THE EFFECT OF MARKER PARAMETERS ON GAP DISCRIMINATION

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ABSTRACT

A preliminary investigation was conducted of the effects on gap discrimination of variation in marker rise/decay, in combination with other marker parameters. Three well-practiced normal-hearing listeners participated. In each, the just noticeable increment (Δt) was measured for silent gaps of 10, 20 and 100 ms, within the context of sixteen different marker conditions. These reflected variations in bandwidth (octave and 1/3 octave), centre frequency (500 and 4000 Hz), intensity (75 and 85 dB SPL) and rise/decay time (5, 25 and 50 ms). The results showed that Δt increased significantly with an increase in rise/decay time. Marker intensity and bandwidth had no effect. Discrimination improved with an increase in marker frequency only for the longest gap, given the shortest rise/decay.

SOMMAIRE

Nous présentons les résultats d'une étude préliminaire qui a pour but d'étudier l'effet du temps de montée/descente et d'autres paramètres sur l'habileté du système auditif à détecter une variation de la durée d'un silence compris à l'intérieur d'un signal-marqueur. Trois sujets bien entraînés et possédant une audition normale ont participé à l'étude. Nous avons mesuré pour chacun des sujets la plus petite variation de durée détectée (Δt) pour des silences de 10, 20 et 100 ms en fonction de seize paramètres caractérisant le signal-marqueur. Ces paramètres étaient: la largeur de la bande passante (octave et tiers d'octave), la fréquence centrale (500 et 4000 Hz), l'intensité (75 et 85 dB SPL) et le temps de montée/descente (5, 25 et 50 ms). Nos résultats démontrent que Δt augmente de façon significative avec le temps de montée/descente. Par contre, l'intensité et la largeur de bande n'affectent pas les résultats. Δt décrôit si la fréquence centrale du signal-marqueur augmente, mais seulement dans le cas du silence le plus long et du temps de montée/descente le plus court.

1. INTRODUCTION

Auditory temporal acuity is generally assessed in one of two ways, by measuring either the just noticeable difference in the duration of a tone or noise burst or the just noticeable difference in a silent gap bounded by a pair of markers (Abel, 1972a, 1972b). Investigators who used these methods in the 1960s and early 1970s thought the latter method might provide a way of studying the perception of time unconfounded by perceived changes in loudness and pitch that might provide a cue to a change in duration (e.g., Garner, 1947). Experiments demonstrated, however, that the characteristics of the markers in the latter paradigm do affect the perception of the gap (e.g., Plomp, 1964; Penner, 1977).

In an experiment designed to investigate the effect of marker duration and intensity, Abel (1972b) measured just noticeable differences (Δt) for standard gaps ranging from 0.63 to 640 ms. Three different Gaussian noise burst markers were compared, two with the same energy (10 ms/85 dB SPL and 300 ms/70 dB SPL) and a third with the same duration as the first and the same intensity as the second (10 ms/70 dB SPL). The results indicated that Δt was shortest for the marker with the highest intensity. Neither marker energy nor marker duration were significant determinants of performance. Subsequent studies have shown that intensity will only be an important parameter, when markers are not clearly audible (Florentine and Buus, 1982; Fitzgibbons, 1984). The effect of marker duration is somewhat controversial. Penner (1977) found that temporal acuity decreased as the marker preceding the gap increased from 2 to 200 ms. Forrest and Green (1987) found no change for markers ranging between 5 and 400 ms. The discrepancy in outcome may have been due to procedural differences.

Temporal acuity has also been shown to improve with increases in marker frequency in the range below 5000 Hz (Fitzgibbons and Wightman, 1982; Fitzgibbons 1984). The effect of marker bandwidth interacts with frequency. Shailer and Moore (1983; 1985) found that the minimum detectable gap decreased with an increase in marker bandwidth. This was particularly evident for a low-frequency marker of 400 Hz. For higher frequencies the effect was negligible for bandwidths greater than 0.25 times the centre frequency.

The present experiment was undertaken to investigate the interaction of four marker parameters on the just noticeable increment in a silent gap: frequency, bandwidth, intensity and rise decay time. The effect of systematic variation in the rise decay time (RD) of the marker has not been studied previously. Generally, in such studies, the marker RD is relatively short. This has necessitated the use of background masking noise to overcome possible spectral cues due to the onset and termination of the marker (e.g., Shailer and Moore, 1985).

