Frequency representation

The ability to use the spectrum or the fine structure of sound to detect, discriminate, or identify sound.

By frequency representation, we really mean the accuracy with which the frequency or frequencies in a sound can be identified. Remember that there are two codes for frequency that listener might use, the place code and the frequency code. Sometimes both of these codes are available; sometimes only one would be available.

Frequency representation

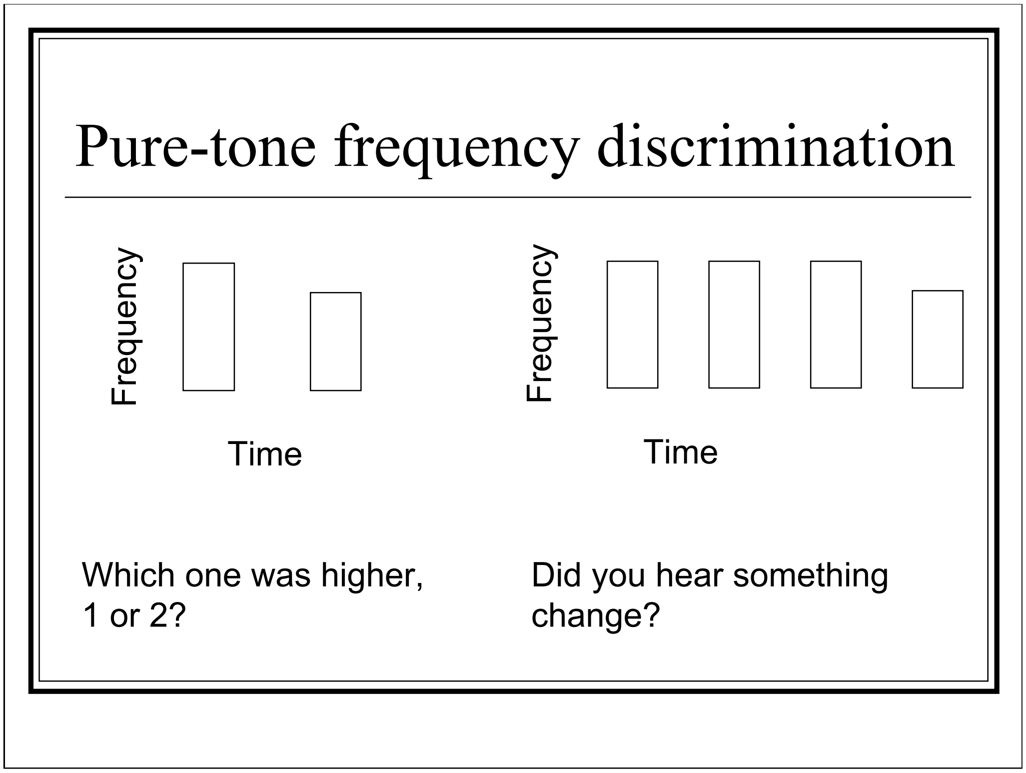
1. Development of frequency discrimination and frequency resolution
2. Development of mechanisms involved in frequency representation

So first we'll talk about how frequency representation changes with age; then we will try to figure out what about the auditory system is maturing to produce these changes.

Tasks involving frequency representation

- Frequency discrimination
- Masking
- Pitch and timbre perception
- Speech perception and much, much more.

I will concentrate on frequency discrimination and masking in this lecture, returning to pitch perception later on.



So first I’ll talk about pure tone frequency* discrimination. The basic question is, how small can I make the frequency difference between two tones and still have the listener tell that the tones are different in frequency. You might remember that human adults are very good at this task. For example, they can hear a frequency difference of 1 Hz in a 1000 Hz tone presented at a moderate level.

The way we might test adults in this task is to present 2 tones and ask them to push button 1 or button 2 to indicate which they thought was higher in frequency. This is your standard two-alternative forced choice task. Such a task works with children who are 4 or 5 years old.

Infants aren’t that great at pushing buttons and it’s hard to explain what you want them to do, so we typically use a procedure that looks something like the situation on the right side of the slide. We play a series of tones at one frequency, then change the frequency and ask whether the infant noticed the change.

•In psychoacoustics we say frequency discrimination rather than pitch discrimination, because although people probably are using the perceived pitch of a tone to perform this task, we aren’t really measuring pitch.

•Reference for adult frequency discrimination:
Frequency discrimination as a function of frequency and sensation level
Craig C. Wier, Walt Jesteadt, and David M. Green
J. Acoust. Soc. Am. 61, 178 (1977)

How do you get a baby to tell you that she heard something change?

So now we will take a little detour to talk about psychoacoustic testing of infants, returning to frequency discrimination momentarily. There are two basic procedures that are used to do psychoacoustic testing of infants, habituation based procedures and conditioned response procedures.

Habituation-based procedures

- One stimulus or type of stimulus is presented to the infant repeatedly.
- The infant responds to the stimulus in some way, but on repeated presentations the response decreases (“habituates”).
- Once habituation has occurred, the stimulus is changed.
- If the infant’s response increases (“recovers”) then discrimination has occurred; if not, we don’t know anything.

In habituation based procedures, the basic idea is that if an infant hears the same sound over and over, she will stop responding to it. If the sound changes, then the infant will start responding again if she notices the change. There are many technical issues associated with habituation-based procedures, such as how you decide that habituation has occurred, whether you present the same number of stimuli to all subjects or keep presenting stimuli until the response decreases by some criterion amount, which trials you use to define response recovery, etc. We won’t go into those, but you should be aware that they exist.

Variations on habituation-based procedure

- Habituation (heart rate deceleration)
- High amplitude sucking
- Visual fixation

There are several variations on this theme. Many early studies used a straight habituation procedure. You present a sound; you measure the infants’ response to the sound--frequently a change in heart rate; when the response habituates, you change the sound and see if the response is reinstated.

Because young infants in particular do not make many overt responses to sound, these other variations first teach the infant to respond in some way and reinforce the response with the presentation of the sound. So for example, if you suck on this pacifier (which happens to be attached to a pressure transducer), you get to hear a tone. This is the high amplitude sucking paradigm. It is called high amplitude sucking because they only accept high amplitude sucks as responses; babies will make lots of small amplitude sucks unintentionally you might say, so you want to make sure they were really trying to hear the sound. Of course after a while, one gets tired of listening to a tone, so the sucking rate will decrease. Then you change the tone, and look to see if the response is re-instated.

Visual fixation works the same way: the baby learns to look at a picture or pattern to get the sound to come on.

High amplitude sucking

This movie explains the application of the high amplitude sucking method to speech discrimination, but it would work the same way for any sort of sound discrimination.

Advantages and disadvantages of habituation-based procedures.

