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Temporal Integration and Discrimination of Equally Detectable, Equal-Energy Stimuli: The Effect of Frequency

Daniel Algom, Harvey Babkoff*, and Yehuda Ben-Uriah

Department of Psychology, Bar-Ilan University, Ramat-Gan, Israel

Summary. The results of several experiments are reported which indicate: 1) complete auditory temporal summation for threshold of up to 32 msec for tones of 493, 1967, and 7874 Hz using a three-alternative forced-choice technique. 2) Equal-energy, equally detectable stimuli constructed of different intensities and durations within the range of complete integration are discriminable from one another. 3) Discrimination level increases as a function of the overall energy level and, consequently, as a function of detection level. 4) When discrimination level is plotted against detection level on normal-normal coordinates, the result is a straight line with a slope (b) greater than unity ($1.41 \leq b \leq 1.68$). 5) The extent of the discrimination capability, as well as the slope of the function relating discrimination level to detection level, was found to be independent of the frequency of the tone.

Introduction

Psychophysical studies of auditory temporal integration have demonstrated a reciprocal relation between the stimulus intensity and duration required to obtain a constant threshold response. The critical duration (i.e., the longest duration producing reciprocity) and the time constant of the function relating intensity to duration for a given response are among the most frequently used indices to describe these data.

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* All communications regarding this paper are to be addressed to Dr Harvey Babkoff. Dr Babkoff is spending the 1979-1980 academic year at the Military Medical Psychophysiology Laboratory of the Walter Reed Army Institute of Research, Washington, D.C., USA

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Offprint requests to: Dr. H. Babkoff, Department of Psychology, Bar-Ilan University, Ramat-Gan, Israel

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In addition to the studies of temporal integration which have stressed the effects of stimulus parameters, several studies have stressed the influence of a variety of methodological and response variables on the intensity-duration relation (e.g., Bruder and Kietzman 1973; Clark and Blackwell 1959; Grossberg 1968, Lewis 1967; Raab and Fehrer 1962; Wasserman and Kong 1979; Zacks 1970). Estimates of critical duration as well as the form of intensity-duration reciprocity functions vary with the subjects' task (Hunter and Sigler 1940; Kahneman and Normal 1964; Zacks 1970; Bruder and Kietzman 1973; Wasserman and Kong 1979).

Zacks (1970) tested the hypothesis that over some range, visual flashes differing with respect to intensity and duration but equal in energy should be indiscriminable if they produce essentially identical neural events. Zacks reported that even within the range of total reciprocity, equally detectable equal-energy stimuli were discriminable from one another, and rejected the hypothesis that equal-energy stimuli produce identical neural events.

Although the auditory system can integrate energy over durations of up to 200 ms (Zwislocki 1960), the distribution of the acoustic energy over time can be discriminated even within durations shorter than 200 ms (Green 1971).

Patterson and Green (1970) reported that it is possible to discriminate between two complex transient signals having identical energy spectra, but differing in phase spectra although the duration of these transients is 2.5 ms. Babkoff and Sutton (1971) reported similar acuity with the discrimination of mirror-image pulse pairs having large interpulse ratios.

In a recent paper, two of the present authors (Algom and Babkoff 1978), reported that equal-energy, *equally detectable* 998 Hz tones of different intensities and durations are discriminable from one another although their energies are equal and the durations (16 and 64 ms) do not exceed the limits of complete reciprocity for detection. These results indicate that subjects are able to discriminate between stimuli that are integrated with respect to detection. A question may be raised, however, regarding the extent to which these results typify auditory system behavior. The stimuli used in the previous study were tone pulses of 988 Hz. Can those results be generalized to other frequencies?

Conflicting findings have been reported (e.g., Zwislocki 1960; Wright 1969) regarding the effect of stimulus frequency on temporal integration. Watson and Gengel (1969) report a systematic reduction in the value of the time constant for integration as frequency is increased. The estimates of critical duration range from 125-175 ms at low frequencies, to approximately 30-70 ms at high frequencies. These data suggest a dependence of the integration process on frequency and raise the question as to whether the disciminability of equal-energy, equally detectable brief stimuli may also be related to the frequency of these stimuli. Perhaps fully integrated stimuli are discriminable from one another only when they are in a given frequency region, but not when they are in another region. Alternatively, one may hypothesize that as long as the same response criterion is met, namely, that the stimuli are fully integrated, e.g., with respect to detection, then frequency is no longer a relevant variable with respect to the discriminability of these stimuli.

