ARCHIVES OF ACOUSTICS
11, 1, 3-12 (1986)

REACTION DELAY TIME IN THE PROCESS OF DETECTION AND DISCRIMINATION OF ACOUSTIC SIGNALS*

ANDRZEJ RAKOWSKI, ANTONI JAROSZEWSKI

F. Chopin Academy of Music
00-368 Warszawa, ul. Okólnik 2

Reaction delay times in listeners with musical training to auditory stimuli at a level near the threshold of hearing were determined. Listeners were to detect these stimuli (detection) or state whether successive stimuli have the same or different pitch (discrimination). Reaction times in listeners in discrimination were distinctly longer than in detection tasks. Reaction delay time provide information about the relative difficulty of the task.

Introduction

In 1940 Rene Chocholle [3] proved that the auditory reaction time can be used as an evaluation criterion of sound loudness. This idea was then applied by Stebbins and Miller [18], Kohfeld [7], Moody [10], [11], O'Connor *et al.* [12], Pfingst *et al.* [13], [14], Stebbins and Miller [18] and Stebbins [19] in investigations of the threshold of hearing and of the loudness of signals with people and animals. It was also used by Beaton and Miller [1] and Miller *et al.* [8], [9] in research on the response of single neurons, and by Sidley *et al.* [18] in investigations of visual reactions.

It seems obvious that, as Pfingst *et al.* [13] state, the dependence of the time of reaction to auditory stimuli on the sound pressure level and frequency "*illustrates the characteristic properties of the organ of hearing*". It should be emphasized though, that until now the greater part of research on auditory reaction times was concerned with the simplest reaction forms connected with functioning of the organ of hearing, mostly detection. In this case

---

* Research was conducted in the framework of an Interdepartamental Programme MR. I. 24.

the reaction time consists mainly of the delay of the motor reaction in relation to the acoustic stimulus. But measurements of the reaction time can also be applied in more complex tasks related to the functioning of the organ of hearing, such as comparison, discrimination and recognition of auditory stimuli. These tasks require the engagement of qualitatively different functions of the auditory perception system (e. g. memory) and it may take a much longer time. It seems that the time neccessary to fulfill these tasks should be in such a case referred to not as the "*reaction time*" but "*time of auditory processing*". This notion results from the following argumentation. The reaction time in a listener consists of two components: "*time of the motor reaction*" and "*time of data processing*". It can be assumed (although the confirmation of this thesis in respect to detection and discrimination processes requires separate research) that the motor reaction time depends in a very small extent on the type of task. This component dominates in the simplest, detection type, tasks; therefore the term – "*reaction time*" seems appropriate in that case for the definition of the total time between the stimulus and reaction. In more and complicated tasks, concerning auditory discrimination for example, longer and longer part of the time between the stimulus and reaction is taken up by the process of analysing and data processing. For this reason the total reaction time may be more accurately referred to as the signal "*processing time*" or "*auditory processing time*".

The aim of this paper is the presentation to what extent, and how, the auditory processing time of signals at a level near the threshold of hearing increases with the rise of the difficulty of a task; from simple signal detection to detection of progressively decreasing differences of their pitchs, in particular. The experiment was conducted in certain correlation to the experiment by CARDOZO [2], who investigated the detection and discrimination of short sound pulses. However, a different measurement methodology was applied; better trained listeners participated in the experiment, and first of all together with the correctness level of response of the listeners, the reaction time was noted, what allowed the comparison of these two characteristics of the response to a given task. Experimental results show that the time of reaction to auditory stimuli can provide a measure of task difficulty in the detection process as well as in the discrimination process.

1. Procedure

The experimental procedure comprised a cyclic presentation of two sinusoidal pulses with 1500 ms duration, separated by a 700 ms interval, to the listeners. Pulse duration was long enough to ensure optimum evaluation of the sound pitch. The duration of the interval between the pulses was chosen, to fulfill two conditions at the same time: a) strong enough memory trace of the pitch of the first pulse in the moment of appearance of the second pulse, with which the first pulse was compared and b) lack of an influence of the first pulse on the second pulse, that would cause a pitch shift of the latter due to poststimulatory masking [16]. Repetition periods of presented pulse pairs were randomly arranged in such a way that the begining of every following pair was separated from the begining of the preceeding pair by a $n \cdot 6250$ ms time interval, where n was a natural number changing randomly in a range from 1 to 4. Therefore, listeners did not know in which moment of the observation time of a maximal span of 4×6250 ms the signal to be detected or discriminated will appear.

