Detection and discrimination of gliding tones as a function of frequency transition and center frequency

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Two experiments were performed to investigate subjects’ ability to detect and discriminate 50-ms up-glides in frequency in several different conditions. In the first experiment, the subjects indicated which of two signals increased more in pitch. The comparison, or standard signal, was a sinusoid which increased in frequency by either 0, 250, or 500 Hz. Center frequencies were 0.5, 1, 2, 4, and 6 kHz. Discrimination thresholds were obtained in both nonroved and roved conditions. In the roved condition, the actual center frequencies of the signals were varied randomly over a range equal to 0.1 times the nominal center frequency. The second experiment was the same as the first, except that the standard signals were swept over a frequency range equal to 0.5, 1, and 2 times the equivalent rectangular bandwidth (ERB) of the auditory filter at the nominal center frequency. Discrimination thresholds expressed as ΔHz/ERB varied little as a function of center frequency as long as the frequency transition of the standard was a constant proportion of ERB. In addition, discrimination thresholds did not vary significantly as a function of the frequency extent of the standard when the extent was one ERB or less, but doubled when the extent was two ERBs. The relatively small amount of variation in threshold across center frequency and the pattern of variation across different standard transitions supports a place mechanism of frequency coding for these signals based on the detection of changes in the excitation pattern.

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INTRODUCTION

Frequency glides have interested psychoacousticians for various reasons, including their similarity to formant transitions (Collins, 1984). A major issue that remains only partially understood is whether place or temporal coding is used in the perception of these sounds. It is known that both types of information are available in the responses of auditory-nerve fibers to frequency-modulated tones (see Sinex and Geisler, 1981 for evidence of temporal coding). This paper addresses this issue by measuring glide detection and discrimination thresholds across a range of center frequencies and comparison signals.

Most researchers who have worked in this area (e.g., Sergeant and Harris, 1962; Pollack, 1968; Tsumura et al., 1973; Arlinger et al., 1977) have measured glide detection, the ability to distinguish glides from tones that do not change in frequency. The general finding is that transition extent at detection threshold is similar to the difference limen for frequency (the DLF) and does not change greatly as a function of signal duration, at least for durations greater than about 500 ms. Thresholds increase greatly above 2 kHz, even when expressed as a proportion of center frequency. In a more recent study, however, Dooley and Moore (1988a) obtained up-glide detection thresholds that were relatively constant from 0.25 to 8 kHz when expressed in this manner.

Few researchers have investigated glide discrimination, the ability to distinguish one glide from another. Tyler et al. (1983) and Dooley and Moore (1988a) measured the glide direction difference limen, as well as the difference limen for frequency (DLF). In both studies, variation in the glide direction difference limen across frequency was very similar to that of the DLFs, with Δf/f increasing at higher center frequencies. Tyler et al. concluded that the correlation between the glide difference limen and the DLF supported temporal coding of gliding tones, since it is generally thought that only temporal coding can account for DLFs obtained with pulsed tones (Moore, 1973). Attempting to account for their results using Zwicker’s excitation-pattern model of frequency discrimination (Zwicker, 1970), Dooley and Moore found that the data supported an excitation-pattern model through 2 kHz, but departed from its predictions above that center frequency. They concluded that the data did not fully support the model, but did not provide strong evidence against it, either.