If equally detectable, equal-energy stimuli of different intensities and durations are discriminable regardless of frequency, then the results obtained in our previous paper

(Algom and Babkoff 1978), may be regarded as describing a general auditory phenomenon.

Experiment I

Apparatus and Procedure

The apparatus and the psychophysical methods employed were the same as those used in a previous experiment (Algom and Babkoff 1978). Stimuli were trapezoid-shaped tones of 8 and 32 ms,[1] whose rise and decay times were 1.0 ms. Stimuli were presented monaurally to the right ear via a pair of Scintrex MK IV earphones. The stimuli were generated by a Heathkit Audio Generator Model IG-72. Tone frequencies of 493, 1967, and 7874 Hz were used as stimuli and were calibrated by a Monsanto Type 120 A Counter-Timer. Stimulus energy was calibrated with a flat plate coupler by a Type 4133 condenser microphone coupled to a Bruel and Kjaer Audio Frequency Spectrometer Type 2113. All measurements of acoustic energy were made with continuous tones, and not with the short duration stimuli.

Seven normal hearing subjects took part in this experiment. The order of stimulus presentation, that is, the order in which the psychometric functions were generated for the two durations at the three frequencies, was randomly and independently determined for each subject.

The range of stimulus intensities to be used was determined during the last of three preliminary training sessions.

The purpose of the first experiment was twofold: 1) to determine the extent of integration for the two stimulus durations at the three frequencies used in this study, and 2) to obtain the basic detection data for the stimulus pairs to be used in the second experiment to test discrimination.

Each subject was tested over a 36-session period to generate the psychometric function for the three frequenceis (12 sessions for each frequency).

All testing took place in a Medtechnic Silent Cabin. Subjects were seated facing a panel with a warning light. A three-interval forced-choice method with feedback for correct responses was used. The stimulus was presented during one of the intervals, the other intervals were silent. The duration of the three intervals, indicated by the presence of a light, as well as of the two intervals separating them, was 1 s. Stimulus onset coincided with the onset of the presentation interval. A trial lasted 5 s. The intertrial interval was 8 s during which the subjects responded.

Three to five stimulus intensities, randomized by trial, were used to generate each psychometric function. Each stimulus intensity was presented 100 times.

Results

The psychometric functions were analyzed by probit analysis on an IBM 370 computer.[2] The results for the three frequencies are shown in Tables 1-3.

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[1] The choice of 8 and 32 ms stimuli as the short and long durations was based on several considerations. First, so as to be within the critical duration for detection for all of the frequencies tested including 7874 Hz (Watson and Gengel 1969). Second, so as to avoid the 'shallow' segment of pure tone integration functions reported for short duration low frequency tones

[2] (See next page)

Table 1. Probit analysis and constants of the linear least squares analysis of the psychometric auditory functions. F = 493 Hz

Subject	Stimulus duration	Intercept (a)	Slope (b)	Mean (μ) threshold dB SPL	Standard deviation (σ) dB	R^2	F	χ^2	df	P*
G.L.	8	-9.416	.366	25.70	2.72	.999	7557***	0.05	2	N.S.
	32	-6.900	.3525	19.65	2.78	.999	1712***	0.40	2	N.S.
	Difference in means			6.05						
I.Z.	8	-3.785	.185	20.3	5.4	.991	225*	0.38	1	N.S.
	32	-3.176	.216	15.0	4.6	.950	17.6	8.50	1	SIG.
	Difference in means			5.3						
M.K.	8	-9.814	.447	21.93	2.20	.993	273.50**	1.45	2	N.S.
	32	-6.754	.424	15.91	2.35	.995	402.18**	0.80	2	N.S.
	Difference in means			6.02						
G.N.	8	-6.910	.545	12.36	1.95	.939	15.47	3.06	1	N.S.
	32	-3.366	.548	6.18	1.90	.997	794.40**	2.59	2	N.S.
	Difference in means			6.18						
M.H.	8	-7.26	.4197	17.3	2.28	.961	24.78	3.7000	1	N.S.
	32	-4.89	.4242	11.5	2.35	.999	136.30	0.0068	1	N.S.
	Difference in means			5.8						
A.T.	8	-7.98	.3538	22.5	2.67	.994	334.9**	0.20	2	N.S.
	32	-6.10	.3707	16.5	2.56	.994	331.7**	0.06	2	N.S.
	Difference in means			6.0						
M.A.	8	-10.00	.3772	26.4	2.70	.957	45.1*	9.5	2	SIG.
	32	-7.64	.3765	20.2	2.66	.962	68.21	6.3	2	SIG.
	Difference in means			6.2						
Average threshold difference (8-32 ms)				5.97						

