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Absolute Pitch and Its Frequency Range

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This paper has two distinct parts. Section 1 includes general discussion of the phenomenon of "absolute pitch" (AP), and presentation of various concepts concerning definitions of "full", "partial" and "pseudo" AP. Sections 2–4 include presentation of the experiment concerning frequency range in which absolute pitch appears, and discussion of the experimental results. The experiment was performed with participation of 9 AP experts selected from the population of 250 music students as best scoring in the pitch-naming piano-tone screening tests. Each subject had to recognize chromas of 108 pure tones representing the chromatic musical scale of nine octaves from E0 to D#9. The series of 108 tones was presented to each subject 60 times in random order, diotically, with loudness level about 65 phon. Percentage of correct recognitions (PC) for each tone was computed. The frequency range for the existence of absolute pitch in pure tones, perceived by sensitive AP possessors stretches usually over 5 octaves from about 130.6 Hz (C3) to about 3.951 Hz (B7). However, it was noted that in a single case, the upper boundary of AP was 9.397 Hz (D9). The split-halves method was applied to estimate the reliability of the obtained results.

Keywords: auditory memory, pitch, absolute pitch.

1. Introduction

1.1. The notion of absolute pitch

Absolute pitch (AP) is one of the most intriguing phenomena of auditory memory (Ward, 1999; Miyazaki, 1988; 2007). It is the ability of some musicians to permanently remember the exact values of musical pitch like C, C#, D... etc. Full AP means remembering all 12 steps of within-octave musical chromatic scale. For the AP possessors these pitch values are qualitatively different from each other and are recognized as such, across various octaves of a musical scale. This characteristic quality of each chromatic step preserved across most of the musical scale was called by one of the most effective AP investigators, Albert

Bachem, a musical chroma (Bachem, 1937). Absolute pitch may be most accurately described as "permanent memory for musical chromas" and the purpose of the experiment described in this paper was to estimate the maximum pitch range in which musical chromas can still be recognized by the selected, most sensitive AP possessors. It was also designed to find the methods which may be used in qualifying the possessors of absolute pitch to participate in psychoacoustic experiments, where their particular ability may be used in solving various psychoacoustic problems; e.g. in assessing the pitch strength of sounds (Rakowski *et al.*, 2008; Rogowski, Rakowski, 2010).

The English term "absolute pitch" is not very fortunate as not referring to the notions here relevant, neither to hearing nor to memory. It emerged from shortening the 4-word expression "memory for absolute pitch" by eliminating two initial words. Still more improper seems to be a sometimes used expression "perfect pitch", which brings in the nonlegitimate element of evaluation. Absolute pitch is more often possessed by people with highly developed musical talent (like well-known composers) but is not necessarily connected with particular musical abilities. Absolute pitch is possessed by only about 3–5% of European or American musicians but probably appears more frequently among Asian musicians (Deutch *et al.*, 2006) and this may have some connections with the prosody of language (Rakowski, Miyazaki, 2007).

1.2. Various kinds of absolute pitch

The phenomenon of absolute pitch may appear in various, quite different forms (Bachem, 1937). At first it must be stated whether we have to deal with a genuine (authentic) absolute pitch or rather with some other, similar phenomenon called pseudo absolute pitch. Such category of non-genuine (non-authentic) absolute pitch was introduced by Bachem (1955) together with a slightly different notion of quasi-absolute pitch. The difference between these two phenomena has been presented not very clearly, so Parncutt and Levitin (2001) in the New Grove Dictionary of Music and Musicians, in place of these two, introduce only one category of non-genuine absolute pitch, namely **pseudo absolute pitch**. Most important feature of this phenomenon in comparison with full, genuine absolute pitch, is its incompleteness and limited accuracy. It appears quite often as fixing in the long-term memory of a subject only one, single value of pitch (the pitch, but not the chroma which would mean recognition of the same musical pitch label in various octaves).

Pseudo absolute pitch appears most frequently as a result of using one single musical pitch repeatedly for months or years of educational or professional activity. Its typical example is memorizing by many students of musical schools in France the pitch of the note "C", due to the fixed *do* method by Jacques Dalcrose. Another typical example of pseudo absolute pitch is frequent memorizing the note A4 by musicians playing the violin, an instrument that is tuned everyday to that exact value of pitch. Still another example of such kind of memory may be found in some non-musicians; e.g. in technicians, frequently referring in their work to standard pure tone 1000 Hz, or to pitch of some other standard frequency.

The special kind of pseudo absolute pitch may develop in singers who can remember the tension of the muscles of their larynx for performing the lowest or the highest note of their own voice scale. Taking the note produced in this way as a standard and using permanently remembered melodic intervals the singer may recognize or produce any desired musical pitch value. Unfortunately, the accuracy and stability of that operation is not very great. This action is based mainly not on auditory but rather on muscular memory.

Similar kind of a possible pitch standard that can be obtained within a person's own body concerns the internal tones and noises produced by the patient's ear and in many cases received as a troublesome disturbance (a *tinnitus*). Such sounds, if appearing at very low loudness level may be quite harmless and tolerable. If it happens that the internal tones have constant and stable pitch, they may be used as standards and as a point of departure for appropriate musical-interval operations. According to Ward (1999) such was the case of the eminent psychologist Carl Stumpf, whose partial absolute pitch was based on an internally generated pitch standard. As may be seen, the pseudo absolute pitch sometimes may be based not on auditory memory, but on auditory pathology.

