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The Loudness of Short Duration Sounds

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1. Introduction

The results of different studies on the growth of loudness with stimulus duration have been so varied as to force one eminent reviewer to comment: "Following no orderly pattern...they show how difficult it is to measure loudness as a funtion of duration"[1].

The first studies in this field using rather crude equipment were performed in the latter part of the 19th century by Exner[2] and a few subsequent workers who found rather varying results, agreeing only that the general phenomenon of temporal integration occured. The first modern study came with the work of Békésy[3], who, using 800Hz tone-bursts, showed a rapid rise of loudness with stimulus duration reaching a maximim at about 180ms. He stated that over the frequency range 300-2000Hz which he used, this maximum was attained at shorter durations at the higher frequencies and at shorter durations with increasing intensity. His results were based on loudness balance, studies, balancing the test tone against a 200ms standard in the opposite ear.

Since that time a large number of studies have been performed using a wide variety of stimuli and experimental techniques. Not, surprisingly, perhaps, there has been relatively little agreement between different groups of workers. These differences cover the slope of growth of loudness with stimulus duration, the critical duration or time constant of this slope, and whether or not these are frequency or intensity dependent.

Some of these differences may arise from averaging the results over a large number of individuals, and Garner[4] has pointed out that certain subject fail to show any temporal integration of loudness. Further differences can arise from the choice of control stimulus. This has been discussed by Reichardt and Niese[5] who showed that a shorter integration time-constant is obtained when a relatively short duration control stimulus (30ms) is used as compared with a longer duration (450 ms) stimulus. This is in accord with the work of Garner[6] who showed that the accuracy of the match, as expressed in terms of the standard deviation of the results, increases with increasing difference in duration between the test and control tones.

In the past few years there have been a number of studies 7,8,9 on the temporal integration of loudness using loudness estimation techniques, which have been shown to be very susceptible to many different aspects of experimental techniques[10] and individual differences[11].

The present study investigated the loudness of energy-equalised tone bursts of different durations with the same subjects performing loudness estimations under conditions of different emphasis in

their instructions, and also performing both loudness estimations and loudness balances on the same stimuli in order to directly compare the two techniques.

2. Procedure

2.1. Equipment The basic equipment used has been described elsewhere[14] Summarising, the subject was seated in a sound-insulated booth. The stimulus was produced by a Ferguson TG 11 tone-burst generator which produced rectangular tone bursts of adjustable duration and phase from a continuous sinusoid produced by an audio frequency oscillator. This tone-burst generator could be triggered either mannually or by short-circuiting the input by a repetitive timing device as used in the loudness balance experiments. In those experiments, two identical tone-burst generators were used, one of which produced the test stimulus and one the control. The attenuation of the test stimulus was under the control of the experimenter, that of the control stimulus was adjusted by the subject using a sone potentionater. The levels were set and measured using a probe microphone inserted through the headphone cushions.

2.2.1 Experiment 1

For this experiment six subjects who had already participated in a study on the detectability of short duration sounds, were used. None had performed loudness estimations before, and all had normal hearing. They estimated the loudness of 1000 Hz rectangular tone-bursts equal in energy to a 1 sec tone-burst of 50dB SPL. They were provided with a 32 ms modulus which was ascribed a numerical value of 100. Additional stimuli were provided at 10dB above and below the equal-energy points to give the subjects a wider range of loudness. The range of durations was split into three overlapping sections to reduce the subjectives difficulties arising from comparing a very short tone-burst which is subjectively "clicky" with a long duration tone-burst which is subjectively tonal.

In the first series of estimations by this group of subjects, they were instructed to estimate the loudness of the tone-bursts and to ignore differences in duration. In the second part they were told that despite instructions to estimate loudness alone, they had incorporated components arising from the duration differences, and were now asked to estimate the subjective "amplitude" of the tone-bursts.

