th percentile for gestational age and healthy on physical examination). There were 26 male and 19 female infants with an average birthweight of 3582 grams (SD ± 459 grams). Maternal age averaged 28.5 years (SD = 4.3 years); 56% were primiparous; and 84% had vaginal deliveries. Seventy-five term fetuses (38–41 weeks GA) were recruited from prenatal information sessions at the Port-Royal University Clinic of Paris, France. All fetuses were born healthy at term (i.e. birthweight > 10th percentile for gestational age). There were 44 male and 31 female infants, with an average birthweight of 3361 grams (SD ± 447 grams). Maternal age averaged 30.3 years (SD = 5.3); 87% were primiparous; and 80% had vaginal deliveries. Sixty-nine had complete data and were included in analyses. At both sites, gender was determined at delivery and studies were carried out following institutional research ethics board approval.

Equipment/stimuli

The 5-minute piano music stimuli consisted of three tape recordings of Brahms' Lullaby (Op. 49, No. 4 in D flat major) generated for the study. In Kingston, a tape of the music at a tempo of 69 beats per minute was played on a TASCAM DAT 20 system, amplified (University amplifier) and delivered through a Auratone 5C Super-Sound Cube loudspeaker. Instantaneous sound levels were measured in-air, at a distance of 10 centimetres from the loudspeaker, using the A scale of a Bruel & Kjaer Impulse Precision Sound Level Meter model 2235. Fetal heart rate was recorded continuously using a Hewlett Packard 1040 A cardiotachograph, with an event marker to indicate trial onset. To obtain a fetal heart rate for each second, records were scored using an Abaton Macintizer ADB digitizing tablet connected to a Macintosh computer (for details see Coleman, Kisilevsky & Muir, 1993). The sampling rate was set at 10 times per second with the average of the 10 scores becoming the fetal heart rate for that second. Body movements were ultrasonographically visualized using an ATL Ultramark 4 and video-recorded.

In Paris, two tapes of the music, one at 69 beats per minute and one at 118 beats per minute, were played on a JVC TD-W118BK dual cassette player through a BST Stereo Mixer – MR60 and delivered via a loudspeaker (AUDAX HR37) supported by a movable C-shaped table placed 20 centimetres above the maternal abdomen. Average sound levels (Leq) were measured in-air, at a distance of 20 centimetres from the loudspeaker, using an ACLAN Sound Level Meter model SDH80. Analogic fetal heart rate data were collected from a Hewlett Packard series 50 A cardiotacograph via a combined interface module (J10) connected to a PC Lab A/D board to be sampled at a rate of 10 values/s and stored into an IBM compatible computer. Fetal heart rate in beats per minute computed by the cardiotacograph was continuously displayed in digital and analogic formats. Body movements were ultrasonographically visualized using an ALOKA SSD 500 and video-recorded.

The cardiotacographs and real-time ultrasound equipment at both sites are comparable and yield similar data. Instantaneous and averaged sound level measurements in Kingston comparing the Bruel & Kjaer and ACLAN instruments (A scale) showed both stimulus measurements to be similar: instantaneous 95 dB = 95.2 dB Leq over 1 minute; instantaneous 105 dB = 105 dB Leq over 1 minute; instantaneous 110 dB = 109.8 dB Leq over 1 minute. The principal investigator conducted all studies in Kingston and testing of the first 43 subjects in Paris.

Procedure

Each fetus received one or two episodes of a 5-minute piano recording of Brahms' Lullaby, preceded and followed by 5 minutes of a no-sound control period. The music was delivered at an average sound level of 95 dB, 100 dB, 105 dB or 110 dB (A) through a loud speaker located about 10 (Kingston) or 20 (Paris) centimeters above the maternal abdomen. In Paris, two variations in tempo ('normal', 69 beats per minute, and 'fast', 118 beats per minute) were included; tempo was counterbalanced over subjects. Fetal heart rate was recorded continuously for all subjects. Body movements were video-recorded from a cross sectional view of the fetal abdomen which may or may not have contained limbs. Movement data were collected for all Kingston subjects and for the first 31 subjects recruited in Paris, where technical difficulties precluded the video-recording of body movements for subsequent subjects. During the procedure, mothers wore headphones through which either vocal country (Kingston) or guitar (Paris) music was used as an effective mask.