*$P \leq 0.05$; **$P \leq 0.01$; ***$P \leq 0.001$

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[2] All of the data were adjusted for chance guessing given that the subject could make the correct choice with a priori probability of 0.33. A correction was made to extend the range from 0% to 100%. The final adjusted percent was computed as (percent correct -0.33/1-0.33) The adjusted percent correct data were transformed to Z scores for all further computations and statistical analyses. The results of the probit analyses indicate that the corrected psychometric functions can be described by cumulative gaussian functions. Some adjusted psychometric functions are not described by cumulative gaussian functions; while others can be so described (for further details and discussion of this issue see Oatley, Robertson, and Scanlan 1969).

Table 2. Probit analysis and constants of the linear least squares analysis of the psychometric auditory functions. F = 1967 Hz

Subject	Stimulus duration	Intercept (a)	Slope (b)	Mean (μ) threshold dB SPL	Standard deviation (σ) dB	R^2	F	χ^2	df	P*
G.L.	8	-0.621	.3195	2.12	3.22	.856	17.88*	33.7	3	SIG
	32	1:334	.3125	-4.1	3.31	.8898	24.2*	25.66	3	SIG
		Difference in means		6.22						
I.Z.	8	-2.829	.361	7.82	2.68	.959	71.0*	10.2	3	SIG
	32	-0.7096	.3636	1.95	2.63	.976	122.8**	4.89	3	N.S
		Difference in means		5.87						
M.K.	8	-2.05	.3393	6.01	2.79	.984	18.5*	4.32	3	N S
	32	-0.03	.3282	-0.1	3.17	.99	369.**	.194	3	N.S
		Difference in means		6.02						
G.N.	8	-1.248	.3439	2.77	3.4	.952	39.4*	11.2	2	SIG
	32	1.1	.359	-3.67	2.99	.976	81.*	7.6	2	SIG
		Difference in means		6.44						
M.H.	8	-10.75	.6075	17.7	1.49	.969	31.5	3.4	1	N.S
	32	-7.155	.615	11.7	1.4	.933	14.	8.2	1	SIG
		Difference in means		6.0						
A.T.	8	-1.7	.3596	4.73	2.78	.999	30225.***	0.0002	1	N.S
	32	0.56	.3549	-1.54	2.78	.999	890.8**	0.158	1	N.S
		Difference in means		6.27						
M.A.	8	-.166	.3396	0.5	2.94	.999	9482.5***	0.29	2	N.S
	32	1.79	.3329	-5.38	2.99	.999	1578.6***	.22	2	N.S
		Difference in means		5.88						
Average threshold difference (8-32 ms)				6.01						

*$P \leqslant 0.05$; ** $P \leqslant 0.01$; ***$P \leqslant 0.001$

The data presented in Tables 1 to 3 indicate that 27 of the 42 functions can be fitted by a cumulative gaussian equation (χ^2 not significant).

The standard scores (Z scores) were then plotted as a function of stimulus intensity (dB SPL). The linear component is highly significant when the data are fitted by a least squares equation (all F values are significant) and accounts for over 95% of the variance ($.95 \leqslant R^2 \leqslant .999$) for 37 of the 42 functions. Threshold is defined as the median of each subjects' cumulative guassian distribution. Although the thresholds differ for the seven subjects both within and between frequencies, all of them show almost total integration for the durations and frequencies studied.

