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EXPERIMENTS ON LONG-TERM AND SHORT-TERM MEMORY FOR PITCH IN MUSICIANS

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A series of experiments on the memory for pitch was performed with 18 musicians. They had to pass a pitch-naming and a newly-designed pitch-producing test meant to check their passive and active absolute-pitch ability. On that ground two of them, who revealed faultless, full absolute pitch and one who had most typical relative (non-absolute) pitch, were selected to take part in a case-study-type experiment on short-term memory for pitch. The experiment partly confirmed the previous finding (RAKOWSKI, [5]) of the about 2-minute time range for short-term pitch memory in relative-pitch listeners. It also explained cases in which absolute-pitch possessors, when required to repeat after short-term delay an external pitch standard, either use for that purpose their authentic short-term memory for pitch, or rather relay on comparisons with their absolute-pitch standards.

Keywords: pitch, absolute pitch, relative pitch, chroma, short-term memory.

1. Introduction

Pitch is one of the most important auditory sensations exploited by music. However, both in music and in everyday life more important than actual values of pitch (absolute pitch) are distances between subsequent pitch values (relative pitch). These various distances occurring at proper moments of time are perceived as melody in music and as elements of prosody in speech.

The terms absolute pitch (AP) and relative pitch (RP) have been given in Anglo-American terminology an additional, quite unexpected meaning. This meaning referred actually not to the description of pitch as a sensory phenomenon, but to the individual properties of human auditory memory. It was found (STUMPF, [7]) that some people can preserve in their long-term memory the absolute values of musical pitches like C, C#, D, etc. together with their octave replications. For such musical pitch qualities, recognized across octaves as identical, several researchers proposed to give the name "chromas" (BRENTANO, [3]; BACHEM, [1]). This property was first called "memory for absolute pitch" (e.g. BAIRD, [2]) but later, as a sort of shortening, this particular memory phenomenon itself began to be called "absolute pitch" (AP) and the people who had such a kind of memory were called absolute pitch possessors.

The ability to preserve in memory all 12 standards of musical pitch (chromas), or, in other words "the full AP" occurs among Polish musicians only in about 3÷5% of their population (RAKOWSKI and MIYAZAKI, [6]), but is sometimes replaced by partial absolute pitch. Partial AP possessors have an exact long-term memory trace for only one (or sometimes for two) musical pitch standards. Nevertheless, most of them can recognize or produce also all other standards by using long-term memory for musical intervals, or in other words, using their memory for relative pitch (RP). This kind of pitch memory, in contrast to AP, can be trained at any age. After some training musicians can learn to recognize and to produce from memory any musical interval (e.g. as a minor third or as a major seventh). The same ability in more natural form exists also in majority of musically untrained people, and means the ability to recognize and to produce a sequence of musical intervals, or simply – a melody.

The present paper describes two series of experiments. The first series was used to demonstrate certain features of memory for pitch exhibited in a group of 18 music students, with the purpose of selecting subjects for future psychoacoustics experiments (also for the experiments described in second part of this paper). It seems to be very important to know who among the subjects participating in experiments on pitch perception and pitch memory can be qualified as a typical or true RP (a musician unable to store in LTM any stable and exact within a semitone value of pitch), and who belongs to an AP group (full or partial, active or passive absolute pitch). Sometimes the qualification is clear, sometimes (but not as often as generally believed) quite uncertain. Then, it should be remembered that every musician having or not AP is usually well advanced in operating musical intervals, as most of a musical code is based on relative pitch.

The second part of this paper concerns the performance of two AP musicians in the realm of short-term memory for pitch. This special kind of short-term memory, extremely important in music, has been previously studied in musicians not having AP (RAKOWSKI, [5]). The present experiment, with only two AP possessors and one relative-pitch listener for comparison is a typical example of a single-case study without firm statistical grounds. However some of its results may lead to interesting conclusions.

