PROFESSIONAL
ACOUSTICS

PRZESTRZENIE AKUSTYKI

PROFESSIONAL ACOUSTICS

2

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Introduction

We are delighted to present Volume Two of *Przestrzenie akustyki (Professional Acoustics)* as a continuation of our publishing series exploring musical acoustics and sound design. This new volume features several key changes, including an English-only format and a free open-access version available for online download with the paper edition. The internal and external design of the book has been improved to make it even more accessible to readers, both in Poland and internationally.

This year we are honoured to present a multi-author monograph, entitled *Przestrzenie akustyki 2 (Professional Acoustics 2)*. It varies considerably compared to volume I in that it is published in English – the language of the Congress. Importantly, it has not been translated from Polish, but written by all artists and scientists in English, to avoid errors in translation which may appear in the professional literature. It is of great scientific significance, as Poles' accomplishments can be noticed outside Poland, which is particularly important in the process of the internationalisation of science and art. This publication helps them to go hand-in-hand and be complementary to each other.

The multi-author monograph, entitled *Przestrzenie akustyki 2 (Professional Acoustics 2)*, is devoted to various areas and disciplines of science and art, where the issue of sound in a non-uniform acoustic space appears. The space, in this case, is not understood as a mathematical-physical object, nor is it strictly physical acoustics, but it is humanistic – based on various sources, values, studies, inspirations and interpretations.

The general idea behind the *Przestrzenie akustyki 2* is to present the scientific work of both people who deal with acoustics in their professional capacity as well as those who experience it on various levels of scientific cognition. Subjective experiences (individual and immeasurable), e.g. of musicians performing in various halls, and objective experiences (general and measurable), e.g. sound directors, sound engineers, acoustics, who arrange sound systems, record concerts or design studio and concert equipment or construct concert halls or recording studios, are increasingly often regarded in the same manner, as equally important. Hence, a fast-developing sub-discipline of acoustics – *psychoacoustics* – has originated.

The phenomenon of space is constantly defined in different ways, depending on the approach by artists or scientists to its understanding. It is noteworthy that there are multiple approaches concerning space from the artistic, mathematical and physical, medical and philosophical perspectives. Moreover, there are rather distant interpretations of space even within one discipline of science, e.g. art, in which an instrumentalist who is an orchestra musician, and the orchestra conductor, understand space in two completely different ways. The aspect of space in the musician's work is not uniform, and it cannot be described in one way, typical to all. Differences in interpretation and the various factors affecting how this term is understood have made scientists reflect on it, and their considerations have provided the foundations for this scientific monograph.

Przestrzenie akustyki 2 is not a random title because – as was written above – it points to various and interdisciplinary issues taken up in research work. On the other hand, the English title, *Professional Acoustics 2*, is not the direct translation of the volume title but rather a guideline for a foreign-language reader that the research taken up here concerns acoustics in a broad sense of the term, and it is important from the perspective of scientists and artists working in various areas and disciplines of science and art. A problem with the title translation is caused by translational difficulties. This is because it cannot be translated directly into English, as it has only the equivalent of the Polish term *spatial acoustics*. The direct translation of *przestrzenie akustyki 2* could be incomprehensible or misleading by implying that the volume consists of chapters on architectural, urban acoustics or psychoacoustics, which is why it was decided to keep the English language title: *Professional Acoustics 2*. Incidentally, the term *spatial acoustics* is much narrower, and it concerns studies of sound location on the right or left side of the listener; hence this title of the monograph would not convey the sense of considerations presented in it.

The monograph opens with the text written by Maciej Lange, entitled *Sonoristics as an acoustical element in percussion music on examples of selected works of Marian Borkowski, Alicja Gronau and Paweł Kwapiński*. It was written from the perspective of a percussionist, who – as a performer – focuses on sonorism, which harmonises with acoustics and is an element of it. The author presents: techniques of composition; the performing possibilities for this kind of music; advanced sound technologies, and the accessories used, which are all very important for creating a suitable acoustic layer for a piece of music.

The text also provides statements of composers, which are intended to help performers substantially to understand the author's purpose during the process of composing and how a piece of music should sound in an acoustic space – which is particularly noteworthy.

In other considerations by Paulina Wojciuk, who takes up the subject of *Acoustic Mediation in Parrots*, she describes how this area is important for communication between a human and a parrot and between two parrots. The language, incomprehensible to people in general, is analysed in depth by the researcher, who – owing to her experiments – points out that despite individual differences, there are certain intra-species correlations which should be analysed and explored. This text shows how necessary good acoustic conditions are in the communication of various creatures and that parrots have a specific way of communication, which is being explored by humans.

In their text entitled, *Computer Applications for Popular Music Composers in Creative Work and Teaching*, Milena Waśkiewicz and Adam Rosiński point out that digital technologies are increasingly often used in classes at universities. The authors refer to the sound of virtual instruments emitted by loudspeakers to the acoustic field made by a traditional instrument, while at the same time showing how much remains to be done with respect to sound engineering, as both acoustic fields are not even close to each other, but only an element responsible for the simulation of individual instrument sounds. The results of a survey among popular music composers show the direction which should be followed by contemporary music.

As a music theoretician, Katarzyna Szymańska-Stułka analyses *The Space of Cultural Communication in the Perspective of the New Humanities*. The research considers a piece of work as an object of cognition, which allows her to analyse the existing and adopted theories or schemes from a new perspective. The new humanities is purposefully a form of invasive intervention as opposed to the neutral and objective view of the world. Owing to a different approach, pieces of work known earlier can be rediscovered, and, most importantly, it is achievable to push the limits of cognition, which can be of great importance in various analyses, even acoustic ones.