The way in which the above-described kind of pseudo absolute pitch is often used has little in common with the normal way in which absolute pitch functions. A person with that kind of pseudo absolute pitch treats his memorized pitch standard as if it were a tuning fork. He takes his internal standard pitch as an initial point at the pitch scale to find an interval between this standard pitch and the pitch to be recognized. Recognition of that interval gives an easy answer to what is the musical name of the investigated pitch. Such a strategy may create the impression of possessing full absolute pitch. It has its unquestionable virtues, as it leads to acquiring a perfection in the use of relative pitch (musical intervals) – most important for music. However, a person with pseudo absolute pitch employing that strategy can be easily distinguished from someone who has full, genuine absolute pitch. The pseudo absolute pitch possessor needs a relatively long time to summon any musical pitch not being his standard, while the reactions of a person with full, genuine absolute pitch are always spontaneous and immediate.

There are several features that may help in trying to distinguish a case of **genuine absolute pitch** from that of pseudo absolute pitch; one of this is speed of pitch recognition. For genuine absolute pitch possessors the musical pitch values (e.g. F and F#) differ from each other qualitatively, like colors in vision: they differ in chroma. The inventor of this term, Albert Bachem had that much to say (Bachem, 1955, p. 1182): "*The expression 'C-chroma' refers to the common aspect of all the C's (C-ness); and the general term 'tone chroma' refers to the* *quality common to all musical tones with identical denomination*". Identification of a given chroma by the AP possessors is very similar to recognition of a color as yellow or blue, – it is immediate.

While discussing various cases of **pseudo absolute pitch** it was mentioned that pseudo absolute pitch appears as long-term memory only for a single musical pitch (not a chroma) or sometimes for a slightly greater part of the scale of pitch. The possibility of identifying musical pitch values across the whole frequency scale remains only for those pseudo absolute pitch subjects who are perfectly experienced in operations on musical intervals. Without that help from the relative hearing the pseudo absolute pitch remains a phenomenon only partial in relation to the whole musical pitch scale.

This obligatory (as it seems) partial appearance of pseudo absolute pitch could have been taken as a main sign of its being different from the genuine absolute pitch, were it not for the cases when genuine absolute pitch itself takes the form of a partial phenomenon. In developmental studies on the acquisition of absolute pitch by children (Miyazaki, Ogawa, 2006) it was finally confirmed that a high percent of very young children might acquire the genuine absolute pitch if properly learned. However, their learning must proceed gradually. In the transitional process they acquire a selected part of a diatonic scale and in that early period their absolute pitch ability might be probably defined as **partial genuine absolute pitch**.

It should also be mentioned that generally there are two forms of the AP activity, passive and active (Teplov, 1947). **Active absolute pitch** enables its possessors both to recognize a given musical pitch without referring it to an outside standard and to produce it with his voice or with some not provided with a pitch scale instrument. The active absolute pitch possessor in his activity is usually non sensitive to the timbre of estimated sound.

Passive absolute pitch does not allow one to produce required pitch, but only to recognize it. Although possessing the basic attributes of genuine absolute pitch (the recognition of individual chromas is spontaneous, and the reception of each of them is connected with an individual, specific auditory impression), passive absolute pitch has many limitations in relation to active absolute pitch. Besides the basic restriction, which is the inability to sing or play the required pitch, passive absolute pitch usually displays a considerable dependence on the timbre of tones whose pitch is investigated. Often, the effect of the absolute recognition of a chroma is limited here to the sounds of one's own instrument, e.g. piano or violin.

Also derived from the area of passive absolute pitch is another important variety of the phenomenon under discussion, which, it would seem, can only partly be classified as genuine absolute pitch. This is the case of the ability to recognize the key of a musical piece without the capacity to identify the chroma of a note presented in isolation. Besides being able to identify particular notes, every person with genuine (active or passive) absolute pitch is also capable of recognizing the key of a performed work. However, there exist a substantial percentage of listeners, who, although unable to recognize absolute note pitches, have no great difficulty in naming the key in which a musical piece is played. One may assume that acoustic information received by the auditory system in listening to fragment of a tonal melody is much richer and more complete than that provided by a single pitch value. The internal harmonic structure of the piece is easily recognized and points at the definite tonal centre – a single pitch whose label corresponds to the recognized key. The above phenomenon is to some degree analogous with the mechanism of identifying a missing fundamental from a bunch of harmonically structured higher harmonics (Schouten *et al.*, 1962). This sort of ability, where attention is drawn to the characteristic subjective feeling associated with a character of particular key (e.g. calmness, bliss, aggression), is termed sometimes **absolute tonality** (Ward, 1999).

1.3. Frequency limits of absolute pitch in previous studies

It seems quite evident that absolute pitch, if occurs at all in a given subject, may be observed only in those frequency regions where apart from tone height (natural pitch, Rakowski, 2009) the proper system of pitch classes (tone chroma) could develop. Then, according to Takeuchi and Hulse, "*several studies have reported a decline and eventually a total loss in accuracy of absolute pitch identification for tones above about 4000 Hz*" (Takeuchi, Hulse, 1993, p. 345). Bachem (1948) believed that the upper limit is higher, about 5000 Hz but that these very high tones are perceived all as the same chroma of about C# or D#. The lower frequency limit, according to him was impossible to assess due to "*disturbing aural and extra aural overtones*". Nevertheless, there a "*similar fixation of chroma seems to exist*" (Bachem, 1955, p. 1182).