- Based on naturally occurring infant responses
- Relatively easy to get data from an infant

- Can't test adults as comparison
- Can't measure thresholds
- Interpretation of negative result.
- Depends on infant wanting to hear the sound you are studying.

The advantages and disadvantages of habituation type procedures are listed here. A strong advantage of these procedures is that they all are based on a response that infants frequently make-- like sucking or looking at things, so the baby is very likely to make that response and quickly learn the contingencies.

Not many trials are required to get data from infants-- maybe 8-20; so it's pretty easy to get data from most of the infants you test.

The disadvantages are on the right. A big problem is that if you want to know if babies are as good as adults, you don't have a good adult comparison, because this procedure won't work with adults (or even older kids).

You can test one stimulus difference in a run. In other words, you can see if the baby can tell 1000 from 1500 Hz. But if you want to know if they can tell 1000 from 1200 Hz, you have to start all over. And you would need many of these runs to figure out the difference that infants can just discriminate. The problem is that infants won't keep responding in this way indefinitely. So you can't really measure a threshold this way.

Another issue is the interpretation of a failure for a response to recover when the sound is changed, We'd like to say that the infant couldn't hear the change, but we can't be sure whether the infant couldn't hear the change or the infant could hear the change, but just didn't care.

Finally, the whole procedure is built on the idea that infants will respond to the sound and that they will do something so that they can hear it. In other words, the infant has to want to hear the sound you are studying. If the infant doesn't care about the sound at all, it's going to be hard to get him to respond.

However, many studies have used this technique to establish that infants can discriminate many changes in sounds or to study the conditions under which infants are able to discriminate sound.

Conditioned response procedures

- The stimulus is a sound or a change in an ongoing sound, but it serves as a signal to the infant that he should respond.
- If the infant responds when he hears this "signal", he gets to see something interesting (e.g., a mechanical toy or video comes on)

Variations on conditioned-response procedures

- Conditioned head-turn procedures
  - Visual Reinforcement procedures
  - 2 spatial alternative procedures
- Observer-based procedures

There are several sorts of conditioned-response procedures. In a common procedure, the response that the infant is required to make is a head turn in one direction. In some procedures, the infant turns in one direction--often toward the sound source--and the infant is is reinforced, or rewarded,for responding by the presentation of a mechanical toy or video positioned on the side to which he turns. This method originated as Visual Reinforcement Audiometry, but it is often used to test discrimination. For example, the infant might hear a repeating syllable “bah” and learn that when the syllable turns to “pah”, turning toward the reinforcer will make it come on.

Another procedure that uses a conditioned head turn but that is only useful when we are asking infants to detect a sound is the 2 spatial alternative procedure. Here there are speakers on the infant’s right and left. A sound comes on from one speaker. The infant learns to turn toward the speaker playing the sound to see the reinforcer. They’ll have a mechanical toy or video near each speaker. The advantage of the 2 spatial alternative procedure is that it controls for the infant’s tendency to respond, or response bias, just like the two alternative forced choice procedure that we use for older kids and for adults. The disadvantage is that it cannot be used for many different psychoacoustic tasks.

Head-turns are really great responses to use, because many infants make them spontaneously so it’s easy for them to learn the contingencies. Furthermore, it is pretty easy for someone with even a little training to reliably judge head turns. If two people watch the same baby, they will agree on head turns something like 95-99% of the time.

The second variation on conditioned response procedures is observer-based procedures. These are the procedures we use in my lab. A disadvantage of conditioned head-turn procedures is that not all babies make head turns toward a sound source. You have already probably learned that infants don’t make head turns toward a sound source before they are 6 months old. Actually they do make head turns to sound sources but they are very slow responses-- hard to use in a conditioning experiment. Young infants do make responses to sound--like changes in facial expression or in motor activity-- but they tend to vary from infant to infant and from one time to another within the same infant. Procedures that are based on asking whether the infant made one of these responses (e.g., behavioral observation audiometry) tend to produce very high, unbelievable infant thresholds and the results are not very reliable (repeatable).

Observer-based procedures kind of turn the tables on the experimenter. Instead of asking the person watching the baby to decide whether the baby responded on that trial, the observer-based method asks the person to decide whether or not a signal was presented to the infant, solely on the basis of the infant’s behavior. So this “observer” knows when a sound might be presented to the infant, but does not know whether a sound (or a change in a sound) actually occurred. The observer has to figure out whether there was a signal on or not by looking at the infant’s behavior. Obviously, if the observer can do this well, then the infant must have responded to the sound. The infant can respond to the sound in whatever way she wants.

So why is this a conditioned response procedure? Infants generally will not continue to make these responses when they hear the sound indefinitely. We have to provide them with some motivation. That’s where the reinforcement and conditioning come in. Whenever the observer correctly identifies a signal, which would mean that the infant made an observable response, then the mechanical toy or video is turned on to reinforce the infant’s response. So the infant learns to do something observable when he hears a sound to get to see the reinforcer.

Observer-based methods

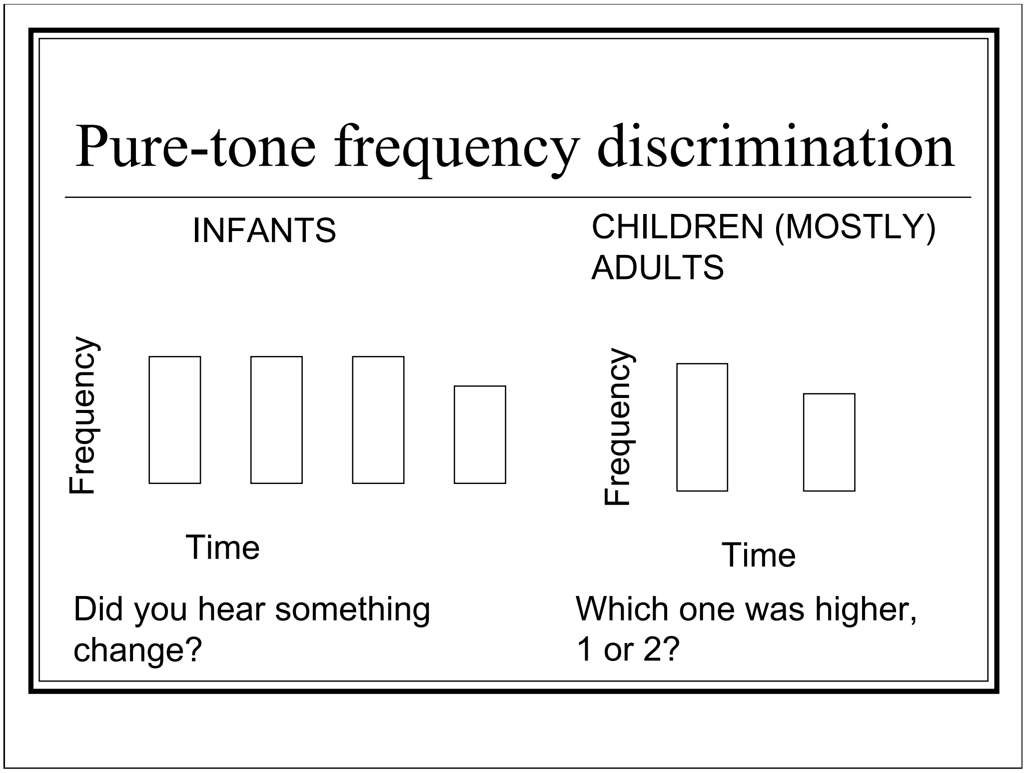
The left picture shows the inside of the booth. It looks a lot like VRA. The mechanical toy in this picture is over to the baby's right. On the outside is the observer, shown on the right, who tells the computer when to start a trial, but doesn't know whether the computer will present a sound or not. The observer can watch through the window or on the monitor to decide whether the sound was presented.