2. Selection of subjects

Sixteen randomly selected students of the first and second year of Sound Engineering Department, Chopin Academy of Music were tested with a piano-tone pitch-naming test. To this group were added two subjects who had scored 100% correct in the same pitch-naming test performed with first-year students in the Department of Composition, Conducting and Music Theory of Chopin Academy (subjects A1 and A2). All of these young people, though only students, were already expert musicians, as before entering the Academy they had been studying 12 years in primary and secondary professional music schools.

Prior to passing the pitch-naming test, each of 18 students had to declare in a questionnaire what kind of pitch memory in his own opinion does he or she posses, and, in particular, whether he or she has absolute pitch. Those who declared themselves as having AP were signed with the letter A (absolute pitch). Those who declared not having any absolute-pitch ability or declared having only the possibility of guessing sometimes the musical-pitch name of a given tone by referring its pitch to the pitch of the lower end of their own singing-voice scale (so-called pseudo AP, BACHEM, [1]) were signed the letter R (relative pitch). Two subjects, who had declared having in their auditory memory a single fixed standard which they could recognize or produce without mistake, were signed with letter P (partial absolute pitch or quasi AP according to BACHEM [1]. The numbers were added later for identification of subjects within each group.

After having passed the pitch-naming test estimating their passive absolute pitch all 18 students passed the pitch-producing test to check their ability to generate the absolute pitch values (active absolute pitch). Both tests were used to select proper candidates for subjects in short-term memory experiments. These tests are described below in some detail. It should be stressed that declaration of all 18 subjects concerning their memory for pitch (A – absolute pitch, P – partial absolute pitch or R – relative pitch) were confirmed by the results of testing.

3. Tests for passive and active absolute pitch

3.1. Musical pitch-naming test

Musical pitch-naming test consisted in a sequence of 25 piano tones quasi-randomly distributed within the range of five octaves (from first to fifth). Each chroma in the test was represented two times except for the chroma C# which appeared three times. Five tones appeared in each of the five octaves. The piano tones were recorded monophonically on a compact disc in a rhythmic order of 6 seconds and presented via loudspeaker at a comfortable loudness level of 70 phons. The test was applied to subjects divided in small groups. The subjects had to write a musical name of each tone (e.g. C, D, A...) on a proper form. No information on the octaves in which the tones appeared was required. As a result of the test the accuracy of chroma recognition (percent scoring) was computed for each subject. The pitch-naming test was designed to check the existence and accuracy of the so-called "passive absolute pitch". The terms "passive" or "active" were introduced by TEPLOV [8] and meant the ability to recognize (passive AP) or also to produce (active AP) a given musical pitch without comparing it to any external standard.

3.2. Musical pitch-producing test

Musical pitch-producing test, applied individually, and meant to check the existence of "active absolute pitch", consisted in tuning a series of pure tones as closely as possible to the pitch values corresponding to equally tempered musical scale based on A4 = 440 Hz. No standard tone was given for comparison. Tuning of twelve musical-pitch values was performed in random order and concerned target tones from F4 (349.2 Hz) to E5 (659.3 Hz). There was no time limit for the tasks of tuning and tuning each tone was performed only once. Listening to all sounds was performed through the earphones with the loudness level of 70 phons.

Performing each of twelve subsequent tasks in a pitch-producing test was initiated by the subject with touching the symbol "start" on a computer screen; then a 30-second signal of continuously changing frequency was heard, meant "to erase" the memory of the pitch values previously perceived by the subject. After that, the name of target pitch (e.g. C# or G) appeared on the screen and the subject could initiate tuning a variable tone to bring its pitch to the desired value. The initial value of the variable tone was located randomly within the range of ±600 cents around the target tone frequency. The subject could change the variable tone freely within the scanning region by continuously changing the position of a trackball type manipulator. The scanning region was limited to ±600 cents from the current target frequency. The process of tuning a variable tone to a desired pitch was composed of a series of consequent trials. After each trial consisting in changing the position of a manipulator (without being able to listen to changing pitch) subject touched a proper key on a monitor screen to play a 1.5-sec tone demonstrating the achieved pitch. These pitch-tracking operations were repeated until the subject stated that the finally obtained pitch value corresponds to target musical pitch and pressed the proper key. At that moment the final value of frequency obtained in tuning was recorded and the next task began.