2. EXPERIMENTAL DESIGN

Each subject served as his/her own control. Gap discrimination, the ability to differentiate between two silent gaps of different duration, was measured for sixteen marker conditions. These were generated by choosing from two levels of noise bandwidth (octave or one-third octave) and two levels of centre frequency (500 Hz and 4000 Hz). Noise bands were used in preference to pure tones in order to minimize possible spectral cues from variation in RD. Within each of the four bandwidth by centre frequency conditions, the effect of four intensity by RD combinations shown in Table 1 were explored. For combinations 1 and 2, the energy of the marker was the same. It was predicted that if marker energy was the critical determinant of performance, then a longer RD (50 ms) and duration of peak amplitude (200 ms) would compensate for a decrease in stimulus intensity (75 dB SPL). Combination 4 allowed us to study the effect of reducing intensity alone for the short marker. A comparison of combinations 2, 3 and 4 allowed an evaluation of variation in RD with marker intensity held constant. Based on previous research, it was assumed that the duration of peak amplitude would not affect gap discrimination. For each marker bandwidth by frequency by intensity/RD combination, the just noticeable increment in temporal gap was measured for three standard gaps of 10, 20 and 100 ms.

Table 1: Marker Intensity and Rise Decay Combinations

Combination	Intensity (dB SPL)	RD (ms)	Peak (ms)	Total Duration (ms)
1	85	5	20	30
2	75	50	200	300
3	75	25	200	250
4	75	5	20	30

3. METHOD

3.1 Subjects

The subjects were three university undergraduates, who had some previous experience as listeners in psychoacoustic experiments. All were under the age of 25 years and had normal hearing.

3.2 Apparatus

The experiment was conducted in a sound proof booth. The stimulus marker was generated using a noise generator (Bruel & Kjaer Type 1405) and band pass filter (Bruel & Kjaer Type 1617). A Coulbourn Instruments modular system allowed for fine adjustment of stimulus level, duration and envelope shaping. The output of the modular system was fed to a manual range attenuator (Hewlett Packard 350D) and integrated stereo amplifier (Rotel RA-1412) for binaural presentation over a matched headset (Telephonics TDH 49P). All devices were controlled by means of a personal computer (AST Premium 286) via IEEE-488 Labline and digital I/O lines. Subjects responded using a handheld response box.

3.3 Procedure

The just noticeable increment (Δt) in temporal gap was measured using a two-interval forced-choice procedure. On each trial, a sequence of two listening intervals was presented. These were cued by successive flashes of light-emitting diodes on the response box. The standard gap (t ms), bounded by a pair of identical markers, was presented in one of the two intervals, randomly determined from trial to trial. The comparison gap ($t + \Delta t$ ms), bounded by the same markers, was presented in the other interval. The duration of the light flashes was the same as the longer of the two periods of auditory stimulation. The time between the flashes was 300 ms. A typical sequence is shown in Figure 1. The subject's task was to choose the listening interval in which the longer of the two gaps had been presented by pressing the corresponding push-button on the response box. No feedback was given about the correctness of judgements.

Within a block of 24 trials, the marker condition, standard gap, and comparison gap remained the same. Across blocks, only the comparison gap was varied, so as to generate a psychometric function with P(C) ranging from 0.60 to 0.90 for the particular marker condition and standard gap chosen. A straight line fit to the data points by eye allowed an interpolation of the just noticeable increment, that value of Δt which generated $P(C)=0.75$. A mimimum of two values of P(C) were required, at least one between 0.55 and 0.75 and at least one between 0.75 and 0.90. In practice, four to five blocks were usually presented.

The order of presentation of the sixteen marker conditions was randomized independently for each subject according to the following scheme. The order of the two bandwidths was randomized within each frequency. The intensity by rise decay time combination was randomized within bandwidth. The order of the three standard gaps was then randomized within the marker intensity by rise decay combination. This scheme was adopted to maximize the subject's familiarity with the various marker combinations, so that cues, if present, could be fully utilized.

A concern in conducting the study was that practice might affect temporal acuity. Based on evidence for learning, the experiment was repeated three times in two of the subjects and four times in the third subject. For each subject the final two replications gave fairly similar just noticeable differences in each marker condition and were averaged for the final statistical analyses.