Data manipulation

In keeping with our previous work, for analyses by age the following age groupings were used: 28 weeks 0 days to 32 weeks 6 days; 33 weeks 0 days to 34 weeks 6 days; 35 weeks 0 days to 36 weeks 6 days; and greater than 37 weeks. The number of participants in each condition by age group are displayed in Table 1. Although data for most fetuses was recorded for 300 seconds in each period, some variability existed in recording time, hence data for only 280 seconds were analysed for each period.

Fetal body movements were scored from the videotapes and included any observed movement of the body or limbs. The latency to the first movement following the onset and offset of the music was determined. The number of body movements and their duration within each 30 seconds of each period were calculated. Because there is no precedent to guide us in the analyses of fetal heart rate, all data for every participant were used in the initial analysis ignoring GA and sound level to find if there is an overall effect of music. In an effort to replicate the analyses performed on vibroacoustic (e.g. Kisilevsky, Muir & Low, 1992) and white noise (Kisilevsky *et al.*, 2000) stimuli in previous studies, the data for the first 30 seconds following music onset and offset were compared to the data for the previous 30 seconds to examine the short-term effects of the music. To examine longer-term effects, following the example of Kisilevsky *et al.* (2003) who used the second-by-second heart rate data for the complete period following the onset and offset of the maternal voice, the heart rates for each second were used in the analyses of the present data.

Table 1 *The number of participants in each decibel by age group*

Age group	Tempo	Sound level 95 dB	100 dB	105 dB	110 dB
28–32 weeks GA	normal	5		6	6
33–34 weeks GA	normal	6		6	6
35–36 weeks GA	normal	14		8	8
Term	normal	11	12	11	
	1/3rd faster	12	12	11	

Results

Movement

When all available data were considered using a 1 between (age: three levels) 2 within (three periods, ten 30-second time intervals) ANOVA, more of the younger fetuses (< 35 weeks GA) moved than the older fetuses, $F(1, 88) = 7.81$, $p < .01$, although there were no significant differences in duration of movement or latency to the first movement between the three periods, neither was there an immediate movement response in the first 30 seconds after stimulus onset. When each age group was examined separately, the younger fetuses did not show any change in the duration of movements across periods (4.21 seconds, 4.28 seconds, 4.48 seconds). However, as shown in Figure 1, during the music period, older fetuses (> 35 weeks GA), showed a change in the number of fetuses demonstrating a body movement from 32% at onset to 55% after 3 minutes, before dropping to 27%