Advantages and disadvantages of conditioned-response methods

- Can test adults as comparison
- Can measure thresholds
- If the baby likes the reinforcer, it doesn't matter if he likes the sound

- May need to train response in some infants (head turns)
- May exclude infants who don't meet control conditions.

Back to frequency representation



So first I'll talk about infant studies of frequency discrimination, then about child studies, some of which used the two-alternative forced choice method.

Early studies of infant frequency discrimination

- 1-month-old infants
- High amplitude sucking
- 200 v. 500 Hz

Wormith, S.J., D. Pankhurst, and A.R. Moffitt, Frequency discrimination by young infants. Child Dev, 1975. 46: p. 272-275

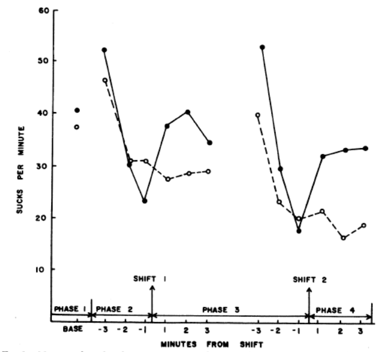


Fig. 1.—Mean number of sucking responses as a function of time prior to and following the first (left) and the second (right) shift in the frequency of the reinforcing tone for the experimental (solid circles) and control groups (open circles). Baseline data are taken from the last 2 min of phase 1, the baseline period.

There were several early studies that demonstrated that even newborns can tell the difference between tones that were really different in frequency. For example, Wormith et al. (1975) used the high amplitude sucking procedure to determine whether 1-month-olds could tell a 200 Hz tone from a 500 Hz tone. Their results are shown here. The curves on the left show the infants response to the habituation tone, then the arrow indicates where the frequency was changed. . The dashed line is for infants who heard the same tone after habituation as before (the control group). Notice that the sucking rate went up for the infants who heard the frequency change but not for the infants who heard no change. In the next phase of the experiment the frequency for the experimental group switched back to the original frequency, then to the comparison once again-- at the arrow. In other words, An infant might hear 200 Hz, habituate, then hear 500 Hz and habituate to that; then they switch back to 200 Hz and finally to 500 Hz again. The control group always hears just one frequency.

The main result is that every time the frequency changes, the infants' response rate tends to recover, indicating that they heard the change.

(Why does their response rate increase in phase 3? Could be regression to the mean.)

References

1. Bench, J., Audio-frequency and audio-intensity discrimination in the human neonate. Int Audiol, 1969. 8: p. 615-25.
2. Wormith, S.J., D. Pankhurst, and A.R. Moffitt, Frequency discrimination by young infants. Child Dev, 1975. 46: p. 272-275
3. Leventhal, A. and L.P. Lipsitt, Adaptation, pitch discrimination and sound localization in the neonate. Child Dev, 1964. 35: p. 759-767..

Frequency discrimination at 3-12 months

- 3, 6, 12 months, adults
- Observer based method
- 500, 1000, 4000 Hz jnd
- adaptive thresholds

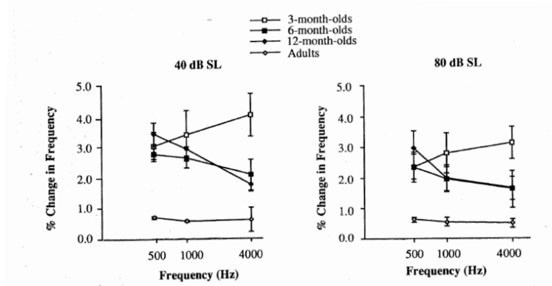


FIGURE 11 Frequency difference limens expressed as a percentage of standard frequency, as a function of standard frequency for infants and adults. Error bars indicate ±1 standard error. SL = sensation level. From Olsho, Koch, and Halpin (1987). Copyright 1987 by Acoustical Society of America. Reprinted by permission.

Olsho, L.W., E.G. Koch, and C.F. Halpin, Level and age effects in infant frequency discrimination. J Acoust Soc Am, 1987. **82**: p. 454-464.

Given that adults could discriminate a change of a few Hz at 200 or 500 Hz, telling 200 from 500 Hz is not much of a challenge. Later studies estimated frequency discrimination thresholds-- the just noticeable change in the frequency of a tone. The subjects were tested at two intensities 40 dB and 80 dB above their own detection threshold for the tone (sensation level, SL)

The adults are shown in the unfilled diamond symbols. At all frequencies they can detect a frequency change less than 1%, and they do a little better at 80 dB SL than at 40 dB SL. They are not as good as trained listeners tested with 2AFC, so it is important that we tested them in the same procedure as we tested the infants.

At 3 months, infants detect 2-4% changes in frequency, and their jnd gets worse as the frequency increases. They are closer to adult performance at 500 Hz than they are at 4000 Hz.

The pattern is different for 6 and 12 month olds. At 500 Hz, they aren't much better than the 3-month-olds. Their jnd is 2-3%. But as the frequency increases, older infants get better at frequency discrimination. At 4000 Hz, their jnd is approaching adults. In fact, in an earlier study Olsho (1984) found that infants in this age range were just as good at adults in frequency discrimination at 4000 and 8000 Hz. So by 6 months, infants seem to be like adults or nearly like adults at discriminating high frequencies, but they remain fairly poor at low frequency discrimination.

