# OPTIMUM RANGE OF TONAL FREQUENCIES FOR QUICKNESS IN AUDITORY REACTIONS

**By M.S. Prakash Rao and N.A. Nayak**

**Defence Science Laboratory, Ministry of Defence, New Delhi**

## ABSTRACT

Quickness of response is an essential characteristic of a sense organ when considered from the point of view of its suitability for use as a channel of information in a display control situation. It has long been known that the human ear is maximally sensitive to tones of frequencies of 2,000—4,000 c/s but it was not clear whether response of the auditory system to tones of frequencies in this range would be the quickest also. In the experiment described here, Reaction time technique was used to measure the quickness of response of the ear to tones of different frequencies, ranging from 600 to 15,000 c/s. The intensity of output of the tones was kept constant. Analysis of the data showed that the average reaction time was shortest for tones of frequencies of 1,500—4,000 c/s. The length of the reaction times increased on either side of this band of frequencies.

## Introduction

Two qualities are essential in a sensory system for its optimum performance as a channel of information. These are, first, the sensitivity of the system for slight changes in the stimuli and secondly, the quickness with which it responds to them. It has long been known that the human ear is maximally sensitive to tones of frequencies of 2,000—4,000 cycles per second. But it was not clear whether the response of the auditory system to tones of this range of frequencies would be the quickest also. One way of measuring the quickness of response of a sensory system is by means of the reaction time technique. The response of person to a stimulus can be split up into three phases. The first phase consists of response of the sensory system to the stimulus. In the second phase, the message from the sense organ is received by the brain and the impulse for appropriate action is sent to the muscle group concerned. The third phase consists in the initiation of action by the muscle group. The time taken for the first phase of reaction varies with the sensitivity of the sensory system. The human ear is said to be more sensitive than the human eye, because of the retinal processes involved in the use of the latter. The visual reaction time is accordingly longer than the auditory reaction time. In the present study it is intended to find out whether there are any variations in reaction time depending upon the frequencies of the stimuli. The hypothesis is that, since the human ear is maximally sensitive to tones of frequencies of 2,000—4,000 cycles per second, the reaction times for tones of frequencies within this range should be lowest.

## Procedure

In this study it was intended to measure reaction times of subjects to tones of frequencies varying from 600 to 15,000 cycles per second. The output intensity of the signals was kept constant at 30 db. The sound signals were audible at this intensity throughout the frequency range tested. The source of the sound signals was an audio-oscillator. The experiment was conducted in a moderately sound proof room. The use of ear phones further cut down interference from outside noise considerably.

The number of subjects participating in this experiment was ten. The age range of the subjects was 20—30 years. None of them had any hearing difficulties according to their own statements. Further they were all tested at different frequencies and at an intensity of 30 db. for hearing ability. The subjects were divided into two groups of 5 members each. One of the groups was started at the lowest frequency of 600 cylces per second and their reaction times to tones of increasing frequencies were obtained. The other group was started at the highest frequency of 15,000 cylces per second and their reaction times to tones of decreasing frequencies were recorded. This was done in order to mask the effects of practice, if there were any.

## Experimental set-up

The experimental set-up consisted of an arrangement of the following apparatus—Audio-oscillator, Head phones, Chronotron, and two telegraph tap keys. The Audio-oscillator is a Hewlett-Packard model 200-C. The reaction times were measured with the help of an electronic device known as Chronotron, manufactured by Electronic Instruments Ltd., England. The particular model used in this experiment was Chronotron 25-B which has a time interval range of 0—400 milliseconds among other ranges. The schematic diagram of the arrangement of the apparatus is shown in fig. 1.