4. RESULTS

The mean values of Δt based on the data for three subjects are shown for each marker by standard gap condition in Table 2 and Figure 2. The relatively large standard deviations were due to one subject, whose values were two to three times greater than those for the other subjects. In spite of this difference in absolute value, the trends were quite similar for all three individuals.

The data were analyzed using two within-subject ANOVAs. In the first analysis, only those data obtained for a marker level of 75 dB SPL were included. The effect of three marker parameters (bandwidth, frequency and rise decay) and standard gap were assessed. The results indicated that the standard gap was significant at the 0.05 level ($F=10.41$, $df=2,4$) and marker RD was significant at the 0.01 level ($F=24.88$, $df=2,4$). The left panel of Figure 3 shows these outcomes. The mean Δt for three subjects is plotted as a function of the standard gap for combinations of RD and frequency. The results have been averaged across levels of marker bandwidth. The functions indicate that the value of Δt increases with an increase in the standard gap. For each standard gap, Δt increases as the RD increases.

The significance of the rise decay time of the marker precluded an ANOVA to compare the equal energy marker combinations 1 and 2. A significant difference in Δt might be due to either the intensity or RD of the marker. However, a second ANOVA was carried out to investigate the significance of marker intensity. The analysis included the data obtained for intensity by rise decay time combinations 1 and 4 for all levels of marker frequency, marker bandwidth and standard gap. The results indicated that the standard gap and the interaction of standard gap by marker frequency were significant at 0.01 level ($F=19.74$, $df=2,4$ and $F=24.80$, $df=2,4$ respectively). Marker intensity and bandwidth were not significant factors. Figure 3 (right panel) shows the mean Δt for three subjects, as function of the standard gap for each level of marker frequency, collapsed across marker bandwidth and marker intensity by rise decay combination. The effect of marker frequency is evident only for the longest of three standard gaps, i.e., 100 ms. The higher the frequency, the lower the value of Δt.

In spite of previous findings to the contrary, a concern in carrying out the first ANOVA was that the variation in rise decay time was confounded with the change in the duration of the marker. Judgments could be based on the duration of the standard gap alone, the standard gap plus the rise decay time of the marker or the standard gap plus the duration of the marker. In order to discern which of these was the critical standard duration, Weber ratios (Δt/t) were computed for the three possible options. In the first case (G), the standard gap was measured from the end of the decay of the first marker to the beginning of onset of the second marker (see Figure 1). In the second case (RG), the standard was computed as the sum of the standard gap plus half the fall of the first marker plus half the rise of the second marker. In the third case (BG), the standard was taken as the sum of the standard gap plus the peak duration and fall of the first marker.

Table 3 shows the Weber ratios (Δt/t), computed using G, RG, and BG respectively for t. The numbers tabulated are means, based on the results for the three subjects. Comparing these data with the results obtained by Abel (1972b) for standards gaps ranging from 0.63 to 640, it appears that Weber ratios calculated using G are two large and those obtained using BG are too small. The RG (rise decay time plus the standard gap) method seems to provide the best match.

5. DISCUSSION

This experiment was carried out to determine the effect of variation in a number of marker parameters on the acuity for a change in the duration of a silent gap. The parameters included centre frequency, bandwidth, intensity and rise decay time. A weakness of this design was that changes in the duration of the marker were confounded with the variation in rise decay time. One possible method of avoiding this problem is the randomization of duration of the markers (Formsby and Forrest, 1991). Allowing covariation permitted the opportunity to study the effect of marker duration in combination with RD.

The results indicated that the centre frequency of the noise band marker had a significant effect on the perception of the gap but only when the rise decay time was relatively short (5 ms) and the standard gap, relatively long (100 ms). The effect of increasing the centre frequency from 500 Hz to 4000 Hz was a decrease in the just noticeable increment (Δt). This outcome was only statistically significant in the second ANOVA, likely because the number of conditions were restricted, and thus the overall variance limited. The same trend was however evident in the data for the first ANOVA (see the left panel of Figure 3).

Shailer and Moore (1985) argue that the peripheral auditory system can be modelled as an array of band pass filters. The bandwidth of the filter increases with the centre frequency of the stimulus. Since "ringing" of the hypothetical filter with cessation of the stimulus varies inversely with bandwidth, these authors predict that temporal resolution will improve as the frequency of the marker increases. In the present study, this effect was apparent only at the longest of the three standard gaps, possibly because for the shorter gaps, the range in Δt was relatively small.