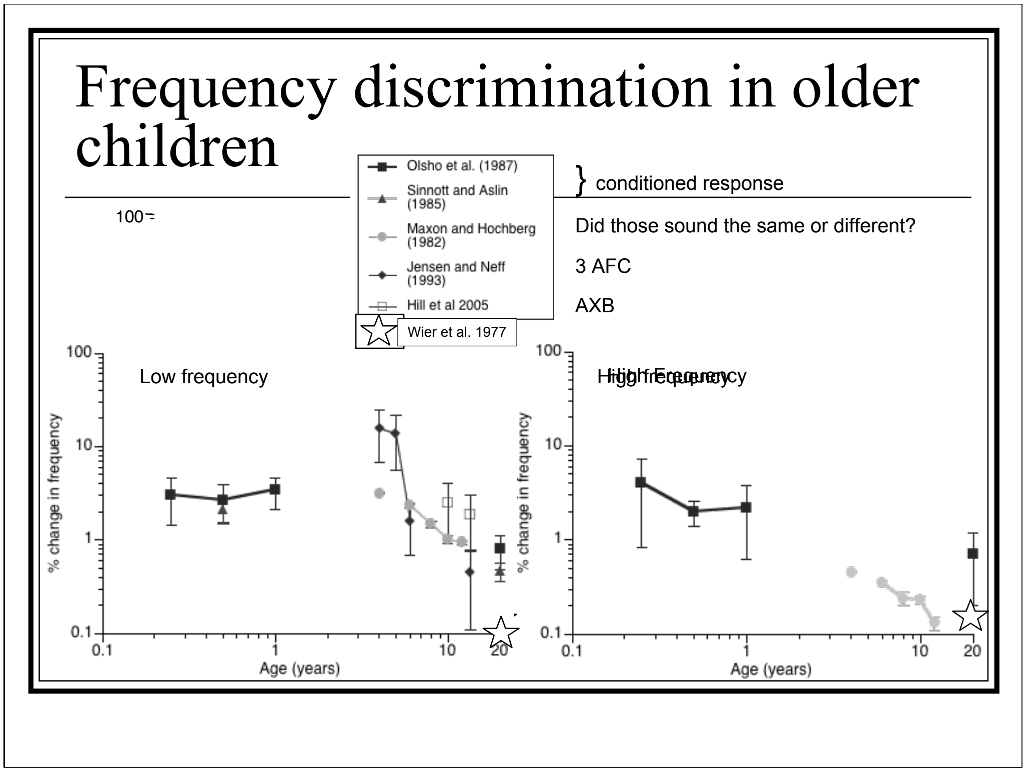
Between 3 months and 6 months there is a big improvement in high-frequency discrimination, but low-frequency discrimination seems to take longer to mature. Notice also that all the infants benefit from the higher intensity tone, but that the benefit is bigger for the 3-month-olds than for older listeners.

References

1.Olsho, L.W., Infant frequency discrimination. Infant Behavior and Development 1984. **7**: p. 27-35.

2.Olsho, L.W., E.G. Koch, and C.F. Halpin, Level and age effects in infant frequency discrimination. J Acoust Soc Am, 1987. **82**: p. 454-464.

3.Sinnott, J.M. and R.N. Aslin, Frequency and intensity discrimination in human infants and adults. J Acoust Soc Am, 1985. **78**: p. 1986-1992.



There have been just a few studies of the development of frequency resolution in older kids. In this slide the results of all the studies are plotted, with the low-frequency results shown on the left and the high-frequency results shown on the right. The data from infants are shown in the blue squares (Olsho et al 9187) and in the red triangle (Sinnott and Aslin 1985); you can see that for the one condition where we can compare, the results are fairly similar.

To see where things are going here, look at the results for adults in the two panels. The blue squares and the red triangle ate the results for adults in the infant studies. These adults were tested in a procedure like the infants, and they didn’t practice the task a lot (like the infants). The stars are the results from a study by Wier et al. in which they obtained data from highly trained psychophysical listeners in a 2AFC task. Obviously the trained listeners in 2AFC do a lot better.

So the kids in different studies were tested with different methods*, and there is less consistency in the results for older kids. Jensen and Neff used a 3AFC procedure, but they didn’t exclude the data of kids who weren’t paying attention. Hill et al. used an AXB procedure, which is also a standard psychophysical procedure. Maxon and Hochberg did things in a less standard way. Basically, the experimenter played two tones to the kids using an audiometer and asked them whether those sounds were the same or different. This is not a very controlled situation, and you can see that Maxon and Hocheberg’s subjects generally get the best thresholds.

If we ignore Jensen and Neff’s results, it looks like 4-5 year olds are only a little better than infants at low frequency discrimination and that kids gradually improve with age, not quite approaching the performance of untrained baby-tested adults at age 13-14 years.

At high frequencies, we don’t have much data. Remember that Olsho et al 1987 reported that the 6 an 12 month olds were as good as adults at high frequencies. Maxon and Hochberg’s kids are still showing improvement, but they are all better than the untrained baby-tested adults and they are close the performance of well-trained 2AFC-tested adults. So kids are a lot like adults at high-frequencies, but not low.

These results are consistent with the idea that high-frequency discrimination matures fairly early, but that low-frequency discrimination takes longer to develop

*3AFC is the 3 alternative forced choice. Three tones are presented. Two are at the standard frequency. One is ΔF higher. The listener picks the highest tone. In AXB, three tones are presented, A, X, and B. A is always the standard tone. B is always ΔF higher. X is either the same as A or the same as B. The listener picks the tone that is different, A or B.

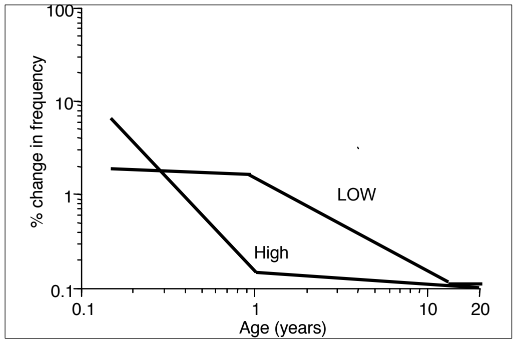
References

1. Hill, P.R., J.H. Hogben, and D.M.V. Bishop, Auditory frequency discrimination in children with specific language impairment: A longitudinal study*.* J Speech Lang Hear Res, 2005. **48**: p. 1136-1146

2. Jensen, J.K. and D.L. Neff, Development of basic auditory discrimination in preschool children*.* Psychol Sci, 1993. **4**: p. 104-107.

3. Maxon, A.B. and I. Hochberg, Development of psychoacoustic behavior: Sensitivity and discrimination*.* Ear Hear, 1982. **3**: p. 301-308.

Development of frequency discrimination



Possible explanations for differences in development of low and high frequency discrimination

- It takes longer to learn low frequency discrimination and infants/kids need even more practice than adults.
- The codes for low and high frequencies develop differently

One explanation for why low frequency discrimination develops more slowly is that it is harder to learn low frequency discrimination (for some as yet unspecified reason). If kids need more time to learn than adults-- which would not be unreasonable--then they would have a particularly hard time with low frequency discrimination.