Both signal generation and whole experimental procedure were run by the computer. Frequency-level distances in cents between subsequent target frequencies and corresponding final frequencies of tunings were transposed to a common frequency level equal zero for all target frequencies. At that common level all separate results of tuning (frequency-level distances in cents from current targets) were accepted as constituting a common, single distribution. Quartile deviation QD of that distribution was taken as an invert characteristic of a given subject's ability to produce a full series of 12 musical pitch standards without referring to an external anchor-tone. Such ability is typical of active absolute pitch. As it appeared, it may also be achieved by possessors of partial AP if they are well advanced in operating musical intervals.

4. Discussion of joint results of pitch-naming and pitch-producing tests

The results of the tests on pitch naming and pitch producing applied to 18 music students are presented jointly in Fig. 1. Following conclusions may be drawn directly from inspecting the data in the figure:

There is a clear distinction of results obtained in the pitch-naming test (filled circles in Fig. 1) by those who had previously declared having absolute pitch ("A" subjects, scoring 60÷100% correct) and those who had not declared it ("R" and "P" subjects, scoring 0÷20% correct).

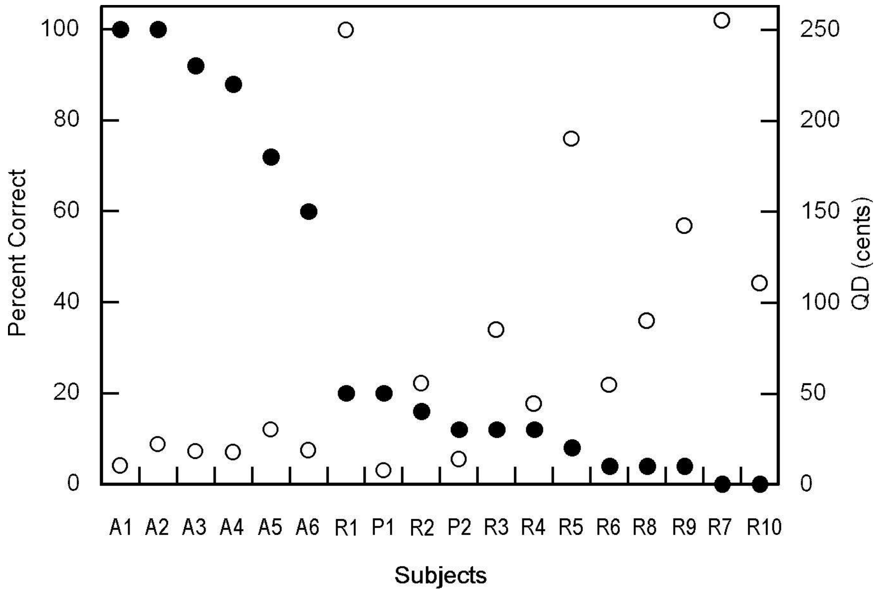

Fig. 1. Joint results of the "pitch naming" and "pitch-producing" tests applied to 18 music students ordered according to their decreasing performance in pitch naming. The pitch-naming test (filled circles referred to left vertical axis) shows the percent-correct recognition of musical chromas in a series of 25 piano-tones randomly presented with 6-sec inter-stimuli distances, across the range of 5 octaves. Subjects are signed with letters according to their absolute-pitch competence declared in pre-test questionnaires. (A, P – full and partial absolute pitch, R – relative pitch). The pitch producing test (unfilled circles referred to right vertical axis), shows the quartile deviations (QD) of joint distributions of tunings around 12 target frequencies of equally-tempered musical tone system.

