Frequency discrimination by the fetus

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Abstract

The ability to discriminate between acoustic signals of different frequencies is fundamental to the interpretation of auditory information and the development of language perception and production. The fact that the human fetus responds to sounds of different frequencies raises the question of whether the fetus is able to discriminate between them? To investigate whether the fetus has the ability to discriminate between different pure tone acoustic stimuli and different speech sounds the following study used an habituation paradigm and examined whether the fetus could discriminate between two pure tone acoustic stimuli, 250 Hz and 500 Hz, or two speech sounds, [ba] and [bi], at 27 and 35 weeks of gestational age. The results indicated that the fetus is capable of discriminating between the different sounds, i.e. 250 Hz and 500 Hz and [ba] and [bi] at 35 weeks of gestational age but less able at 27 weeks of gestational age. The implications of this for the development of the auditory system are discussed.

Key words: Auditory development; Discrimination; Habituation; Language

1. Introduction

The ability to discriminate between acoustic signals of different frequencies is fundamental to the interpretation of auditory information and the development of language perception and production. The fact that the human fetus responds to pure tones of different frequencies [11] raises the question of whether the fetus is able to discriminate between them? This paper examines whether the fetus can discriminate between different sounds, and if so, is this ability present when the fetus first responds to sound or does it develop later during gestation.

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In adults assessment of the smallest perceivable difference, difference limen (DL), in frequency between two tones has found that quite small differences in frequency can be detected. Expressed in absolute terms adult listeners are most sensitive between 100–1000 Hz where differences of the order of 2–4 Hz between two pure tone signals can be detected [4], however above 1000 Hz the difference in frequency between two pure tone signals that is required in order to be perceived increases [4]. When expressed in terms of a percentage change of the original frequency required for the difference to be detected it can be seen that 'sensitivity' is greatest between 500 Hz and 2000 Hz, where a percentage change of approximately 0.2% can be detected. Below 500 Hz and above 2000 Hz sensitivity decreases.

Early studies of frequency discrimination in neonates found they were able to discriminate between frequencies which were widely spaced, e.g. 500 Hz vs. 2000 Hz [2,31] but were unable to discriminate between frequencies more closely spaced, e.g. 200 Hz vs. 500 Hz [19], 300 Hz vs. 700 Hz [14], although at 1 month of age individuals have been reported to discriminate successfully between 200 Hz and 500 Hz [35]. These experiments relied on the observation of behavioural responses, e.g. heart-rate change or sucking responses, which have proven not to be reliable indicators of DLs between frequencies in infants [28]. More sophisticated techniques, using operant head-turning [1,21,23,28] or an observer-based behavioural procedure [22] have been used to assess frequency DLs in 3- to 6-month-old infants and have found these to be higher than adults; at 1000 Hz the DL for infants is around 20 Hz whilst for adults the DL is 3–6 Hz using the same techniques. These techniques have not been applied to newborns and hence the ability of neonates to discriminate frequencies remains largely unknown.

There is now little doubt that the fetus is capable of perceiving sound and responding to it. Many studies have observed the response of the fetus to pure tone acoustic stimuli but these have been largely conducted in late pregnancy: Goodlin and Lowe [6] during the third trimester; Grimwade et al. [8] between 38 and 42 weeks of gestation; Lecanuet et al. [18] 37–40 weeks of gestational age; Trudinger and Boylan [34] after 34 weeks gestation. In a recent study Shahidullah and Hepper [29] showed that the fetus was capable of responding to a sound stimulus from as early as 20 weeks of gestational age and certainly by 26/27 weeks of gestational age. Since the fetus is able to perceive and respond to an acoustic stimulus from this gestational age the following experiment assessed the ability of fetuses to discriminate between sounds using an habituation, or more properly a dishabituation, technique.

Habituation can be defined as the decrement in response to repeated presentation of the same stimulus [32]. A number of studies have demonstrated that the fetus can be habituated to both vibro-acoustic [3,15,16] and acoustic [6,7] stimuli.

