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IN SEARCH FOR THE CRITERIA OF ABSOLUTE PITCH

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A series of experiments has been performed in order to find specific features of pitch memory in persons possessing the so-called absolute pitch.

Sixty one music students were given a test of passive absolute pitch (pitch-naming test); then a part of this group was subjected to another test in order to determine their ability to produce required musical pitch without being given any reference tone (active absolute pitch). A criterion for absolute pitch was proposed on the basis of the evaluation of the precision of tuning a pure-tone generator to the required musical pitch. Finally, two musicians, one of them possessing absolute-pitch, were given a task of tuning a pure-tone generator to the pitch of a standard after various delay times. The results were presented in the form of pitch-forgetting curves.

1. Introduction

Absolute pitch is the ability, possessed by some people, to recognize exactly or reproduce musical pitch without reference tones. The ability to recognize musical pitch of tones is called passive absolute pitch, while the ability to imagine and then reproduce a given pitch is called active absolute pitch. People without absolute pitch usually can recognize and reproduce the pitch of definite musical tone only when they are presented with another tone and know its name. In such a case the so-called relative pitch is employed, i.e., the knowledge of the learned and permanently memorized musical intervals. Absolute pitch is only possessed by a small part of the human population, probably about one to several percent. It is positively related to other music talents, though not necessarily a condition for their occurence. Hitherto, absolute pitch has been the subject of many investigations. Results of some of these works have been recently discussed by WARD and BURNS [1].

It is accepted by most authors that absolute pitch is an inborn talent and that people with this talent differ greatly from people without absolute pitch in the domain of pitch recognition. However, many musicians who initially did not distinguish absolute pitch of tones developed this ability to a certain extent through practice and utilization of additional evaluation criteria. Such additional criteria usually consist of remembering one musical pitch and having it as a standard reference point in evaluating pitch of other tones. In some people the phenomenon of absolute pitch is limited to recognizing the pitch of tones of one familiar instrument, or it consists of remembering a specific colour of a given musical key.

The present experiments were designed to investigate in detail some of the unknown properties of absolute pitch, compare the features of auditory memory in people with absolute and relative pitch, and try to determine criteria for both types of audition.

2. Investigations of passive absolute pitch

Sixty one listeners, who were students at the Academy of Music in Warsaw, participated in the experiment. Every student had completed at least a two-year course in ear training at secondary music school and currently attended courses on this subject at the Academy. Students listened to tests recorded on tape and reproduced from a loudspeaker at a comfortable listening level of approximately 75 dB *SPL*. Listeners were divided into 6 groups, each consisting of about ten persons.

The listeners' task was to recognize the names and tone registers (octaves) of 24 or 23 notes of the musical scale presented in random order. Each tone was presented only once in a test; it lasted for two seconds and was separated from the next tone by a two-second time interval. Identification of tones and octaves was performed by subjects to make the process of answering as quick and simple as possible. The answer was given by marking out one of twelve names of tones (chromatic tones were marked twofold, e. g. *G♯/A♭*) and additionally, by marking out one of eight octaves on a draft piano keyboard (see Fig. 1).

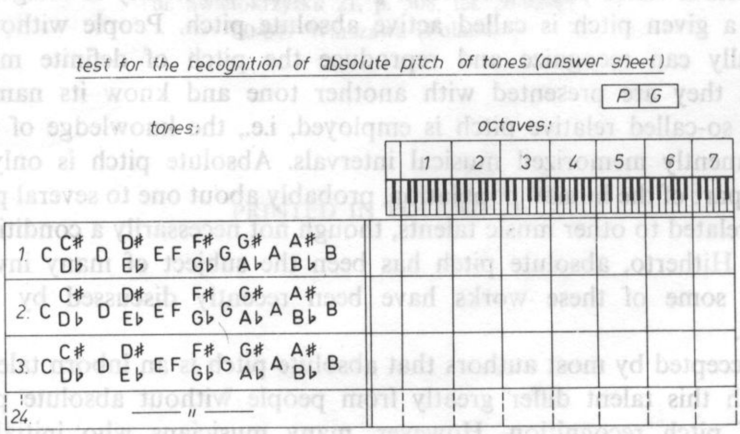

Fig. 1. Part of the answer sheet in a pitch-naming test

There were two versions of the test: first, with the application of piano tones recorded on tape (*P*), second, with the application of pure tones from a generator (*G*). Tones with the lowest frequency were not presented in the generator test due to technical difficulties. Instead other tones from the low register were presented, and the number of tones was decreased to 23; there were 24 tones in the piano test. The piano test was conducted first, and the generator test followed after a few days.