Studies of frequency modulation (FM) detection are also of interest, because, as Dooley and Moore (1988a) state, frequency glides can be regarded as nonperiodic modulations.” Findings from recent studies by Moore and Sek (Moore and Sek, 1995; Sek and Moore, 1995) strongly support the hypothesis that a place mechanism is used to detect frequency modulation when the rate of modulation is greater than about 4 Hz. For a modulation rate of 10 Hz, for example, frequency modulation difference limens (FMDLs) expressed as a proportion of the equivalent rectangular bandwidth (ERB) declined slightly with increasing center frequency between 0.25 and 2 kHz and were essentially constant between 2 and 8 kHz. The authors concluded that FMDLs for carrier frequencies below 4 kHz and low modulation rates (in the neighborhood of 2 Hz) are determined by a temporal mechanism, whereas FMDLs for higher modulation rates are determined by a place mechanism, based on changes in the excitation pattern, at all carrier frequencies.
Thus some previous studies suggest that changes in frequency are temporally coded (e.g., Tyler et al., 1983), some suggest that they are time or place coded depending on the rate of change (Moore and Sek, 1995; Sek and Moore, 1995) and some are equivocal (Dooley and Moore, 1988a). The present study was designed to extend this area of research by measuring glide discrimination thresholds over a range of standard (i.e., comparison signal) transition sizes, and across a range of center frequencies. Glide detection thresholds also were measured. The results then were analyzed to determine how well they support a place mechanism of glide perception. If frequency change is encoded by such a mechanism, then an excitation-pattern model should account for the overall pattern of results.

A relatively new procedure was included in the study that requires some explanation at the outset. The glide discrimination threshold determinations measured the ability to distinguish between a standard signal that increased in frequency by a fixed amount and a target signal that increased by a greater amount. If the center frequencies of two such signals are the same, the subject could simply compare the end points of the two signals and select the one that is higher in pitch. If this is the case, the subject is performing a between-signal pitch comparison which is similar to a DLF determination, rather than estimating pitch increase from within-signal information. It is possible that the subjects in previous glide discrimination studies were making this endpoint comparison. If so, the agreement noted above between DLFs and glide discrimination thresholds is not surprising. In the present study, access to between-signal pitch comparisons was denied by roving the center frequencies of the signals, an approach developed by Feth and his colleagues (Neill and Feth, 1990). This procedure is described in the next section. To determine the effect of roving the center frequencies, the same threshold determinations also were carried out with nonroved signals.

I. EXPERIMENT 1: GLIDE DIFFERENCE LIMENS FOR STANDARDS OF FIXED TRANSITION EXTENT

A. Subjects

Four subjects with normal auditory sensitivity participated. All had hearing thresholds of 15 dB HL or less at the audiometric test frequencies and were paid for their participation.

B. Procedure

In a two-alternative, forced-choice task, the subjects were asked to identify a target signal which either increased in frequency (for the glide detection condition) or increased more in frequency than the standard signal (for the glide discrimination conditions). The signals were presented monotonically. Thresholds were determined using three standard conditions: (1) a standard that did not change in frequency (the 0-Hz standard, in the glide-detection task), (2) a standard that increased by 250 Hz, and (3) a standard that increased by 500 Hz. Center frequencies were 0.5, 1, 2, 4, and 6 kHz, and the end points of the stimuli were linearly equidistant from their center frequencies. Stimulus duration was 50 ms, with additional rise–fall times of 5 ms. The intent was to use a signal duration and a range of frequency transitions that were similar to those of formant transitions, at least in the lower frequencies.

All center frequency/standard combinations were run in both a nonroved and a roved condition. In the roved condition, the center frequencies of the signals were randomly drawn from a uniform distribution with a range equal to 0.1 times the “nominal” center frequency. Thus the actual center frequencies of the 1-kHz signals ranged from 950 to 1050 Hz, the 2-kHz signals from 1900 to 2100 Hz, and so on. The center frequencies of both the standard and the target were varied independently both within and between trials. For example, on one trial at the 1-kHz center frequency the subject might hear a standard with a center frequency of 981 Hz and a target with a center frequency of 1028 Hz; on the next trial these values might be 1045 and 1022 Hz, etc. In the nonroved condition, center frequencies did not vary. All signals were presented at 70 dB SPL, with an interstimulus interval of 500 ms.

Thresholds were measured using an adaptive procedure that estimated the 70.7% correct response point on the psychometric function (Levitt, 1971). After two consecutive correct responses the change in frequency of the target signal was decreased; after one incorrect response it was increased. Step size was decreased after the first six reversals and varied depending on the center frequency and condition. At center frequencies of 0.5 and 1 kHz, for the 0-Hz condition, the initial step size was 10 Hz; at higher center frequencies and for the 250- and 500-Hz conditions, where thresholds were greater, initial step sizes ranged up to 40 Hz. Final step sizes ranged in a similar fashion between 2 and 10 Hz. The frequency increase of the target was not permitted to fall below that of the standard.