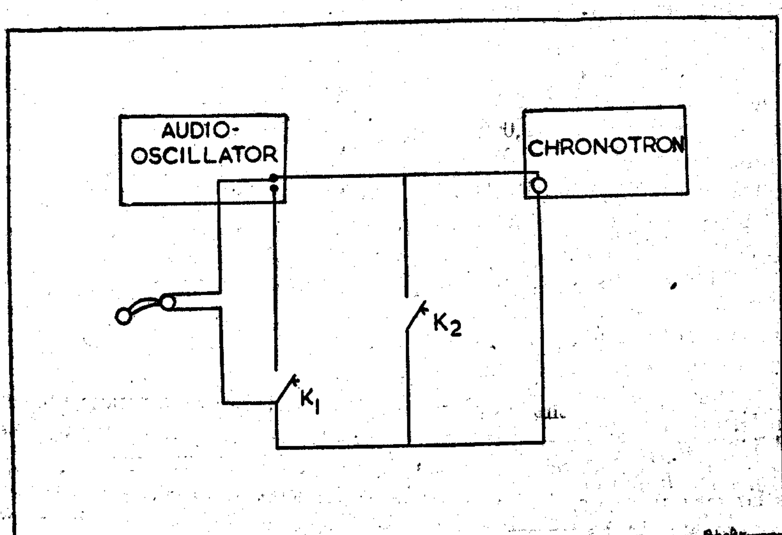


FIG. 1—Schematic diagram of the arrangement of apparatus.

Pressing of the key $K_1$ by the experimenter closes the circuits through the head phones and the Chronotron simultaneously. Closing of these two circuits makes the sound audible to the subject and at the same time starts the Chronotron. As soon as the subject hears the sound he presses the key $K_2$ thereby shorting both the chronotron and the head-phones. The time elapsing is read off the Chronotron and a fresh cycle is started.

The subjects were instructed at the beginning of the experiment to keep themselves in readiness as soon as the warning signal came on, and then to react as quickly as possible on hearing the tone by pressing the key $K_2$ (fig. 1). A foreperiod of 2 to 4 seconds was allowed. This was varied from trial to trial in order to avoid anticipatory reactions. The duration for which the tone could be heard was equivalent to the reaction time of the individual as the closing of the key $K_2$ cut off the oscillator from the head-phones circuit. Each individual was given two trial runs at each frequency to enable them to have practice before beginning the test runs.

**Results**

Five readings were obtained from each individual at each frequency. The average reaction times for the different frequencies for each individual are shown in the Appendix. The mean reaction times for different frequencies averaged over all the ten subjects are shown in Table 1.

TABLE 1

*Mean Reaction Times for Tones of Different Frequencies*

| Frequency cycles/sec. | Mean Reaction Time (milliseconds) |
|---|---|
| 600 | 153 |
| 800 | 149 |
| 1,000 | 143 |
| 1,500 | 139 |
| 2,000 | 135 |
| 3,000 | 135 |
| 4,000 | 137 |
| 5,000 | 140 |
| 6,000 | 143 |
| 8,000 | 146 |
| 10,000 | 148 |
| 15,000 | 150 |

It is observed from the table that starting with the lowest frequency of 600 cycles per second, the mean reaction time for the group as a whole decreases gradually till a minimum is reached at the 2,000—3,000 cycles per second level. Thereafter a rise in the mean reaction time is observed. This trend is evident in each individual case as can be seen from the table in the Appendix. In order to find out whether these differences in reaction times are really significant Analysis of Variance was carried out. The details of this are shown in Table II.

TABLE II

*Analysis of Variance*

| Source of Variation | Degrees of freedom | Sum of squares | Mean sum of squares | F—test |
|---|---|---|---|---|
| Between frequencies | 11 | 573·1 | 52·1 | 15·9* |
| Between persons | 9 | 857·6 | 95·3 | 29·1* |
| Interaction | 99 | 731·9 | 7·4 | 2·26* |
| Error | 480 | 1570·2 | 3·3 | |
| Total | 599 | 3732·8 | | |

* Significant at 1 per cent level.