Figure 2 shows the distribution of all errors made by the listeners during the first presentation of both tests. Both non-octave (false tone name) and octave (falsely determined octave) mistakes were included. Also a lack of an answer was considered as an error.

The results in Fig. 2 show that fewer mistakes were made in the piano test than in the generator test. Most probably this was caused by better familiarity of the

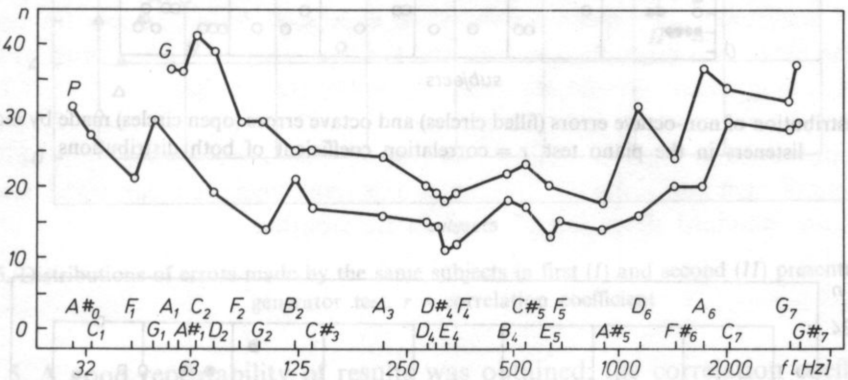

Fig. 2. Distribution of errors made by 61 listeners when 24 piano tones (*P*) and 23 pure tones from a generator (*G*) were presented for the first time

listeners with the timbre of piano tones than with the timbre of pure tones from the generator. It can also be noted that sounds from the middle tone register were recognized better than those from extreme registers.

Figure 3 presents the distribution of errors made by individual listeners during the first presentation of the piano test. This distribution, arranged according to the increasing number of non-octave errors, is shown as filled circles. The corresponding octave errors are presented as open circles. In groups of listeners, who had made equal numbers of non-octave errors, sequential arrangements of listeners (affecting their octave-error distributions) were randomized. The correlation coefficient, calculated for so-arranged distributions of non-octave and octave errors in the whole group of 61 listeners, equalled − 0.45.

The tests were repeated with a part of the previous group of listeners two weeks after the first presentation; 31 listeners participated in the repeated piano test and 30 listeners in the generator test. The distributions of errors made by the listeners in the first and second presentations of the piano and generator tests are shown in Figs. 4

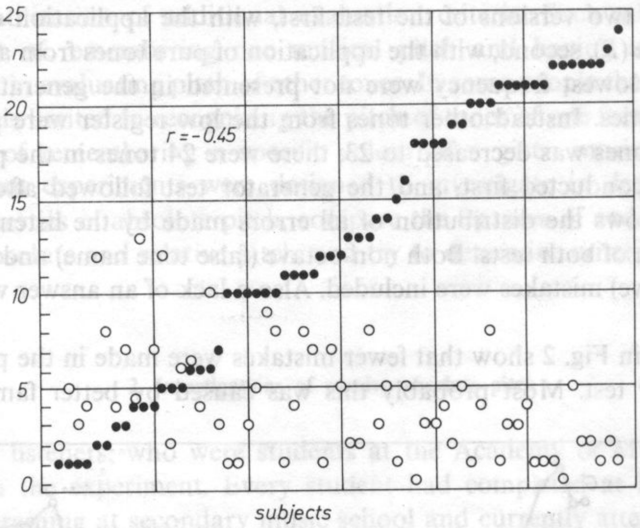

Fig. 3. Distribution of non-octave errors (filled circles) and octave errors (open circles) made by individual listeners in the piano test. r = correlation coefficient of both distributions

