

The Domain of Pitch in Music

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The aim of this paper is to discuss some of the physical and psycho-physiological mechanisms that contribute to transformation of the unidimensional sensation pitch into the important medium where most significant elements of music-communication code could develop. It is argued that pitch in music should not be regarded as a simple, unidimensional sensation, but it should be seen as a complex auditory system (PITCH DOMAIN) of four sensations, two in the subdomain of PITCH VALUE (*natural pitch* and *categorized pitch* or *a system of pitch classes*) and two in the subdomain PITCH DISTANCE (*natural pitch distance* and *a system of musical intervals*). In such a multidimensional structure pitch is particularly suited to overcoming the limitations of memory.

Another part of analysis concerns the role of short-term memory (STM) and long-term memory (LTM) operating in relation with various forms of pitch. In particular, an important role of STM for natural pitch is emphasized, in maintaining the stability and coherence of any musical performance. In the remaining parts of this paper the analysis concerns specific forms of the auditory memory that contribute to the sensation of pitch distance, and problems of psychological scaling of pitch.

Keywords: pitch domain, pitch value, pitch distance, natural and categorized pitch, short-term and long-term memory for pitch.

1. Introduction

The communicative code used in music appears as more complex than the language code. The music code, unlike most languages, cannot be seen as a series of not very numerous elements following each other in time, with basic information encoded in the details of their time permutations. Music, according to specific requirements of the information it carries, must, in a much more complex way than language, appeal to various domains of human auditory perception. The most promising domain in which an important part of music-communication

code could develop was the domain of pitch. This was due to the extreme acuity of ear in frequency discrimination and, moreover, due to the extreme suitability of pitch sensations for being organized into stable perceptual categories. As a result, pitch, described in most dictionaries simply as a sensation which enables ordering sounds on a scale from “low” to “high”, should be understood in reference to music as a much more complex phenomenon.

2. Various kinds of pitch sensation developed in music

As has been suggested before [32, 34] the complex **domain of pitch in music** splits into two subdomains, that of pitch value and that of pitch distance. The subdomain of **pitch value** might be called *absolute* pitch, simply in contrast to the subdomain of *relative pitch*. However, the term “absolute pitch” has acquired in British and American terminology a special meaning after shortening its initial form “memory for absolute pitch”. The first, most important words disappeared and “absolute pitch”, contrary to the actual meaning of these two words, is now understood not as a description of a certain pitch subdomain, but as a phenomenon of auditory memory, and as such, will be referred to a little further. The subdomain of musical *pitch value* was the first to attract the attention of scientists to the fact that it encompasses two orthogonal scales of pitch, initially called *tone height* and *tone chroma* [6, 40]. The terms used for those scales in the present paper are correspondingly natural pitch and categorized pitch. **Natural pitch** (primarily called “tone height”) means an uncategorized sensation, best fitted to common understanding of the word “pitch”, simply as a feature that may be used for “ordering sounds on a scale from low to high”. **Categorized pitch** (primarily called “tone chroma”) means *a system of within-octave pitch classes* or pitch value categories. Their width roughly corresponds to a result of dividing the distance of an octave into twelve equal parts. Most often the system of pitch classes has a strong internal organization based on tonal relations expressed in musical intervals [19]. **Musical chromas** are pitch classes whose central frequencies belong to a generally recognized musical system of tuning [3, 5].

The subdomain of **pitch distance**, though basically different from that of pitch value, has an identical internal structure. It is divided into two parts: an uncategorized continuum of **natural pitch distance** and a strictly categorized **system of within-octave musical intervals**. These two sensations create together the most important part of the music-information-transmission code (see Fig. 1).

The system of musical intervals offers an excellent example of the universal character of laws that govern human sensory information exchange. It is also that part of a complex musical code which most truly mirrors the basic structure of natural language. Musical within-octave intervals, like phonemes of language, are limited in number and follow all the rules of categorical perception in restricted meaning of that word. Categorical perception occurs in the categorized