Table 3. Probit analysis and constants of the linear least squares analysis of the psychometric auditory functions. F = 7874 Hz

Subject	Stimulus duration	Intercept (a)	Slope (b)	Mean (μ) threshold dB SPL	Standard deviation (σ) dB	R^2	F	χ^2	df	P^{**}
G.L.	8	-10.53	.3452	30.55	3.10	.96	48.8*	5.84	2	N.S.
	32	- 8.46	.3415	24.62	3.11	.971	100.8**	6.48	3	N.S.
	Difference in means			5.87						
I.Z.	8	-11.67	.35	33.46	2.7	.965	27.8	1.35	1	N.S.
	32	- 9.58	.3475	27.88	2.6	.916	10.9	4.17	1	SIG.
	Difference in means			5.58						
M.K.	8	-12.55	.4139	30.30	2.4	.995	202.7*	.86	1	N.S.
	32	- 9.74	.4014	24.23	2.49	.996	263.2*	.657	1	N.S.
	Difference in means			6.07						
G.N.	8	- 7.704	.444	17.5	2.17	.965	56.6*	9.75	1	SIG.
	32	- 5.343	.463	11.6	2.04	.974	74.*	7.6	1	SIG.
	Difference in means			5.9						
M.H.	8	- 9.82	.421	23.70	3.24	.925	24.7*	7.32	2	SIG.
	32	- 7.62	.438	17.96	2.9	.952	39.5*	2.56	2	N.S.
	Difference in means			5.74						
A.T.	8	-11.76	.4694	24.40	2.35	.89	15.8	24.6	2	SIG.
	32	- 8.83	.4793	18.65	2.19	.941	31.8*	11.6	2	SIG.
	Difference in means			5.75						
M.A.	8	-13.07	.682	18.95	1.6	.989	179.95**	1.391	2	N.S.
	32	- 8.83	.668	13.05	1.64	.989	182.5**	1.511	2	N.S.
	Difference in means			5.9						
Average threshold difference (8-32 ms)				5.83						

$^{*}P \leq 0.05$; $^{**}P \leq 0.01$; $^{***}P \leq 0.001$

The results are shown in Fig. 1. (panels a-g) in which the psychometric functions are plotted for the seven subjects. Detection levels in standard scores (Z scores) are plotted on the ordinate as a function of total stimulus energy in dB, (i.e., intensity in dB + 10 times log duration) on the abscissa. Data are plotted for all three frequencies for each subject.

Note that for almost all of the functions, a single line can be drawn through the data points representing the two stimulus durations for each of the frequencies when plotted on a total stimulus energy axis, thus illustrating total integration for these frequencies for the 8 and 32 ms stimuli.