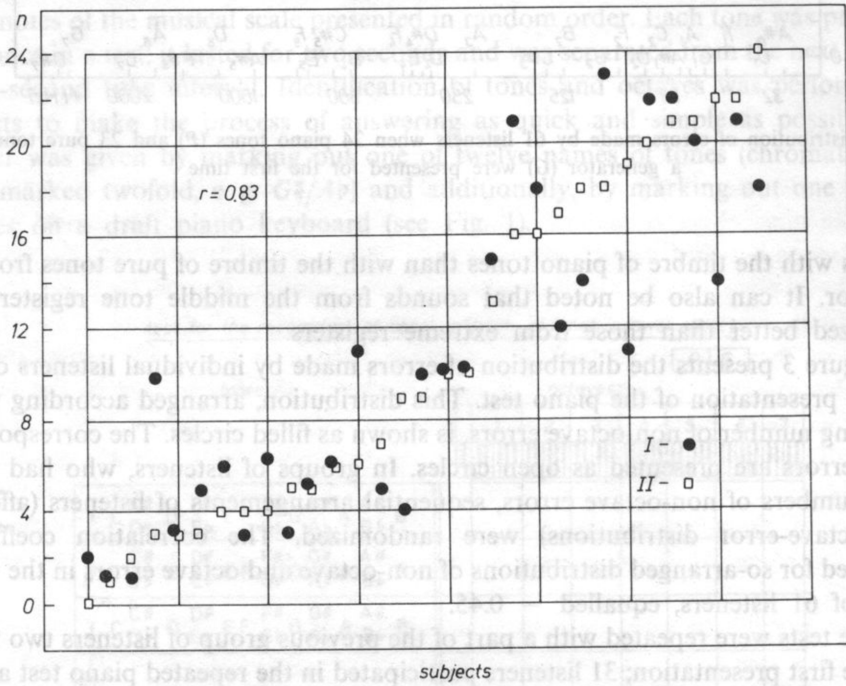

Fig. 4. Distributions of errors made by the same subjects in first (*I*) and second (*II*) presentation of the piano test. r = correlation coefficient

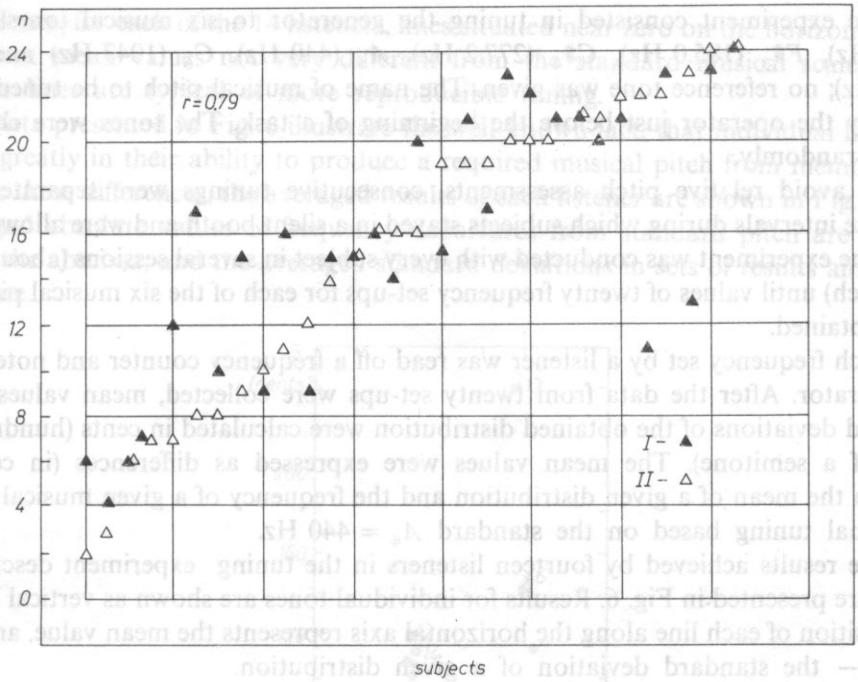

Fig. 5. Distributions of errors made by the same subjects in first (*I*) and second (*II*) presentation of the generator test. r = correlation coefficient

and 5. A good repeatability of results was obtained; the correlation coefficients of distributions were +0.83 and +0.79 for piano and generator tests, respectively.