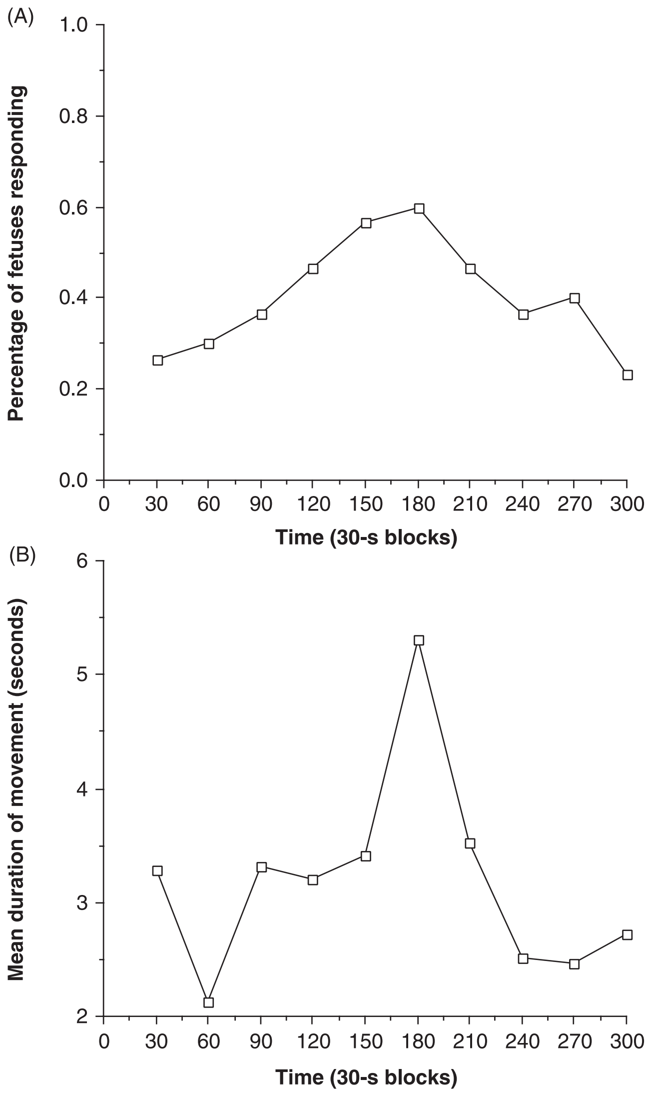

Figure 1 *Body movement in each 30-second interval in response to hearing Brahms' Lullaby by fetuses greater than 35 weeks GA: (A) percentage of fetuses showing a body movement, and (B) the mean duration of movement in seconds.*

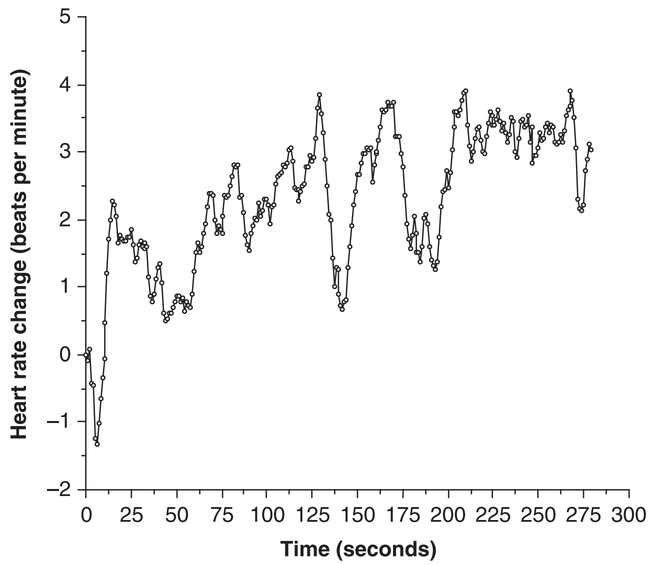

Figure 2 *Mean heart rate change for all fetuses and sound levels over 5 minutes after the onset of Brahms' Lullaby.*

by the end of the period (quadratic change over time, $F(1, 54) = 19.75$, $p < .01$). The duration of movements changed from 2.7 to 5.3 seconds after 3 minutes before dropping to 2.5 seconds by the end of the period (quadratic change over time, $F(1, 54) = 8.67$, $p < .01$). No effects of sound level or tempo were seen.

Heart rate preliminary analyses

As there is a correlation between body movement and fetal heart rate accelerations, it is possible that any increase in fetal heart rate could be attributed to increased body movement. To test this possibility, the average heart rate for each 30 seconds of the music period was analysed using the presence or absence of a body movement in the same 30 seconds as a covariate. This 2 between (GA, dB), 1 within (10 levels of time) analysis showed an effect of body movement on fetal heart rate, $F(1, 36) = 6.49$, $p < .05$, but there was also a main effect of time, $F(9, 36) = 2.03$, $p < .05$, indicating that the increase in fetal heart rate over time cannot be attributed to fetal movements alone.

The immediate effect of music was examined by comparing the second-by-second data for the last 30 seconds pre-music with the first 30 seconds following music onset, using a 2 between (age, dB), 2 within (two periods, 30 seconds) ANOVA. There was a significant time × period effect, $F(29, 3509) = 3.27$, $p < .01$; and a time × period × dB triple interaction, $F(87, 3509) = 1.33$, $p < .01$. Music had an immediate effect on fetal heart rate.