The results of the pitch-producing test (unfilled circles in Fig. 1) show values of the measure of dispersion (quartile deviation, QD) in tuning a pure tone to 12 musical standards preserved in memory of a given subject. Those values are generally low for those subjects that are possessors of absolute pitch (the "A" subjects). The results of this test bring some new information about the "A" subjects. Low values of dispersion obtained in tuning pure tones to unisone with the internal musical pitch standards prove that all AP possessors participating in the experiment have not only passive absolute pitch (which was revealed as high scoring in pitch-naming test) but also a higher form of AP, namely active absolute pitch.

Subjects who had declared not having full absolute pitch and, accordingly, scored low in the pitch naming test, were divided in two groups. One of them, consisting in ten subjects (labeled "R" for relative pitch) declared having neither full absolute pitch nor any permanently and accurately remembered pitch that could be used for them as a reference point in recognizing other musical pitches. Two of them admitted having the possibility (sometimes successful) of using as a reference the lowest pitch of their vocal scale. This reference point was, according to them, not fully reliable in accuracy as dependent on psychological and physiological factors, such as fatigue. Such a kind of pitch memory was called by BACHEM [1] "pseudo absolute" and is generally qualified as relative pitch. The results obtained by two pseudo AP possessors, PJ and RW, appear in Fig. 1 as R1 and R6. Typical of all members of the relative pitch group is low scoring in pitch naming test (filled circles in Fig. 1) and relatively high values for the measure of dispersion (open circles in Fig. 1).

Another group of subjects (actually two of them) who did not possess full absolute pitch presented themselves in interview as being able to recognize and produce accurately standard musical pitch A (440 Hz). These two subjects, KW and JJ, were classified as possessors of partial absolute pitch ("quasi AP" after BACHEM [1]), P1 and P2. They both were violinists and as such had to listen very often to the tone A4 as a musical tuning standard. These subjects scored relatively low in the pitch-naming test (correspondingly 20 and 12% correct), however, unlike in all other subjects that had declared "not having absolute pitch" (subjects "R") their results in musical pitch-producing tests have shown extremely low values of dispersion (quartile deviation QD equal 8.1 and 14.3 cents correspondingly).

Explanation for these unexpected results of low dispersion in tuning pure tones to the pitch of 12 musical standards (musical pitch production) by the two subjects with partial AP is rather simple. Possessors of partial AP learn to use a single standard pitch fixed in their long-term memory as a point of departure for sets of operations performed with the use of relative pitch. After several years of intensive ear training in musical conservatory (primary and secondary music school) they have learned to recognize and to produce all within-octave musical intervals. To solve the task of producing a given musical pitch they have to tune a musical interval that occurs between that pitch and a permanently memorized standard. The indispensable condition that must be fulfilled to secure for them proper accuracy of tuning concerns having enough time for each of twelve tasks. That particular condition was certainly fulfilled in the present form of musical pitch-naming test, as the decision when to finish every operation of tuning was left entirely in the hands of a subject.

The requirement of having sufficient time for operations connected with the use of musical intervals, that could have been employed by partial AP possessors, was evidently not fulfilled in the test of musical pitch naming. The time of 6-seconds between the tones presented was certainly enough to perform the easiest operations like recognizing the tone A4, naming the tones one semitone apart or perhaps some other tones but, as it appeared, was not enough to score more than 20% correct, as it was in the case of subject P1.

5. The experiment on short-term memory for pitch in absolute pitch possessors

The phenomenon of memory has been thoroughly investigated by psychologists for more than a century. The division between the notions of short-term memory (STM) and long-term memory (LTM) was first introduced by JAMES [4] who distinguished between *primary memory* as a part of "psychological present" and *secondary memory* referring to events that have left consciousness and constitute the "psychological past". Many thousands of scientific discourses on memory have been conducted since James's times and many complicated theories presented, but his simple idea seems always convincing. In particular, when we consider memory for such undimensional sensation as natural pitch (tone height according to BRENTANO [3]). In that particular case, short-term memory appears to be very accurate and stays for quite a long time of 2–4 minutes; after that time the decrease of the pitch memory trace starts to accelerate, as has been shown in experiments with repetitions of vocal intonation after controlled time delays (RAKOWSKI, [5]). Those experiments have been conducted with musicians not having absolute pitch. It was interesting to compare in a joint experiment the efficiency of STM for pitch in subjects having very good AP with that of a typical representative of relative pitch listeners.