3. Investigations of active absolute pitch

Fourteen subjects, members of a group which participated in the tests of passive absolute pitch, took part in the next experiment concerning active absolute pitch. Some subjects were selected because they achieved best results in the first test of piano tones recognition, while the others were picked randomly.

Each of the 14 subjects was given a task of tuning a sine-tone generator to a series of musical pitches. Experiments were carried out in individual sessions, in an acoustically isolated booth with the use of high quality binaural earphones at a loudness level of 40 phons. Subjects tuned the tone generator starting alternately from the upper or lower position outside the audible range. Tuning was done with one knob. The scale of the generator was covered, and all other visual or mechanical criteria were also eliminated, so listeners could only employ their auditory memory in tuning the required pitch.

The experiment consisted in tuning the generator to six musical tones: $A\sharp_2$ (116.5 Hz), $F\sharp_3$ (185.0 Hz), $C\sharp_4$ (277.2 Hz), A_4 (440 Hz), C_6 (1047 Hz) and D_7 (2349 Hz); no reference tone was given. The name of musical pitch to be tuned was given by the operator just before the beginning of a task. The tones were chosen pseudo-randomly.

To avoid relative pitch assessments, consecutive tunings were separated by 4-minute intervals during which subjects stayed in a silent booth and were allowed to read. The experiment was conducted with every subject in several sessions (about one hour each) until values of twenty frequency set-ups for each of the six musical pitches were obtained.

Each frequency set by a listener was read off a frequency counter and noted by the operator. After the data from twenty set-ups were collected, mean values and standard deviations of the obtained distribution were calculated in cents (hundredth parts of a semitone). The mean values were expressed as differences (in cents), between the mean of a given distribution and the frequency of a given musical tone in normal tuning based on the standard $A_4 = 440$ Hz.

The results achieved by fourteen listeners in the tuning experiment described above are presented in Fig. 6. Results for individual tones are shown as vertical lines. The position of each line along the horizontal axis represents the mean value, and its length – the standard deviation of a given distribution.