The decrement in response observed following repeated presentation of the stimulus may be due to habituation, a property of the central nervous system [13], alternatively it may be due to either adaptation of the sensory system, i.e. the sensory receptor is no longer able to respond, or receptor fatigue, i.e. the motor system is no longer able to sustain a response. In order to distinguish between these possibilities a dishabituation procedure is used. Here after presentation of the original stimulus and the observation of a decrement in response, a new stimulus is presented. If the response decrement is due to habituation then presentation of the
new stimulus should re-instate the response [32]. If due to motor fatigue or sensory adaptation then no response will be observed. Whilst dishabituation is used to assess whether true habituation has occurred [32] it may also be used to examine sensory abilities [10]. In order to dishabituate the second stimulus must be perceivably different from the original stimulus, thus assessment of the dishabituation response may be used to inform regarding the individual's sensory and perceptual abilities.

Recently Hepper and Shahidullah [11] reported the ability of normal fetuses to habituate to pure tone auditory stimuli between 34 and 36 weeks of gestation. Two sound stimuli were used, a 250 Hz pure tone sine wave and a 500 Hz pure tone sine wave. Fetuses were found to habituate to both pure tone stimuli and moreover following habituation fetuses dishabituated, i.e. responded, to the presentation of the novel stimulus. The results of this study demonstrate first, that the observed response decrement was the result of true habituation and second, that the fetus at this age is able to discriminate between a 250 Hz pure tone sine wave and a 500 Hz pure tone sine wave.

The first experiment reported here examined the ability of the fetus to discriminate between two pure tone sine waves of different frequencies (250 Hz and 500 Hz) using an habituation-dishabituation paradigm. It was hypothesised that if the fetus could discriminate between the two stimuli the presentation of the second, novel, pure tone should elicit a response. If unable to discriminate then no response should be observed. The two frequencies examined were 250 Hz and 500 Hz which have been demonstrated to be the first pure tone frequencies the fetus appears to respond to [28]. Furthermore the responsiveness of the fetus to these two frequencies appear to have similar developmental time courses [28].

2. Experiment 1 — The ability of the fetus to discriminate between pure tone frequencies

2.1. Subjects

The study was performed in Royal Maternity Hospital, Belfast where all the mothers were attending for their routine antenatal care. All were singleton pregnancies with no known complications and all were appropriately grown for gestational age. Gestational age had previously been confirmed by the date of the last menstrual period and ultrasound scan carried out in the first trimester of pregnancy.

All studies were performed at a similar time of day. None of the mothers smoked or consumed alcohol during the pregnancy. All of the mothers who participated in the study had been fully briefed as to the aims and procedures of the study and gave verbal consent to participate in the study. Ethical approval for the study was obtained from Research Medical Ethical Committee of Queen's University of Belfast (Chair Prof. G. Johnston).

The study examined the response of 48 fetuses. Fetuses were divided into two groups depending upon their gestational age at the time of the study. The first group were studied at 27 weeks of gestational age (n = 24) and the second group were studied at 35 weeks of gestational age (n = 24).
2.2. Apparatus

The response of the fetus was observed using an ultrasound scan. The ultrasound machine used for all the experiments was an Ultramark 4 plus machine with a 7 cm, 3.5 MHz curvilinear head. Two sound stimuli, 250 Hz and 500 Hz pure tone sine waves, generated by a synthesized function generator (Wavetek model 23) were used. The signals were fed into a modified headphone (one half of a pair of AKG headphones, consisting of a speaker (capsule K-160) and surround (1-cm plastic encased foam rubber, AKG components Z-61A and Z-60A)). When placed on the maternal abdomen an effective seal between the maternal skin and the speaker was formed so that the sound could not be heard by the mother. Presentation of the stimuli was controlled by a BBC computer. All observations were recorded on videotape for later analysis. Also the BBC computer superimposed onto the ultrasound image of the fetus a mark that indicated both the start and duration of stimulus presentation. The video record thus contained information of both fetal response and stimulus presentation.