Selection of subjects to this study was based on the results of the previous experiment where the possession of both passive and active form of AP was investigated (Fig. 1). Students AS and MC (A1 and A2), both scoring 100% correct in the pitch-naming test for passive AP, were chosen as best possessors of absolute pitch. They have also shown very low values of quartile deviations in tuning to internal standards (test for active AP or, – under certain conditions – for partial AP). Student DD (R5), scoring about 8% correct in the pitch-naming test (a result typical for pure guessing), was chosen as a representative of relative-pitch listeners. He also obtained a very high measure of dispersion (near to QD = 200 cents) in a pitch-producing test, showing that he certainly does not have neither active, nor partial AP.

Investigation on the short-term memory for pitch may be conducted by tracing changes in the accuracy of an exact value of pitch remaining in the subject's memory store after exposition of external standard. This may be done in several ways; one of those is through performing by a subject multiple operations of producing tones (vocally or by tuning a tone generator) with the pitch equal to that stored in the memory. A measure of dispersion of the set of frequencies obtained by a series of such separated tunings (e.g. standard deviation or quartile deviation of the distribution) may serve as an invert measure of the strength of a memory trace of pitch. Such measurements performed at various time delays from the exposition of standard pitch illustrate the process of decay of the memory trace for pitch in a given subject. The lines showing the measures of uncertainty of the pitch-memory trace, increasing with time distance from the memorized standard, may by called "pitch-forgetting curves" (RAKOWSKI, [5]).

The experiment investigating short-term memory for pitch was performed with the subjects previously tested (see Secs. 3 and 4). These were two absolute pitch subjects (A1, A2) and one relative pitch subject (R5). To compare joint results obtained by two absolute pitch subjects with those of a single relative pitch subject, the RP subject performed most of the experimental tasks twice, so the number of his decisions per measuring point was equal to that produced jointly by two APs.

The scenery of the experiment was the following: The subject listened to a 500-ms pulse of a standard tone (pure tone with loudness level 70 phons); he had to tune a variable tone to equal pitch with that standard. The variable tone first appeared after a given time delay as a 500-ms pulse of a pure tone with loudness level 50 phons. Its initial frequency was random within a $\pm$600-cent distance from a target tone. The subject's task was to change the variable tone's frequency by continuously changing the position of a trackball type manipulator to arrive at a desired pitch. The subject did not hear the changes of pitch, but after correcting the frequency and pressing the virtual key on a computer screen he could listen to a variable tone with a new pitch. Such operations were repeated several times until the desired pitch of a variable tone was reached. At that time subject pressed the proper key on a computer screen, the chosen frequency was recorded, and the next task had begun. It should be noted that the region of scanning frequency in search of a target pitch was limited to $\pm$600-cents from the target. All sounds were heard through the earphones.

The loudness difference between standard and variable tones was applied to minimize the disturbing effect of variable tone on the memory trace of standard during the process of tuning. The effect of loudness change on pitch of the variable tone was negligible (ZWICKER and FASTL, [9], p. 106).

There were 6 parts of each experimental series corresponding to 6 values of the time delay between exposition of the standard pitch and the first appearance of a variable frequency tone. These time delays were 1 and 10 sec, 1, 2, 4 and 6 min. In each part 4 standard pitch values were used in random order: F4 (349.2 Hz), G4 + 50 ct (403.5 Hz), A#4 (466.2 Hz), and C5 + 50 ct (538.6 Hz). Each of 2 absolute pitch subjects performed 12 and the relative pitch subject in most cases performed 24 series of the experiment.