Studies of training frequency discrimination suggest that this is true, but that the effect is not great enough to account for the infant-adult difference in low frequency discrimination. Furthermore, this explanation doesn't address why high-frequency discrimination is so poor in infants younger than 6 months of age.

What about the codes for frequency? There are a couple of options. Maybe people use the place code to perform frequency discrimination, and that the place code develops first at high frequencies-- beginning early in infancy and maturing rapidly, while the place code at low frequencies develops more slowly.

We know thought that adults probably depend more on the temporal code for discriminating low frequencies, while they are forced to depend on the place code at high frequencies. That might mean that the place code is developing rapidly during infancy, but that the temporal code develops very slowly.

References

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2.Moore, B.C.J., Frequency difference limens for short-duration tones. J Acoust Soc Am, 1973. **54**: p. 610-619.

3.Olsho, L.W., E.G. Koch, and E.A. Carter, Nonsensory factors in infant frequency discrimination. Infant Behav Dev, 1988. **11**: p. 205-222.

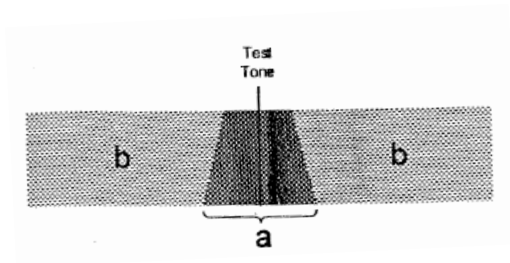
Development of frequency resolution (place code)

- Thresholds in noise
- Psychophysical tuning curves
- Critical bandwidth
- Auditory filter width

So if the development of frequency discrimination has something to do with the place code, then if we measure the accuracy of the place code--also known as frequency resolution--we should find that it improves with age like frequency discrimination does.

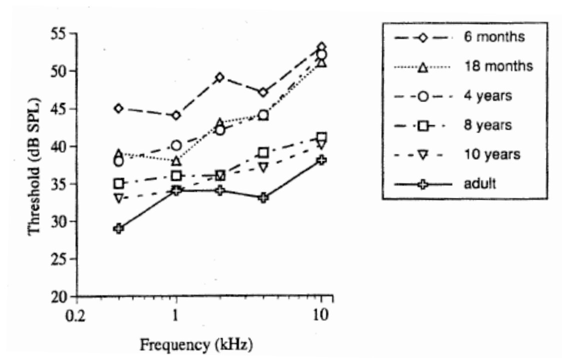
There are several ways to measure frequency resolution, and these have been studied in infants and children.

The critical band concept



Thresholds in noise are a measure of frequency resolution, based on the logic of the critical band concept. If there are some sorts of filters in the auditory system that we listen through, then when we are detecting a tone in noise, we listen through the filter that is centered on the frequency of the tone we are detecting. The only the noise in that filter (a) actually interferes with the perception of (MASKS) the tone. The person detect the tone when its intensity is high enough to cause a noticeable change in the sound intensity coming through that filter. The rest of the noise (b) gets filtered out. But if one person has a broader filter than another, then that person will have a higher threshold for the tone, because more of the noise will pass through the same filter as the tone.

Development of thresholds in noise



Schneider et al. (1989) summarized a series of studies that they did to measure thresholds for detection of a 1/3 octave band of noise masked by a broadband noise. (Although they didn't use tones, the results don't change if you use tones rather than noise bands.)

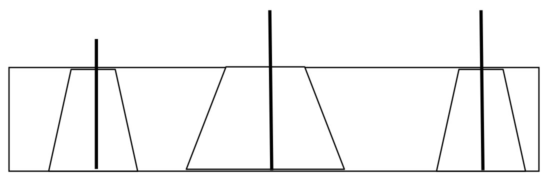
In this graph threshold is plotted as a function of the center frequency of the noise band, for listeners between 6 months of age and adulthood. All of the listeners were test with a similar method-- the 2 spatial alternative conditioned response for the infants, and then the kids and older adults were tested in the same set up except that they pushed a button on the left or right arm of the chair they were sitting in to indicate whether the noise band came from the left or the right.

So detection in noise definitely changes with age. A 6-month-olds threshold is about 15 dB higher than an adults, and 8 or10-year-olds' thresholds are pretty close to adults'. So that would be consistent with a change in frequency resolution between infancy and adulthood. But development occurs pretty much in parallel across frequencies-- which isn't true of frequency discrimination.

Reference

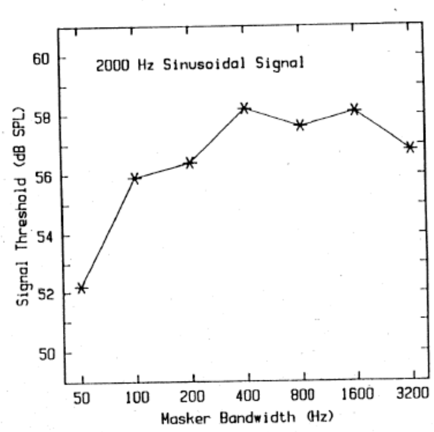
1.Schneider, B.A., S.E. Trehub, B.A. Morrongiello*, et al.*, Developmental changes in masked thresholds. J Acoust Soc Am, 1989. **86**: p. 1733-1742.

Both frequency resolution and intensity resolution affect thresholds in noise



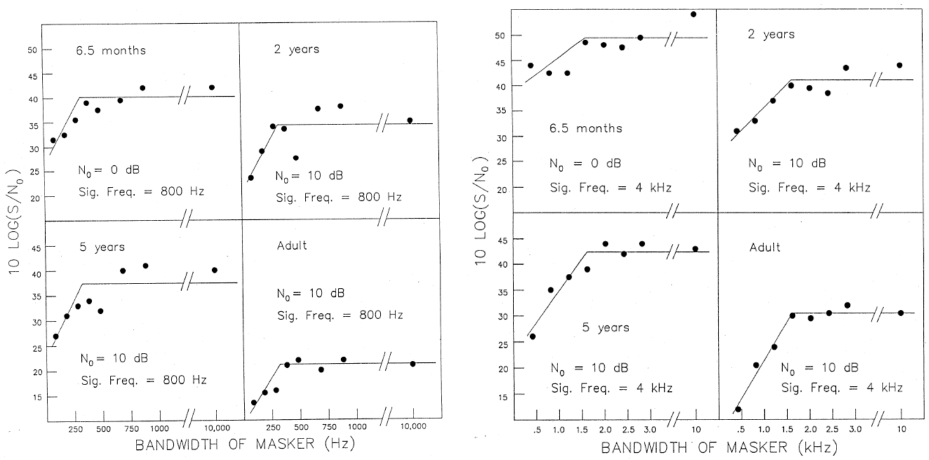
The problem with using thresholds in broadband noise as a measure of frequency resolution is that the thresholds depend on both frequency and intensity resolution. A person could have a normal filter width (frequency resolution) but just need to have a bigger change in the intensity within the filter to tell that the tone was there.