2.3. Procedure

The mother lay in a semi-recumbent position on a standard couch at a 45 degree tilt. The procedure was explained to her and any ensuing questions answered. A standard longitudinal section view of the fetus was obtained so as the fetal head, upper body and arms could be visualised. The ultrasound scanhead was moved as necessary throughout the session to maintain this view at all times. The speaker was placed on the maternal abdomen directly over the fetal head. Fetuses at both gestational ages were subdivided into two groups (n = 12). Half of each age group received the 250 Hz tone as the habituating stimulus followed by the 500 Hz tone as the dishabituating stimulus. The other half received the 500 Hz tone as the habituating stimulus and once habituated the 250 Hz tone was used as the dishabituating stimulus.

The habituation procedure consisted of two stages and commenced after a period of inactivity (120 s with no spontaneous movement). This study was performed using fetuses at 27 and 35 weeks of gestational age. Although well defined fetal behavioural states are not observed until 38 weeks of gestational age [10], fetuses at these gestational ages are observed to exhibit activity/inactivity cycles. To ensure that fetuses at both gestational ages were in comparable ‘states’ at the start of the procedure the first stimulus was presented only after a period of 120 s of inactivity, when no movements were observed. In Stage 1, a series of tones (250 Hz or 500 Hz depending on the experimental group) at 110 dB(A), measured 1 cm from the speaker face, of 2 s duration and 5 s inter-stimulus-interval, were presented to the fetus. This continued until no response was observed from the fetus on five consecutive stimulus presentations. For the purpose of this experiment a response was defined as either any observable movement of the trunk, head or arms of the fetus together or independently during presentation of the sound stimulus or during the 2.5 s after its cessation if the fetus was inactive prior to the stimulus being presented. However if the fetus was moving when the next stimulus was presented, i.e. 5 s after the previous stimulus presentation, then the fetus was considered to have responded if it interrupted its
movement or changed the direction, speed or force of its movement during the presentation of the stimulus or during the 2.5 s after its cessation. This latter case occurred only rarely, and consisted of the fetus exhibiting a slow movement prior to the stimulus presentation which was changed to a fast forceful movement, a 'startle', upon presentation of the stimulus. The number of stimulus presentations to habituate was documented. Stage 2 commenced after the fetus had ceased to respond to the initial tone. In Stage 2 the fetus was presented with a single stimulus (500 Hz pure tone if the 250 Hz tone had been used in Stage 1, or a 250 Hz pure tone if the 500 Hz tone had previously been used) of 2 s duration at 110 dB(A). If the fetus responded to the second tone within 4.5 s of the stimulus onset a score of 1 was recorded, if no response was observed then a score of 0 was recorded. All of the scans were recorded on videotape for later independent analysis.

2.4. Results

All individuals, at both gestational ages, were observed to habituate to the stimuli. In order to assess whether the two tones differed in their ability to habituate the fetus, an un-paired t-test compared the number of stimulus presentations to habituate to the 250 Hz tone and the number of stimulus presentations to habituate to the 500 Hz tone at both gestational ages. There was no difference between the number of stimuli to habituate between the 250 Hz and 500 Hz tones at either 27 \( t = 0.033; df = 22; \text{n.s.} \) mean number of stimuli to habituate (± standard error) to the 250 Hz tone = 18.417 (±1.952); and to the 500 Hz tone = 18.5 (±1.952) or 35 \( t = 1.276; df = 22; \text{n.s.} \), mean number of stimuli to habituate (± standard error) to the 250 Hz tone = 12.333 ± 0.987; and to the 500 Hz tone = 10.667 ± 0.856) weeks of gestational age. Since the order of tone presentation had no effect on the number of stimuli required for habituation the results for the different tone presentation orders were combined for further analyses at each gestational age.

The number of individuals responding to each stimulus presentations is presented graphically in Fig. 1. As can be seen all fetuses habituated at both gestational ages. An unpaired t-test comparing the number of stimuli to habituate at 27 and 35 weeks of gestational age indicated there was a significant difference between the number of stimuli to habituate at each age \( t = 5.012; df = 46; P = 0.0001 \). Fetuses required fewer stimulus presentations to habituate at 35 weeks of gestational age than at 27 weeks of gestational age (mean number of stimuli to habituate (± standard error) at 27 and 35 weeks of gestational age = 18.456 ± (1.22) and 11.5 ± (0.662), respectively).

