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CATEGORICAL PERCEPTION IN ABSOLUTE PITCH

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Three music students, possessing of absolute pitch, participated in an experiment of categorical identification of two adjacent musical pitch categories A$\#_4$ and B_4. Next, they also participated in the experiment in which their ability to differenciate between two tone pulses separated by frequency level distance of 25 cents was tested. When ABX procedure was used with the tone-pulse length reduced to 20 msec and the interstimulus interval extended to 10 sec, the between-category discrimination in two sucjects markedly exceeded the within-category discrimination, which signalled the existence of categorical perception.

1. Introduction

The words "absolute pitch" (AP) mean the ability of some musically trained people to recognize musical tones of a desired pitch (passive AP) or both to recognize and produce them (active AP) without being given any tone of reference (Bachem [1], Rakowski and Morawska-Bungeler [15]). Most poeple, also including professional musicians, do not possess this ability, which possibly can be developed only in early childhood (Ward [16]). Instead, they can practice and develop the ability to recognize and to produce a number of frequency-ratio categories called musical intervals. The ability to deal with musical intervals and their sequences (melodies) is called "relative pitch" (RP).

The phenomenon of absolute pitch can be described as the existence in the long-term memory of a set of 12 standards and corresponding "chromas" or categories. These standards, which are imprinted in the long-term memory with considerable accuracy, serve in the formation of those categories as salient points along the frequency-ratio continuum (Morawska-Bungeler and Rakowski [12]). The chroma categories are nearly a semitone wide and in "good quality" AP possessors have sharp, well-defined boundaries.

The shapes of chroma-category boundaries are very similar to those obtained in experiments concerning the perception of synthetic speech sounds. In course of such experiments performed at Haskins Laboratories, Liberman et al. [7] found and described a phenomenon called "categorical perception". Categorical perception means sharp and well-defined boundaries between adjacent perceptual categories and systematic differences in possibility to discriminate sounds. Differences depend on whether the two sounds being compared belong to the same category or to different categories.

A large number of experiments confirmed the above-described property of categorical perception in speech sounds. A study by Liberman and his colleagues from Haskins Laboratories may serve as an example (LIBERMAN et al. [8]). They produced synthetic speech stimuli which varied in acoustically equal steps through the range sufficient to produce the initial stop consonants /d/ and /t/. Such stimuli were perceived as members of two discrete categories separated by a relatively sharp boundary. Additionally, when listeners heard adjacent pairs of these stimuli they could either easily discriminate between them or could not find any difference. The condition under which the adjacent stimuli were perceptually different was that they were taken from both sides of the boundary separating phonemic categories. When they were both taken from the same category, subjects could not discriminate between them, though the physical distance which separated both stimuli was in both cases exactly the same.

The theory that underlies the above-described phenomenon says that in the speech-perception mode people can discriminate among speech sounds only in as much as they can identify them. This statement lies within the context of the motor theory of speech perception (LIBERMAN et al. [9]); categorical perception is assumed to result from the categorical nature of speech production. Different sounds are produced and perceived under the same articulatory set of commands.

The ideal case of categorical perception under the assumptions of the above-mentioned theory is shown in Figure 1. Eight stimuli are spaced at equal intervals along a physical continuum. The stimuli 1–4 are identified as members of Category A, stimuli 5–8 as members of Category B. The identifications are completely consistent and boundaries between the categories are sharp. When stimuli 1–8 are successively presented subjects hear no change between stimuli 1–2, 2–3, 3–4, and then perceive an abrupt change between stimuli 4 and 5, as category changes from A to B. Adjacent stimuli in the range 5–8 are again perceived as identical. If the discrimination is measured, e.g. by an ABX procedure, performance is at chance level for all pairs of adjacent stimuli except for the pair 4–5 where it is perfect.