A run consisted of 80 trials, with a break after the first 40. The break was included to maintain alertness, and the subject was encouraged to remove the headphones, or even leave the booth, if necessary. The first six reversals were discarded, giving the subject sufficient opportunity to “home in on” the threshold area, and threshold was computed as the arithmetic mean of the subsequent reversals (always at least eight). The subjects were practiced for at least 10 h before data collection began. For each combination of rove, center frequency, and standard, they then were tested until performance did not consistently improve over six runs. Of these six, the runs that varied by more than 1 s.d. from the mean were discarded, and the threshold calculated from the remaining data (always at least four runs). This procedure was used because for some combinations of conditions considerable within-subject variation was noted. As it turned out, however, the discarded thresholds were virtually always those of both the highest and lowest runs, and the resulting means in fact differed little from the means of all the data in nearly all cases.

Data collection was completed for each center frequency-standard-rove combination before the next combination of conditions was begun to facilitate optimal learning of detection/discrimination cues. The order of standard conditions was counterbalanced within each center frequency.
rover combination, but the order in which the latter combinations were completed was not randomized or counterbalanced. Performance in the various roved conditions was rechecked from time to time during data collection, however, and these thresholds were within the ranges of the previously obtained thresholds in all cases.

Stimulus presentation and response acquisition were controlled by a PC. Stimulus and response intervals were indicated on a computer monitor. The subjects received visual feedback after every trial indicating the stimulus interval containing the target signal.

C. Stimulus generation

Digital representations of the stimuli were generated by an array processor (TDT-QAP2) running on a PC. A 16-bit D-to-A converter (TDT-DD1) operating at a 50-kHz sampling rate converted the digital representations to analog waveforms which were low-pass filtered at 8 kHz (TDT-FLT3), attenuated (TDT-PA3), and sent through an output amplifier (TDT-HBUF3) to an earphone (Sennheiser HD-414SL). The frequency response of this earphone has been reported to be relatively smooth over the range of the test frequencies (see Moore and Sek, 1995), and this was confirmed in this laboratory. Signal spectra were verified using Hypersignal/Workstation spectrum analysis software.

D. Results and discussion

All subjects exhibited the same overall pattern in threshold variation, so only the average thresholds for the various conditions, expressed as a proportion of the ERB at the corresponding center frequency, are presented in Table I and Fig. 1. The roved thresholds are higher than the nonroved in nearly all cases, but the two sets of results display the same general trends. There was an effect of standard which varied with center frequency. Thresholds increased as standard transition increased in the lower center frequencies (0.5 to 2 kHz) but were relatively constant across standard at 4 and 6 kHz. There also was an effect of frequency that varied with standard. Glide detection thresholds (the 0-Hz standard) changed little with frequency, but glide discrimination thresholds (the 250- and 500-Hz standards) increased as frequency decreased at center frequencies below 4 kHz.

To test the statistical significance of the above observations, a three-way analysis of variance (ANOVA) was performed with rove, standard, and center frequency as factors and the average thresholds of each subject in each condition as the dependent variable. The effect of rove was significant $[F(1,119)=31.9, p<0.001]$, as was the interaction between rove and standard $[F(2,119), p=0.012]$. As these results indicated a difference in the effect of standard for the two rove conditions, the roved and nonroved data were analyzed sepa-

TABLE I. Discrimination thresholds expressed as a proportion of equivalent rectangular bandwidth (ERB) for the data from experiment 1. Figures in parentheses are standard deviations. ERBs were calculated using the equation $ERB=24.7(4.37F+1)$ from Glasberg and Moore (1990).