The signal frequency in the first pulse of every presented pair equalled always 1000 Hz, while every second pulse was subjected to the following randomization procedure: In detection tasks it was completely damped in randomly chosen pairs and in pitch discrimination tasks it was detuned in relation to the first pulse by a certain frequency difference $\pm \Delta f$ in randomly chosen pairs. The number of pairs in which the second pulse was completely damped or detuned in relation to the first pulse always constituted 50% of the total number of pulses in a series, while the number of pulses detuned positively $(+\Delta f)$ equalled the number of pulses detuned negatively $-\Delta f$. The pulse frequency difference in a pair, Δf, was 9, 3 and 1Hz in individual tasks.

The time, Δt, between the begining of the second pulse in a pair and the signalling by the listener of a decision was taken as the measure of the reaction time (auditory signal processing). The decision was signalled by pressing a button and it could mean

a) in detection tasks: "*I heard that the second pulse* ***was present***"

b) in discrimination tasks: "*I heard that the second pulse* ***differed*** *from the first one*".

Listeners were instructed to press the button as quickly as possible, but only when they were sure that:

a) in detection: the second signal was present

b) in discrimination: the sceond signal was different.

The reaction time values and the values of the percentage level of correct answers in every experimental series was read of digital clocks, which were switched on with the begining of the second pulse and stopped by the decision signal. Every presented test consisted of a series of 100 pairs of signals.

Experiments were carried out in a silenced chamber with the use of a *QUAD* electrostatic loudspeaker. In detection tasks stimuli were presented at the threshold level (*sensation level* 0 dB *SL*) and at levels: 2.5, 5.0 and 7.5 dB *SL*. In discrimination tasks stimuli were presented at levels: 5, 10 and 15 dB *SL*. Sound pressure levels corresponding to the given dB *SL* values were determined separately for every listener at the begining of every session. Individual thresholds of hearing were determined using the method of limits.

2. Listeners

Two men and two women-students of the Academy of Music, aged 24–27, with an otologically normal audition, made up the group of listeners. They were chosen from a group of 25 students from the same school, as they achieved best results in the initial tests of pitch discrimination. Three persons from the group have previously taken part in psycho-acoustic experiments, the remaining three persons passed additional training, so the results achieved by all listeners in the described experiment were similar. Two listeners had the same response time to visual stimuli, equalling 160 ms. All listeners were paid for the participation in the experiment and were therefore strongly motivated.

Prior to the begining of measurements every listener stayed in an acoustically isolated, silenced chamber for at least 10 min in order to stabillize the threshold of hearing. Moreover, listeners were informed that they should give up the participation in measurements in case of a bad psychophysical disposition.

3. Results

Fig. 1 presents results of detection experiments, expressed as medialn values of the percentage of correct answers at various signal sensation levels.

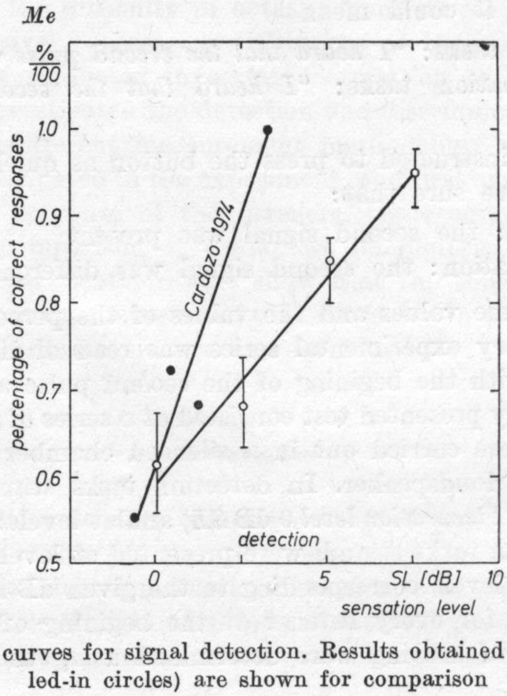

Fig. 1. Psychrometric curves for signal detection. Results obtained by B. L. CARDOZO (filled-in circles) are shown for comparison

Each of the four data points represents a median calculated from 120 hundred individual decisions made by the group of four persons. Vertical bars mark the dispersion of results, determined as interquarter intervals.