A second-by-second data analysis for all fetuses in each period using repeated measures (280 seconds) ANOVA showed that the music had some effect on fetal heart rate. For the pre-music (control) and post-music periods, there was no overall change in fetal heart rate over time, but in the analysis for the music period, as shown in Figure 2, an effect of time was found, $F(279, 35\,712) = 1.60$, $p < .01$, that included a linear increase, $F(1, 128) = 7.50$, $p < .01$. Variability was stable over periods; the SD varied from 9.7 and 13.7 in the first no-stimulus period to 9.7 and 13.4 in the music period and 10.7 to 14.9 following the offset of the music.

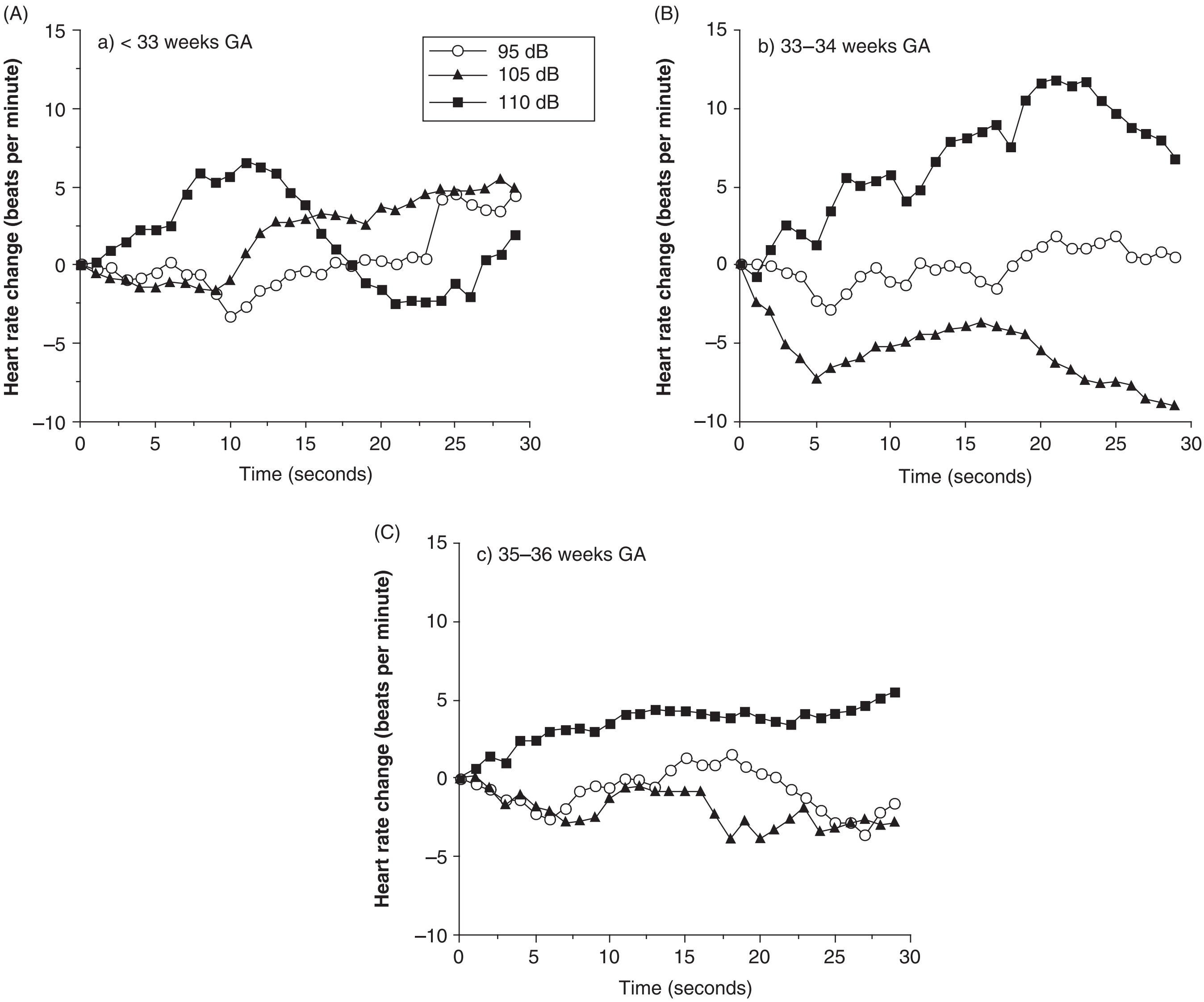

Figure 3 *Mean fetal heart rate change during Brahms' Lullaby as a function of time and decibel level for preterm fetuses at: (A) 28–32 weeks GA, (B) 33–34 weeks GA, and (C) 35–36 weeks GA.*

Maturation of heart rate responding: music period

Fetuses 28–32 weeks GA

A 1 between (dB), 1 within (time) ANOVA was conducted for each age group separately, using the first 30 seconds following music onset. For the 28–32 weeks GA group, it showed a significant time × dB interaction, $F(58, 348) = 2.26$, $p < .01$; there was no effect on fetal heart rate for the music played at 95 dB while there was a linear increase for 105 dB, $F(29, 116) = 2.32$, $p < .01$; and a rapid increase over 12 seconds followed by a return to baseline for 110 dB, $F(29, 116) = 2.59$, $p < .01$, as shown in Figure 3A. There was no further effect of music on fetal heart rate for this group.

Fetuses 33–34 weeks GA

Figure 3B shows a change in heart rate during the onset of music. The analysis of the first 30 seconds following music onset showed a significant time × dB interaction, $F(58, 435) = 2.48$, $p < .01$. Again, there was no effect on fetal heart rate of music played at 95 dB, while there was a reduction in fetal heart rate for 105 dB, $F(29, 174) = 1.96$, $p < .01$, and a gradual increase followed by a decrease for 110 dB, $F(29, 174)$