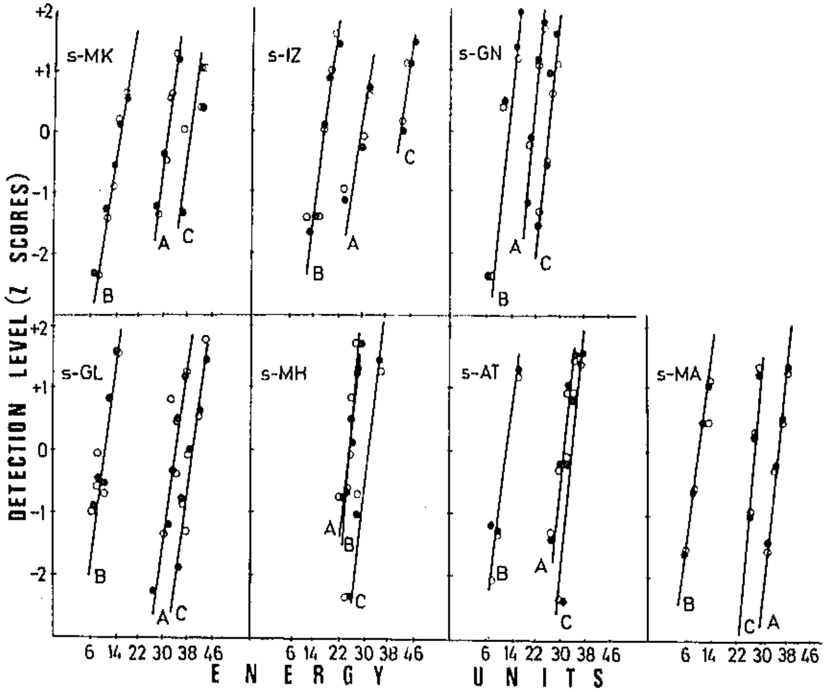

Fig.1. (panels a through g). Psychometric functions are plotted for seven subjects separately in each panel. Detection level in Z scores is plotted on the ordinate as a function of total stimulus energy in dB on the abscissa. Total stimulus energy is defined as the stimulus intensity in dB SPL + 10 log stimulus duration (re, 1 ms duration stimlus). Data are plotted for three frequencies for each subject. The open circles (○) represent the data for the 32 ms duration stimulus, while the closed circles (●) represent the data for the 8 ms duration stimulus. The parameter is tone frequency: A 493 Hz; B, 1967 Hz; C, 7874 Hz

In summary, the results of the first experiment indicate that there is complete temporal integration for the durations tested for the three frequencies, 493, 1967 and 7874 Hz. A fourfold increase in stimulus duration results in approximately a 6 dB decrease in threshold.

Experiment 2

Procedure

The second experiment was performed to measure discrimination between two stimuli of equal energy at approximately equal detection levels, but constructed of different intensities and durations.

Pairs of stimuli were chosen for each subject at each of the three frequencies such that the two approximately equally detectable members of each pair were equal in energy, but differed in intensity and duration (8 and 32 ms). Four such stimulus pairs at four different overall detection levels (20%, 40%, 60%, and 80% were determined for each subject for each frequency from the psychometric functions.

A three-alternative forced-choice technique was used to measure discrimination. The 8 ms tone was presented in two of the three intervals while the 32 ms tone was presented in one of the three intervals (the 'different' one). The subject was required to indicate which one of the three tones differed from the other two, i.e., to discriminate between the interval containing the 32 ms tone and the two intervals containing the 8 ms tones.

Stimuli at each of the four different energy (detection) levels for each of the three frequencies were presented 100 times to each subject. A fixed energy level and a fixed stimulus frequency was presented during a single session. The order of presentation across energy (detection) levels and across frequencies was random and independent for each subject. Each subject was tested over 12 sessions in this experiment.

Results

The results were analyzed by a two-way analysis of variance with repeated measurements (detection levels X frequencies). The results are presented in Table 4 and indicate that the only significant factor in determining discrimination level is detection level. For the three frequencies tested, discrimination between the 8 and 32 ms equal-energy stimuli increases as a function of detection (or overall energy level) in a similar manner. The lack of significance for the frequency x detection interaction implies that approximately the same slope describes the discrimination-detection level relationship for the three frequencies.

The data of each subject at each frequency were fitted by a linear function[3] using the least squares technique. The results of this analysis are presented in Tables 5-7,

Table 4. Two-way analysis of variance with repeated measurements. Level of discrimination by frequency and detection. Data for seven subjects

Source	SS	df	MS	F
Frequency	37.987	2	18.99	< 1
Detection	51292.4286	3	17097.48	154.03***
Subjects	2526.22	6	421.036	
Frequency x Detection	524.79	6	87.46	1.96
Frequency x Subjects	1252.55	12	104.38	
Detection x Subjects	2001.988	18	111.22	
Frequency x Detection x Subjects	1618.767	36	44.965	
TOTAL	59254.7381	83		

***$P \leq 0.001$

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[3] Since both the percent of detection and the percent of discrimination in terms of standard Z scores are linear functions of the energy level of the stimulus, the expectation is that the percent of discrimination (Z scores) should be a linear function of the percent of detection (Z scores) over that energy range

Table 5. Constants of the linear function relating discrimination level to detection level. F = 493 Hz

Subject	Intercept (a)	Slope (b)	95% Confidence limits around slope (b)	R^2	df	F
G.L.	- .5075	1.797	±0.339	.981	1,2	107.8**
I.Z.	- .5825	1.7068	±0.653	.929	1,2	26.3*
M.K.	-1.361	1.683	±0.18	.996	1,1	317.4*
G.N.	- .785	1.3245	± .882	.81	1,2	8.35
M.H.	- .258	1.208	± .111	.997	1,1	330.3*
A.T.	- .526	.9387	± .119	.996	1,1	235.4*
M.A.	- .982	1.782	±0.85	.943	1,1	16.8
Median		1.68		.981		