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Rove</th>
<th>Standard</th>
<th>0 Hz</th>
<th>250 Hz</th>
<th>500 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>R</td>
<td>0.17 (0.015)</td>
<td>0.25 (0.073)</td>
<td>0.41 (0.078)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NR</td>
<td>0.14 (0.049)</td>
<td>0.43 (0.061)</td>
<td>0.46 (0.210)</td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>R</td>
<td>0.08 (0.004)</td>
<td>0.20 (0.065)</td>
<td>0.29 (0.047)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NR</td>
<td>0.10 (0.020)</td>
<td>0.29 (0.044)</td>
<td>0.45 (0.107)</td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>R</td>
<td>0.07 (0.019)</td>
<td>0.10 (0.022)</td>
<td>0.15 (0.037)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NR</td>
<td>0.11 (0.054)</td>
<td>0.17 (0.016)</td>
<td>0.26 (0.094)</td>
<td></td>
</tr>
<tr>
<td>4000</td>
<td>R</td>
<td>0.08 (0.034)</td>
<td>0.07 (0.026)</td>
<td>0.10 (0.048)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NR</td>
<td>0.08 (0.045)</td>
<td>0.11 (0.018)</td>
<td>0.21 (0.025)</td>
<td></td>
</tr>
<tr>
<td>6000</td>
<td>R</td>
<td>0.11 (0.023)</td>
<td>0.10 (0.029)</td>
<td>0.12 (0.029)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NR</td>
<td>0.13 (0.033)</td>
<td>0.13 (0.012)</td>
<td>0.17 (0.027)</td>
<td></td>
</tr>
</tbody>
</table>

FIG. 1. Average discrimination thresholds for fixed standard transitions expressed as a proportion of the ERB and plotted as a function of center frequency. Error bars indicate one standard deviation.


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A two-way ANOVA was applied to the nonroved data with standard and frequency as factors. The main effects of both standard \(F(2,5)=19.0, p<0.001\) and frequency \(F(4,5)=22.1, p<0.001\) were significant, as was the interaction \(F(8,5)=4.2, p<0.001\). Pairwise comparisons were performed to determine the effect of different levels of standard within the various center frequencies. No significant differences in threshold were found at the 4- and 6-kHz center frequencies \(p<0.05\). At 2 kHz, the thresholds for the 500-Hz standard were significantly greater than those for the 0-Hz standard. At 1 kHz, the 500- and 250-Hz thresholds were significantly greater than the 0-Hz thresholds, and at 0.5 kHz, the 500-Hz thresholds were significantly greater than the 250- and 0-Hz thresholds. Pairwise comparisons were also performed to determine the effect of different levels of frequency within the three standard conditions. There were no significant differences in threshold within the 0-Hz standard. For the 250-Hz standard, thresholds at the 0.5 and 1-kHz center frequencies differed from those at 2, 4, and 6 kHz; the 0.5- and 1-kHz thresholds did not differ from one another; and the 2-, 4-, and 6-kHz thresholds did not differ from one another. For the 500-Hz standard, the 0.5- and 1-kHz thresholds differed from all others and the 2-, 4-, and 6-kHz thresholds did not differ from one another.

A two-way ANOVA with standard and frequency as factors was also applied to the roved thresholds. The results were similar to those for the nonroved condition. The main effects of both standard \(F(2,5)=25.0, p<0.001\) and frequency \(F(4,5)=13.1, p<0.001\) were significant, as was the interaction \(F(8,5)=3.7, p<0.002\). Pairwise comparisons for the effect of standard within center frequency indicated no significant differences between thresholds within the 4- and 6-kHz center frequencies. At 0.5 kHz, thresholds for the 500- and 250-Hz standards differed from those at 1 kHz; at 1 kHz all conditions differed; at 2 kHz, the 500- and 0-Hz thresholds differed from each other. Pairwise comparisons for the effect of frequency within standard indicated no significant differences across frequency for the 0-Hz standard. For the 250-Hz standard, thresholds at 0.5 kHz differed from those at 2, 4, and 6 kHz; all other thresholds were the same. For the 500-Hz standard, the 0.5-and 1-kHz thresholds differed from those at 2, 4, and 6 kHz but not from each other. Overall, the ANOVA results support the observations made on the basis of Fig. 1 and Table I.