The early adherents of categorical perception strongly insisted that the phenomenon was a unique feature of speech perception. However, it soon became clear that to some degree it may be observed in experiments with non-speech stimuli and even with non-human listeners. MILLER et al. [11] found categorical perception using stimuli constructed of a wide-band noise and a low-pitched buzz. The buzz started with varying time delay after the noise onset; this simulated the voice onset time (VOT) in various stop consonants. KUHL [5] found categorical perception in exploring chinchillas' ability to diferentially "label" stimuli with various VOT. LOCKE and KELLAR [10] uncovered evidence of categorical perception in trained musicians judging triadic

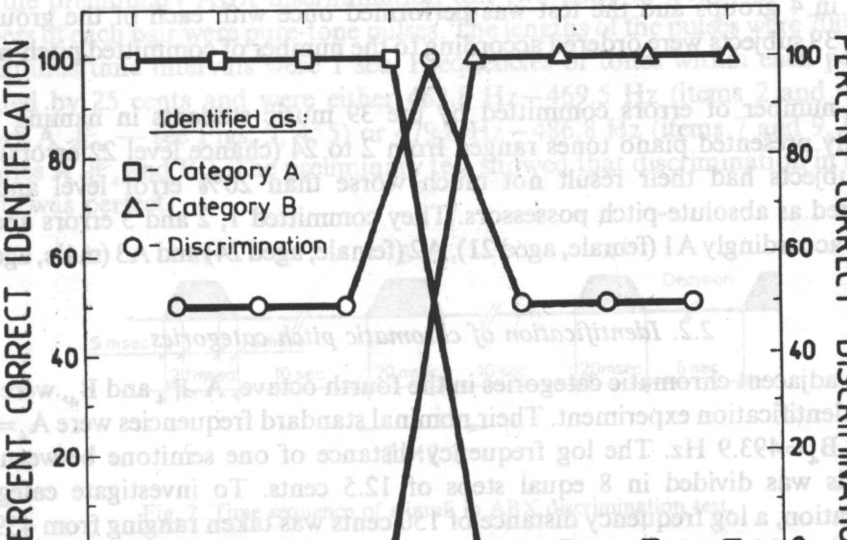

Fig. 1. Idealized identification of stimuli belonging to two categories and corresponding discrimination of adjacent stimuli according to categorical perception.

chords whose middle note varied. Burns and Ward [2] studied categorical perception of melodic musical intervals, and Clarke [3] found it in listening to musical rhythmic patterns. The aim of the present experiment was to check whether elements of categorical perception may be found in the perception of musical pitch categories by the possessors of absolute pitch.

2. Experiments

2.1. Subjects

In order to find subjects who possessed absolute pitch and could participate in the main experiment, the so-called pitch-naming test was applied to a group of 39 music students. The test, which was previously used in testing another group of students (Rakowski and Morawska-Bungeler [15]) consisted in a 24-item series of piano tones taken semi-randomly from the whole range of the instrument. The tones were recorded on tape and presented to the subjects through a loudspeaker and with moderate loudness. Time distances between the onsets of subsequent tones were 4 seconds and the subjects had to write the musical name of each tone (e.g. G, C or D) on an answer sheet. The subjects were divided in 4 groups and the test was performed once with each of the groups. As a result, 39 subjects were ordered according to the number of committed pitch-naming errors.

The number of errors committed by the 39 music students in naming the 24 randomly presented piano tones ranged from 2 to 24 (chance level 22 errors). Only three subjects had their result not much worse than 20% error level and were considered as absolute-pitch possessors. They committed 1, 2 and 5 errors and were labelled accordingly A1 (female, aged 21), A2 (female, aged 24) and A3 (male, aged 24).

2.2. *Identification of chromatic pitch categories*

Two adjacent chromatic categories in the fourth octave, A$\sharp_4$ and B_4, were taken for the identification experiment. Their nominal standard frequencies were $A_4 = 466.2$ Hz and $B_4 = 493.9$ Hz. The log frequency distance of one semitone between these standards was divided in 8 equal steps of 12.5 cents. To investigate categorical identification, a log frequency distance of 150 cents was taken ranging from 459.5 Hz (A$\sharp_4$ minus 25 cents) to 501.0 Hz (B_4 plus 25 cents) and 13 pure tones with frequency levels of 12.5 cents apart from each other were produced within this range. Then a test containing 20 replications of each of the 13 frequency items in random order was recorded on magnetic tape. The time sequence of the tape recorded signals was as follow: Pure-tone signal 700 msec (rise/decay 50 msec), silent interval 2.500 msec. The whole test lasted nearly 14 minutes and was presented to the subjects with 5 three-minute breaks. Before the testing started, subjects were given some practice in recognizing chroma categories in pure-tone stimuli. Frequencies of tones used in this pre-testing were taken from categories other than A$\sharp$ and B.