$^*P \leqslant 0.05$
$^{**}P \leqslant 0.025$

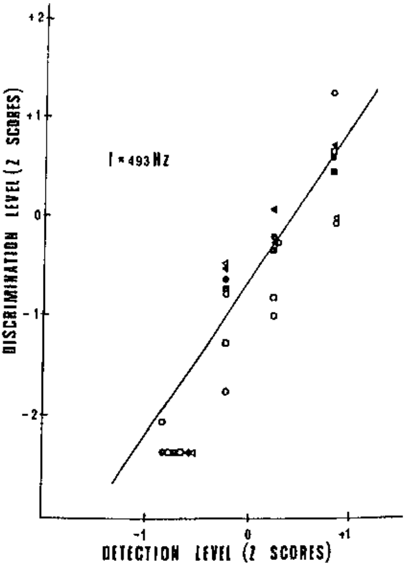
Table 6. Constants of the linear function relating discrimination level to detection level. F = 1967 Hz

Subject	Intercept (a)	Slope (b)	95% Confidence limits around slope (b)	R^2	df	F
G.L.	-0.7	1.609	±0.58	.94	1,2	29.5*
I.Z.	- .58	1.8122	±0.47	.965	1,2	56.4**
M.K.	-1.1325	1.407	±0.55	.925	1,2	24.7*
G.N.	- .5325	1.8436	±0.71	.928	1,2	25.9*
M.H.	- .063	1.0248	±0.862	.843	1,1	5.4
A.T.	- .914	1.076	±0.266	.984	1,1	62.6
M.A.	- .6428	1.26	±0.241	.99	1,1	103.9
Median		1.41		.940		

$^*P \leqslant 0.05$
$^{**}P \leqslant 0.01$

and indicate that for 18 of the 21 functions, a linear function accounts for 93 to 99% of the variance ($.93 \leqslant R^2 \leqslant .99$). These data are shown in Figs. 2-4 in which discrimination level in Z scores is plotted as a function of detection level in Z scores for the four pairs of equal energy, equal detection level, stimuli.

The data indicate that as the detection level increases, there is an increase in the ability to discriminate the longer stimulus from the shorter one. For the three frequencies, discriminability increases at a faster rate than detection for the same energy levels. This can be seen by an examination of the slope variable (b) in Tables 5 through 7. Fifteen of the 21 slopes are greater that 1.3, while the median slope value for the three frequencies ranges from 1.41 to 1.68.



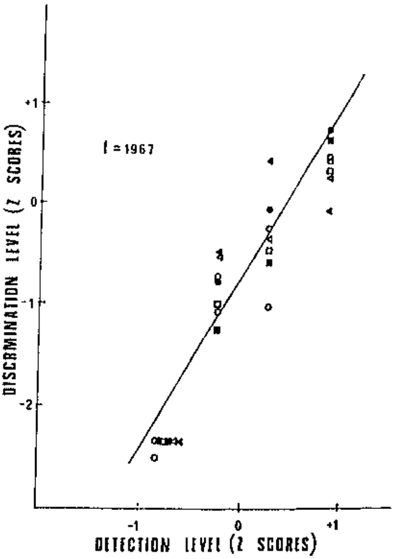


Fig. 2. Discrimination level in Z scores is plotted on the ordinate as a function of detection level also in Z scores on the abscissa for four pairs of equal-energy, equal-detection-level stimuli. Data are plotted for each subject; a single linear function is drawn through the data based on the median slope (see Table 5). The frequency of the tone is 493 Hz

Fig. 3. Discrimination level in Z scores is plotted on the ordinate as a function of detection level also in Z scores on the abscissa for four pairs of equal-energy, equal-detection-level stimuli. Data are plotted for each subject; a single linear function is drawn through the data based on the median slope (see Table 6). The frequency of the tone is 1967 Hz