= 2.12, $p < .01$. Over the 5 minutes of the music period, 33–34 weeks GA fetuses showed an increase in heart rate, $F(279, 4185) = 1.23$, $p < .01$, that had a linear component, $F(1, 15) = 4.33$, $p < .05$, but no effect of dB.

Fetuses 35–36 weeks GA

In the first 30 seconds after music onset there was a quadratic effect for 95 dB, $F(29, 203) = 2.01$, $p < .01$, and for 110 dB, $F(29, 203) = 1.80$, $p < .01$. Over the 5-minute music period, the 35–36 weeks GA preterm fetuses showed an increase in heart rate, $F(279, 7533) = 2.15$, $p < .01$, that had a linear component, $F(1, 27) = 4.33$, $p = .05$.

Term fetuses, from 37 weeks GA

The data analysis for the first 30 seconds after music onset was performed for each tempo separately.

In the normal tempo, shown in Figure 4A, over the first 30 seconds after onset there was a time effect, $F(29, 899) = 3.5$, $p < .01$, that was linear, $F(1, 31) = 8.1$, $p < .01$, with no effect of dB level. The increase peaked at about 30 seconds followed by a return to baseline. Over the 5-minute music period, there was no overall increase in fetal heart rate for this group.

When the music was played a third faster, as shown in Figure 4B, during the first 30 seconds of music there was a main effect of time, $F(29, 899) = 2.53$, $p < .01$, and a time × dB interaction, $F(58, 899) = 1.99$, $p < .01$. These fetuses showed a decline in fetal heart rate followed by an increase. The minimum occurred at about 28 seconds for the 95 dB stimulus and at about 7 seconds for the 100 dB and 105 dB stimuli. Also, for this group, there was an overall increase in fetal heart rate over the whole period, $F(279, 8370) = 1.43$, $p < .01$, that had a linear component, $F(1, 30) = 4.62$, $p < .01$.

Table 2 *Direction of significant fetal heart rate changes over age and sound level during the music period*

Tempo	Gestational age	Direction of fetal heart rate change* Sound level (dB)	30 s after onset	5 min music (all dB)
Normal	28–32 weeks	95		
		105	↑	
		110	↑	
Normal	33–34 weeks	95		↑
		105	↓	
		110	↑	
Normal	35–36 weeks	95	↓	↑
		105		
		110	↑	
Normal	Term	95	↑	
		100	↑	
		105	↑	
Fast	Term	95	↓	↑
		100	↓	
		105	↓	

Note: * only statistically significant changes in fetal heart rate are shown.