The most striking aspect of the results is the change in the relationship among the thresholds for the various standard conditions as a function of center frequency. The clear differences between standards that are present in the low frequencies decrease as frequency increases and are mainly absent above 2 kHz. Note that the relationship between standard and number of ERBs traversed also changes with frequency. At 6 kHz all three standards fall within the ERB of a single auditory filter (672 Hz). On the other hand, at 1 kHz both the 250- and 500-Hz standards span a range greater than one ERB (133 Hz). The data are consistent with the idea that thresholds are relatively constant as long as the comparison signal in each standard condition spans less than 1 ERB, but when the standard span is increased beyond one ERB, the threshold increases as well. If this is true, glide discrimination, like glide detection, appears closely linked to auditory filter bandwidth. Experiment 2 was designed to test this idea.

### II. EXPERIMENT 2: GLIDE DIFFERENCE LIMENS FOR STANDARDS THAT SPAN A CONSTANT PROPORTION OF ERB

In this experiment, the standard transitions were fixed proportions of the ERBs at the various center frequencies. It was hypothesized that discrimination thresholds for transitions of one ERB or less would be roughly equal but that the threshold would increase significantly for a standard with a transition significantly greater than one ERB.

#### A. Conditions

Signal generation and the procedures for threshold estimation were the same as those of experiment 1. The experiment differed only in the magnitude of frequency change for the standards, which were a fixed proportion of the ERB at each test frequency. Three standard signals were used: one-half ERB (the 0.5ERB standard), one ERB (the 1ERB standard), and two ERB (the 2ERB standard). Table II gives the transition excursions for these standards at the various center frequencies. Three of the subjects from experiment 1 participated.

#### B. Results and discussion

The results for experiment 2 are presented in Table III and Fig. 2. The results from the 0-Hz condition of experiment 1 (from the three subjects who participated in both experiments) are included for comparison. The overall pattern was the same across subjects, so only the average thresholds are presented. The data clearly support the prediction that discrimination thresholds would be relatively constant as long as the frequency transition of the standard signal was within a single ERB, but would increase significantly when the standard signal spanned a range greater than a single ERB. Generally, the 2ERB thresholds are about twice those of the other standard conditions. The thresholds do not vary greatly across frequency, particularly in the roved condition, but they are lowest at 1 and 2 kHz.

The data were analyzed statistically to verify these conclusions. As in experiment 1, a three-way ANOVA was performed with rove, standard, and center frequency as factors and the average thresholds of each subject in each condition as the dependent variable. The effect of rove again was significant \(F(1,119)=29.5, p<0.001\), as was the effect of frequency \(F(4,119)=12.4, p<0.001\). The interaction between

<table>
<thead>
<tr>
<th>Frequency</th>
<th>0.5ERB</th>
<th>1ERB</th>
<th>2ERB</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>40</td>
<td>79</td>
<td>158</td>
</tr>
<tr>
<td>1000</td>
<td>67</td>
<td>133</td>
<td>266</td>
</tr>
<tr>
<td>2000</td>
<td>121</td>
<td>241</td>
<td>482</td>
</tr>
<tr>
<td>4000</td>
<td>228</td>
<td>456</td>
<td>912</td>
</tr>
<tr>
<td>6000</td>
<td>336</td>
<td>672</td>
<td>1344</td>
</tr>
</tbody>
</table>
TABLE III. Discrimination thresholds expressed as a proportion of equivalent rectangular bandwidth for the data from experiment 2. Figures in parentheses are standard deviations.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Rove</th>
<th>0 Hz</th>
<th>0.5ERB</th>
<th>1ERB</th>
<th>2ERB</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>NR</td>
<td>0.15 (0.012)</td>
<td>0.09 (0.016)</td>
<td>0.12 (0.032)</td>
<td>0.25 (0.060)</td>
</tr>
<tr>
<td>1000</td>
<td>R</td>
<td>0.18 (0.040)</td>
<td>0.14 (0.033)</td>
<td>0.14 (0.026)</td>
<td>0.29 (0.028)</td>
</tr>
<tr>
<td>2000</td>
<td>R</td>
<td>0.10 (0.020)</td>
<td>0.10 (0.009)</td>
<td>0.10 (0.012)</td>
<td>0.24 (0.050)</td>
</tr>
<tr>
<td>4000</td>
<td>R</td>
<td>0.10 (0.032)</td>
<td>0.09 (0.016)</td>
<td>0.12 (0.050)</td>
<td>0.21 (0.026)</td>
</tr>
<tr>
<td>6000</td>
<td>R</td>
<td>0.12 (0.021)</td>
<td>0.15 (0.012)</td>
<td>0.15 (0.012)</td>
<td>0.24 (0.044)</td>
</tr>
</tbody>
</table>