6. Results of the experiment on short-term memory for pitch and discussion

The overall result of the experiment is presented in Fig. 2. It shows general similarity of results obtained by the absolute-pitch listeners (APs) and the non-absolute-pitch listener (RP). The differences are small, however in Fig. 2 the general tendencies may by clearly seen. Quartile deviations of the equal-pitch distributions shown in the figure may by taken as a measure of uncertainty of pitch memory trace in the subjects. This uncertainty at very short time delays (up to about $1\frac{1}{2}$ minute) seems to be lower in the subject RP, who used to relay firmly on his short-term auditory memory. The situation changed at longer time delays, when strength of the standard pitch stored in the STM of all listeners became more and more blurred. In that situation the strategy of absolute-pitch listeners, who relied mostly on their own internal memory standards became more effective and their results showed less dispersion than those of the relative-pitch listener.

Some details of those processes may be seen in Fig. 3, in particular in case of tuning to tones F4 and A#4 with frequencies belonging to generally acknowledged set of musical tone standards. In that case, probably even at very short time delays, AP subjects relayed on their internal pitch standards. The RP listener who had to rely only on his

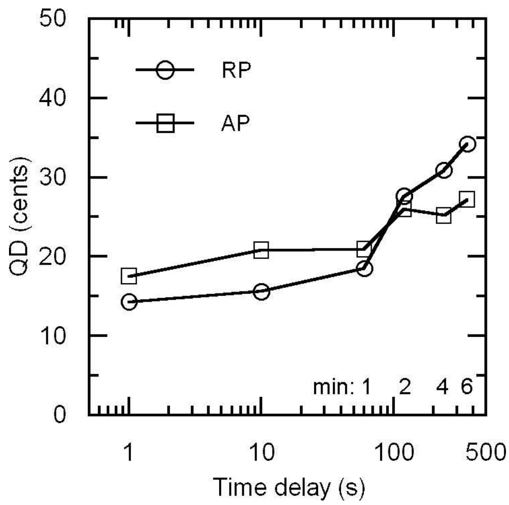

Fig. 2. Quartile deviations of joint distributions of tunings around four standard frequencies in "delayed tunings to equal pitch" by two absolute pitch listeners (squares), and a relative, non-absolute pitch listener (circles). Each measuring point is based on 96 decisions of the subjects.

short-term memory for pitch began loosing this possibility after 1 or 2 minutes showing increased dispersion of tunings.

More complicated seems to be the situation when frequencies of standards to be tuned are well outside the acknowledged tuning system (G4 + 50 ct and C5 + 50 ct). Here the possibilities and the strategy were probably for both kinds of listeners more similar. There seems to be, however, a slight difference between the results shown in two lower panels of Fig. 3. In particular, in the panel showing the process of forgetting the tone C5 + 50 cents all subjects seem to retain relatively good memory of standard pitch up to 6 minutes. For most Polish conservatory students, both for those having, and those not having absolute pitch, tone "C" opening the "white key" diatonic scale is most frequently heard from early childhood and somehow "special" (like tone "A" for the violinists). The tones C and A are most likely candidates for creating in subjects the authentic, partial absolute pitch, and if not so, at least for being recognized more frequently than other pitch values. This is probably the reason for relatively low values of dispersion, even at 4 and 6 minutes' delay, in the results of the relative pitch subject (circles in right lower panel of Fig. 3).