Discussion

In this study, we demonstrated a maturation of music perception over the last trimester of pregnancy using both movement and heart rate measures. Body movement responses were not observed until 35 weeks GA, when both the number of fetuses showing body movements and the duration of the movements increased to a maximum after about 3 minutes of stimulation. These findings are similar to those of Hepper (1991). In his fetal learning study, he demonstrated an increase in body movements over baseline at 3 minutes after the onset of a familiar piece of music for near-term fetuses, 36–37 weeks GA, but not for a group of younger fetuses, 29–30 weeks GA, or for fetuses to whom the music was not familiar. What is clear from these two studies is that near-term fetuses can show an increase in body movements when hearing music; the specific aspect of music eliciting the increase in movements or learned by the fetus is unknown at this time.

Fetuses in all age groups (28 weeks GA to term) showed some heart rate response to the music stimulus, summarized in Table 2. The maturation of cardiac response was shown by changes in the direction of the response as a function of fetal age and sound intensity. Over the first 30 seconds, music at the highest sound level generally elicited a heart rate acceleration (thought to indicate arousal) while lower intensities elicited a deceleration until by term all of the sound levels tested elicited a deceleration at music onset (thought to indicate attention).

Over the course of the 5-minute music period, fetuses from 33 to 37 weeks GA showed a gradual heart rate acceleration that did not differ over sound levels. The term fetuses showed an increase in heart rate to the faster tempo, whereas the lullaby played at the normal tempo had little effect on heart rate. Both Sontag *et al.* (1969) and Kisilevsky *et al.* (2003) examined fetal heart rate response to continuous, prolonged airborne sounds using music and voice stimuli respectively. In Sontag's music study, fetuses of varying ages responded with a heart rate acceleration within two minutes of music onset played at an average of 75 dB SPL. In the voice study, term fetuses responded with an increase in heart rate over a 2-minute period to their mothers' voices and a similar decrease to a stranger's voice, both delivered at