It was found that the differences between the mean reaction times for different frequencies are statistically significant at 0·01 level. It is also observed from the Analysis of Variance table that the interaction between persons and frequencies is significant. This shows that apart from the effect of tonal frequency on the reaction time, there is, another personal factor, whose effect may not be uniform throughout the frequency range, that is coming into play here. The practical significance of this is that, if subject A is better than subject B (*i.e.* A has shorter reaction time than B) for a tone of a particular frequency, then it does not necessarily mean that this would be true for tones of all frequencies. This is to be expected, since the ears of different individuals are sensitive to tones of different frequencies to different extents. Whether the interaction observed is actually due to this could not be checked, however, because the detailed audiograms of the subjects were not obtained.

By further treatment of the data based on the Analysis of Variance and by adopting a procedure of grouping of frequencies it was found that the frequency range 1,500—4,000 cycles per second yielded the shortest reaction times. The mean reaction times for various frequencies are shown graphically in fig. 2.

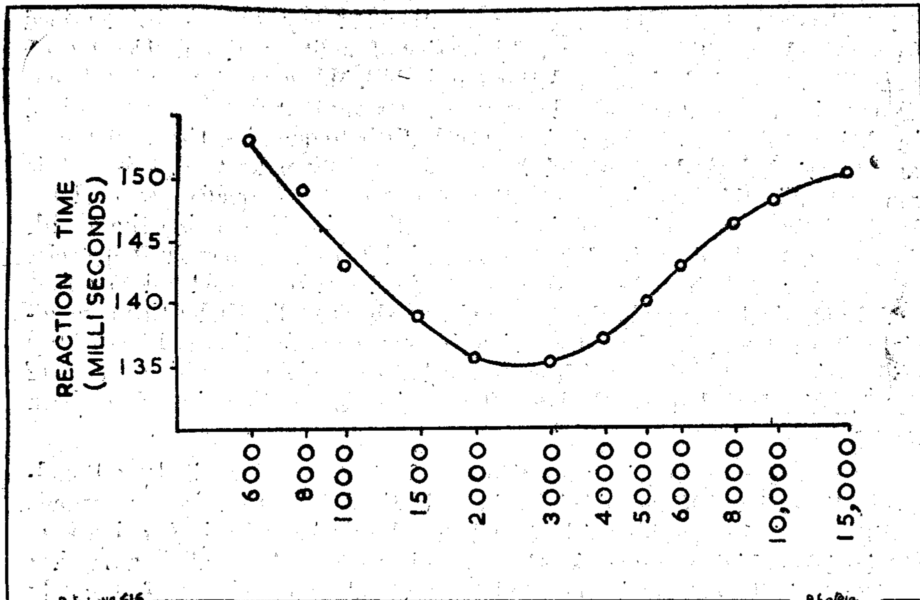


FIG. 2—Changes in mean reaction time with frequency

The drop in reaction time was maximum between tones of 600 cycles per second and tones of 2,000—3,000 cycles per second, being of the order of 11·8 per cent. The average reaction time for the group as a whole for tones of frequencies below 2,000 cycles per second level is 146 milliseconds whereas the average for frequencies of 2,000 cycles per second and above is 142 milliseconds approximately. Thus, if 2,000 cycles per second is taken as the cross-over point between higher and lower frequencies, then the average reaction time is shorter for higher frequencies and longer for lower frequencies (within the frequency range studied).