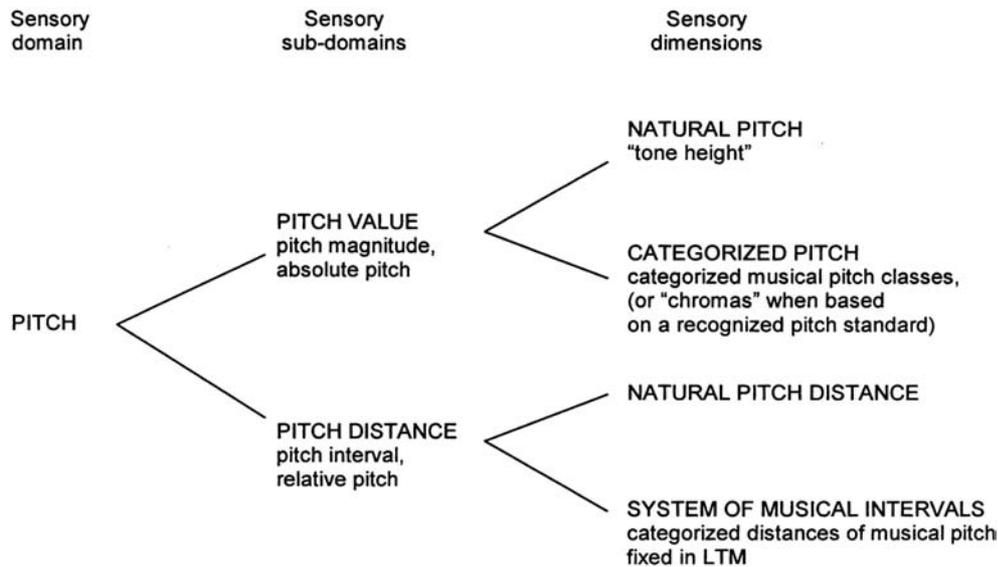


Fig. 1. Sensory domain of pitch in music and its division.

medium when just noticeable difference (jnd) measured exactly at the border between two neighbouring categories appears smaller than jnd within a single category [8, 20, 35]. Musical intervals reveal also great similarity to phonemes in developing the within-category intonation variants, functionally similar to allophones [27, 41].

3. Memory for the pitch value

3.1. Memory for natural pitch value

Long-term auditory memory for natural pitch more or less closely follows the rules described by GEORGE MILLER [21] in his well-known paper about the magical number seven. In this paper Miller described the results of experiments by several authors concerning the capacity of long-term memory to remember and accurately recognize the intensities of various uni-dimensional sensations, like brightness of light, loudness or pitch of sound etc. The actual experiment with pitch memory described in Miller's paper was done by POLLACK [25], who found that the number of pitch magnitudes (values), unmistakably recognized by human subjects in a nearly full audible-frequency range (100–10000 Hz) is only five. No matter how strange that finding may seem, we should bear in mind that musicians often make mistakes in pitch identification that consists in assigning a pitch chroma to a wrong octave. Choosing the proper position for a given chroma on a row of musical octaves means operating on a scale of natural pitch divided in "artificial" for that dimension, octave-wide regions. The

distribution of these regions on a scale of natural pitch is narrower than the distribution of natural pitch categories which can be permanently stored in the LTM [24]. So, as a result of such “context coding” [11], the memory for octaves is not perfect.

Just the opposite to how strongly limited is the long-term memory (LTM) for natural pitch, the accuracy of short term memory (STM) for natural pitch in very short time intervals seems really perfect (“trace coding” [11]). It may be best estimated in experiments conducted to determine the just-noticeable frequency difference (difference limen for frequency). In such experiments listeners usually have to compare two short tones differing in frequency and decide which of them is higher in pitch. The two tones to be compared are presented one after another with a very short break (usually about 500 ms). During that break the STM for pitch must keep the pitch sensation of the first tone with possibly highest accuracy to enable the comparison of both pitches (more precisely: both pitch values). The accuracy of STM for pitch may be estimated by the size of frequency jnd which at 500–3000 Hz is as low as 3 cents or 3 hundredth parts of a semitone (see Fig. 2 adapted from RAKOWSKI and MIŚKIEWICZ [38]).