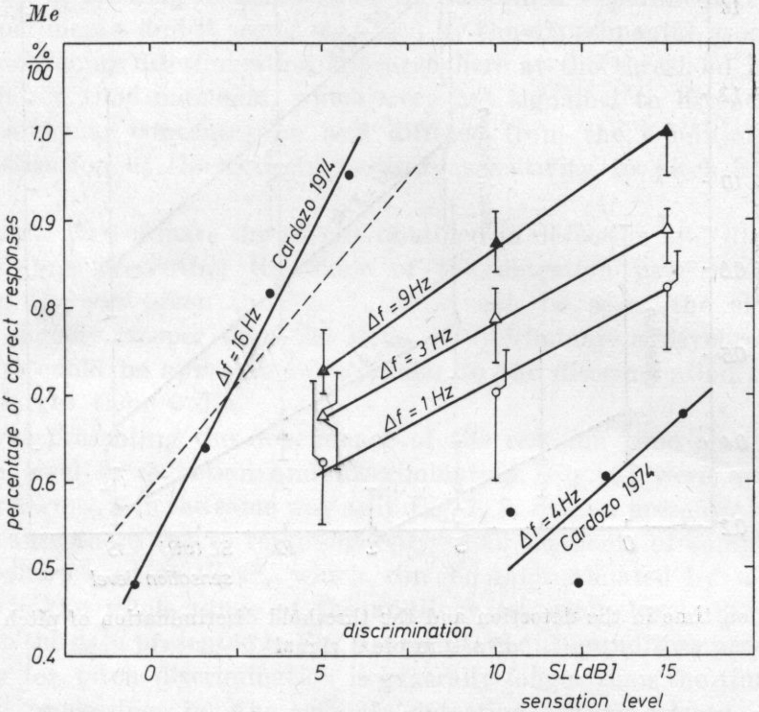

Fig. 2. Psychrometric curves for signal frequency threshold discrimination. Signals with varying frequency intervals Δf. Results obtained by B. L. CARDOZO (filled-in circles) are shown for comparison. Dashed line marks the slope of the psychrometric curve durin signal detection (according to Fig. 1)

Fig. 2 presents medians of percentage levels of correct answers in near the threshold pitch discrimination experiment. Vertical bars mark the dispersion of the results, determined as interquarter intervals. Each data point is determined by 120 hundred (at $\Delta f = 9$ and 3 Hz) or 80 hundred (at $\Delta f = 1$ Hz) individual decisions of listeners. Measurements obtained by CARDOZO [2] for $\Delta f = 16$ and 4 Hz are given for comparison. However, it has to be noted that the results by Cardozo presented here for comparison are based on a significantly smaller number of observations (50 decisions for data point) than the results of the experiments presented here.

Fig. 3 shows the values of response times of the group of listeners in the described above detection and discrimination experiments. The median values are given and the dispersion as intraquarter intervals.

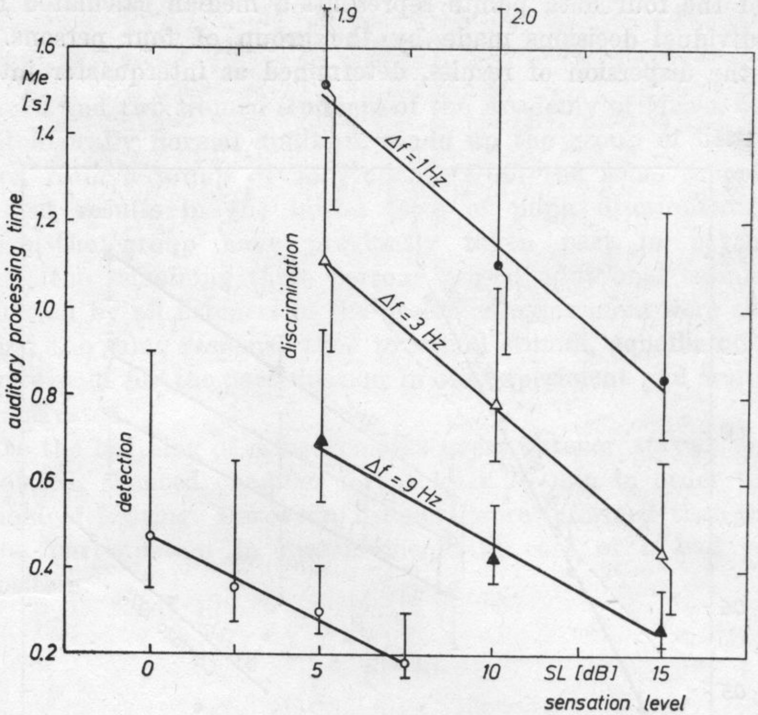

Fig. 3. Reaction time in the detection and the threshold discrimination of pitch in pulses of a sinusoidal signal

4. Discussion of the results and conclusions

A comparison of results obtained in the detection experiment (Fig. 1) with CARDOZO's results [2] proved that psychrometric curves obtained here are less steep. This can be caused by the fact that the tasks of CARDOZO's listeners were slightly different. They were informed in which time moments pulses for detection or discrimination can appear.