Critical bandwidth



Another way to measure frequency resolution is to measure the threshold for a tone masked by noises of different bandwidths. As long as the bandwidth of the noise is less than the width of the auditory filter, increasing the bandwidth of the masker will increase the threshold for the noise. But once the masker bandwidth is broader than the auditory filter, further increases in bandwidth do not affect the tone's threshold.The bandwidth at which the threshold levels off is at the width of the auditory filter, and is called the critical bandwidth.

Development of the critical bandwidth

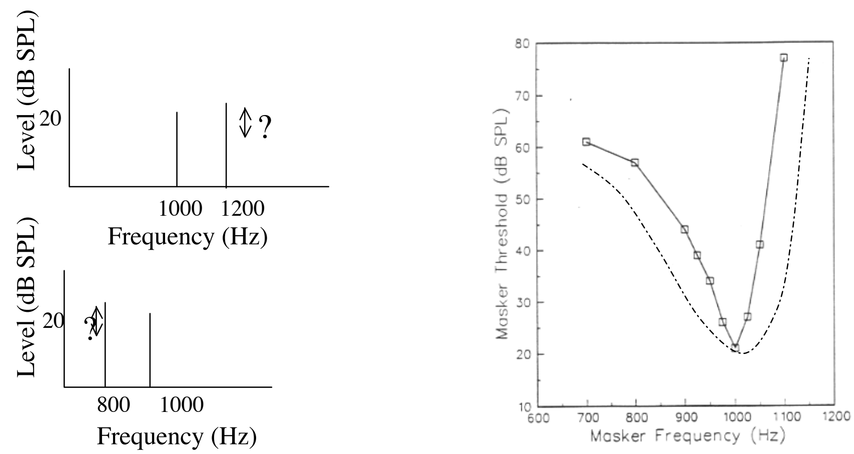


These are critical bandwidth data collected by Schneider et al (1990).The left panel is for 800 Hz; the right panel is for 4000 Hz. The data are shown in the filled circles. The lines are best fitting “critical bands”. If you look at the break point between the rising portion of each curve and the flat portion and compare that across ages (6.5 mo, 2 yr, 5 yr, adult) they all look about the same, at both frequencies. So these results agree that once you are 6 months old or so your auditory filter is like an adults.

Reference

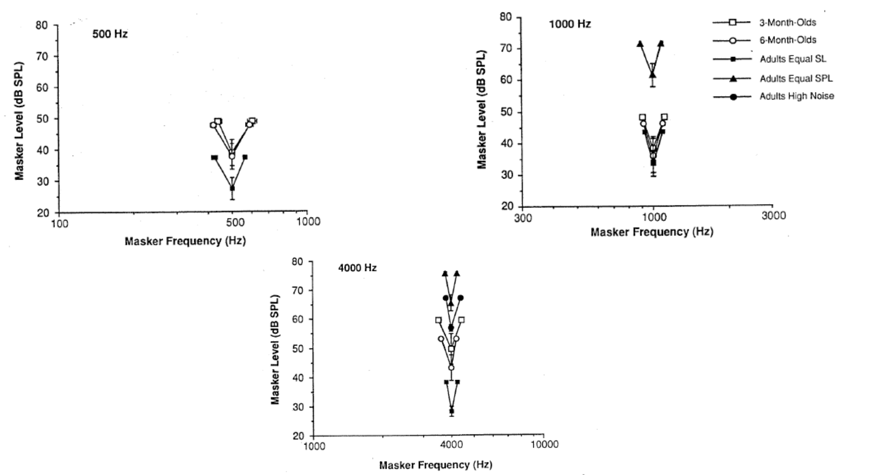
1.Schneider, B.A., B.A. Morrongiello, and S.E. Trehub, The size of the critical band in infants, children, and adults. J Exp Psych [Hum Percept Perform], 1990. **16**: p. 642-652.

Another measure of frequency resolution: Psychophysical tuning curve



In the psychophysical tuning curve experiment, the listener detects a tone that is presented at a fixed low level. The tone is masked by another tone or a noise band. The level of the masker is adjusted to find the masked threshold for the tone. This process is repeated for different masker frequencies. When the frequency of the masker and tone are very close, , then the masker level won't have to be very high, because the tone and masker pass through the same auditory filter. As I move the masker frequency away from the tone frequency, the masker level has to be higher and high, because less and les of the masker passes through the same filter as the tone.. So the result you get is shown on the right. The tone frequency in this graph was 1000 Hz, and the lowest masker level they need to mask that tone was right at 1000 Hz. As the masker frequency moves away from 1000 Hz, higher and higher masker levels are need to mask the tone. The dashed curve represents what might happen if the listen has a broad (or immature) auditory filter, a broader range of masker frequencies will mask the tone at a low level; you have to move the masker further away from the tone before more of the masker falls outside the filter centered on the tone.

Infant psychophysical tuning curves



These are “little” tuning curves-- just the tips-- from a study by Spetner and Olsho (1990). They were measured at 500 Hz (top left), 1000 Hz (top right) and 4000 Hz (bottom), Three month olds are shown with unfilled squares; 6 month olds are shown with unfilled circles; adults are sown in filled symbols-- they were tested in several control conditions you don’t need to worry about.The thing to look at is how “spread out” the tuning curve is for the infants compared to the adults. At 500 Hz they are pretty similar; at 1000 Hz they are pretty similar; at 4000 Hz, there is one curve, that kind of sticks out. It is the curve for the 5 month olds. In fact, if you directly compare the “widths: of the tuning curves, the 3-month-olds are significantly wider than the 6 month olds and the adults-- only at 4000 Hz. The 6-month-olds are like adults at all frequencies.

Note that 3month olds are also poorer than 6 month olds at frequency discrimination at 4000 Hz.

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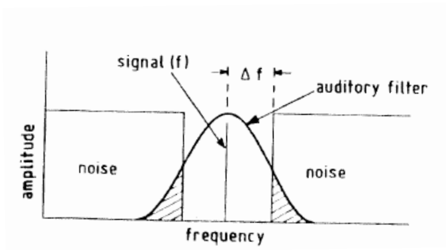
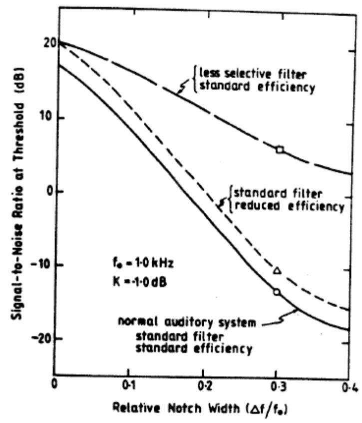
1.Olsho, L.W., Infant auditory perception: Tonal masking. Infant Behav Dev, 1985. **7**: p. 27-35.