For the roved data in the first experiment, the ratio of the discrimination thresholds was 1.3 times that of the nonroved signals. This indicates that the within-signal cues, the data suggest that mainly within-signal cues, as indicated in the legend.

III. GENERAL DISCUSSION

A. The effect of roving the signals

The interaction between rove and frequency was not significant in either experiment, but the interaction between rove and standard was significant in the first experiment and very close to significance in the second. However, in both experiments separate analyses of the roved and nonroved data led to essentially the same conclusions. Thus in terms of threshold variation across center frequency and standard, the two procedures yielded similar results. If we accept the assumption that roving the signals forced the subjects to use within-signal cues, the data suggest that mainly within-signal cues also were used with the nonroved signals.

On the other hand, roving the signals increased the size of the discrimination thresholds. The overall mean threshold for the roved signals in the first experiment was 1.3 times

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**FIG. 2.** As in Fig. 1, but for standard transitions that are a fixed proportion of the ERB, as indicated in the legend.
that of the mean of the roved signals. There are at least two possible explanations for this. One is that listeners were able to make at least some use of end-point comparisons between (as opposed to within) signals in the nonroved condition. If between-signal end-point comparisons cause the task to resemble a DLF determination, as was suggested in the Introduction, one would expect an increase in threshold at 4 kHz and especially at 6 kHz. Figure 2 shows a steady increase in the nonroved thresholds from 2 to 6 kHz that is not as apparent in the roved data. This increase is much smaller than that found in DLF data (e.g., Moore, 1973), however, indicating that the use of the between-signal end-point cue was of limited utility, possibly because of the short duration of the signals. An alternative explanation for the smaller nonroved thresholds may be that the standard was repeated across trials in the nonroved condition. This would have enabled the subjects to sharpen their mental representation of the standard over the course of a run, thus improving their performance.

B. Comparison with previous studies

There are no studies in the literature that are directly comparable to the glide discrimination component of this study. The most similar study of glide detection is that of Dooley and Moore (1988a) mentioned in the Introduction, which included a level-tone versus up-glide condition. They obtained thresholds of from 0.7% to 0.9% of center frequency over a frequency range from 0.25 to 8 kHz, with the lowest thresholds at 1 and 2 kHz. Expressed in Hz, these thresholds are roughly 0.75 the size of the nonroved thresholds observed in experiment 1, but Dooley and Moore used 500-ms signals in their experiment. They also tested over a range of durations at 2 kHz, however, and obtained a threshold of around 25 Hz for a 50-ms signal, which is about the same as the 2-kHz glide detection threshold of experiment 1 in the roved condition. In the present study the lowest average glide detection thresholds also were obtained at 1 and 2 kHz.

In Sek and Moore’s (1995) study of FM detection, FM-DLs expressed as ΔHz/ERB ranged between 0.04 and 0.055 for the 10-Hz modulation-rate condition. These thresholds are roughly half those of the present study, but the FM signals would have given the subjects multiple “looks” at the modulation. For Sek and Moore, FM detection thresholds were nearly constant, differing by a factor of only 1.4, at center frequencies between 0.25 and 8 kHz. Thus the glide detection results of the present study generally are similar to these previous studies with the exception of the greater magnitudes of the thresholds, which are almost certainly due to the duration and type of the stimuli.