## Discussion

Measurements of thresholds of hearing indicate that the human ear is maximally sensitive to sounds of frequencies of 2,000—3000 cycles per second[1]. Below and above this frequency band the sensitivity falls off gradually. On account of this differential sensitivity of the ear, sounds of different frequencies, but of the same physical intensity, appear to have different loudness levels. This is at least true at the lower levels of intensity. Thus, it appears, the ear reacts to sounds of different frequencies to different extents depending upon its own sensitivity to them. On account of the maximal sensitivity of the ear to tones of medium frequencies (*i.e.* 2,000—4,000 c.p.s.) tones falling outside this frequency range must be physically stronger than at these medium frequencies to sound equally loud. When we say two tones of different frequencies sound equally loud, then the term loudness should not be considered synonymous with intensity, for loudness and intensity are two different, though overlapping, dimensions of a sound. Similarly when we talk of a high pitched or low pitched tone, the word 'pitch' refers to something more than the frequency of the tone. "The important thing to note......is that pitch and loudness are names for separate aspects of auditory sensation and they are not to be identified in our thinking with frequency and intensity of auditory stimuli. The former concepts are psychological, the latter physical."[1]. When two tones of different frequencies are equalised in loudness, we cannot say that the difference noticed in their tonal character now lies only in their frequencies. These differences are of a psychological nature and are not, as yet, fully understood. It is for this reason that in this experiment no attempt was made to equalise the loudness levels of the tones while studying the variations in the reaction times with frequency. The loudness levels naturally varied depending upon the frequencies of the tones and thus the responses obtained can be considered to reflect mainly physical changes in the frequencies of the stimuli. Under these conditions, it was found that lowest reaction times were obtained in the 1,500—4,000 cycles per second region, which corresponds to the highly sensitive region of the ear. For both lower and higher frequencies the reaction times have been longer.

It is necessary in this connection to refer to two papers cited by Broadbent[2]. Fessard and Kucharski[3] in an investigation of reaction times for sounds of different pitches and intensities found that shorter latencies in reaction were obtained from higher frequencies than from lower ones. Chochalle[4] in another study of a similar nature found equal latencies to all frequencies. Unfortunately it has not been possible to go through either of these papers; but it is obvious that these experiments must have been conducted under different conditions. Broadbent[2] in his study on effects of noises of high and low pitch on human behaviour found that the reaction time is lower for high pitched noises than for low pitched ones. However, as Broadbent himself says, these results do not necessarily apply to pure tones. The results of the present study differ from those of all the previous studies mentioned above, probably because of the different methodology adopted by us. It was found that the reaction time was lowest in the 1,500—4,000 cycles per second region and it increased gradually for lower and higher frequencies. Since reaction time depends to a large extent on the sensitivity of the sense organ concerned, it is not surprising to find that auditory reaction time to the frequency band 1,500—4,000 cycles per second is the shortest.

## Summary and conclusions

Reaction time readings were obtained from a batch of 10 subjects for pure tone stimuli of different frequencies ranging from 600 to 15,000 cycles per second. The intensity of output was kept constant at 30 dbs. Analysis of the data showed that the average reaction time was shortest for tones of frequencies between 1,500 and 4,000 cycles per second. The reaction times increased on either side of this band of frequencies.

## Acknowledgement

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## References

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# APPENDIX

*Mean Reaction Times for Tones of Different Frequencies*

| Frequency Cycles/sec. | Mean Reaction Times (milliseconds) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 600 | 150 | 148 | 136 | 172 | 153 | 145 | 152 | 161 | 155 | 158 |
| 800 | 149 | 144 | 132 | 165 | 149 | 141 | 148 | 160 | 148 | 154 |
| 1000 | 146 | 138 | 129 | 150 | 145 | 139 | 145 | 153 | 137 | 148 |
| 1500 | 149 | 134 | 119 | 148 | 142 | 137 | 144 | 150 | 123 | 144 |
| 2000 | 144 | 131 | 123 | 139 | 140 | 134 | 143 | 140 | 118 | 139 |
| 3000 | 145 | 130 | 129 | 134 | 143 | 138 | 144 | 130 | 118 | 140 |
| 4000 | 149 | 132 | 130 | 131 | 146 | 141 | 146 | 133 | 120 | 142 |
| 5000 | 155 | 135 | 138 | 135 | 149 | 140 | 147 | 134 | 122 | 145 |
| 6000 | 156 | 138 | 139 | 143 | 151 | 142 | 153 | 136 | 124 | 148 |
| 8000 | 160 | 141 | 144 | 143 | 154 | 143 | 161 | 138 | 125 | 151 |
| 10000 | 164 | 143 | 147 | 141 | 155 | 145 | 164 | 142 | 126 | 153 |
| 15000 | 168 | 145 | 150 | 140 | 155 | 148 | 163 | 146 | 130 | 155 |