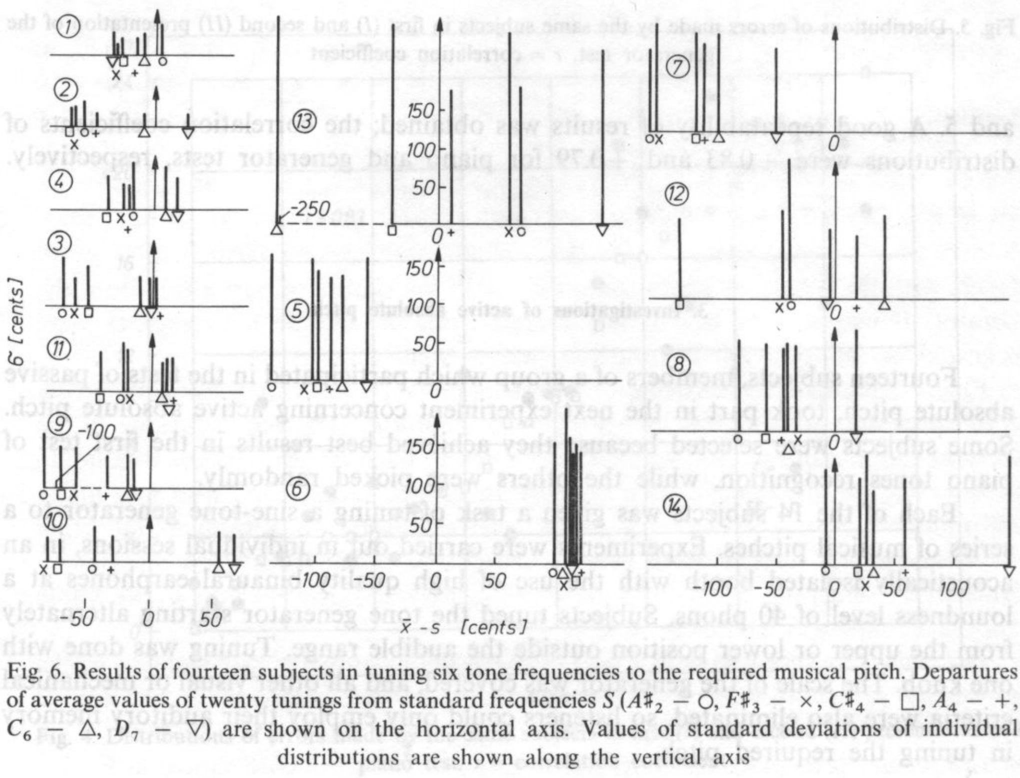

Fig. 6. Results of fourteen subjects in tuning six tone frequencies to the required musical pitch. Departures of average values of twenty tunings from standard frequencies S ($A\sharp_2$ – ○, $F\sharp_3$ – ×, $C\sharp_4$ – □, A_4 – +, C_6 – △, D_7 – ▽) are shown on the horizontal axis. Values of standard deviations of individual distributions are shown along the vertical axis

Hence, for each of the 14 listeners, lines situated near zero on the horizontal axis represent mean values not very different from the standard musical scale, while shorter lines are typical of more reproducible tuning.

Data presented in Fig. 6 illustrate the well-known fact, that individual listeners differ greatly in their ability to produce a required musical pitch from memory. To expose these differences, the averaged results of each listener are shown in Fig. 7. The averaged absolute values of frequency departures from standard pitch are shown along the abscissa, and the averaged standard deviations in sets of results along the ordinate.

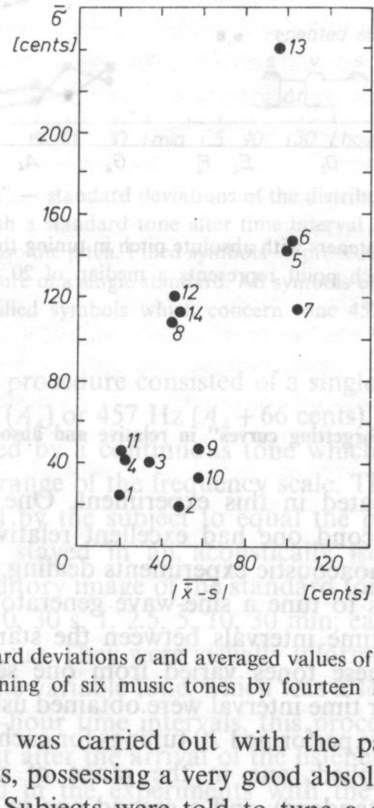

Fig. 7. Averaged values of standard deviations σ and averaged values of constant errors $(\bar{x}-s)$ obtained in free tuning of six music tones by fourteen listeners

The next experiment was carried out with the participation of three new subjects, who were students, possessing a very good absolute pitch, according to the opinion of their teachers. Subjects were told to tune a sine-wave generator to 13 musical notes from C_4 to C_5. The experiment was conducted under conditons similar to those in the previous one. Tunings were performed in a pseudo-random order with 5-minute time intervals in between, in order to eliminate the influence of short-term memory and relative pitch. About 13 frequency set-ups, corresponding to 13 chromatic tones, were obtained during a one-hour session. Twenty sessions were conducted with each subject within approximately one month; the medians of the distributions are shown in Fig. 8. It appears that all three listeners tended to raise the frequency of lower tones and reduce the frequency of higher tones in relation to standard tuning.