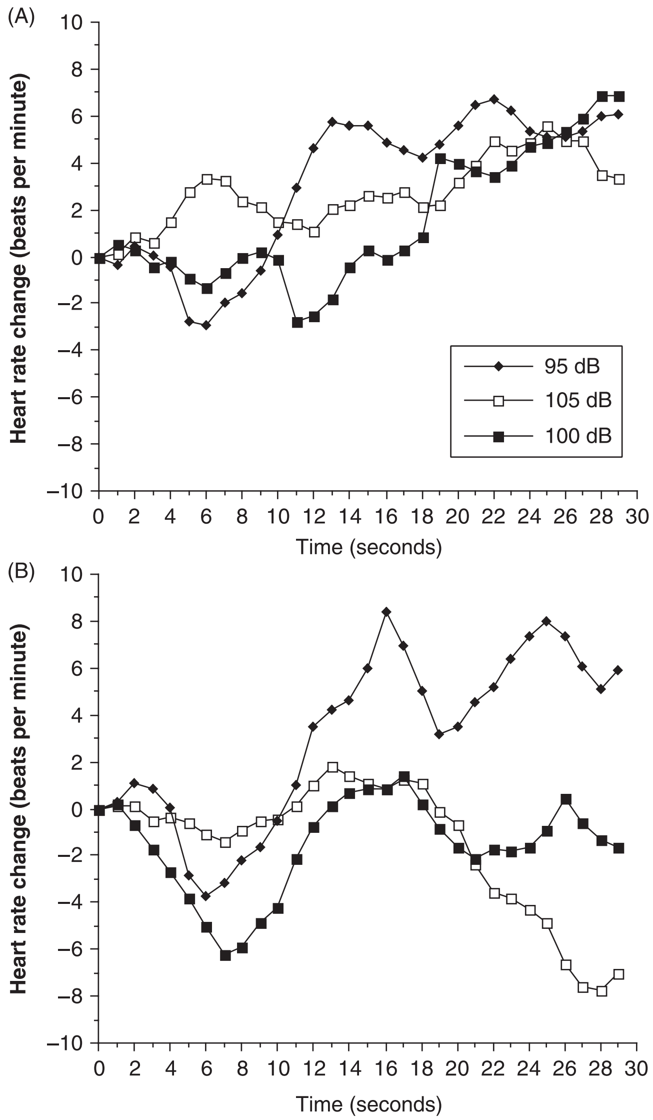

Figure 4 *Mean fetal heart rate change in term fetuses as a function of time and decibel level for Brahms' Lullaby played at: (A) normal tempo, and (B) one third faster.*

95 dB. The sustained heart rate acceleration response to music observed in the previous study and in this study, as well as to the mothers' voices (Kisilevsky *et al.*, 2003), may represent the influence of experience.

In adults, auditory experience changes the make-up of areas in the cerebral cortex that are involved in the processing of complex sounds, including music, and the changes in auditory cortical representations are based on activity-dependent modifications of synaptic circuitry (Rauschecker, 2001). However, fetal music response is probably not cortical in origin as, at this time, mature axons are present only in the most superficial layer of the cortex (Moore, 2002). However, processing of musical elements such as frequency (e.g. Giraud *et al.*, 2000) and pitch (e.g. Braun, 2000) probably occurs in the inferior colliculus in adults, so that it is possible that the fetal behaviour observed here signifies the onset of these abilities. The maturational changes observed here may reflect maturation of the peripheral auditory system and physiological development of the different brainstem auditory nuclei that will transmit basilar coding up to the inferior colliculi (Frisina, 2001). The neural basis of hearing begins with maturation of cochlear hair cells over early to mid-gestation (e.g. Pujol, Lavigne-Rebillard & Uziel, 1991; Rubel & Fritzsch, 2002). Beyond the cochlea, there is a complexity of overlapping cell layers in the pathways leading to the auditory cortex. In the brain stem, path length increases (Moore *et al.*, 1996) and axonal conduction time reaches maturity by 40 weeks GA (Ponton, Moore & Eggermont, 1996).

The effect of tempo on the responses of the term fetuses can be explained in terms of arousal. A faster tempo gives rise to more activation of the cochlea and auditory fibres, so that the differential response to tempo by term fetuses might reflect a difference in arousal levels as a result of more stimulation of the reticular formation. Alternatively, it may provide evidence that tempo is a salient stimulus for term fetuses, suggesting continuity in pre- and post-natal music perception. If the assumption is made that there is continuity from fetus to newborn, then it is also feasible that changes in the direction of the fetal heart rate response over late gestation represent a change in processing from simple discrimination of the signal to attention, reflecting primitive cognitive function.

Continuity of responding before and after birth has been demonstrated previously with brief duration (2.5 seconds) sound and vibration (e.g. Kisilevsky & Muir, 1991) and with short musical melodies (Granier-Deferre *et al.*, 1998). Finding a systematic change in fetal heart rate following the onset of the music suggests that the fetuses were aware that the music was different from the ongoing background uterine sounds that have a rhythmic quality (e.g. discriminating the music from the maternal heart rate) or that the music masks these background sounds.

In summary, our findings add to the small body of knowledge concerning fetal cognitive abilities. Although it is difficult to demonstrate the same abilities in the fetus that have been demonstrated with newborns, this study has explored the time course of the origins of these abilities. It seems that near-term fetuses are able to make simple discriminations (i.e. renew responding or respond differently to a change in stimulus parameter) based on a number of dimensions (e.g. tempo, reported here; loudness and pitch, Lecanuet *et al.*, 2000), and have some rudimentary memory of music (Hepper, 1991) and short speech sequences (i.e. child's rhyme, DeCasper *et al.*, 1994). Also, not only can they distinguish between some complex auditory stimuli (voices) but also respond differentially to variations. Our findings characterize the maturation of responding to a complex auditory stimulus and provide evidence that higher order auditory perception begins before birth.

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