Interdisciplinary Studies in Musicology 8, 2009

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Investigating the pitch strength of short pure-tone pulses in middle frequency range through their chroma recognition by absolute-pitch listeners[1]

ABSTRACT: A method is proposed for estimating the pitch strength of sounds by measuring the proportion of correct recognitions of their musical pitch (chroma) by expert listeners possessing full absolute pitch. Full absolute pitch (AP) is the ability of some musicians to preserve in their long-term auditory memory the pitch templates of the twelve chromatic tones of the contemporary music system (C, C#, D... etc.) based on the frequency A4 = 440 Hz. This ability is preserved across different octaves in most of the musical pitch scale. Five expert AP listeners, in individual, computer-run sessions, were asked to identify and name the pitch chromas of short tone pulses cut out of twelve sinusoidal vibrations corresponding to the chromatic scale C5 – B5 (523.3 – 987.8 Hz). These tone pulses were composed of n cycles. The value of n was 4, 8, and 16, and so the total number of stimuli investigated was 12 x 3 = 36. All these stimuli were presented in random order to the five AP listeners in a single test, which was run twenty-six times in consecutive sessions (the results of the first session were not used in computations). The results show an increase in correct chroma recognition (and consequently of the pitch strength of a pulse), with n rising from 4 to 16. At n = 4 or 8, the results show also a dependence of chroma recognition on the total pulse duration. Thus, for tone pulses with a low number of cycles (at n=4 and 8), the pitch strength diminishes with increasing pitch and is different in neighbouring parts of a within-octave musical scale. The discovery of these differences may indicate the relatively high precision of the newly-presented method in estimating the pitch strength of musical sounds.

KEYWORDS: pitch, absolute pitch, pitch strength, chroma, musical scale, vibrations, tone pulses

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[1] This work was supported by Grant No. N105 028 31/3210 from the Polish Ministry of Science and Higher Education (2006–2008).

Introduction

Pitch strength is a useful acoustical characteristic for the sounds of those musical instruments which are classified between two existing categories: those with definite pitch and those with indefinite pitch. The formal musicological terminology does not recognise that between these two extremities both natural and synthetic musical sounds may be produced with pitch strength gradually passing from extremely low values (e.g. bass drum or white noise) through intermediate levels (e.g. kettle drum or narrowly filtered noise) to perfect pitch strength (e.g. violin or pure tone). The possibility of choosing or changing the selected pitch strength of sounds is occasionally required by avant-garde composers.

Apart from artistic purposes, some quite different applications may require the production and aural estimation of sounds with limited pitch strength. There are some hitherto unsolved problems relating to the auditory mechanism of pitch perception and the role of its 'place' and 'time' components. Experiments in this domain may need to use stimuli whose pitch strength can be estimated with great precision.

To date, several methods have been used for measuring or estimating pitch strength: the multiple tuning of a reference pure tone to unison with the investigated sound,[2] the measuring of just noticeable pitch differences[3] and the direct numeral assessment of the salience of pitch, with or without its comparison to standard sounds with arbitrarily declared pitch strength[4]. The method proposed here, first suggested by I-Hui Hsieh and Konrosh Saberi,[5] is based on working with a group of selected listeners possessing so-called 'absolute pitch'. Absolute pitch (AP) is the relatively rare ability of some musicians to preserve in their long-term auditory memory the permanently fixed 'pitch chromas', or pitch values, of octave-generalised, chromatic steps of frequency, based on a generally recognised standard of musical pitch. The group of sounds of which the pitch strength is to be assessed is presented in random order, in individual computer–run sessions, to AP expert listeners. In

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[2] Andrzej Rakowski, 'Measurements of pitch', *Catgut Acoustical Society Newsletter* 27 (1977); Rakowski, 'Pitch strength, pitch value and pitch distance', *Acustica* 82 (1996), 80; Rakowski, 'From acoustics to psychology: Pitch strength of sounds', in *The music practitioner*, ed. Jane W. Davidson (Sydney, 2004), 67–78.

[3] Tomira Rogala, 'Siła wysokości dźwięków muzycznych' [Pitch strength of musical sounds], unpublished Ph. D. dissertation. Fryderyk Chopin University of Music, Warsaw, 2009.