2. Experiment: frequency range of absolute pitch in pure tones

2.1. Selecting the subjects

The more accurate assessments of the frequency range of AP were initiated only recently (Rakowski *et al.*, 2008), but concerned only one AP possessor. Now it appeared necessary to increase the number of subjects investigated, and to base their recruitment on some stable criterion. So it was decided to rely on a relatively broad population of music students and to look there for subjects with maximum faultlessness in the screening pitch-naming test (Makomaska, 2008; Rakowski *et al.*, 2008). The population investigated here was a randomly selected group of 250 students from The Fryderyk Chopin University of Music. The screening test was performed with a number of small groups of students (not larger than 15 participants) within the time period of several weeks. The test stimuli were 25 quasi-randomly selected piano tones distributed along 5 standard octaves (No. 2 through No. 6). The tones were recorded on CD and presented diotically through high quality loudspeakers with loudness level of about 65 phon. The subjects were listening and writing their answers in the test forms (only the name of a chroma, without indicating the octave). Finally 9 students top scoring in piano-tone screening test (PC $\geq$ 96%) were accepted as AP experts to participate in the main experiment.

As stated above, the results obtained in the piano pitch-naming test was decisive in the selection of subjects for participation in the wide frequency-range experiment. However, that experiment had to be performed with pure tones, so it was expected that those of the subjects whose pitch perception and memory was timbre-sensitive may show significantly lower scoring. Allowing for that hypothetical non-conformity of subjects was intentional as giving additional possibility for observations and measurements in various types of AP.

2.2. Stimuli, apparatus and experimental procedure

The set of stimuli consisted of 108 tones whose joint pitch covered a chromatic scale of 9 octaves from E0 (20.60 Hz) to D#9 (9996 Hz). The stimuli were pure-tone pulses 1500 ms long in the lower part of the scale and 1000 ms long in the upper part of the scale (starting at G#2); the initial and final transients were 100 ms long (50 ms in the upper part of a scale) with linear rise and decay.

A personal computer, equipped with a 16-bit MultiSound Fiji TurtleBeach digital-to-analog converter, was used for the generation of the stimuli, recording listeners' responses and its preliminary processing. Signals were presented diotically through Sennheiser HD 25-13 II headphones. The loudness level for all stimuli was about 65 phon (but no more than 95 dB SPL). The headphones ensured low level of non-linear distortions at high sound pressure levels, especially at very low frequencies.

The experiment was fully computerized and mouse operated. The procedure was based on a one-interval stimulus presentation paradigm with a 12-alternative forced-choice answer pattern. The listeners' task was to identify the tone's pitch chroma. The measuring procedure was as follows. The subject initiated the task. After having heard the tone he had to recognize it and to touch a proper key of the octave-wide keyboard on a computer screen using mouse pointer. After 3 s next tone was heard. The time for answering was unlimited. The computer recorded the stimulus pitch, subject's response (chroma identified) and response time. The experimental series consisted of full set of 108 stimuli presented in random order. Each subject in individual testing was exposed 60 times. The experimental sessions were not longer than 90 min and consisted of 4–10 series. The experiment was preceded by two training sessions for each subject with the same tasks as in the main experiment. The subjects were paid for the participation in the experiment.

3. Results and discussion

3.1. Results of chroma recognition in pure tones at wide frequency range

The basic results of the experiment concern faultlessness of chroma recognition in pure tones by highly sensitive absolute pitch possessors, across wide frequency range. These results expressed as percent of correct chroma recognitions (PC) are shown in Figs. 1, 2, and 3, ordered along the musical pitch scale (semitones from E0 to D#9) with frequencies corresponding to white and black keys on a musical keyboard, marked by color of the symbols.