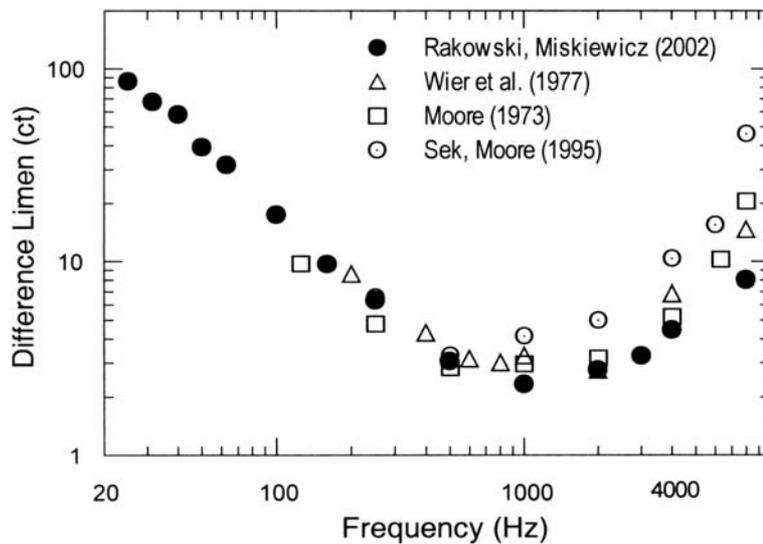


Fig. 2. Frequency difference limen (or just noticeable differences) for pure tones, according to various authors. Adapted from RAKOWSKI, MIŚKIEWICZ [37]⁽¹⁾, as well as WIER *et al.* [50], MOORE [24], and SEK, MOORE’S [43] data.

The STM for pitch slowly degrades in time [9] and up to about 2, or sometimes even to 3 minutes, its accuracy is sufficient to recognize or to reproduce a given

⁽¹⁾ The results shown in Fig. 2 were obtained using similar procedure (adaptive, 2I, 2AFC), as that of WIER *et al.* [50]. Rakowski and Miśkiewicz’s subjects were students of musical engineering. Frequency DLs in very low pure tones were in 2002 first published.

pitch class or, in other words: to stay more or less within the range of a given semitone [30, 31]. This is a fact of greatest importance for musical perception and activity.

3.2. Memory for the values of categorized pitch. “Absolute pitch”

As has been said before, the short-term memory for pitch fades relatively slowly. In musicians not using fixed-tuning musical instruments (e.g. in singing) the STM for pitch supports the continuous existence of the currently active system of pitch classes. This currently active system had developed in the auditory imagination just before singing had begun, due to the “anchor pitch” supplied from outside (e.g. from striking a tuning fork, or from auditory imagination), and to immediate appearance of musical intervals drawn from LTM, displayed in relation to the anchor pitch. If the tuning fork had not been used at all, or used not frequently enough, singing might not have any relation to standards of the recognized tuning system. In most cases such a fact will pass unnoticed, unless some of the singers or listeners possess absolute pitch.

Absolute pitch (AP) means the ability of some people of storing in their long-term auditory memory the pitch values of musical chromas [3, 5], i.e. octave multiplied pitch classes based on the recognized pitch standard with frequency $A_4 = 440$ Hz. This ability may concern all 12 musical chromas (**full AP**) or only one or a few chromas (**partial AP**). AP may be **active** (can identify and produce desired pitch) or **passive** (can only identify). Possession of AP seems to be very rare in Europe and America [23], but appears much more frequently in Asiatic Countries [10, 39].

4. Memory for the pitch distance

4.1. Memory for natural pitch distance

ATTNEAVE and OLSON [2] performed a particularly informative experiment on transposition of melodic musical intervals between various frequency ranges. Subjects were three musicians (including two professional musicians) and three subjects with normal hearing, but totally deprived of any musical knowledge or practice. Subjects listened to a short rhythmic pattern composed of interchangeably appearing two pure tones. Each of the tones appeared in this pattern three times and their sequences presented repetitions of a given interval. In all randomly distributed tasks, this interval had 12 different magnitudes corresponding to 12 within-octave, equally-tempered musical intervals. Twelve rhythmic patterns demonstrating all 12 within-octave melodic intervals were presented to the subjects in 7 octave-wide frequency regions, from 92.5 Hz to 11840 Hz. The total number of standard patterns presented randomly to each subject was then $7 \times 12 = 84$ and was repeated 8 times.

Immediately after having heard the standard pattern the subject heard the same rhythmic pattern where in place of previously sounding melodic interval was only one tone which had to be taken as a new base (one of the two tones of the transposed standard interval). The response pattern was always located in a frequency region from about 1000 Hz to about 2000 Hz, and also, the transposed musical interval was never in any octave (or multi-octave) relation to its standard stimulus. The subject's task in each case was to create a transposition of the standard pattern to transfer a given interval from one of seven frequency regions into the response pitch region, by tuning the missing "second tone" of the response pattern. This was done by manual tuning of an electronic oscillator initially set at extremely high or extremely low frequencies. The tuning performed by the subject automatically changed the pitch of the "second tone" in all its appearances within the response pattern. While adjusting the response pattern to obtain the impression of equal intervals (equal pitch distances) in both patterns the subject was always free to switch back to the standard pattern. The results of the experiment were shown by Attneave and Olson in a form of transposition curves separately for each of the 6 subjects. Transposition curves were designed to show deviations from the exact transposition of each of 12 musical intervals through more or less large pitch distance to always the same response region of 1–2 kHz.