[4] Hugo Fastl and Gerhard Stoll, 'Scaling of pitch strength', *Hearing Research* 1 (1979), 293–301.

[5] I-Hui Hsieh and Kourosh Saberi, 'Temporal integration in absolute identification of musical pitch', *Hearing Research* 233 (2007), 108–116.

each case, the listeners identify the actual pitch chroma (out of twelve possible values), and the proportion of correct recognitions is taken as a measure of a given sound's pitch strength.

There are two important requirements to fulfil in applying this method. First, the AP expert listeners must be carefully selected and the stability of their performance regularly controlled. Second, the sounds whose pitch strength is to be assessed should, in most cases, possess some physical characteristics indicating one of the frequencies of the recognised musical-tone system responsible for producing, more or less clearly, a definite pitch value. This particular condition is met securely in the present experiment, where all the stimuli are parts of pure tones with frequencies belonging to the contemporary musical tuning system.

The selection and training of absolute-pitch expert listeners

The selection of subjects for the present experiment was performed over two consecutive stages. In the first stage, a screening 'pitch naming test' was performed with 250 students (including 10 former students) of the Fryderyk Chopin University of Music in Warsaw. The test recorded on a compact disc contained 25 piano tones, distributed among 5 octaves (from first to fifth); each chroma was represented by 2 tones, except one (D#) which appeared 3 times. The test was prepared in two versions, which differed in respect to the time lapse between the onsets of consecutive tones (6 seconds and 2 seconds), and each version appeared in several slightly differing, quasi-randomly constructed sub-versions, avoiding tone sequences which might appear as easily recognised musical intervals.

Out of the 250 persons tested with the screening test, only eleven, who in each version made no more than one mistake, were taken to further trials. This second stage of trials included testing with two-second pitch-naming tests of a structure similar to that applied earlier, although using not piano but rather pure tones and harmonic complex tones with a spectral envelope of -6 dB per octave. The candidates were then individually tested for chroma recognition in harmonic complex tones with lower partials cut off; this testing was preceded by a short training session in seeking a 'missing fundamental'. As a result of the second-stage testing, five persons were selected for a team of AP-expert listeners and participated in further research. Their work was remunerated.

Experiment

Choosing the material

The aim of the present research was to estimate the pitch strength of tone pulses cut out of twelve sinusoidal vibrations, constituting a chromatic scale from C5 (525.3 Hz) to B5 (987.9 Hz). Following the results of informal preliminary trials, for each of the twelve frequencies, three different pulse-durations (*D*) were created, corresponding to the number of vibration cycles (n = 4, 8 and 16). The tone pulses were gated on and off at zero crossing and contained the full number of vibration cycles (periods). The period's length (*T*) depended on the vibration frequency (*f*) according to the formula: $T = 1/f$. The duration of the tone pulse *D* depended on *T* and on *n*: $D = n \cdot T = n/f$. No correction was given for on and off transients. The total number of stimuli in the present research was 36 (12 chromatic steps x 3 investigated numbers of vibration cycles), and their pitch strength was investigated in a single chroma-recognition test.

Experimental procedure

The five AP expert listeners participated in the chroma recognition procedure by performing the recognition test twenty-six times within about two weeks. The results of the first performance were not computed. For the duration of the experiment, the listener was seated in a sound-insulated room and listened binaurally through Beyerdynamic DT 990 PRO earphones with earcushions. A loudness level of about 75 phones was kept equal for the longest stimulus at each frequency without compensation for the decreasing loudness of very short items. The signal generation, stimulus presentation, data acquisition and computation of results were carried out with the use of a computer.

The listener started the procedure, listened to the sound, chose one of the twelve possible chromas and pointed at the relevant key in the keyboard section shown on the computer screen.

Results and discussion

As expected, the proportion of correct chroma recognitions increased with the growing number of vibrations *n*. Nevertheless, it would appear (see Fig. 1) that the available number of vibrations was not the single important factor for chroma recognition (or, as was assumed, for pitch strength). An equally, or perhaps even more important factor in the creation of pitch strength in short tone pulses appeared to be the pulse duration *D* taken by the whole process of vibrations entering the hearing organ. So, lower tones with longer periods of vibration were better recognised than higher tones of the same octave, whose vibration periods were shorter. (See Figure 1.)