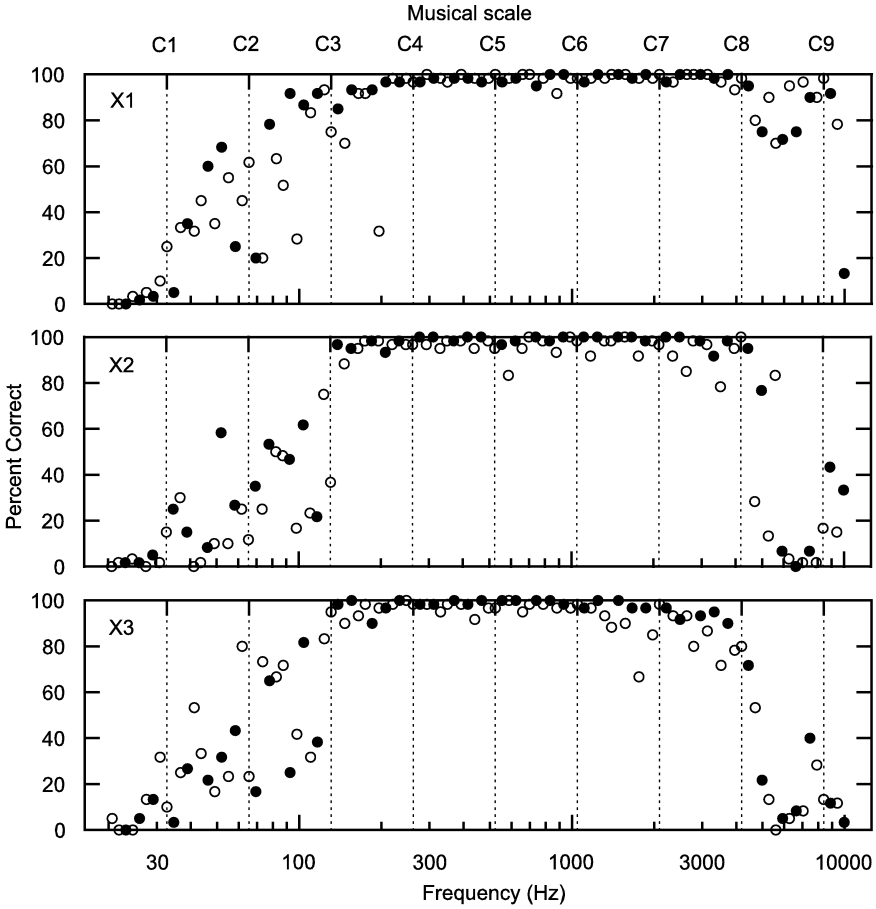

Fig. 1. Percent of correct chroma recognitions in chromatic series of pure tones in normal musical tuning (A4 = 440 Hz; equally-tempered semitones, range E0–D#9; 20.60–9956 Hz). Open and closed symbols correspond to white and black keys of the piano. Subjects X1, X2, and X3.

Nine subjects participating in the experiment have been previously selected as best scoring in piano-tone scoring test with participation of 250 randomly selected music students. In spite of practically equal and very high scoring of selected nine

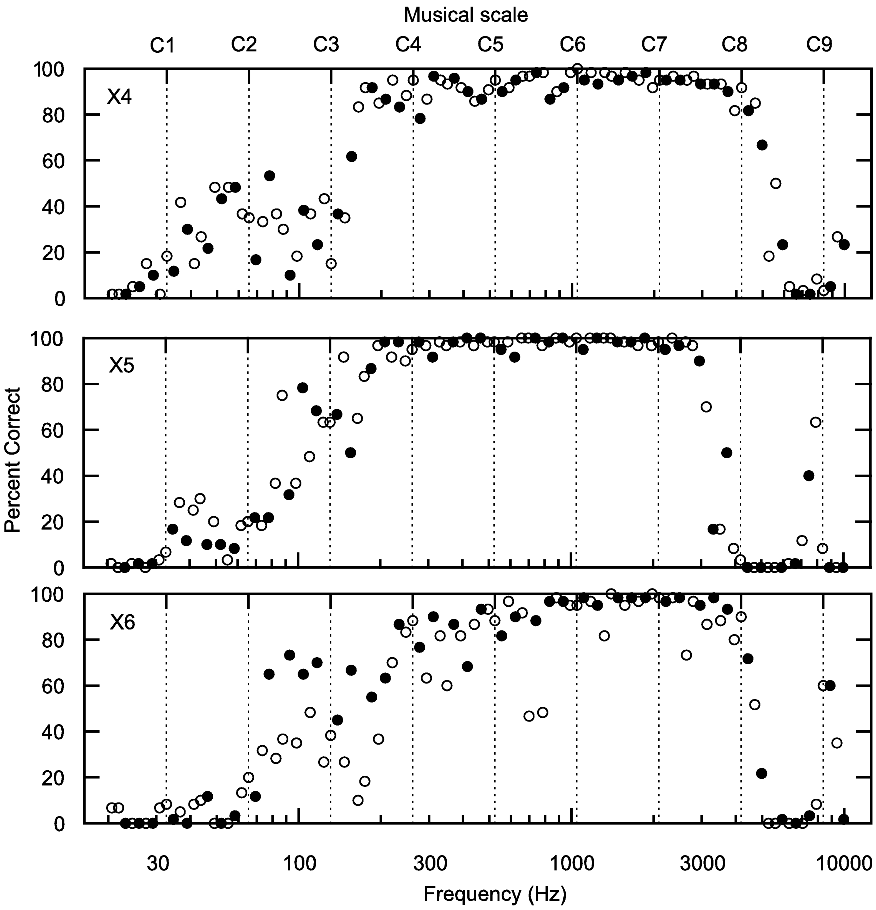

Fig. 2. Percent of correct chroma recognitions in chromatic series of pure tones in normal musical tuning (A4 = 440 Hz; equally-tempered semitones, range E0–D#9; 20.60–9956 Hz). Open and closed symbols correspond to white and black keys of the piano. Subjects X4, X5, and X6.

subjects in the piano-tone screening test, for some of them the performance in the main test with pure tones as stimuli appeared much less perfect. Inspection of the data on chroma recognitions in Figs. 1–3 leads to some general conclusions. The team of experts on piano-tone pitch recognition does not necessarily means a group of subjects top scoring in all tasks requiring excellent performance in AP. As two most obvious examples of this inconformity may serve two cases of absolute pitch in subjects X1 and X9. Subject X1, with his over 90% correct recognitions of chromas in the vicinity of 10 kHz contradicts the widespread opinion on non-existence of pitch chroma at frequencies over 5 kHz. Subject X9, scoring nearly 100% chroma recognitions in all pitch-naming tests involving piano tones, appears nearly helpless as far as the test requires recognitions of AP in pure-tone stimuli, in particular when the pitches of pure-tone stimuli correspond to black keys of the piano.