A change in the bandwidth of the marker from one-third octave to one octave did not affect temporal acuity, confirming the conclusion of Fitzgibbons (1983). It may also be the bandwidths chosen for this study were outside the effective range (Shailer and Moore, 1985). The level of the marker also did not provide a critical cue. As suggested previously, marker intensity is unlikely to have an effect, so long as the marker is clearly audible.

The effect of systematic variation in the rise decay of the marker on the perception of the gap had not been previously explored. This experiment represented a preliminary investigation of the effect. The results of the first ANOVA indicated that the value of Δt increased as rise decay time increased from 5 ms to 50 ms. A comparison of Weber ratios computed using either the standard gap alone or the standard gap corrected for either the rise decay time or the duration of the first marker, suggested that the rise decay time has its effect by increasing the effective duration of the standard gap. It appeared highly unlikely that the total duration of the marker had an important role in the judgment of silent gaps, confirming previous studies by Abel (1972b) and Forrest and Green (1987).

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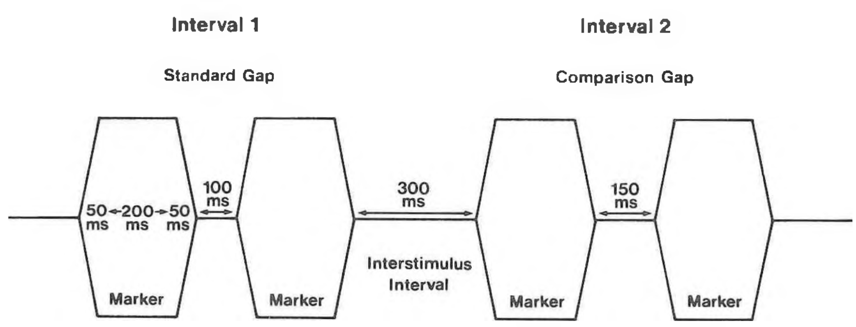

Fig. 1 A typical sequence presented during a two-interval forced-choice trial.

Table 2. Gap discrimination as a function of marker parameters.

Freq. (Hz)	Band-width	Ampl. dB SPL	RD/Pk (ms)	Standard Gap (ms) 10	20	100
500	1/3	85	5/20	6.3± 3.1[+]	11.2± 6.9	31.5±14.5
		75	50/200	32.3±12.5	34.7±16.6	51.6±10.3
		75	25/200	22.6± 8.1	32.6± 9.0	51.9±27.2
		75	5/20	11.0± 8.3	11.7± 8.7	45.4±28.0
	1/1	85	5/20	10.0± 7.3	13.7± 6.8	27.8± 8.3
		75	50/200	29.0± 5.5	36.1±17.7	48.2±20.9
		75	25/200	24.7±11.2	32.8±19.4	47.4±23.3
		75	5/20	10.7± 7.5	18.2±15.5	34.3±10.5
4000	1/3	85	5/20	13.5±10.7	14.4±10.1	31.9±15.2
		75	50/200	27.8± 9.3	22.9± 2.2	49.0±24.2
		75	25/200	26.1±14.2	25.2± 8.1	41.4±28.3
		75	5/20	12.8± 7.2	11.2± 8.4	26.0±15.8
	1/1	85	5/20	13.5± 8.7	13.0±10.9	24.0±14.2
		75	50/200	28.3± 3.8	28.0± 9.7	37.3±19.1
		75	25/200	31.8±16.6	21.1± 9.4	41.1±23.5
		75	5/20	13.8± 9.5	14.7±12.3	23.4±13.1