Whilst all fetuses, at both gestational ages, habituated to the original stimulus the amount of dishabituation exhibited by fetuses differed greatly. At 27 weeks of gestational age, six of the 24 fetuses dishabituated whereas at 35 weeks of gestational age 23 of the 24 fetuses dishabituated. A chi-squared analysis revealed a significant difference between the number of fetuses dishabituating at 27 weeks and 35 weeks \( (\chi^2 = 37.40; df = 1; P < 0.001) \). The results suggest that at 35 weeks of gestational age the fetus could discriminate between the two tones, hence the dishabituation response. At 27 weeks of gestational age, when there is much less evidence of dishabituation, the fetus may be unable to discriminate between the two stimuli.
2.5. Discussion

The fact that fetuses at 35 weeks of gestation dishabituated and responded to the new stimulus indicates that at this age the fetus is able to discriminate between the two stimuli. At 27 weeks of gestation much less of a response was observed to the new stimulus. This may be due to an inability to discriminate hence no dishabituation, alternatively it may be due to motor fatigue. The fetus, because of its physical immaturity, may become fatigued after stimulation with the original tone stimulus and, although able to discriminate a difference on presentation of the second tone
stimulus, the fetus may be unable to respond due to fatigue. This would give the impression of being unable to discriminate although in reality the fetus is able to do so.

Leader et al. [16] report that individuals from as early as 24 weeks of gestation are able to habituate to a vibro-acoustic stimulus (VAS) and dishabituate to a novel stimulus. However this study used both a VAS and a vibrational stimulus rather than an acoustic stimulus as used in the above experiment. Not only were the stimuli used by Leader et al. [16] different from those used in this study but they also differed from one another. One contained vibration and acoustic stimulation the other just vibration. Thus the question of whether fetuses at 27 weeks of gestational age can dishabituate to acoustic stimuli has yet to be proven.

3. Experiment 2 — Is the lack of dishabituation in the 27-week fetus due to motor fatigue?

In order to determine whether fetuses are able to dishabituate to acoustic stimuli at 27 weeks of gestational age a further study was performed. The method was almost identical to that reported above and only procedural differences will be reported below. Ten new fetuses aged 27 weeks of gestation were studied. All fetuses were habituated to the 250 Hz tone and after live stimulus presentations where no response was elicited, fetuses were presented with a broad-band stimulus, 80-2000 Hz at an intensity of 110 dB(A) measured one cm from the speaker face, as the dishabituating stimulus.

All ten fetuses in the study habituated to 250 Hz tone. There was no difference in the number of stimulus presentations to habituate between the 10 fetuses studied in this experiment and those in the initial study (n = 12) who were habituated to the 250 Hz tone at 27 weeks of gestation (t = 0.164; df = 20; n.s, mean number of stimuli to habituate (± standard error) to the 250 Hz tone in Experiment 1 and 2 = 18.417 ± 1.952 and 18 ± 1.506, respectively). However in contrast to the previous study, nine of the 10 fetuses in this study responded upon presentation of the novel stimulus, i.e. dishabituated. This indicates that the results obtained above in Experiment 1 from fetuses at 27 weeks of gestational age were due to an inability to discriminate between the two auditory stimuli and not physical immaturity or a lack of ability to habituate/dishabituate at this early gestation.