In Fig. 3, adopted from ATTNEAVE and OLSON [2] some, most important features of the results obtained by these authors are shown. The figure presents part of the data of two subjects, a professional musician (JF) and a listener with normal hearing but without any musical competence (SD). The transposition curves presented in Fig. 3 show only halves of each subjects' results (only the intervals with even numbers of semitones). Nevertheless they represent well all the data, both for the complete sets of transposition curves, and for two groups of subjects ("musical" and "non musical"). The frequency scale at the bottom of the sets of curves needs special explanation. The subsequent frequencies "C" mean central points of 7 octave-wide pitch regions where the standard melodic patterns were located to be transposed.

Numbers on the vertical axes of the figure represent musical intervals (here only intervals with even number of semitones: major second (2), major third (4), tritone (6), major sixth (8), minor seventh (10), and pure octave (12). Perfect transposition of a given interval from all seven frequency ranges (from C3 to C9) to the medium frequency range would have been shown by a straight horizontal line starting at that interval's position on the left vertical axis and running horizontally across all the figure. All deviations from such ideal performance may be interpreted as a distortion occurring at transpositions from various frequency ranges to the medium frequency range. Their amount may be estimated by the distances created between the actual shape of a given interval's transposition curve and the virtual straight line of that interval's ideal transpositions.

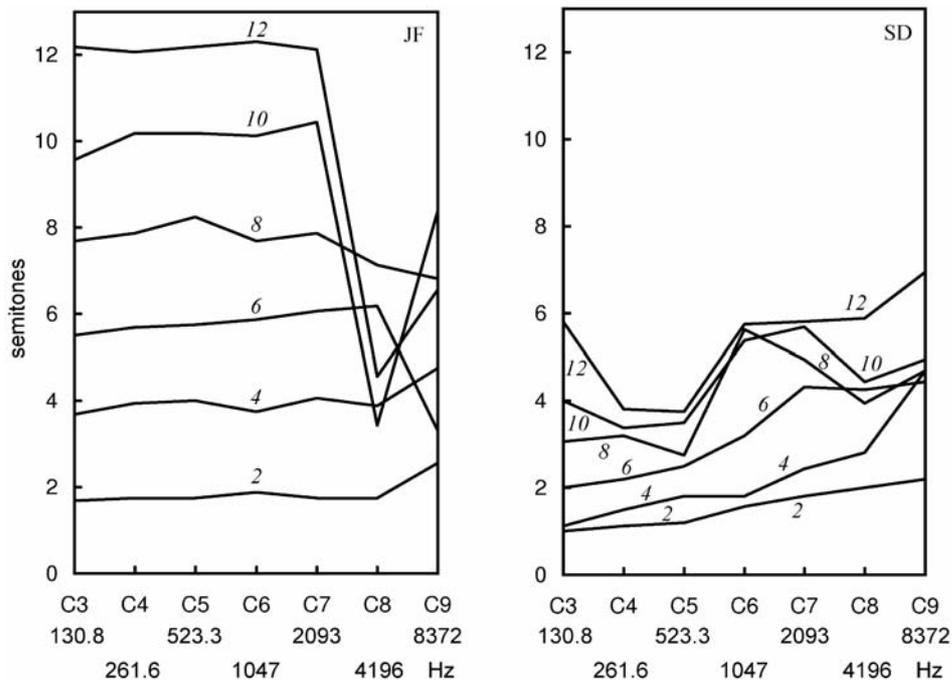


Fig. 3. “Transposition functions” obtained in transposing pure-tone melodic intervals from 7 within-octave frequency regions (their central points are shown as a horizontal “scale”) to always the same frequency region C6-C7, excluding any octave relations. The graphs are adapted from ATTNEAVE and OLSON [2] with data reduction. Only intervals with even number of semitones and their transposition functions are shown. The performance of a musically educated (JF) and non-educated (CD) subject is shown in two graphs.