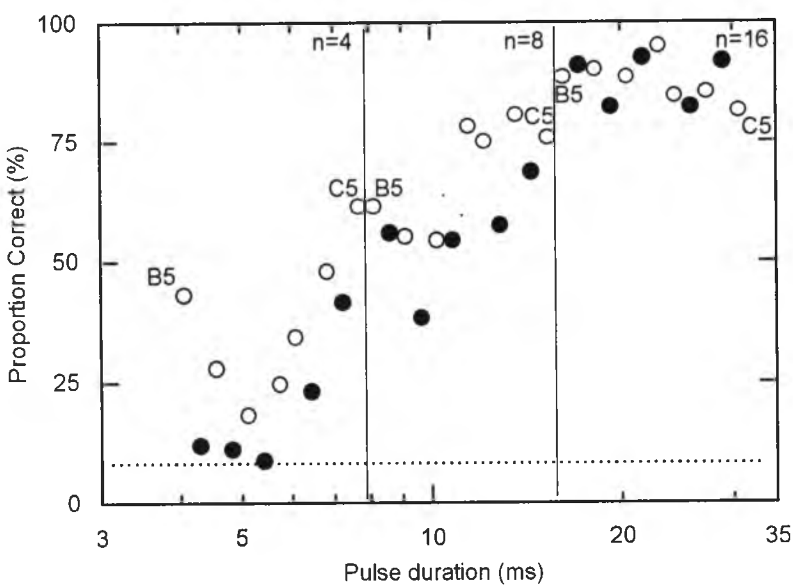

Figure 1. Chroma recognition in pure-tone pulses of sinusoidal vibrations containing n=4, 8 and 16 cycles. The proportion of correct recognitions at each n is shown separately for the twelve steps of the within-octave chromatic scale; however, not in frequencies, but in corresponding duration of pulses (in milliseconds). Consequently, the rising scale of the tone frequencies (from C to B at each n value) should be read from right to left. The white and black circles correspond to the white and black keys on a piano keyboard. The dotted line shows a random-guessing level of 1/12 (8.3%)

This tendency is most clearly seen in pulses with four cycles of vibration (n=4). In that section, at least for pulse durations longer than 5 ms, with each 6% increase of pulse duration (or a 1 semitone frequency decrease), chroma recognition shows an improvement.

The increase in chroma recognition (rise of pitch strength) continues in section n=8. The exact pitch-strength equality of the longest n=4 pulse C5 with the shortest n=8 pulse B5 seems to indicate the decisive weight of pulse length, rather than number of cycles, in establishing the pitch strength of given tonal pulses.

Analysis of the results shown in sections n=4 and n=8 also allows us to show another important effect. All the AP expert listeners who participated in the present research performed exceptionally well in all the preparatory pitch-naming tests, including those with piano tones, pure tones and complex synthetic tones. In none of these tests was any difference noted between the accuracy of the recognition of tones corresponding to the white and black keys of a piano. In the present testing, in the extremely difficult conditions of trials at n=4 and n=8, such an evident difference of chroma recognition did appear. This interesting phenomenon may be taken as proof of the existence of a two-level structuring of pitch memory in absolute-pitch possessors. Most of them acquired absolute pitch in early childhood,[6] practising with the diatonic scale of white-key tones, and their primary acquisition of absolute-pitch templates was limited to about seven items. This primary set was later supplemented with the chromatic tones of black keys, and their surface-level performance presented equal memory for all twelve standards. Only in extremely difficult conditions did it suddenly appear that the primarily acquired set of white-key tones was more strongly fixed in the memory and its performance was much more effective. The above-described possibility of detecting some hidden phenomena with a method of counting correct chroma recognitions may be an indication of the usefulness of this method.

Translated by John Comber

[6] Simak Baharloo, Paul A. Johnston, Jane Gitschier and Nelson B. Freimer, 'Absolute pitch: An approach for identification of genetic and non-genetic components', *American Journal of Human Genetics* 62 (1998), 224–231; Ken'ichi Miyazaki and Yoko Ogawa, 'Learning absolute pitch by children: A cross-sectional study', *Music Perception* 24 (2006), 63–78; A. Rakowski and K. Miyazaki, 'Absolute pitch: Common traits in music and language', *Archives of Acoustics* 32 (2007), 5–16.