A second factor which should be considered is to what is the fetus responding when dishabituating? There are two possibilities: a difference in frequency or a difference in intensity. There is obviously a difference in frequency between the two stimuli and this provides one cue which may be used. There may also be an intensity difference between the two stimuli which may provide a further cue for discrimination. Both stimuli were presented at 110 dB(A) measured externally. Previous studies have reported that the mother’s abdomen differentially attenuates different frequencies [26]. Thus a 250 Hz tone reportedly undergoes a 2 dB attenuation whereas a 500 Hz tone is attenuated by 15 dB [26]. Thus for tones of equal intensity measured outside the womb there may be a 13 dB difference in intensity when perceived by the fetus in the womb. If this is the case then the dishabituation response may be due to a perceived intensity difference between the two stimuli.
It is known that stimulus intensity affects the rate of habituation. In very general terms the less intense a stimulus the faster the habituation, i.e. fewer stimulus presentations are required before habituation occurs [32]. If there were an intensity difference between the two stimuli, it would be expected that the 500 Hz tone would result in quicker habituation than the 250 Hz tone since this would be a quieter, less intense, stimulus in the womb. Comparison of the number of stimuli to habituate to the 250 Hz and 500 Hz tones at both age groups suggests that this is not the case since there was no difference in the number of stimulus presentations to habituate between the two tones. However, in order to confirm that possible intensity differences did not play a role in the dishabituation response a further experiment was conducted.

4. Experiment 3 — Do intensity differences account for the observed dishabituation?

The procedure was identical to that reported above (Experiment 1) except that new subjects were used and the two stimuli now differed in intensity. Only these differences are reported below.

Ten new subjects from singleton, uncomplicated, pregnancies at 35 weeks of gestation were observed. Observations of the attenuation of the abdomen suggest that a 500 Hz tone will be 13 dB quieter in utero compared to a 250 Hz tone [26]. In this experiment, therefore the two frequencies were presented at unequal intensities as measured outside the womb to compensate for this. The 250 Hz tone was presented at 105 dB(A) and the 500 Hz tone at 118 dB(A). In this experiment all subjects received the 250 Hz tone as the habituating stimulus and the 500 Hz tone as the dishabituating stimulus.

There was no difference in the number of stimulus presentations required to habituate to the 250 Hz tone between this Experiment and the fetuses experiencing the 250 Hz tone as the habituating stimulus at 35 weeks gestation in Experiment 1 (t = 0.235; df = 20; n.s.: mean number of stimuli to habituate (± standard error) for 250 Hz tone in Experiment 1 and Experiment 3 = 12.333 ± 0.987 and 12 ± 1, respectively). All 10 of the fetuses in this experiment dishabituated, i.e. responded, when presented with the novel, 500 Hz, stimulus.

Thus when possible intensity differences are controlled for the fetus at 35 weeks of gestational age still dishabituated suggesting that the observed dishabituation response is based on frequency differences and that the fetus at this age is able to discriminate between a 250 Hz and 500 Hz pure tone frequency.

5. Experiment 4 — The ability of the fetus to discriminate between vocal sounds

5.1. Background

Whilst there have been comparatively few studies examining the newborn’s response to differences in single frequencies more attention has been paid to the newborn’s ability to discriminate between more complex sounds, in particular components of speech. Given the importance of language and speech for communication, and development in general, the ability to discriminate between different speech sounds is crucial and it is perhaps not surprising that individuals, very early in
development, show the ability to discriminate different speech sounds. Infants 1-month-old are able to discriminate between different voiced and voiceless forms of stop consonants, \([b] - [p], [d] - [t]\), and vowels, \([a] - [i], [i] - [u]\) [33]. At 2 months of age infants are able to discriminate the place of articulation, \([ba] - [ga]\), and place of articulation differences for stop consonants in the final segments of both vowel–consonant–vowel syllables, \([bad] - [bag], [bag] - [bam]\), and vowel consonants, \([ad] - [ag]\) [20].