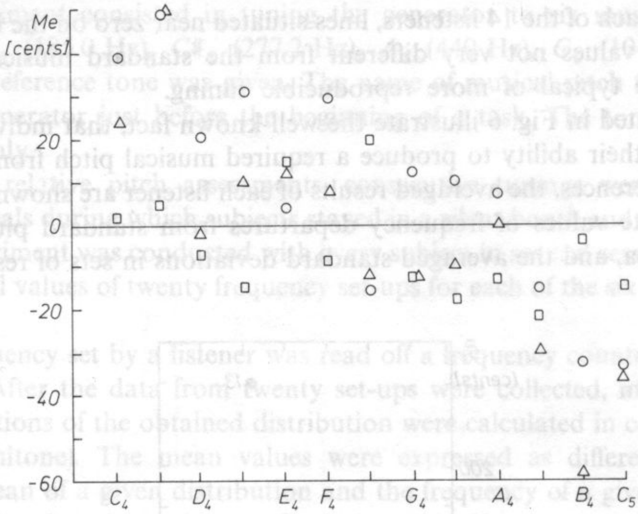

Fig. 8. Results achieved by three listeners with absolute pitch in tuning thirteen tones of the musical scale from C_4 to C_5. Each point represents a median of 20 frequency set-ups

4. "Pitch forgetting curves" in relative and absolute pitch

Two subjects participated in this experiment. One of them had very good absolute pitch, and the second one had excellent relative pitch. Both had considerable experience in psychoacoustic experiments dealing with pitch discrimination.

The subjects' task was to tune a sine-wave generator to match the pitch of a standard tone at various time intervals between the standard and variable tones. Time intervals between these tones varied from one second to 30 minutes. (In addition, data for a 24-hour time interval were obtained using a procedure which will be described later). Listeners performed 20 tunings for each value of the time interval. Two procedures were applied: one in the range of short time intervals only (procedure of a repeated standard), and a second one in both short and long time interval ranges (procedure of a single standard).

In the procedure of a repeated standard, 3-second pulses of the standard and variable tones were presented interchangeably, separated by time interval a Δt. The variable tone (subject to tuning) was additionally signalled by a light. The tones were presented binaurally through headphones at a loudness level of 40 phons while the subject was seated in a sound-isolated booth. The presentation of stimuli was continuous until the subject announced that tuning was completed. Twenty frequency set-ups were taken at each of the 4 values of Δt (1, 5, 10 and 25 s), and standard deviations calculated. The results are presented in Fig. 9.

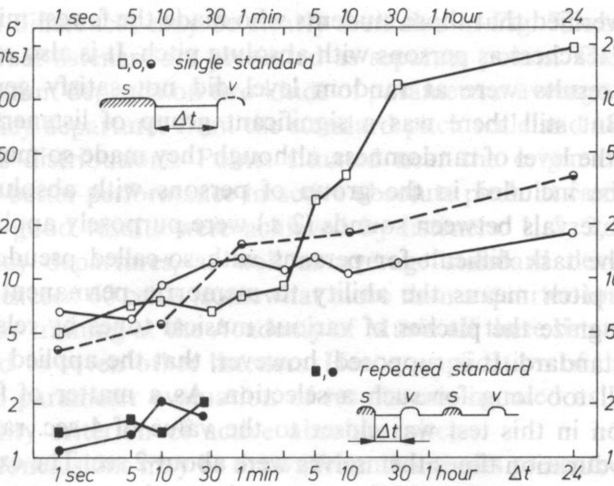

Fig. 9. "Pitch forgetting curves" – standard deviations of the distributions of frequency set-ups of tuning a pure tone to equal pitch with a standard tone after time interval Δt. Squares – subject with relative pitch; circles – subject with absolute pitch. Filled symbols – procedure of a repeated standard; open and half–filled symbols – procedure of a single standard. All symbols concern tuning of a tone 440 Hz (A_4), exluding half-filled symbols which concern tone 457 Hz ($A_4 + 66$ cents)