The subject's task in the identification test was to respond to each sound stimulus by marking on an answer sheet the name of the category (A$\sharp$ or B) to which the item belonged. The number of the item was signalled visually, and the choice was obligatory. The test was presented from a loudspeaker with a loudness level of 65 phons to each subject individually in a sound insulated room. The results of the identification test are shown as percent correct identification for subjects A1, A2 and A3 in Figs. 3, 4 and 5.

2.3. *Discrimination across and within categories*

In order to check the existence of categorical perception discrimination tests should be performed using pairs of stimuli taken either from the same category or from neighbouring categories across the boundary. The width of the border region between the chromatic categories of our subjects required that a two-step discrimination test should be applied. It meant that the stimuli to be discriminated should have their frequencies 25 cents apart. However at such large frequency differences frequency discrimination is very easy (RAKOWSKI [14], WIER et al. [17]). To check this a preliminary test of frequency discrimination was applied.

In the preliminary ABX discrimination test two pairs of frequencies were used. Members of each pair were pure-tone pulses. The lengths of the pulses were 700 ms and interstimulus time intervals were 1 sec. Frequencies of tones within each pair were separated by 25 cents and were either 462.8 Hz–469.5 Hz (items 2 and 4 within category A♯$_4$ — see Figs. 3, 4, 5) or 479.8 Hz–486.8 Hz (items 7 and 9, between categories A♯$_4$ and B$_4$). The preliminary test showed that discrimination in all three subjects was perfect.

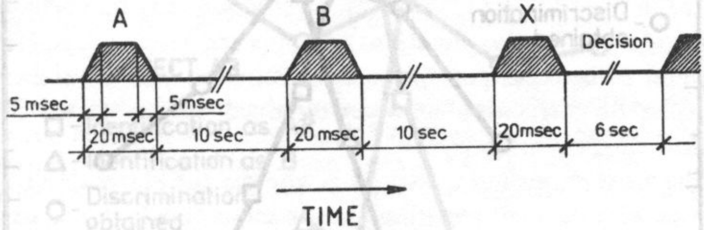

Fig. 2. Time sequence of stimuli in ABX discrimination test.

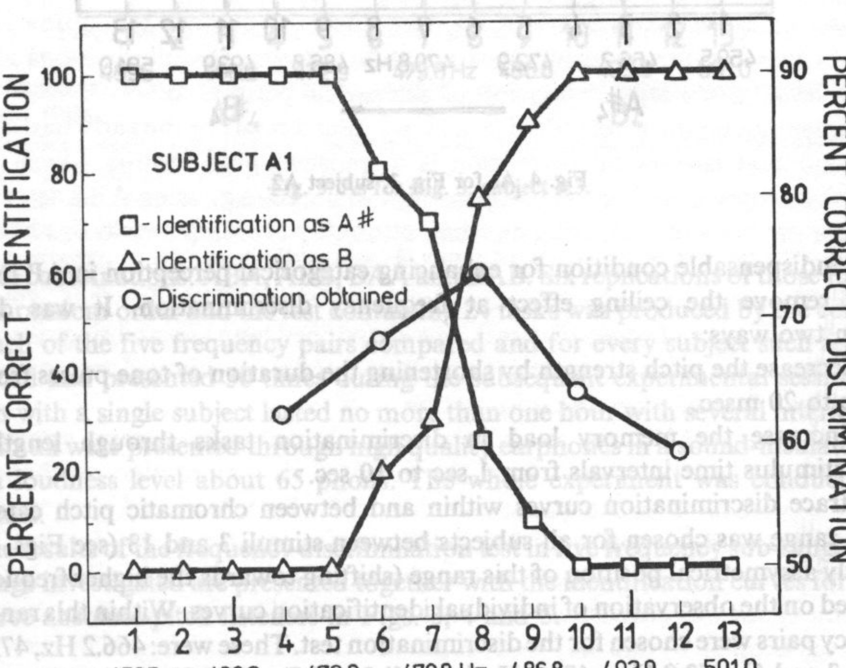

Fig. 3. Categorical identification by subject A1 of thirteen 700-milisecond tone pulses with various frequencies as belonging to pitch category A or B. Discrimination between pairs of 20-milisecond stimuli separated by two frequency steps shown for the same subject (720 decisions per point in ABX test with 10 sec interstimulus intervals).