2.2.2 Experiment 2.

In this study 12 normal-hearing members of staff of the acoustics section of NPL were used as subjects. The purpose of this experiment was to examine the growth of loudness over the range of 1-9ms tone-bursts of 1000H_z, as the results of experiment 1 and of other studies by the present author[12] had shown certain incongruities at these short durations the stimuli were either equal in energy to a 50dB SPL stimulus of 1 second duration; or equal in amplitude to the 3 ms stimulus used in the equal energy determinations. In all the magnitude estimates the 3ms stimulus was ascribed a numerical value of 10 and was given as the modulus at the beginning of the experimental run. It was also used as the control stimulus in loudness balance studies.

The subjects performed both loudness-balance and loudness-estimations on the equal energy stimuli sf, 1,2,3,5 and 9ms durations. They also performed loudness estimations and duration estimations on both equal energy and equal intensity stimuli over this range.

2.2 3 Experiment 3.

In this experiment, ten normal hearing members of the NPL subject panel performed loudness estimations and loudness

balances over a wide range of stimulus durations at the three frequencies 250, 1000, and 4000Hz. Equal-energy stimuli to a 1 second stimulus of 50dB SPL were used at each frequency. For each frequency a stimulus near the geometric mean of the duration range was used as the modulus and ascribed a nemerical value of 10. The same stimulus was used in each case as the control stimulus in the loudness balance experiments. As in experiment 1, the duration ranges were split with overlapping components to minimize the difficulties arising from comparing very short with very long durations. Again stimuli 10dB above and below the equal energy points were used in order to give the subjects a greater range of loudness and to reduce any tendencies to estimate on the basis of duration rather than loudness.

3. Results and Discussion

3.1. Experiment 1 The results of this study support the findings from detection studies[13,14] that when equal energy stimuli are used there is a plateau of equivalence of the psychophysical response. These results were in accord with those obtained from a different group of subjects reported elsewhere[12]. They do, however, differ from the detection results obtained from theses same subjects in that the plateau of psychophysical equivalence was shifted towards longer durations. This is at least partially explained by the results of the comparison between the two different instruction sets, which show that the results were significantly different in the direction that would be predicted from the increased emphasis on the duration components in the first instruction set.

3.2. Experiment 2 The results of the comparison between loudness balance and loudness estimation of these short duration stimuli show rather different patterns. In the loudness balance study, none of the estimates was significantly different from any other, whereas in the loudness estimation the 9ms tone was estimated as significantly louder than those of the other durations, so supporting the concept that in loudness estimation, the subject finds it difficult or impossible to separate the components of duration from those of loudness.

The loudness estimations of equal energy and equal intensity stimuli differ as might be predicted with the equal amplitude stimuli estimated as softer for the shorter durations and louder for the longer durations. However, this same difference was found in the duration estimations, confirming some previous reports that intensity may influence duration estimation, although the difference in stimulus intensities used in the present study was smaller than those of previous studies.

3.3. Experiment 3 The results of this study show that for all three frequencies examined, there is a marked and significant difference between the results for the loudness balances and loudness estimation. Thus in every case the plateau of equal loudness occurs at shorter durations in the loudness balance studies than in the loudness estimations. The results of the loudness balance in fact are remarkably close to the detectability of signals of the same intensity in a background of noise, suggesting that this represents a better approximation to the true pattern of the growth of loudness with duration than is shown by the loudness estimation studies. A further point arising from this experiment is that with both techniques, a frequency-dependent critical duration was found, occurring at shorter durations with higher frequencies. This supports the early findings of Bekesy[3] and the results of most recent threshold and detection threshold studies[15], but is in conflict with the reported findings of Port [15]. The actual measure

does depend, however, on the approach to the critical duration or integration adopted in any particular study, and here the choice of the end point of complete energy integration results in different figures from a criterion of no further integration.

4. Conclusions

The present study has shown that particularly in loudness estimation experiments, the subjective duration of the stimulus can influence considerable its loudness. Likewise the finding of subjective duration being influenced by intensity has been supported. The third experiment also supports the concept of a frequency-dependent critical duration in loudness studies, which had been previously definitively shown in threshold determinations although there had been doubt cast on the existence of this phenomenon in loudness studies.

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