While data obtained in thes present experiments concerning the percentage level of correct answers in the signal detection (Fig. 1) approximately correspond with the values encountered in CARDOZO's papers [2], data concerning the precision of pitch discrimination (Fig. 2) differ from the data published previously. In comparison with the data obtained by Cardozo it can be observed that our listeners had higher efficiency in pitch discrimination. This is due to the applied procedure (longer duration of pulses), as well as most probably to the differences in the predispositions and experiences of listeners.

If the results of pitch discrimination presented here were to be compared with the results of different experiments published previously by the authors of this paper [4–6], 15, 17 the situation would 100k differently. This confrontation shows that listeners in the described experiment demonstrated lower sensitivity to pitch differences. This is partially caused by a slightly lower level of training of listeners in the described experiment, than in previous experiments, and it seems that also by the experimental procedure used. Signal undergoing discrimination appeared here at the threshold level in randomly chosen time moments, which were not signalled to listeners. This required particular concentration and differed from the conditions in which the investigation of the extreme auditory sensitivity to pitch differences is possible.

In order to compare the results obtained in detection and discrimination a dashed line presenting the slope of the detection psychrometric curve from Fig. 1, was given in Fig. 2. As it can be seen, the slope of this curve is slightly steeper than the slope of discrimination psychrometric curves and it cuold be approximately similar to the discrimination curve if the Δf was larger than 9 Hz.

Curves presenting the dependence of the reaction time on the auditory sensation level in detection and discrimination (Fig. 3) were approximated by line ar segments in the same way as in Fig. 1, 2. Such a presentation was possible, because these curves represent only small segments of complete "*curves of the auditory reaction time*", which can be approximated by a hyperbolic function in the whole range of the auditory sensation levels [13].

From the data presented in Fig. 3 it results that the auditory processing time necessary for pitch discrimination is generally longer than the time of simple auditory processing in the signal detection. Furthermore, the auditory processing time depends on: a) the difficulty of the task, b) the auditory sensitivity level in the region near the threshold. From the comparison of detection and discrimination curves done in Fig. 3 it results that in the experimental conditions of the described investigation the reaction time in the detection of a signal at a threshold level, 0 dB *SL*, corresponds approximately to the auditory processing time in the discrimination of pitch in pulses differing by $\Delta f = 9$ Hz presented at the 10 dB *SL* level or pulses differing by $\Delta f = 3$ Hz presented at the 15 dB *SL* level.

Vertical bars mark interquarter intervals corresponding to each data point. As it can be seen, the dispersion like the reaction time, increases with increase of the task difficulty. A similar features characterize the intraindividual variability not marked in the figure, what is consistent with the general rules of the detection theory.

Data shown in Fig. 1–3 were obtained in the course of the same experiments and are complementary. Therefore, it can be evaluated for each data point to what extent the auditory processing time is related to the obtainment of a specific percentage level of correct answers,

P_c. Fig. 4 shows the relationship between the percentage level of correct answers and corresponding values of the auditory processing time in various tasks.

Dependences shown in Fig. 4 illustrate indirectly the relationship between the degree of difficulty of an auditory task and the time, in which

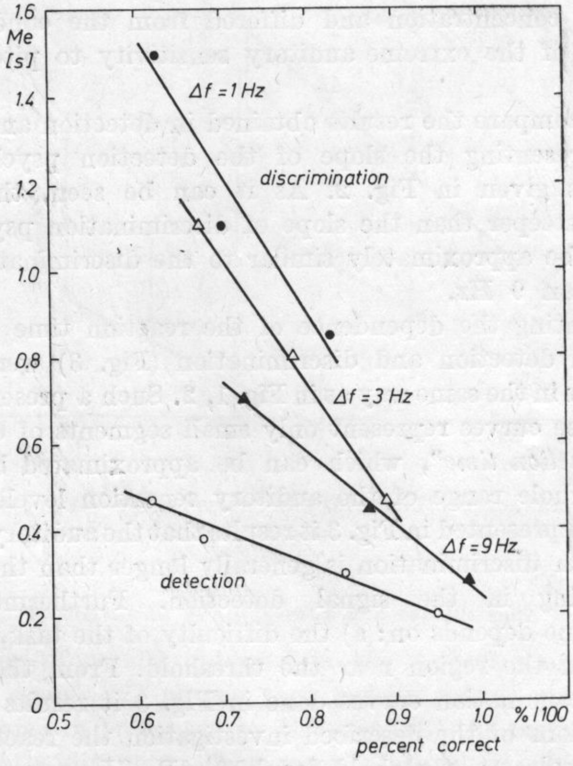

Fig. 4. Relation between the degree of performance correctness and the auditory reaction time in the of detection and threshold discrimination of acoustic signals

this task can be performed. Assuming a definite percent correct level of answers, the auditory reaction time (alias auditory processing time) can provide a difficulty measure of a task.