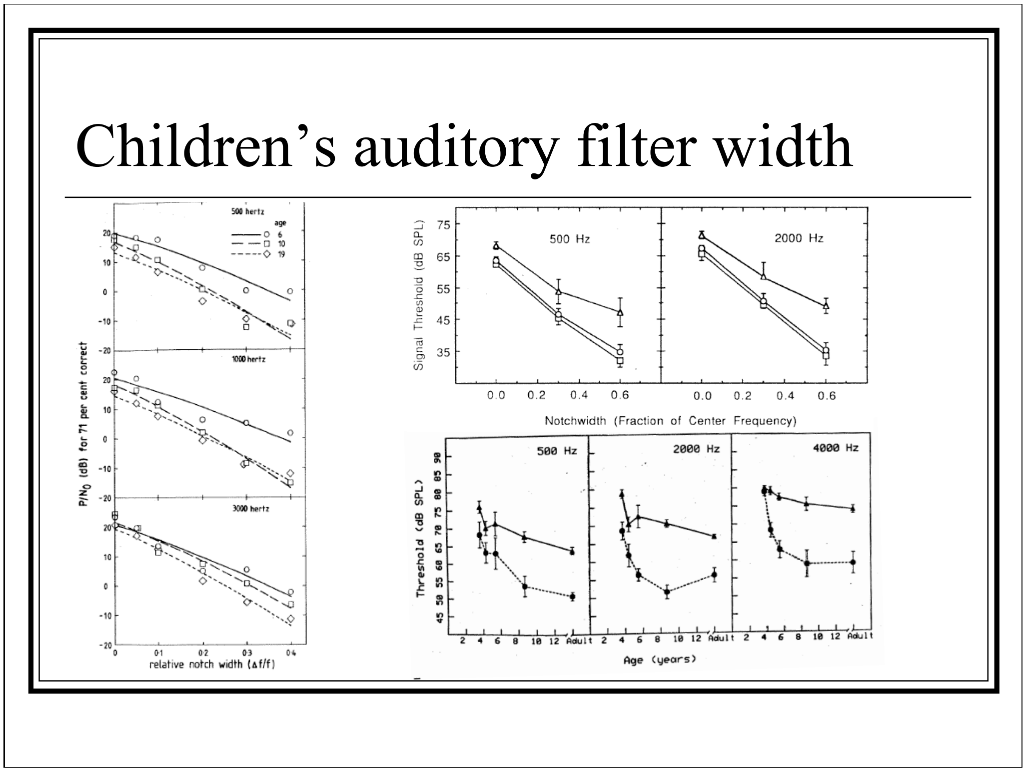
2.Spetner, N.B. and L.W. Olsho, Auditory frequency resolution in human infancy. Child Dev, 1990. **61**: p. 632-652.

Auditory filter widths





Finally, another way to measure auditory filter width is called the auditory filter width procedure (!) Here was we do is measure the threshold for a tone in a noise that has a hole, or “notch” in its spectrum. The notch is centered on the tone frequency. If the listener is listening through the auditory filter centered on the tone frequency, then when I make the notch really small, a lot of the noise will go through the filter with the tone, and the threshold for the tone will be high, If I make the notch bigger, the threshold for the tone should go down, because less noise is going through the filter with the tone. By measuring how threshold changes as I change the width of the notch, I can figure out how wide the filter is. A broad filter will show more gradual changes in threshold, like the top curve in the graph at the right, while a narrow filter will show more abrupt changes in threshold as the notch width is increased



There are three studies of auditory filter width in children; none to date in infants, but they produced inconsistent results.

Irwin et al tested 6 and 10 year olds and adults at three frequencies and got the results in the left hand graph. Notice that the threshold curve for the 6 year olds is more gradual at 500 and 1000 Hz than the older listeners. At 3000 Hz, they re pretty much all the same. So Irwin et al concluded that low-frequency filter widths were still immature at 6 years.

Hall and Grose tested 4 year olds, 6 year olds and adults at 500 and 2000 Hz. Their results are in the top right graph, where the 4 years olds are plotted in triangles, the 6 year olds are plotted in circles and the adults are plotted in squares. The 6 year olds look just like the adults at both frequencies. The 4 year olds sowed more gradual improvement in threshold at both frequencies suggesting broader auditory filters at both frequencies. They did not test any higher frequencies.

Allen et al repeated the experiment with the results on the right. The format is different in this graph. In each panel the solid line is the threshold for a noise with a 0-Hz notch (I.e., no notch) and the dashed line is the threshold with a medium sized notch. If these two lines are close together at some age, that would mean only a gradual threshold change as the notch width is increase; if they are far apart, it would mean an abrupt improvement in threshold with increasing notch width. So Wightman et al tested 3.5 year olds, to 12 year olds, and up to adults. They find that the solid and dashed lines are about the same distance apart for kids who are over 6 years old and adults. For younger kids, the lines are closer together-- that would mean younger kids have broader auditory filters than older kids and adults. The results look pretty similar at 500 and 2000 Hz-- but at 4000 Hz, the youngest kids have NO difference between the two lines. That would mean they basically have NO auditory filter-- it’s infinitely wide.

So Irwin et al say 6 year olds are immature at lower frequencies. Hall and Grose say 6 year olds are mature but 4 year olds aren’t at those frequencies. Allen et al say 6 years olds are mature, but that younger kids have broader filters, especially at high frequencies.