The single standard procedure consisted of a single presentation of a 10-second standard tone of 440 Hz (A_4) or 457 Hz ($A_4 + 66$ cents). After a time interval Δt, this presentation was followed by a continuous tone which appeared alternatively in a very high or a very low range of the frequency scale. This second stimulus (variable tone) had to be adjusted by the subject to equal the pitch of the previously-heard standard tone. Subjects stayed in an acoustically isolated booth and were encouraged to keep the auditory image of the standard tone in mind during the silence time intervals Δt. (1, 5, 10, 30 s, 1, 2.5, 5, 10, 30 min; each value applied at separate session or group of sessions). They were visually informed about the time remaining until the appearance of the variable tone, which was also signalled by light 3 seconds ahead. In the case of 24-hour time intervals, this procedure was not used, and the results were obtained just after the arrival of the listener at the laboratory, knowing that he had participated in the experiments with the same standard on the day before. Although the time of tuning was not limited, it generally did not exceed 3 seconds. By shortening the tuning process, subjects tried to minimize the interfering effect of a variable tone on the memorized pitch of a standard.

5. Discussion and conclusions

As can be seen in Figures 3–5, the experiment on pitch identification (pitch-naming test) did not give results sufficient for establishing a criterion for absolute pitch. The distribution of errors made by the subjects in the tests was rather continuous.

However, it was verified that those students who made the fewest mistakes would be qualified by their teachers as persons with absolute pitch. It is also certain that those listeners, whose results were at random level did not satisfy general criteria of absolute pitch. But still there was a significant group of listeners, whose results greatly exceeded the level of randomness, although they made so many mistakes that they could not be included in the group of persons with absolute pitch.

Short time intervals between sounds (2 s.) were purposely applied in the test in order to make the task difficult for persons with so-called pseudo-absolute pitch. Pseudo-absolute pitch means the ability to memorize permanently one standard pitch and to recognize the pitches of various musical tones by relative judgements refering to that standard. It is supposed, however, that the applied duration of time intervals was still too long for such a selection. As a matter of fact the time for making a decision in this test was closer to the value of 4 sec. rather than 2 sec., because the tone duration times themselves were about 2 sec. The experiment should be repeated in future for shorter time intervals or shorter tone durations.

Although the experiment on pitch identification did not enable the identification of all possessors of absolute pitch, it led to another very important observation. It can be seen in Fig. 3 that persons who made a small number of non-octave mistakes, had rather poor results in distinguishing octaves. The correlation between octave and non-octave errors was negative ($r = -0.45$). This result strongly supports the theory of a two-dimensional character of musical pitch sensations (REVESZ [2]; BACHEM [3]). These two dimensions of pitch are: pitch quality ("chroma") and pitch register (octave). The following hypotheses can be made to explain the negative correlation between distributions of non-octave and octave errors:

1. The recognition of the "musical name" of a tone (i.e. chroma) as a pitch category is done nearly independently of the recognition of its pitch register (octave).

2. Listeners with the ability of chroma recognition (those, who have "absolute pitch") usually do not exibit any specific ability of octave recognition better than that exhibited by listeners with relative pitch.

3. The fact that listeners who made fewer non-octave mistakes had worse results than other listeners in tests of octave recognition was explained in the following way: Listeners who were sure of their abilities in pitch naming (recognition of pitch names) and who justly considered this part of the test as fundamental, devoted more attention to it, as well as a greater part of the limited answering time. Recognition of the octave was considered by them as secondary, and they spent less time on this task. Listeners, who knew from practice that recognition of chroma is for them practically impossible, acted appositely. They spent most of the time on the task which they justly considered as solvable, i.e. on recognition of the octave. This way they had a lower percent of octave errors.

Experiments on pitch tuning were supplementary to identification experiments and led to establishing criteria of active absolute pitch. It can be concluded from Fig. 6 that individual listeners differed greatly in the precision of tuning individual tones. Individual differences may be clearly seen also in Fig. 7, where the averaged results of individual listeners are presented as separate points. The arrangement of points in the diagram depends on two kinds of parameters: averaged absolute values of tuning frequency departures from the standard pitch scale and averaged standard deviations of the distributions. Points situated near the origin of the coordinate system represent better performance in active absolute pitch. It can be seen in Fig. 7 that particularly good results were achieved by listeners: 1, 2, 3, 4, 9, 10 and 11. Average frequency departures, as well as average standard deviations for these listeners did not exceed 60 cents (somewhat more than a quarter-tone). According to the teachers of ear training at the Academy of Music all these listeners had absolute pitch, as opposed to seven other listeners. Hence, application of the active method (tuning) and two-parameter evaluation of results can be used as a foundation for operational quality criterion of active absolute pitch.