C. Evaluation of an excitation-pattern model of glide detection and discrimination

The most commonly used place model of frequency discrimination is that of Zwicker (1970), which predicts that the threshold for detecting a change in frequency should correspond to a fixed change in excitation level on the low-frequency side of the excitation pattern generated by the stimulus. Zwicker’s model was developed to account for the detection of frequency modulation, but it possibly can be extended to account for these glide discrimination results. Let us assume that in the process of glide discrimination the listener compares signals by comparing the change in frequency between their respective start and end points. The accuracy with which this change can be measured would be determined by the resolution of the location of these points along the basilar membrane, which in turn would be a function of the steepness of the excitation patterns. Glide discrimination is thus a function of the slope of the excitation pattern, which in turn is determined by the bandwidth of the auditory filters centered at and just below the test frequency (Sek and Moore, 1995). Therefore, this type of model predicts that the threshold for detection of a change in transition extent should be a fixed proportion of filter bandwidth.

The results of experiment 2 indicate that when the transition of the comparison signal is either 0 Hz or a constant proportion of ERB, the discrimination thresholds for the roved signals in particular approach this prediction. The thresholds shown in Fig. 2 are replotted as line graphs in Fig. 3 for ease of comparison, along with the average of the thresholds for all four standard conditions. The 0-Hz and 1ERB conditions display the greatest amount of variation across frequency, the 2ERB condition the least. The averaged thresholds differ by a factor of 1.4 over the range of center frequencies. This ratio is very similar to that observed at the 10-Hz modulation rate by Sek and Moore (1995). (The Sek and Moore ratio would doubtless have been smaller if the range of comparison had been limited to that of the present study; their highest threshold was at 0.25 kHz.) Thus the results can be said to constitute a “near miss” with respect to the predictions of an excitation pattern model.
D. Explaining the effect of transition size

The results of experiment 2 also indicated that discrimination thresholds are essentially the same as long as transition size is within one ERB but that discrimination performance begins to worsen at some point (the precise location of which cannot be inferred from this experiment) between transitions of one ERB and two ERBs. In fact, the average of all thresholds (roved and nonroved) for the 2ERB standard (0.238) is almost exactly twice that of the thresholds for standards that are one ERB or less (0.120). This result suggests that the discrimination of glides in frequency follows Weber’s law, but only when the standard exceeds a certain transition size. It is of interest that Dooley and Moore (1988b) found that for glides in level, the Weber fraction for rate of change discrimination was essentially the same when standard size was doubled from 5 to 10 dB. This similarity in the pattern of results for glides in frequency and glides in level is predicted by an excitation-pattern model, in which changes in both level and frequency are detected through changes in level of excitation.

IV. CONCLUSIONS

For the 50-ms tones used in these experiments:

1. Glide discrimination results obtained under roved and nonroved conditions were not statistically equivalent, but the main conclusions that emerged from the statistical analyses were the same.

2. Glide discrimination thresholds expressed as ΔHz/ERB varied little across center frequencies ranging from 0.5 to 6 kHz when the frequency transition of the comparison signal was either 0 Hz or a fixed proportion of the ERB of an auditory filter at the signal center frequency.

3. Glide discrimination thresholds were essentially invariant at a given center frequency when the frequency transition of the comparison signal was 0 Hz, 0.5 ERB, or 1 ERB. The average discrimination threshold when the transition of the comparison signal was two ERBs was about twice the threshold in the other conditions.

4. The small variation in threshold across center frequency when the transition of the comparison signal is a fixed proportion of ERB supports an excitation-pattern model of the discrimination of frequency change. Also, the pattern of threshold variation as the frequency transition increases suggests that the auditory filters play an important role in mediating the coding of frequency change.

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1Moore defines the ERB of a filter as “the bandwidth of a rectangular filter which has the same peak transmission as that filter and which passes the same total power for a white noise input” (Moore, 1989, p. 334).