[+]mean Δt for 3 Ss

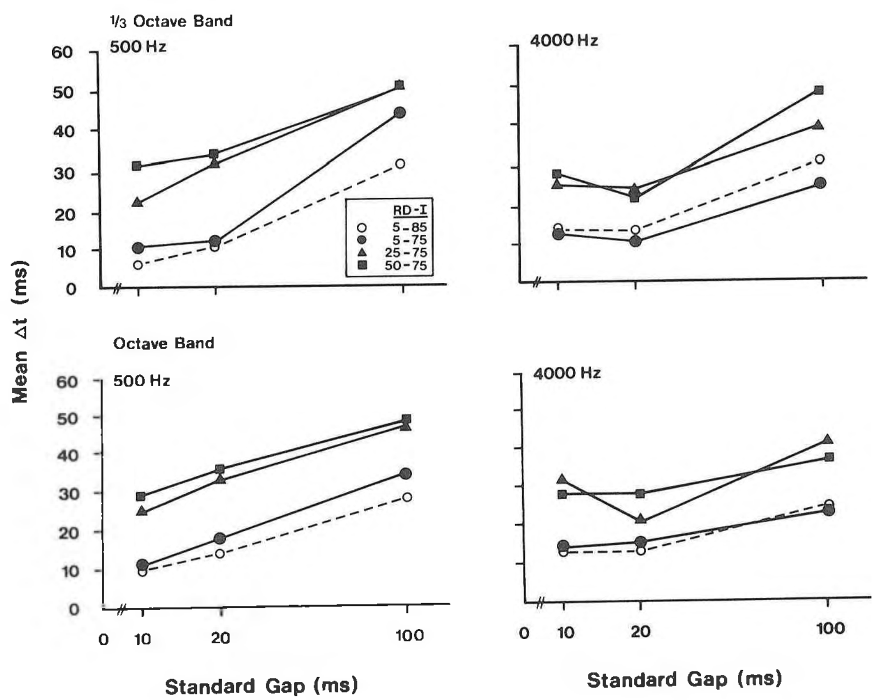

Fig. 2 The just noticeable increment in gap as a function of the duration of the standard gap. The parameters are marker bandwidth, centre frequency, intensity and rise decay time.

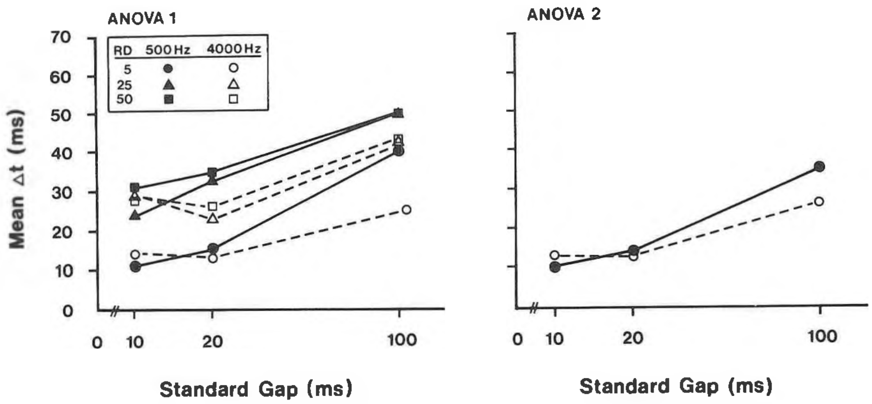

Fig. 3. The significant outcomes for two analyses of variance.

Table 3. Weber ratios calculated using the standard gap (G), rise decay plus gap (RG) and burst plus gap (BG).

			Calculation Method					
Gap (ms)	Freq. (Hz)	RD (ms)	G (ms)	Δt/G	RG (ms)	Δt/RG	BG (ms)	Δt/BG
10	500	5	10	1.09	15	0.73	35	0.31
		25	10	2.37	35	0.67	235	0.10
		50	10	3.07	60	0.51	260	0.12
	4000	5	10	1.33	15	0.89	35	0.38
		25	10	2.90	35	0.83	235	0.12
		50	10	2.81	60	0.47	260	0.11
20	500	5	20	0.75	25	0.60	45	0.33
		25	20	1.64	45	0.72	245	0.13
		50	20	1.77	70	0.51	270	0.13
	4000	5	20	0.65	25	0.52	45	0.29
		25	20	1.16	45	0.51	245	0.10
		50	20	1.28	70	0.36	270	0.09
100	500	5	100	0.40	105	0.38	125	0.32
		25	100	0.50	125	0.40	325	0.15
		50	100	0.50	150	0.33	350	0.14
	4000	5	100	0.25	105	0.23	125	0.20
		25	100	0.41	125	0.33	325	0.13
		50	100	0.43	150	0.29	350	0.12