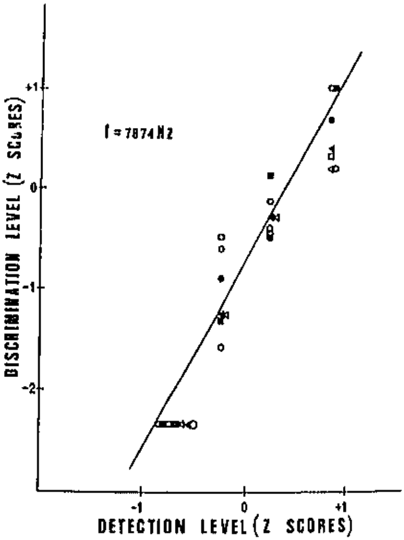


Fig. 4. Discrimination level in Z scores is plotted on the ordinate as a function of detection level also in Z scores on the abscissa for four pairs of equal-energy, equal-detection-level stimuli. Data are plotted for each subject; a single linear function is drawn through the data based on the median slope (see Table 7). The frequency of the tone is 7874 Hz

Table 7. Constants of the linear function relating discrimination level to detection level. F = 7874 Hz

Subject	Intercept (a)	Slope (b)	95% Confidence limits around slope (b)	R^2	df	F
G.L.	- .4825	1.415	±0.515	.964	1,2	54.58*
I.Z.	- .613	1.501	±0.0627	.956	1,1	21.96
M.K.	-1.026	1.643	±0.704	.9544	1,1	20.94
G.N.	- .779	1.34	±0.664	.939	1,1	15.6
M.H.	- .8375	1.677	±0.274	.986	1,2	143.1**
A.T.	- .618	2.14	±0.719	.971	1,1	34.2
M.A.	- .1989	.591	±0.556	.81	1,1	4.33
Median		1.50		.956		

*$P \leqslant 0.025$
**$P \leqslant 0.01$

Discussion

The results of both experiments may be summarized as follows: 1) Complete temporal integration up to 32 ms was demonstrated for tones of 493, 1967, and 7874 Hz using a three-alternative forced -choice design. These results were expected considering the results reported by Watson and Gengel (1969). 2) For the three frequencies equal energy, equally detectable stimuli constructed of different intensities and durations within the temporal integration range were shown to be discriminable from one another. 3) Discrimination level of the equal-energy stimulus pairs increases as a function of increasing energy level and, as a consequence, as a function of detection level. 4) When the discrimination level is plotted against the detection level on normal probability coordinates, the result is a straight line with a slope greater than unity ($1.41 \leqslant b \leqslant 1.68$). 5) The discrimination detection relationship is independent of frequency.

Several studies have reported results indicating that auditory acuity (auditory temporal discrimination) is of the order of 1.5 to 3 ms depending upon stimulus parameters for a variety of stimuli (e.g., Babkoff and Sutton 1971; Efron 1973; Green 1971; Patterson and Green 1970). However, the auditory acuity data extant in the literature relate mainly to supra-threshold, complex waveforms whose internal order of stimulus components is discriminable and presumably the basis for discrimination (e.g., Patterson and Green 1970). There are no extant empirical data concerning a direct comparison of fully integrated, equally detectable auditory stimuli. The major contribution of this, and the previous study (Algom and Babkoff 1978) is the demonstration that temporally integrated, equal energy, threshold-level pure tones of different intensities and durations can be discriminated from one another. Auditory acuity for threshold-level stimuli is of importance in the choice of an appropriate model of auditory integration (Penner 1978).

In the previous study (Algom and Babkoff 1978) we tested the ability of subjects to discriminate between equal-energy, equally detectable tones of 988 Hz differing in intensity and duration (16 and 64 ms). As in the present experiment, discrimination increased as a function of energy faster than the detectability of either tone as a function of the same energy levels. The median slope relating discrimination level (Z scores) to detection level (Z scores) of a 988 Hz tone was found to be approximately 1.7, similar to the median value reported in the present study (1.41 and 1.68) for tones of 493, 1967, and 7874 Hz.

Several simple, perhaps even trivial, explanations of the results of the discrimination experiment should be considered.