The results obtained by the absolute-pitch listeners, shown as squares in the right lower panel of Fig. 3, are still more interesting. The values of dispersion of tunings, relatively large at very short delays begin to decrease at delays larger than one minute. It seems like the subjects had decided to change their initial strategy of relying on the uncertain short-term memory of a completely unfamiliar tone, which was quartertone higher than their very strong internal standard "C", and to rely exclusively on that standard. Such hypothesis seems to be fully confirmed with the presentation of medians of tunings in Fig. 4 (lower right panel, triangles). In this figure the results of two absolute-

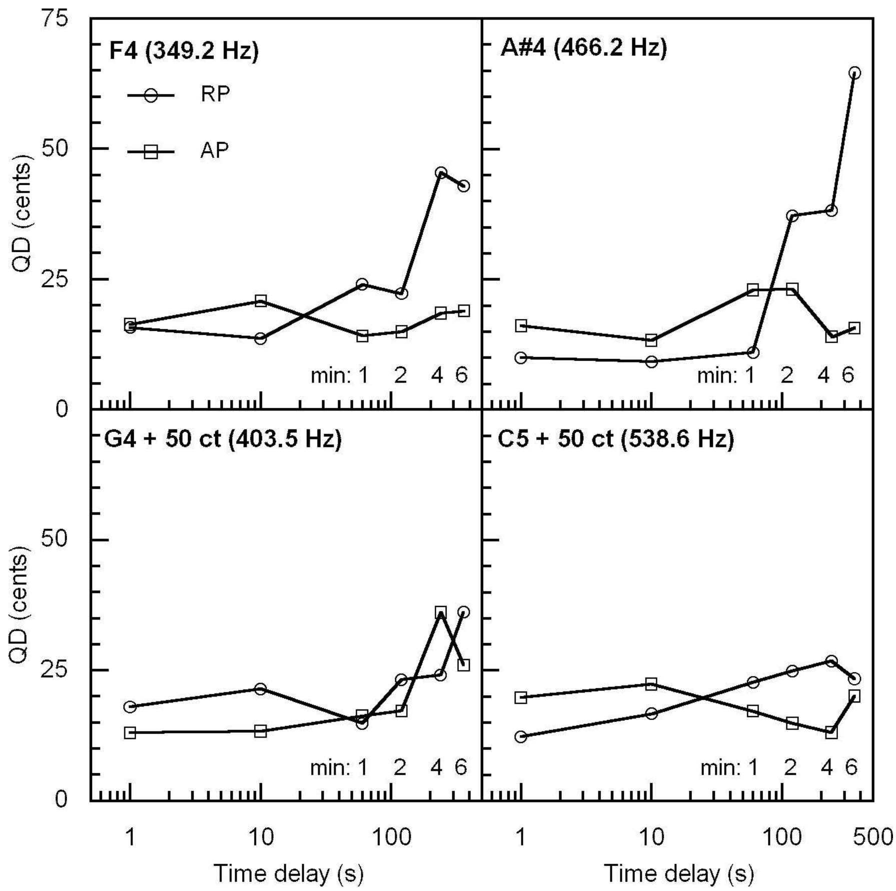

Fig. 3. Quartile deviations of the distributions of delayed tunings to equal pitch with two musical pitch standards (F4 and A#4) and with two pitch standards not belonging to the acknowledged musical tone system (G4 + 50 ct and C5 + 50 ct). Squares: absolute-pitch subjects. Circles: relative (non-absolute) pitch subjects. Each measuring point is based on 24 decisions of the subjects.

pitch possessors are presented separately and the strategy adopted by each of them can be clearly seen. The subject A1 at delay times up to one minute tries desperately to keep his tunings as corresponding to strange external standard C5 + 50 cents. For longer delay times he no longer relies on his short-term memory and concentrates his tunings around his own internal standard corresponding to chroma C, situated exactly 50 cents below the actual standard to be remembered. The other absolute-pitch subject A2 does not even tries to remember the absurd (in his opinion) pitch he was presented and concentrates his tunings around his internal standard C.