The transposition curves have shown fundamental differences between the results of “musical” and “non-musical” subjects. Musicians, and particularly those two, who due to professional ear training had templates for single melodic intervals labelled and stored in their long-term memory, scored quite well or nearly perfect in transposing all 12 musical intervals across all pitch distances, except for transposing large intervals from frequency regions ranging over 4 kHz, where the pitch strength of tones is usually significantly diminished. That result might have been expected as a possible effect of using by the subjects a three-step technique:

1. Recognition of a given musical interval by matching the perceived sound pattern to a set of templates of musical intervals stored in the long-term memory.
2. Preserving the label names of that interval in the verbal memory, and
3. Implementing the given melodic interval into a new pitch material by using
 - a) a new pitch of the base tone (an anchor) supplied from outside, and
 - b) a permanently memorized template of that transposed musical interval.

Far more interesting than the results obtained by thoroughly educated musician (Fig. 3, JF) appeared those obtained by a subject with physiologically normal hearing, however not having any templates for single musical intervals fixed in his long-term auditory memory (Fig. 3, SD). That subject, as well as two other “non musicians” investigated by Attneave and Olson, appeared nearly helpless in his endeavours to reconstruct standard intervals in a new pitch environment. The only consistency that might be traced in his transposition curves was in preserving to some degree the order of the intervals’ magnitudes, and also more or less correctly preserving in transposition the magnitude of a minor second (not shown in Fig. 3). All other intervals were significantly diminished, and even the interval of an octave was often reproduced as a sixth and in some cases even as a third. Interpretation of those results leads to following conclusions:

1. Nothing like accurate short-term memory for natural pitch distance seems to exist (e.g. similar to STM for natural pitch value).
2. Exact transpositions of single intervals cannot be performed by subjects who do not possess in their long-term memory templates and labels corresponding to those single intervals. (Labels are indispensable for the effective use of verbal memory).
3. It might be assumed (though requires experimental verification) that, when such LTM standards are missing, the sensory dimension “natural pitch distance” submits to the rules typical of other “natural” sensations and may be permanently memorized according to these rules. E.g. it may be memorized, in several natural categories or steps of magnitude (maybe 5 or 6) from “very small” to “extremely large”.

Probably, what actually happened was the following: all within-octave musical intervals presented to non-musical subjects appeared to them as belonging to the same natural pitch-distance category of “small” or “very small”. In such a case, while restructuring the perceived interval in transposition, the only thing they could do was to try not to step out of that natural category, e.g. rather diminish than expand the perceived, not very clear sensation of the pitch distance.

Fred Attneave and Richard K. Olson, after having described their influential experiment, discussed it in terms of variability of the data and application of the mel scale to explaining the specific form of results. They did not discuss it from the point of view of the memory phenomena, as it was attempted in the present paper. However, trying to explain the poor results of their non-musical subjects in transpositions of single intervals, and in light of the idea that these subjects nevertheless had some musical abilities, ATTNEAVE and OLSON [2] performed with the non-musicians an additional experiment. Here the task of the subjects was again to transpose a simple melodic element, however, this element was one step more complicated than a single musical interval. Actually, it was composed of two subsequent melodic intervals, so it represented a bit more complex melody than the previous stimulus and could have some musical meaning. Still more: this

simple three-tone melody was already known to all subjects as it was the popular NBC chimes (National Broadcasting Corporation): G3 (196.0 Hz), E4 (329.6 Hz), C4 (261.6 Hz).

The new experiment involved four new subjects selected as not having any knowledge or practice in music, but well acquainted with the NBC chimes. They were first presented with the standard pattern (G3 – E4 – C4) in rhythm and tempo of the original chimes, and then were given a new base tone (an anchor) with an information that it had to replace the first, the second or the third tone of the standard. Knowing the pitch of the base, the subjects had to reconstruct the whole three-tone standard pattern on a new frequency level by tuning two additional tone frequencies. Each subject had to perform such transpositions three times to 14 different frequency levels in a random sequence. This time the result of transpositions by non-musical subjects was completely different from those of transposing by such subjects single musical intervals, and was very similar to the results obtained by professional musicians in the previous experiment.

To explain such result it should be noted that here, in a limited part of musical material (a two-interval structure), pitch distances adopted the strict categorized form and thus were submitted to the rules governing such forms. And one of the first rules for the categorized pitch structures (melodies) is their acceptability for transpositions.