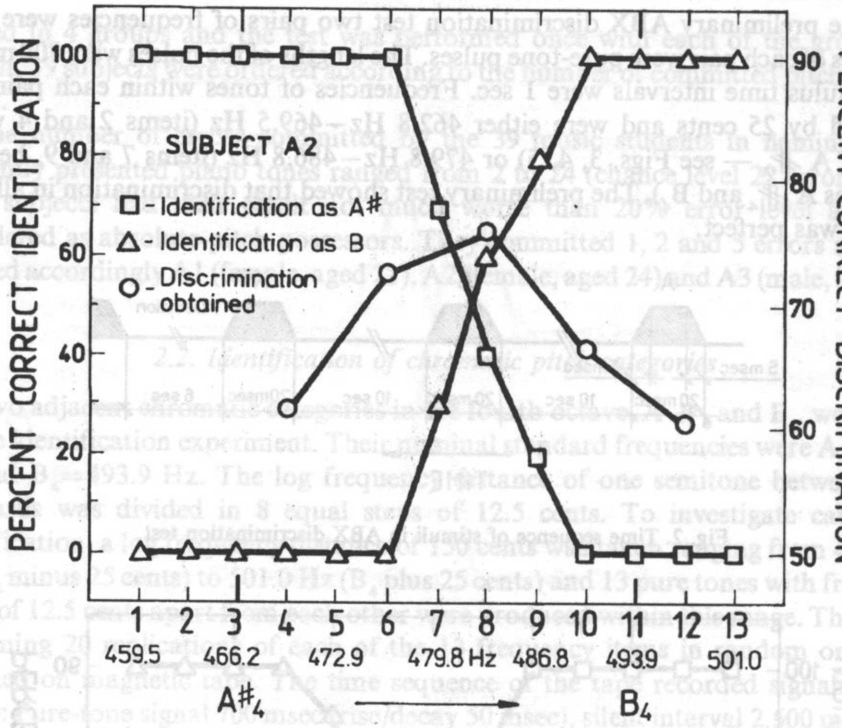

Fig. 4. As for Fig. 3, subject A2.

The indispensable condition for enhancing categorical perception in AP listeners was to remove the ceiling effect at frequency discrimination. It was decided to act in two ways:

1) To decrease the pitch strength by shortening the duration of tone pulses from 700 msec to 20 msec.
2) To increase the memory load in discrimination tasks through lengthening interstimulus time intervals from 1 sec to 10 sec.

To trace discrimination curves within and between chromatic pitch categories a single range was chosen for all subjects between stimuli 3 and 13 (see Figs. 3 – 5). A slightly assymetrical position of this range (shifting towards the higher frequencies) was based on the observation of individual identification curves. Within this range five frequency pairs were chosen for the discrimination test. These were: 466.2 Hz, 472.9 Hz (stimuli 3 and 5), 472.9 Hz – 479.8 Hz (stimuli 5 and 7), 479.8 Hz – 486.8 Hz (stimuli 7 and 9), 486.8 Hz – 493.9 Hz (stimuli 9 and 11), and 493.9 Hz – 501.0 Hz (stimuli 11 and 13).

The time sequence of stimuli in the discrimination test ABX is shown in Fig. 2. A and B were two tone pulses being compared, and X was one of them (with equal probability). The subject's task was to tell whether X was A or B. There were four