As can be seen in both lower panels of Fig. 4, medians of tunings performed by relative-pitch listener (circles) do not deviate from the external standards G4 + 50 ct and C5 + 50 ct. Medians of tunings performed by the same relative-pitch listener at standards F4 and A#4 (upper part of Fig. 4) show fluctuations typical at high level

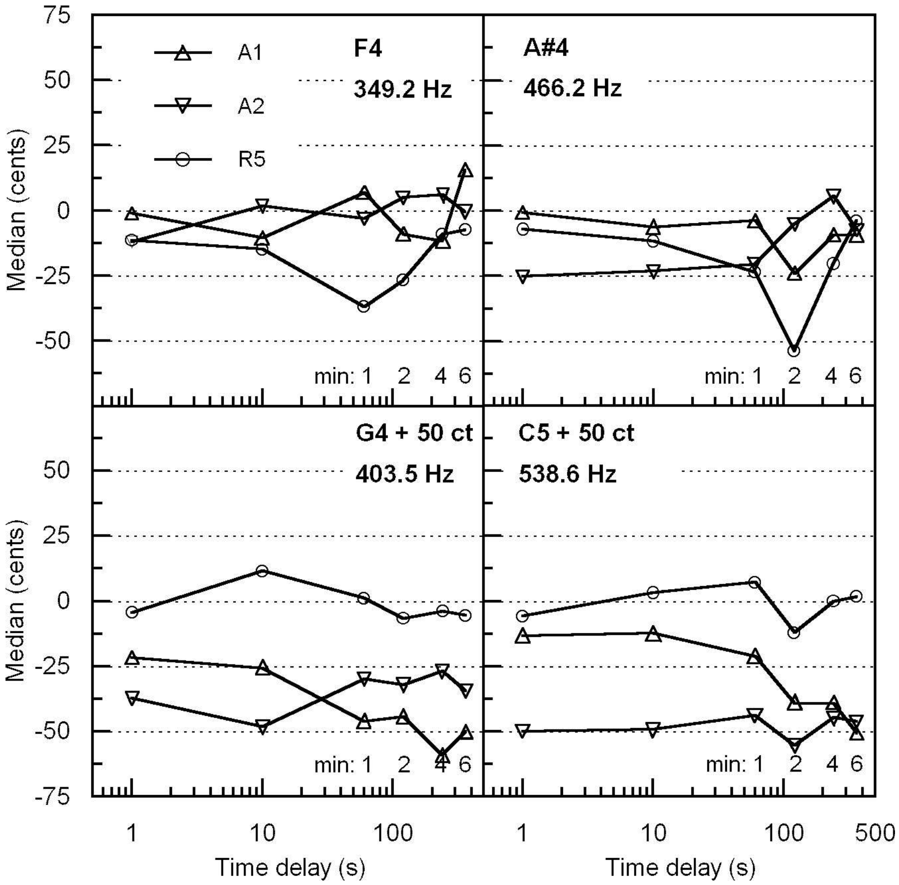

Fig. 4. Medians of the distributions of delayed tunings to equal pitch with two musical pitch standards (F4 and A#4) and with two pitch standards not belonging to the acknowledged musical tone system (G4 + 50 ct and C5 + 50 ct). Triangles: two absolute-pitch subjects A1 and A2, each measuring point is based on 12 decisions. Circles: the relative (non-absolute) pitch subjects R5 (only first part of his results), each measuring point is based on his 12 decisions.

of uncertainty, illustrated by large values of QD for the results of that listener in the corresponding parts of Fig. 3.

The results of the experiments show that possessors of faultless, full, and active absolute pitch have difficulty in neglecting the influence of their internal standards on the external pitch values memorized in their short-term memory store. This influence concerns mostly the constant errors that arise when the pitch value to remember miss-matches the values of permanently memorized chromas.

The strength of an external-pitch memory trace in AP possessors seems not to differ significantly from that in RP listeners (not possessing AP) up to the time delay of about 2 minutes (see Fig. 2). Over that time, at rising time delays, the external-pitch memory trace in relative pitch listener starts to fade more and more quickly while the absolute-pitch possessors use their internalized pitch standards to reproduce the designed external standard freely at any time.

Acknowledgments

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