Here another remark should be made. The non-musical subjects who were unable to remember and transpose single musical intervals but could remember and transpose these intervals as soon as they were connected in a short two-interval melody, were probably not so “unmusical” as it was suggested. Even if they had never participated in any musical activity, they were surrounded by music with its system of interval categories and were prepared to enter into this system, e.g. in its simplest, two-interval form. Also, it may be assumed that some of them were already acquainted with more complicated interval structures, like songs, and probably in a properly designed experiment could demonstrate a natural ability for transposing parts of these songs. Anyway, our everyday acoustic environment makes us prepared to perceive the relative-pitch phenomena both in a form of natural pitch distances and in a categorized form of musical intervals.

4.2. Memory for musical intervals

As it was mentioned earlier, the system of musical intervals is the most important part of the communication code of music. This is due to a very important psycho-physiological phenomenon: selected magnitudes of pitch distance may be learned and permanently stored in long-term auditory memory. In most (not all; [12]) musical cultures of the world the “selected magnitudes of pitch distance” or, simply musical intervals have taken the shapes corresponding to frequency ratios between the lower, resolved by ear harmonic components of a typical sound

of music – harmonic complex tone. In “the natural interval system”, sometimes being used for tuning historical instruments, they still preserve exactly their pure, natural forms 2:1 (an octave), 3:2 (a fifth), 4:3 (a fourth), 5:4 (a major third) etc. In now generally adopted system of equal temperament (dividing an octave into twelve equal semitone intervals) the “pure” musical intervals appeared slightly diminished or augmented (between 2 and exceptionally about 20 cents). Nevertheless, in spite of the reserve of conservative musicologists, the equal temperament became easily accepted by musicians and general public.

The exact conformity of “natural” musical intervals with the relations between harmonic components of typical musical sounds was considered by music theoreticians for many decades as a fact of greatest importance. HELMHOLTZ [16] described this coincidence as a gift of nature offering humanity a model of tonal system included in the structure of a single musical complex tone. Not only hundred years ago but nearly to the last decades of 20th century most of music theoreticians and musicologists of the world believed that the essence and purity of music depends on preserving exact “natural” frequency ratios while singing or playing the instruments with free intonation, like violin or cello. They were convinced that the equally-tempered system of tuning, very convenient due to the ease of performing all kinds of musical transpositions used for tuning pianos or organs, distorts the naturalness of music.

Surprisingly slowly and only in the last decades the real facts about the intonation of musical intervals became known to musicians and musicologists. When new technical devices made the measurements of intonation in musical performances possible, it appeared, that in playing violin [13–15], in singing [48], or in free tuning by musicians of isolated melodic intervals [26, 27, 37], musical intervals significantly differ both from their natural and from equally tempered values, following the autonomic rules of musical expression.

The present view on the functioning of musical intervals within the communication-code of music shows many similarities between them and the elements of the language code. Basic similarities of musical intervals to the phonemes of language concerns their limited number, their categorized structure, their categorical perception [8], and the rule of permutations used in formation of higher-order structures. To these basic similarities, another one may now be added. Intonation of musical intervals in real production of music, while singing or playing free-tuned instruments, requires slight changes of their magnitudes imposed by musical context and used mostly to increase harmonic tensions within the melodies. The changes, mentioned above, are larger than the differences between “equally-tempered” and “pure” forms of the intervals concerned. These variations of interval magnitudes have been now called “**intonation variants**” [28, 29]. Their regular character is in many aspects similar to the form and function of speech allophones.

An example of zones of intonation produced by three renown violinists during solo performances is shown in Fig. 3. The width of each zone represents the