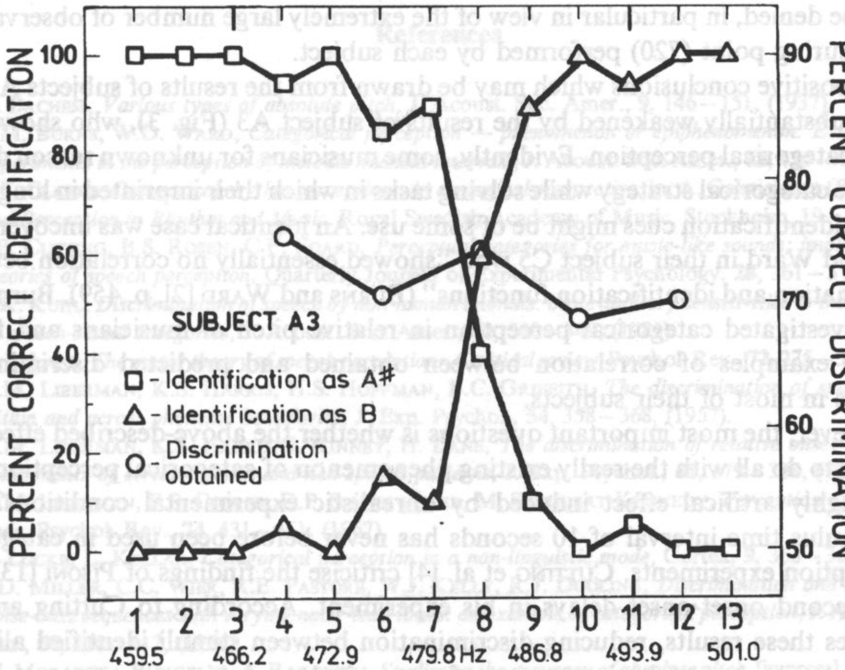

Fig. 5. As for Fig. 3, subject A3.

possible combinations: ABA, ABB, BAA and BAB. Six replications of those four were used in random order and the test containing 24 tasks was produced by the computer. For each of the five frequency pairs compared and for every subject such a test was produced and presented 30 times during the subsequent experimental sessions. One session with a single subject lasted no more than one hour with several intermissions. The stimuli were presented through high quality earphones in a sound-insulated room with a loudness level about 65 phons. The whole experiment was conducted over 3 months.

The results of the frequency discrimination test in five frequency sub-ranges within the range investigated are presented together with the identification curves for each of the three absolute-pitch listeners in Figs. 3, 4 and 5.

3. Discussion and conclusions

As can be seen in Figs. 3 and 4, two subjects, A1 and A2 revealed some enhancement of discriminating ability in the between-category frequency region in comparison with the within-category judgements. The maximum enhancement is only about 15%, nevertheless some degree of categorical perception in subjects A1 and A2 cannot be denied, in particular in view of the extremely large number of observations per measuring point (720) performed by each subject.

The positive conclusions which may be drawn from the results of subjects A1 and A2 are substantially weakened by the results of subject A3 (Fig. 3), who showed no trace of categorical perception. Evidently, some musicians for unknown reason do not adopt the categorical strategy while solving tasks in which their imprinted in long-term memory identification cues might be of some use. An identical case was uncovered by Burns and Ward in their subject C5 who "showed essentially no correlation between discrimination and identification functions" (Burns and Ward [2], p. 459). Burns and Ward investigated categorical perception in relative pitch of musicians and found excellent examples of correlation between obtained and predicted discrimination functions in most of their subjects.

However, the most important questions is whether the above-described effect has anything to do all with the really existing phenomenon of categorical perception. Is it not a highly artifical effect induced by unrealistic experimental conditions? The interstimulus time interval of 10 seconds has never before been used in categorical — perception experiments. Cutting et al. [4] criticise the findings of Pisoni [13] who used 2-second onset-onset delays in his experiment. According to Cutting and his colleagues these results, reducing discrimination between stimuli identified alike to a chance level, give a false impression of categorical perception.

Commenting on those remarks I would say, that already in the early sixties it had been found that categorical perception is a transient phenomenon which can be induced by properly selecting the measuring technique (e.g. using ABX tests rather than other methods of measuring discrimination), by avoiding over-trained listeners etc. (see e.g. Lane [6]). Nevertheless much effort has been put into investigating this effect in the various domains of human communication. The idea that categorical perception is a unique feature of speech was abandoned long ago and since then it has been considered as one of the efficient strategies that an organism adopts to deal with the abundant flow of incoming information.

It may be argued that the special measures adopted in the present experiments, though strange and "artificial" from the point of view of routine psychoacoustic methodology are far from being unrealistic in real life. Both decreased pitch strength of musical signals and comparing pitch through a ten-second time delay do occur in real concert practice. E.g. such situations may be typical of a conductor listening to the intonation of various instruments during a rehearsal. If he does have absolute pitch, the strategy adopted by him may easily follow the one that was adopted by some of our listeners.

Acknowledgments

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