Two lines of evidence, one direct, one indirect, suggest that the fetus is sensitive to, and able to discriminate, differences in speech sounds. Indirect evidence is presented by studies which have examined fetal learning [9,10]. For example, DeCasper and Spence [5] found that newborn infants preferred a story which had been read aloud by their mother before birth over another unfamiliar story. This preference is maintained even if the story is read by an unfamiliar mother. This suggests that the infant is able to recognise the story and remember this as a newborn retaining sufficient information to discriminate it from another unfamiliar story. More direct evidence was provided by Lecanuet et al. [17] who studied fetuses between 35 and 38 weeks of gestational age to investigate whether they could discriminate between different sounds \([babi]\) or \([biba]\). In their study fetal heart-rate was monitored as an indicator of response. The experiment was performed when the fetus was in a low heart-rate variability state (corresponding to the heart-rate pattern associated with 1F state, frequently called quiet sleep) when no spontaneous movements were occurring. The sounds were transmitted at 95 dB spl. One group was presented with the paired syllables \([babi]\) as the habituating stimulus followed by \([biba]\) as the dishabituating stimulus, the other group received \([biba]\) as the habituating stimulus followed by \([babi]\) as the dishabituating stimulus. The results indicated that the fetus habituated to the first stimulus and dishabituated to the novel, dishabituating stimulus. Thus the fetus is able, at 35–38 weeks of gestation to discriminate between the two stimuli.

The following experiment extended the study of Lecanuet [17] and examined whether fetuses could discriminate between two speech stimuli, \([ba]\) and \([bi]\). A similar design to that described above, Experiment 1, was adopted but the stimuli used in this Experiment were speech sounds rather than pure tones.

5.2. Subjects

Thirty-six fetuses were divided into two groups depending upon their gestational age at the time of study. The first group were studied at 27 weeks of gestational age \((n = 18)\) and the second group were studied at 35 weeks of gestational age \((n = 18)\).

5.3. Apparatus

The stimuli used in this study were a pair of spoken syllables, \([baba]\) and \([bibi]\). Each syllable was spoken by the experimenter (S.S.) and recorded onto separate cassette tapes with an inter-stimulus-interval of 5 s. The cassette tapes were played by a cassette recorder (Samsung RCD 1000L) into a speaker and presented at an intensity of 110 dB(A), measured at 1 cm from the speaker face. Presentation of the stimuli was synchronised with the BBC computer such that at the start, and for the duration, of each syllable a mark was superimposed onto the video recording of the fetus by the BBC computer indicating when the stimulus was presented.
5.4. Procedure
Half of the fetuses at each age received the [baba] sound as the habituating stimulus and the [bibì] stimulus as the dishabituating stimulus. The other half received the [bibì] sound as the habituating stimulus and the [babà] sound as the dishabituating stimulus. The method used was identical to that reported for Experiment 1.

5.5. Results
All individuals, at both gestational ages, habituated to the stimuli. In order to assess whether the two syllables differed in their ability to habituate the fetus, an un-

![Graph showing habituation and dishabituation](image)

Fig. 2. The number of individuals responding to each stimulus ([bibì] and [babà]) presentation during the habituation and dishabituation phases of Experiment 4 at 27 (○) and 35 (●) weeks of gestational age.
paired t-test compared the number of stimulus presentations to habituate to the [baba] sound and the [bibi] sound at both gestational ages. There was no difference in the number of stimulus presentations to habituate to the two speech sounds at either 27 (t = 2.000; df = 16; n.s., mean number of stimuli (± standard error) to habituate to the [baba] and [bibi] sounds = 23.111 ± 2.705 and 16.222 ± 2.133, respectively) or 35 (t = 1.175; df = 16; n.s., mean number of stimuli (± standard error) to habituate to the [baba] and [bibi] sounds = 13.667 ± 1.333 and 11.889 ± 0.716, respectively) weeks of gestational age. Since the order of sound presentation had no effect on the number of stimulus presentations to habituate the results for the different sound presentation orders were combined for further analyses at each gestational age.

The number of individuals responding to each stimulus presentation is presented graphically in Fig. 2. All fetuses habituated at both gestational ages. An un-paired t-test comparing the number of stimulus presentations to habituate at 27 and 35 weeks of gestational age indicated there was a significant difference between the number of stimulus presentations to habituate at each age (t = 3.412, df = 34, P = 0.0017). Fetuses required fewer stimuli to habituate at 35 weeks of gestational age than at 27 weeks of gestational age (mean number of stimuli to habituate (± standard error) at 27 and 35 weeks of gestational age = 19.667 ± 1.868 and 12.778 ± 0.765, respectively).