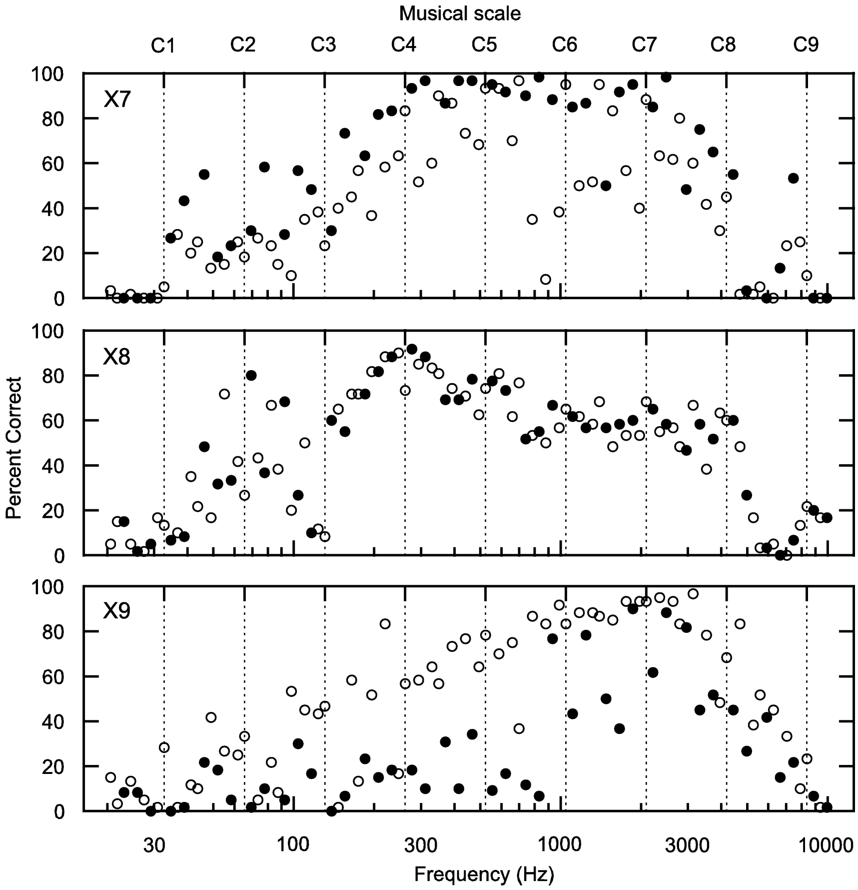

Fig. 3. Percent of correct chroma recognitions in chromatic series of pure tones in normal musical tuning (A4 = 440 Hz; equally-tempered semitones, range E0–D#9; 20.60–9956 Hz). Open and closed symbols correspond to white and black keys of the piano. Subjects X7, X8, and X9.

The case of subject X9 and his strange inefficiency in recognition of all chromas that correspond to black-key tones of a piano (Fig. 3) requires particular attention. It seems to uncover some special bonds connecting the phenomenon of absolute pitch with the time of its initial formation in the auditory memory. The hypothetical reasons for the strange form of scoring by the subject X9 might be the following. In very early childhood of this subject, while formation of the AP standards in the memory most strongly occurred, the white key scale of the piano was for him the only or the main source of the musical sounds and as such was exactly imprinted in the long-term chroma memory (absolute pitch). The acquisition of additional part of a chromatic scale (the "black key" tones) came later in period of life less typical of producing the internal AP standards, and those tones were, therefore, less strongly fixed in memory. That nonhomogeneity of a set of internal pitch standards does not show in easy tasks, like identifying piano tones whose timbre is perfectly well known to musicians, but appears unexpectedly at identifying sounds of unknown timbre, like that of pure tones.

Unfortunately, no matter how convincing the above explanation may be, the results of the present experiment cannot support the above presented theory as general explanation of differences between AP for tones corresponding to white and black keys of the piano. The results of percent correct chroma recognitions, computed separately for tones corresponding to white and black keys, are presented in Table 1. The computations were performed separately for assumed two different frequency ranges, the "wide" nine-octave frequency range (E0–D#9) and an "effective" five-octave range C3–B7. In both cases computations were performed for each subject, separately for white and black keys. As can be seen in Table 1, in the case of subject X9 only the significant majority of white-key chroma recognitions were observed. The differences of PC values between the "white keys" and "black keys" in remaining subjects were non-significant or even opposite. As a conclusion, in the present experiment the results corresponding to white and black keys remained more or less balanced. Nevertheless, the mechanism which results in stronger fixation in AP memory for pitches corresponding rather to white or rather to black piano keys requires some explanation.