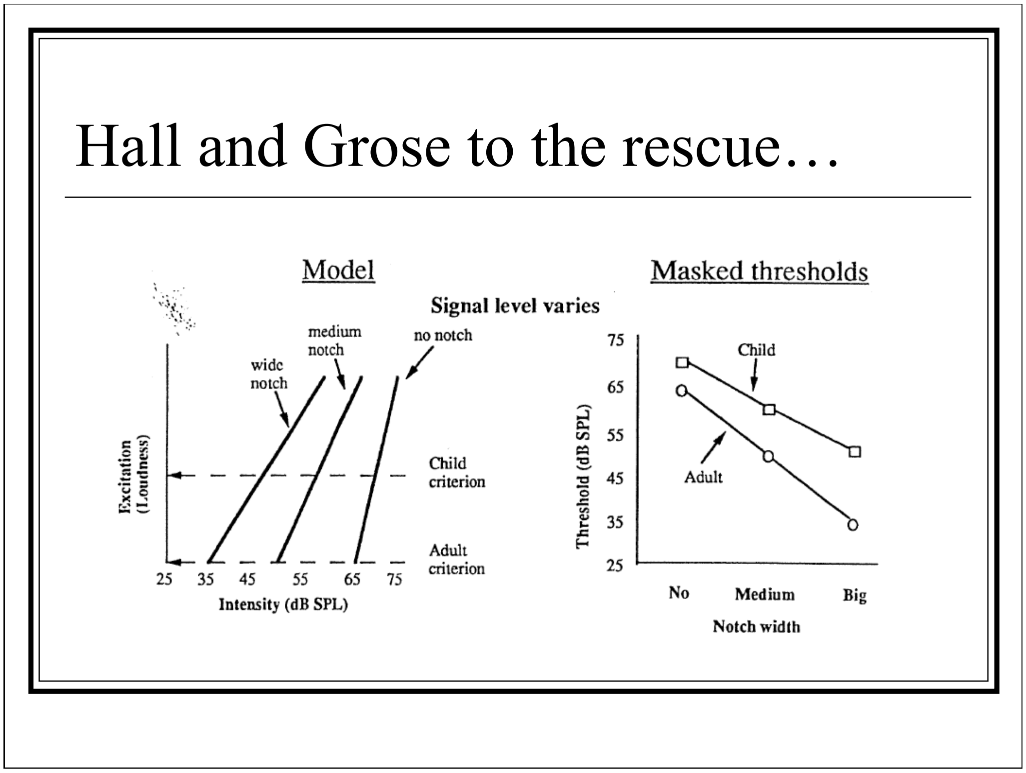
So 2 out of 3 say 6 year olds are mature; but it looks like maybe 4 year olds aren’t, especially at high frequencies. And of course neither of these results agree with the critical band results or the psychophysical tuning curve results that say that we have mature filter widths at 6 months of age.

References

1.Allen, P., F. Wightman, D. Kistler*, et al.*, Frequency resolution in children. J Speech Hear Res, 1989. **32**: p. 317-322.

2.Irwin, R.J., J.A. Stillman, and A. Schade, The width of the auditory filter in children. J Exp Child Psychol, 1986. **41**: p. 429-442.

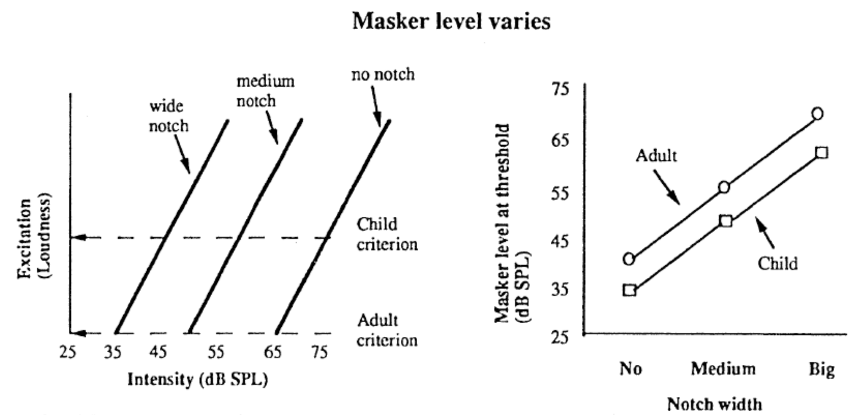
3.Hall, J.W. and J.H. Grose, Notched-noise measures of frequency selectivity in adults and children using fixed-masker-level and fixed-signal-level presentation. J Speech Hear Res, 1991. **34**: p. 651-660.



Hall and Grose noticed that when you changed the level of the tone in a no-notch noise, its loudness seemed to increase faster, than if the masker were a noise with a big notch. And they tested a bunch of adults to confirm that was true. So that's what is shown in the left hand graph. Excitation, or loudness, goes up steeply as you increase the tone intensity for no-notch than for medium notch than for wide notch. They figure that was because with no notch there was a lot of noise in the filter with the tone, while for a wide notch there wouldn't be so much-- and more noise leads to faster growth of loudness.

Now imagine that a listener decides that when he "hears" a certain amount of tone excitation he'll say the tone is there. Adults might pick a lowish amount of tone excitation. But if kids pick a higher level of tone excitation-- then these curves will be closer together for the kids than for the adults. So that means the kids thresholds will be closer together-- and they will look like their filters are broader than the adults, even thought he reason their thresholds look like that is because they just don't response unless you give them a pretty loud tone.

Hall and Grose to the rescue…



So--- Hall and Grose figured that if they could keep the amount of noise in the filter with the tone the same for all the notch widths, then the curves would be parallel for the adults and the kids-- it wouldn't matter if the kids insisted on a loud tone.

The way you could make the noise in the filter the same would be to make the no-notch noise less intense and the notched noise more intense (right?) What they did was to present the tone at a fixed level, and vary the level of the noise to find threshold (like in the psychophysical tuning curve experiment). Because you will always need the same amount of total noise to mask the tone, the wide notch noise will be at a higher level and the no-notch noise will be at a lower level.

So if you measure auditory filter widths by varying the level of the masker, threshold changes just the same way for the 4 year olds as for the adults-- which means that their filter widths are like adults. In all the other studies of kids they had varied the level of the tone, not the noise.

So it is important to realize that there are some results out there that say that kids have poorer frequency resolution than adults, but that they are wrong. 4 year olds don't have broader filters than adults; they just won't respond to a tone unless it sounds pretty loud to them. They want to be really sure that there is something there. Otherwise they just guess.

This is also a lesson that we will come back to when we talk about more central influences on children's hearing.

Conclusions so far

- Both high frequency discrimination and high frequency resolution are immature in listeners younger than 6 months of age, and mature in listeners older than 6 months.
- Low frequency discrimination doesn't mature until childhood, but low frequency resolution is mature in 3 month olds.

Immature frequency resolution could be responsible for 3 month olds poor high frequency discrimination, and since frequency resolution is mature at 6 months, then that could be why high frequency discrimination is pretty much like adults'-- this suggests that like adults, infants use the place code to represent high frequency pure tones.

But apparently frequency resolution can't explain why low frequency discrimination takes so long to mature.

Why is low-frequency discrimination immature?

- Temporal code could be immature
  - No psychophysical evidence for or against
- Temporal code could be mature, but infants and children may take awhile to learn to use this information.

Because there are no psychophysical data bearing on this question, it awaits consideration of physiological and other data that we will consider in the coming weeks.

Development of frequency representation

- Frequency resolution, the accuracy of the place code for frequency, is immature at birth.
- Frequency resolution is adultlike by 6 months of age.
- The development of the temporal code for frequency is less well understood.