Whilst fetuses at both gestational ages habituated to the initial stimulus the amount of dishabituation exhibited by fetuses to the novel stimulus differed. Three of 18 fetuses at 27 weeks of gestational age dishabituated whereas 17 of 18 fetuses (aged 35 weeks of gestational age) dishabituated. A Fisher two-tailed test revealed a highly significant difference (P < 0.00001) between the number of fetuses dishabituating at 27 weeks and 35 weeks of gestational age. The results suggest that at 35 weeks of gestational age the fetus could discriminate between the two syllables, hence the dishabituation response. However much less evidence of dishabituation was observed at 27 weeks of gestational age and the fetus at this age may be unable to discriminate between the two sound stimuli.

5.6. Discussion

The results of this experiment support the previous experiment (Experiment 1) indicating that the fetus is capable of discriminating different sounds, in this case speech sounds, at 35 weeks of gestational age but less so at 27 weeks of gestational age.

6. General discussion

Whilst these experiments do not enable the limits of frequency discrimination in the fetus to be assessed they do demonstrate that the fetus is capable of discrimination between different auditory stimuli in late gestation. The results indicate that the ability to discriminate between the stimuli used in this experiment develops and increases between 27 and 35 weeks of gestational age. The fetus is capable of some discriminations at the earlier gestational age examined, 27 weeks, since dishabituation was observed to the broad-band acoustic stimulus after habituation to the 250
Hz tone. This presumably indicates that the fetus is able to distinguish between a pure tone and a broad-band sound.

The inner ear as well as acting as a sensory transducer, converting the acoustic signal into neural impulses, also plays a role as a sensory analyser, encoding information of frequency and intensity. As the fetus is able to habituate, and dishabituate, at 27 weeks' gestation, it would seem probable that the inability to distinguish between the 250 Hz and 500 Hz pure tones, or the [ba] and [bi] sounds, at this age is due to the inability of the cochlea to differentially encode the frequency information contained in the two signals. However between 27 and 35 weeks of gestation the cochlea matures and is able to differentially encode this information. Although the physical site of the change responsible for increasing the ability to discriminate frequency is unknown and may result from synchronous maturation of a number of different components of the inner ear and more central auditory neural processing, the maturation of the outer hair cells may be particularly important.

The outer hair cells are crucial for 'tuning' the response of the basilar membrane to a particular frequency [25]. In contrast, to the inner hair cells whose development and adult level of organisation is present early in gestation (13 weeks) [25], the development of the outer hair cells continues until late gestation [25].

Thus the ability to discriminate at 35 weeks of gestation may represent the maturation of outer hair cell functioning enabling the encoding of frequency information from the acoustic signal.

Pure tone frequencies used in this experiment, will be encoded in adults by the rate of firing of the auditory nerves [25]. It may be that the development of discrimination is a result of the ability of the auditory nerves to fire at the rate of the stimulus. At 27 weeks the auditory nerves may be incapable of this differential firing and hence the inability to differentially encode the information.

One point, worth mentioning briefly relates to the usefulness of habituation as a tool to explore sensory abilities and the development of the fetus. The fact that the fetus is able to dishabituate enables the examination of its sensory discrimination abilities. In the above example the ability to discriminate frequency has been examined. However, other aspects of auditory functioning, e.g. intensity or temporal patterning, may also be explored and studies are currently underway examining these. Furthermore the exploration of sensory abilities in other modalities known to function in the fetus, e.g. light [24], touch [12], olfaction [27] may also be undertaken using the habituation technique.

The ability of the fetus to discriminate between various sounds reveals that the fetus, during the latter part of gestation at least, is able to discriminate between the various sounds that form part of its uterine environment. This discriminatory capacity is obviously important for learning about auditory stimuli in the womb and may underlie the ability of newborns to discriminate between their mothers voice and that of an unfamiliar female [5]. This study also demonstrated that the fetus is able to discriminate between speech stimuli and this may enable the acquisition of language to commence prenatally [10].

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8. References