Interesting conclusions may be drawn from the results presented in Fig. 8. In the process of tuning thirteen chromatic tones within an octave, a distinct effect appeared as raising low tones and lowering high tones. The explanation of this may be following. Due to prolonged operation within a limited memory standard range (one octave) an effect of partial assimilation of the standards occured in the subjects. This resulted in deviations of these standards in the direction of the centre of gravity of the whole set. Such effects have been observed by psychologists with respect to various sensations. Harris (1948) described them with respect to short-term pitch memory and introduced the term "effective standard". They may also be explained in terms of the adaptation level theory (Helson [5]). Results presented in Fig. 8 reveal this phenomenon in the domain of absolute pitch.

The experiment which led to the construction of "pitch forgetting curves" enabled a more detailed observation of the mechanism of short – and long – term memory in subjects with relative and absolute pitch (Fig. 9). First of all, a very high precision of tuning was observed in both listeners when the repeated standard was applied. The values of standard deviation at $\Delta t = 1$ sec can be interpreted as frequency discrimination thresholds measured with the method of adjustments. The standard deviations increase when the interval between stimuli is increased to 25 sec, but still they remain within a range of 2 cents (1/50 of a semitone). This experiment reveals a surprising accuracy of the short-term pitch memory in experienced musical subjects. It is also worth mentioning that although only one subject possessed absolute pitch, both of them achieved similar results. This is in agreement with previously obtained results (Rakowski and Hirsch [6]) showing that absolute pitch does not interfere with short-term auditory memory.

While comparing the repeated and single standard precedures, one can see that the results obtained with the latter one are much less precise (i.e., standard deviations are larger). This is due both to the disturbing effect of the variable tone in the initial phase of tuning and to the lack of the possibility of repeated comparisons when the method of single standard is applied. With this procedure, the results obtained from both listeners differ significantly at most of the time intervals applied. At shorter time intervals, the results of the absolute-pitch listener appear to be somewhat worse than those of his relative-pitch colleague; however, at Δt longer than 5 minutes they are definitely better. This fact can be explained in the following way: The listener with absolute pitch from the very first presentation of a standard knows that he is dealing with the musical tone A_4. He can tune this tone easily using the internal pitch standard stored in his long-term auditory memory. Such a tuning strategy is somewhat less accurate than the application of short-term memory, but it is less tiring and does not require such great concentration. Hence, it may be assumed that our absolute-pitch subject changed his strategy at time intervals of about 10 sec, and for longer time delays used his long-term pitch memory. In such a case his tuning operations were practically independent of the time delays applied, and his results were more or less constant.

The situation was different in the case of a listener not possessing absolute pitch. He did not have any internal pitch standards at his disposal, therefore he tried to prolong the contact with the external standard by straining his short-term memory. The short-term memory for pitch is very accurate; therefore up to a 3-min delay he achieved even better results than the absolute-pitch subject. But at a time interval of several minutes the short-term memory trace of the non-absolute pitch listener was rapidly decaying and the accuracy of his tuning became worse.

The results achieved by the subject with absolute pitch appeared to be somewhat less accurrate, when the standard frequency was changed from 440 Hz (A_4) to 457 Hz ($A_4 + 66$ cents). This leads to an important conclusion: Absolute pitch is not equivalent with readiness for retentive remembering of a new pitch standard. The process of remembering such a pitch, differing from twelve pitch standards stored in the long-term memory, is carried out by comparing it with these standards and appropriate verbalization. For example the subject states: "This tone is somewhat lower than $A\sharp$". Consequently, the reproduction process of that pitch is more complex; it consists of two phases: 1) recalling the nearest standard; and 2) producing the estimated microinterval in relation to it. Hence, a greater variance results.

It may be concluded, that the "pitch forgetting curves" presented in Fig. 9 are a good illustration of memory processes characteristic of absolute and relative pitch.

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