Table 1. Percent correct chroma recognition in pure tones by 9 AP experts in "wide" (E0–D#9) and "effective" (C3–B7) frequency ranges; PC values for tones corresponding to white and black keys of the piano ("White keys", "Black keys"); the differences of PC values between the "white keys" and the "black keys" ("W-B"). Statistically significant differences (Student's t-test for independent samples, $\alpha = 0.05$) marked by asterisk.

Range	E0–D#9				C3–B7			
Subject	Percent Correct			W-B (%)	Percent Correct			W-B (%)
	All keys	White keys	Black keys		All keys	White keys	Black keys	
X1	**76.9**	76.1	78.0	−1.9	**95.7**	94.6	97.3	−2.8
X2	**64.5**	61.6	68.5	−6.8	**95.5**	93.5	98.4	-4.9^{*}
X3	**65.9**	65.8	66.0	−0.1	**94.8**	92.9	97.4	-4.5^{*}
X4	**61.5**	65.1	63.8	1.3	**89.5**	89.8	89.1	0.7
X5	**57.4**	58.1	56.4	1.7	**89.1**	89.5	88.5	1.0
X6	**54.1**	51.2	58.1	−6.9	**80.8**	76.9	86.2	−9.3
X7	**47.6**	41.0	56.9	-15.8^{*}	**70.2**	62.0	81.8	-19.8^{*}
X8	**47.4**	49.8	50.5	−0.7	**66.8**	66.5	67.3	−0.8
X9	**40.7**	52.6	26.0	26.6^{*}	**54.8**	69.8	33.8	36.0^{*}

The unusual ability of correct recognitions of pure-tone chromas at frequencies near to 10 kHz by subject X1 requires special attention and will be further investigated. It should also be noted, that inspection of the Figs. 1–3 shows another unexpected high-frequency effect, that appeared in chroma recognitions by nearly all (save X9) subjects. This effect was shown as slight but consistent grow of correct chroma recognitions in the vicinity of pitch level C9 (around 8–9 kHz).

3.2. The concept of pure-tone AP profiles

The individual results of the nine subjects (X1–X9) are also shown in Fig. 4A as standard-octave-averaged values of percent correct chroma identifications (E0–D#9, 20.6–9996 Hz) performed on 108 pure tones covering the range of 9 octaves (complete standard octaves No. 1–8 – twelve semitones, and incomplete octaves: No. 0 – eight semitones, and No. 9 – four semitones).

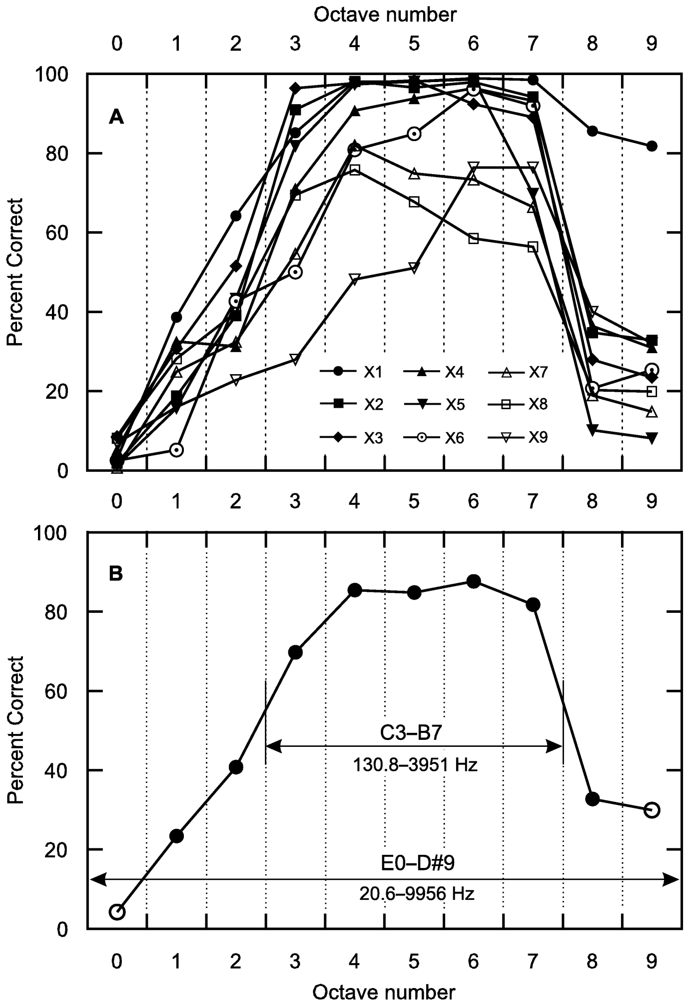

Fig. 4. Percent of correct chroma recognitions in pure-tone stimuli by expert AP subjects calculated in standard octaves in frequency range E0–D#9 (octaves No. 0 and No. 9 are incomplete): individual data of 9 subjects (panel A) and averaged data of all experts (panel B). The "wide" frequency range E0–D#9 and "effective" frequency range C3–B7 are marked by arrows.