References

[1] R. Beaton, J. Miller, *Effects of behavioral manipulations on the activity of single units in the auditory cortex of the rhesus monkey*, 80–th Ann. Conv. AM. Psychol. Assoc. (1972).

[2] B. L. Cardozo, *Some notes on frequency discrimination and masking*, Acustica, **31**, 330–336 (1974).

[3] R. Chocholle, *Variation des temps de reaction auditifs en fonction de l'intensité à diverses frequences*, Am. J. Psychol., **41**, 65–124 (1940).

[4] A. Jaroszewski, A. Rakowski, *Pitch shifts in poststimulatory masking*, No 815, 8th ICA, London 1974. Published: Acustica, **34**, 220–223 (1976).

[5] A. Jaroszewski, *A new method for determination of frequency selectivity in poststimulatory masking*, H-40, 9th ICA, Madrid 1977. Published: Acustica, **41**, 327–333 (1979).

[6] A. Jaroszewski, *Effects of feedback and masking on the data from psychoacoustical experiment*, J. Acoust. Soc. Am. (submitted for print).

[7] D. L. Kohfeld, *Stimulus intensity and adaptation level as determinants of simple reaction time*, J. Exp. Psychol., **76**, 468–473 (1968).

[8] J. M. Miller, M. Glickstein, W. C. Stebbins, *Reduction of response latency in monkeys by a procedure of differential reinforcement*, Psychonomic Sci., 177–178 (1966).

[9] J. M. Miller, D. Sutton, B. Pfingst, A. Ryan, R. Beaton, G. Gourevitch, *Single cell activity in the auditory cortex of rhesus monkeys: behavioral dependency*, Science, **177**, 449–451 (1972).

[10] D. B. Moody, *Reaction time as an index of sensory function*, in: Animal Psychophysics, Stebbins, W. C. Ed., Appleton Centry Crofts, N. York, 277–302 (1970).

[11] D. B. Moody, *Behavioral studies of noise-induced hearing loss in primates: loudness recruitment*, Adv. Oto-Rhino-Laryngol., **20**, 82–101 (1978).

[12] T. O'connor, R. Hienz, J. Miller, *Reaction time as a measure of threshold and suprathreshold hearing III. The effects of stimuls duration*, J. Acoust., Soc. Am. **55**, 451 A (1974).

[13] B. E. Pfingst, R. Hienz, J. Kimm, J. Miller, *Reaction – time procedure for measurement of hearing I. Suprathreshold functions*, J. Acoust. Soc. Am., **57**, 421–430 (1975a).

[14] B. E. Pfingst, R. Hienz, J. Miller, *Reaction – time procedure for measurement of hearing II. Threshold functions*, J. Acoust. Soc. Am., **57**, 431–436 (1975b).

[15] A. Rakowski, *Pitch discrimination at the threshold of hearing*, 20 H6-, 7th ICA, Budapest (1971).

[16] A. Rakowski, I. J. Hirsh, *Poststimulatory pitch shifts for pure tones*, J. Acoust. Soc. Am., **68**, 467–472 (1980).

[17] A. Rakowski, A. Jaroszewski, *Analysis of some factors influencing frequency discrimination*, K-2, 95th JASA Meeting, Providence, Rhode Island 1978, J. Acoust. Soc. Am. 63, Suppl. No **1**, 29–30 (1978).

[18] N. A. Sidley, H. G. Sparling, E. W. Bedarf, R. H. Hiss, *Photopic spectral sensitivity in the monkey: methods for determining and initial results*, Science, **150**, 1837–1839 (1965).

[19] W. C. Stebbins, J. Miller, *Reaction time as a function of stimulus intensity for the monkey*, J. Exp. Anal. Behav., **1**, 309–312 (1964).

[20] W. C. Stebbins, *Auditory reaction time and the deviation of equal loudness countours for the monkey*, J. Exp. Anal. Behav., **9**, 135–142 (1966).

Received on 13 October, 1984; revised version on 7 June 1985.