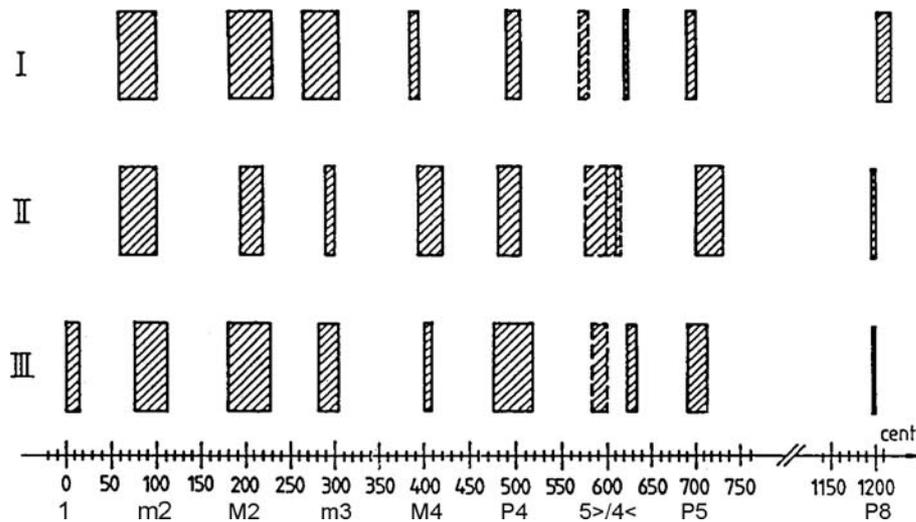


Fig. 4. "Zones of intonation" in violin performance of "Air on G string" (Bach-Wilhelmi) by three renowned violinists, Zimbalist (I), Elman (II) and Jakowicz (III). Width of the zones corresponds to differences between the largest and the smallest size of a given melodic interval used during the recorded performance [36]. The intervals investigated were a prime (1), minor and major seconds (m2, M2), minor and major third (m3, M3), pure fourth and fifth (P4, P5), and a tritone ($5 > /4 <$).

distance in cents between the smallest and the largest size of a given interval produced in various parts of the composition. As can be seen in the figure the largest zones are of the order of 40 cents, more than the differences between various systems of tuning. A more detailed analysis would show that extreme changes of interval values are not incidental, but related to harmonic tensions of music and their emotional expression. They may also show the individual character of performance by various artists.

5. Psychological scaling of pitch

The inadequacy of American National Standard Institute's definition of pitch [1] has been noticed already by several psychoacousticians. This definition states that pitch is "that attribute of auditory sensation in terms of which sounds may be ordered on a scale extending from low to high". According to HOUTSMA ([17], p. 476), such definition "does indeed capture the ordinal properties of pitch sensations, but fails to capture its apparent ratio properties that are well known to musicians". Therefore Houtsma for his experiments redefined pitch as "an auditory sensation attribute that allows to recognize a melody in a sequence of sounds". That definition, perhaps as well as many others, fits well the general concept of pitch as a complex auditory phenomenon proposed in the present paper.

There is however, one serious problem that to some degree contradicts presenting pitch value and pitch distance as two equal-level subdomains of the pitch phenomenon. This problem concerns the generally accepted proposal of S. S. Stevens and his colleagues of dividing perceptual continua in two classes, prothetic and metathetic, differently accessible to psychological scaling [44–47]. According to STEVENS and GALANTER ([47], p. 377) *prothetic scales* (the term after the Greek word “to add”) concern such continua for which the increase of sensation magnitude is based on introducing some new excitation which is *added* to already existing one. Situation like that occurs in sensory magnitudes like heaviness, brightness, loudness etc.⁽²⁾ *Metathetic scales* (the term derives from the Greek word meaning “to change or to substitute”) concern such continua “for which discrimination behaves as though based on a substitutive mechanism at the physiological level”. According to STEVENS and GALANTER [47] this includes the geometric position of an object and e.g., the sensation of pitch. Basically, such phenomena do not qualify to scaling at all.

The above view concerning pitch is easy to justify while looking at the piano keyboard and hearing distinct musical pitches produced with pressing variously positioned keys. However, while we accept the notion of the pitch as a complex auditory domain, we must admit, that Stevens’ concept recognizing pitch as a metathetic continuum, if at all, may concern only one of the pitch sensations, namely that of categorized pitch. There are several hints (also those based on Stevens’ experiments) showing that scaling of natural, uncategorized pitch value may give unbiased and repeatable results, when processed using the methods that were verified by scaling loudness and other prothetic continua [33]. Further research in that direction is currently in progress [22].

6. Discussion

The newly proposed classification of pitch sensations is primarily referred to their appearance in music, however it seems useful also in describing pitch perception and pitch memory at various auditory phenomena. The aim of this discussion, separating various kinds of pitch as “distinct sensations”, is mostly practical, and the described phenomena are generally well known. The present debate does not refer to psycho-physiological, still unresolved problems of hearing, like the conditions for the existence of residue pitch [18, 42, 49] or the frequency range for chromas [4, 7].

It refers mostly to pitch as it occurs and is memorized in everyday life.

⁽²⁾ In last two sentences the word „magnitude” has been used twice in two different meanings. In both cases it contrasted to larger or smaller degree with the word “value” used while speaking of the pitch value.

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