To present more clearly the joint tendencies shown by a group of AP experts in Fig. 4A their results were again averaged in each standard octave and presented jointly in Fig. 4B. The use of information presented in Fig. 4B is rather limited, but perhaps it may facilitate answering the practical question "what is the lowest and the highest frequency limit for absolute pitch in pure tones". The answer could be e.g.: "This range stretches more or less between C3 (130.8 Hz) and B7 (3951 Hz) or between C4 (261.6 Hz) and B7. Most specialists on AP while answering such a question would immediately add that if such sound stimuli as pure tones were replaced by harmonic complex tones e.g. sounds of the piano, the frequency range of existence for AP would definitely shift down, e.g. to the range between C2 (65.41 Hz) and B6 (1976 Hz) or between C2 and B7.

Much more useful information than that presented in Fig. 4B could be obtained directly from Fig. 4A. Individual results of pure-tone chroma recognitions by the listeners possessing absolute pitch present important information about the efficiency of those listeners, e.g. as experts in experiments assessing pitch strength of various sounds (see Rakowski *et al.*, 2008; Rogowski, Rakowski, 2010). The frequency characteristics like those presented in Fig. 4A may be described as "pure-tone AP profiles" of absolute-pitch possessors.

3.3. Typical form of errors

The errors of chroma recognition in most subjects are distributed in such a way that they grow with growing distance from the central parts of the effective frequency range. Except for the highest and the lowest parts of this frequency range they are mostly semitone errors. In the highest and the lowest parts of the effective frequency range the number and distribution of errors changes dramatically. As was first noted by Bachem (1948), typical of the highest frequency range is the cessation of proper perceiving the chromas and as a response to growing frequency always the same chroma is perceived. Similar effect appears at the lowest end of the AP frequency range. Due to technical difficulties it was not observed by Albert Bachem, but was foreseen by him (Bachem, 1948).

Presently the distribution of correct and incorrect chroma recognitions may be easily observed using various computer visualizations. As an example, in Fig. 5 is presented a 3-dimensional representation of part of the data from one of our subjects (namely subject X3). It may be seen that stimuli from the eighth and ninth standard octaves are always perceived as chromas A# or B. The same chromas seem to play an analogous part in the lowest frequency range of the experiment (standard octave number zero, stimuli below C1). Small parts of the data, unseen due to visual masking in Fig. 5 may be uncovered by producing the picture at different angle of presentation. Strong reduction in the sensation of chromas appears around frequencies 32.70 Hz (C1) and 8372 Hz (C9).

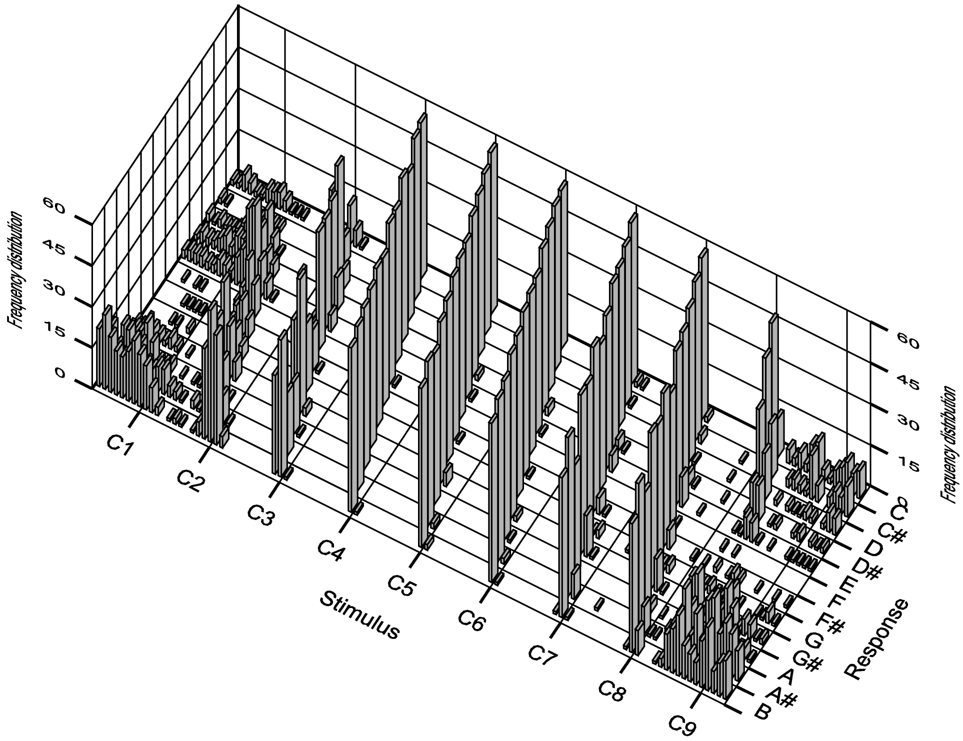

Fig. 5. Frequency distribution of responses by subject X3 (108 stimuli, 60 series).

3.4. Testing the stability of results

As previously described, collection of experimental data was performed using relatively long experimental series (in comparison to other tests for AP listeners). These series contained 108 pure-tone stimuli with randomly ordered frequencies, covering the "wide" range of 9 octaves in semitone steps. A characteristic features of subjects participating in the experiment were easiness and speed showed in producing their responses. They never complained about the length of the series but rather about their number (60).