One possibility is that perhaps the contextual differences between the detection studies of each of the durations separately (Experiment 1) and the discrimination study (Experiment 2) led to the different 'thresholds' or 'criteria' so that subjects 'heard' only one of the two stimulus durations in the discrimination paradigm and responded to the 'presence' of the only stimulus 'heard.' As counter arguments, several points may be considered. First, all of the subjects performing the discrimination experiment had extensive practice in listening to the 8 and 32 ms duration stimuli separately and were aware that a stimulus (of either 8 or 32 ms) was to be presented in each of the three intervals in the discrimination experiment. They therefore had to "attend" equally well to each interval in order to be able to discriminate between them. After the experimental sessions, subjects reported hearing more than one stimulus at any one trial. Second, if the discrimination is possible only because of a difference in detectability between the two stimuli, one would expect a decrease in discrimination as energy level increases, since such an increase is accompanied by increases in detection level for each of the two stimuli; thus leading to a greater probability of detecting 'all' the stimuli on each trial. Discrimination should therefore decrease rather than increase with detection level. Third, the 8 ms duration stimulus apppeared in two of the three intervals, thus yielding a 'second-look' paradigm which tends to lower threshold criterion and, if anything, should have produced a 'lower' threshold for the 8 ms stimulus than measured in Experiment 1 leading to 'better' detection of the shorter duration. It is, therefore, unlikely that the subjects were responding to the longer stimulus because it was the only one 'heard' nd the shorter stimulus was not heard.

Another possible explanation involves the differential spectral energy spread associated with short auditory stimuli of different durations. As duration is shortened, energy spreads over a bandwidth proportional to the inverse of the duration. Therefore, the spread of the spectral energy of the 8ms stimulus differed from that of the 32 ms stimulus. This differential spectral dispersion of energy may have served as the basis for discrimination between the two durations.

Several points may be presented in arguing against this explanation. 1) The use of trapezoid-shaped gated, 1 ms on, 1 ms off stimuli, eliminated 'perceptual' clicks, so that neither the 8 nor the 32 ms stimulus was 'subjectively' noisy, implying that the spectral spread was not 'perceived'. 2) As noted, for frequencies of 1000 Hz and above, the integration functions do not show the shallow segment even when duration is reduced to 2 or 4 ms (e.g., Garner 1947). Three of the four frequencies used in this and the previous study (Algom and Babkoff 1978) were 988 Hz and above. Furthermore, there is no shallowing of slope of the integration function for a 500 Hz tone unless duration is shortened to 4 ms and less. As full integration was found for the 8 and 32 ms stimuli for all frequences, the difference in spectral dispersion must have had minimal effect, if any. 3) The durations used in the previous study (16 and 64 ms) have half the spectral dispersion of the durations used in the present study, yet the results of both studies are the same, and even yield the same slope for the discrimination-detection relationship. 4) If the different spectral dispersions of the shorter stimuli, respectively, were the basis for discrimination, one would expect that the extent of discrimination should differ over the four frequencies tested, since the frequency jnd (Δ f) and the critical bands and ratios change radically as frequency increases from 500 to 8000 Hz (e.g., Hawkins and Stevens 1950, Shower and Biddulph 1931). The absence of any effect of stimulus frequency on either the integration or the discrimination-detection functions argues against such an explanation.

The results of the earlier study (Algom and Babkoff 1978) and of this study point toward a general conclusion regarding the discriminability of equally detectable, equal-energy tone pulses, i.e., discrimination proceeds at a faster rate than detection over the same energy levels. The slope of the function relating discrimination level to detection level reflects the relation of the two standard deviations of the best fitting cumulative normal equations of discrimination and of detection. A slope ranging from 1.41 to 1.7 implies that the variance of the discrimination distribution is smaller than that of the detection distribution. There is no ready explanation for this result; however, a tentative one can be offered in terms of the number of independent, relevant sources of information that are available to the subject and upon which he may base his decision in a sensory psychophysical task. In particular, as the number of such sources for a decision increases, the variability of the subject's responses should decrease proportionally. In a detection task, the only relevant basis for a decision is the presence or absence of the stimulus regardless of its duration or intensity. In the discrimination task, the decision that a difference exists between two equal-energy stimuli may be based on at least two stimulus dimensions, each of which is available as a possible source of information: stimulus duration and intensity. Allan and Kristoferson (1974) posit that the basis for the discriminations of equally detectable equal energy visual stimuli, reported by Zacks (1970), is 'temporal'. Further studies are needed to test this hypothesis as well as the generality of the finding itself in other sensory systems. Although Zacks (1970) presented graphed data for the visual system, no data on curve fitting are available to make the comparison.

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