Nevertheless there was always a possibility of an effect of strain and fatigue growing with time while the long series of stimuli was operated. To check such a possibility a simple split-halves method was used. For each subject the whole of his experimental data (60 series of 108 stimuli) was divided in two halves. The first half contained the results of initial 54 items from each of 60 series, and the second half, the results of remaining 54 items. The results of the first halves of all series produced by a given subject were presented in Table 2 as his "Trials 1–54 PC". The same was prepared for the results of the second halves, as his "Trials 55–108 PC", and the difference between PC values in halves "T2-T1". The calculations were performed for all subjects.

Table 2. The stability of results. The results of split-halves method used for trials in experimental series (108 trials in a series) and for series in the experiment (60 series). The results of the trials 1–54 and 55–108 in all series (marked as T1 and T2) and the difference between halves (T2-T1). The results of the series 1–30 and 31–60 (marked as S1 and S2) and the difference between halves (S2-S1).

Subject	All data	Within series			Within sessions		
		Trials 1–54 (T1)	Trials 55–108 (T2)	T2-T1	Series 1–30 (S1)	Series 31–60 (S2)	S2-S1
	PC	PC	PC	(%)	PC	PC	(%)
X1	**76.9**	76.7	77.2	0.5	75.4	78.4	3.0
X2	**64.5**	64.5	64.5	0.0	63.5	65.4	1.9
X3	**65.9**	65.2	66.6	1.4	66.5	65.3	−1.1
X4	**61.5**	63.7	65.4	1.8	60.6	62.4	1.9
X5	**57.4**	57.2	57.5	0.3	57.0	57.7	0.6
X6	**54.1**	53.8	54.4	0.6	55.9	52.3	−3.5
X7	**47.6**	49.0	46.2	−2.9	47.4	47.8	0.4
X8	**47.4**	47.8	52.4	4.6	47.1	47.7	0.6
X9	**40.7**	41.7	41.3	−0.4	38.2	43.2	5.1

As seen in Table 2, in subjects X1, X2, X3, X5, X6, and X9, the differences of the PC values between the halves are very small, which seems to be a good sign for the reliability of the performed experiment. In most cases the PC values were somewhat grater in the second than in the first half of the series, which contradicts the supposition on increasing fatigue and deconcentration in time of the long duration of each 108-item series. They rather seem to indicate the increasing interest and attention of subjects in performing the subsequent AP recognitions. Some improvement of the results may be due to learning.

The same method was used to evaluate the stability of results. For each subject the proportions of correct chroma recognitions in series 1–30 and series 31–60 were calculated separately. The results and the differences between PC values in both halves were shown in Table 2. The differences between PC values calculated on the basis of 30 experimental series did not exceed 5.1%. It should be noted that the results obtained in series 31–60 were slightly better than results of series 1–30 in most subjects.

3.5. Final remarks

The present experiment was aimed at providing information about the effective frequency range of absolute pitch. It was based on chroma recognition by a group of nine experts carefully selected as best scoring in piano-tone screening test. The group of expert subjects appeared much less homogenous than it was expected. The top-scoring subject X1 could recognize pitch chromas at frequencies around 10 kHz, an octave higher than it was so far noticed in the literature. In spite of the importance of the fact, it could not be included in the "effective AP frequency range" of a typical genuine AP possessor (see Fig. 4) and may be treated only as an exception.

It should be stressed that the effective five-octave frequency range C3–B7 concerns exclusively recognitions of chroma in pure-tone stimuli. As it was shown by informal testing, using other stimuli, e.g. harmonic complex tones or piano-tones, would generally widen that range or at least shift it downwards.

Another unusual phenomenon was observed with subjects X9 and X7. They appeared differently sensitive to tones with frequencies corresponding to black and white keys of the piano. The trouble is that their preferences are in opposition to each other. The general reason for the above phenomena, only partly explained, is strong sensitivity of some absolute pitch possessors to the timbre of sound.

The most important result described in Subsec. 3.4 is the great stability and reliability of chroma recognitions by the genuine AP possessors. Such stability, originally observed also in earlier studies, plays an important part in experiments with participation of the AP possessors, where absolute pitch is used as a tool in assessing the pitch strength of various sounds (Rakowski *et al.*, 2008; Rogowski, Rakowski, 2010).

4. Conclusions

1. The effective frequency range of absolute pitch seems to cover the distance C3–B7 (130.8–3951 Hz). However, in testing 250 young musicians, one person showed full AP up to 10 kHz.
2. Absolute pitch, recognized in some subjects as correctly identifying musical chromas in tones of musical instruments (e.g. of the piano), does not necessarily mean possessing AP of the same quality in pure tones.
3. The quality (faultlessness) of absolute pitch may strongly depend on similarity between the timbre of sounds tested and the timbre memorized by the subjects. In most cases, absolute pitch tested on piano tones outweighs AP on pure-tones in accuracy.
4. The pure-tone AP profiles (see Fig. 4a) present important information on the efficiency of a given AP possessors in using absolute pitch at various frequency ranges. Hypothetically, the genuine AP possessors may be able to improve their AP pure-tone profiles after having practiced and being acquainted with the timbre of pure tones. Similar AP profiles may be produced for a given subject with various kinds of sounds. However, their form may change with progressive familiarity of the subject with a given type of sound.
5. Applying split-halves method showed the remarkable stability and reliability of performance.

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