The history of phonography is dealt with by Krzysztof D. Szatrawski, whose text *Fixing Music: Aesthetic and Cultural Background of Recording Technologies Development* is about inventing the first sound recording devices. Subsequent transformation and development bring technical improvements in the construction of new and better sound playing devices, which, with time, become affordable to people of different social classes. In his considerations, the researcher describes the most important moments in history with the greatest impact on phonography and phonograms. This revolution continues, with a phonogram, in this case being a digital file, uploaded to an internet server, which can be downloaded at any time from nearly every place in the world.

In his work entitled *Influence of Music Education and Pitch Scales on the Grouping of The Ab-Ab Sequence Sound*, Adam Rosiński describes experiments conducted on groups of musicians and non-musicians concerning the impact of the sound scale height on the integration of the perfect fifth interval into one perceptive stream. The results show that both experimental groups differ. This should not be omitted in psychoacoustic experiments, which when qualifying the subjects, in addition to noting whether the hearing is otologically normal, should also include a questionnaire with information on whether the subjects have a musical background or training, or to what extent their musical background may influence the results of the psychoacoustic experiments involving auditory scene analysis in the context of perceptual streaming.

The experiments conducted by Tomira Rogala, Joanna Szczepańska-Antosik, Andrzej Miśkiewicz, Jan Żera, and Jacek Majer, who, as a study team, examined the auditory abilities of musicians and individuals with no musical qualifications concerning the identification of ambient sounds in recordings of natural auditory scenes, can be found in the paper entitled *Identification of Environmental Sounds: Auditory Abilities of Musicians and Non-Musicians*. According to the results, the differences between the groups are small and statistically non-significant, which is contrary to literature reports on the effect of the augmentation of musicians' auditory abilities. Moreover, the response time did not depend on whether the principal sound was consistent with the auditory scene played in the background.

The scientific paper entitled *Anatomy and Physiology of the Voice Organ in Computed Tomography in the Executive Context*, by Hanna Zajączkiewicz, Zdzisław Madej and Anna Żurada presents a combination of various and totally different areas of art and science, which overlap and make up a new research quality. The new area includes laryngology, proper imaging of sound emission organs and its medical description with computer tomography and singing, which is the most important from the musical perspective. By intertwining and complementing each other, these issues show that certain acoustic problems, which can be measured externally, can also be imaged inside the human body. This study pushes common patterns, showing new capabilities of diagnostics and studying elements related directly to music and sound production.

The second volume of Professional Acoustics contains chapters written by thirteen authors representing the following higher education institutions: Stanisław Moniuszko Academy of Music in Gdańsk, six researchers of the University of Warmia and Mazury in Olsztyn, five scientists of the Chopin University of Music in Warsaw, Warsaw University of Technology, and the Krzysztof Penderecki Academy of Music in Kraków. This shows that the number of authors and readers of *Przestrzenie akustyki (Professional Acoustics)* is growing, at the same time extending its reach, which is very satisfying and shows that it is worthwhile to prepare a multi-author monograph whose second volume discusses increasingly important issues of science and art.

The considerations presented in this volume indicate that researchers from around Poland are exploring this area in various and often different aspects, showing that it is topical, interesting and undiscovered to many scientists, which is why the reader will find here texts written by specialists in various areas, often wide apart. A combination of art and science and further research of the area is important for exploration and understanding of its elements affecting 21st-century society.

Adam Rosiński

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Sonoristics as an Acoustical Element in Percussion Music on Examples of Selected Works of Marian Borkowski, Alicja Gronau and Paweł Kwapiński

Sonoristics as a vast aspect of music provides us with tools and possibilities to employ various means of expression. In this case the final tone of the piece is essential. Sonoristics is a field open to creativity and individualism both of the composer and of the performer, which motivates to search for new means of expression that can enrich the piece. These notions accompanied various composers, those in particular that were looking for new, custom sounds. What is particularly noticeable is them being open for unconventional ideas, creativity of the composer and aspects that exceed beyond the matter of sound as the most important in the musical piece. What is important in this case is the role of non-musical expression elements such as lightning, gesturing (described at length by composers themselves) that affect the quality and attractiveness of the piece. Composers employ unseen before methods that expand beyond the use of instruments as we know it. This way of thinking and working shows us that music is not contained in strictly defined forms, but can be open to freedom and avant garde. It also happens that composers use the human voice, which is not perceived as an independent instrument, but its presence enriches the musical material and diversifies the piece.

Although sonoristic[1] composing methods are undoubtedly tied to music of the XX century, some of their elements came to life much earlier. Besides

1 *Sonore, sonoramente* – (it.) sonically, sounding; also in the meaning: with full sound, full voice, A. Chodkowski (ed.), *Encyklopedia muzyki*, PWM, Warszawa 2006, p. 829.

Iwona Lindstedt[2] we could look at the breakthrough of the XVI and XVII age, when voices for each instrument were strictly described in music scores. It is also worth noting the achievements of the Mannheim school in the XVII age that pushed toward individualisation of each instrumental section in an orchestra.

In XX age music a tendency to search for new solutions regarding timbre is noticeable, which leads to emphasizing the sound element as the dominant part of the musical piece. All that leads then to an attempt of defining a new musical aesthetic[3].

In polish music directions of such kind were noticed as early as second half of the XX age, and the first one to document it was Józef Chomiński, who by coining the term "sonoristics" tried to do it so that it would fit also into the context of previous musical eras.

Chomiński[4] considered that all musical eras were characterized by various changes in the range of styles, directions, technical norms of the composers techniques as in their mutual interferences. Regardless of all that it is the sound that is the common denominator between the XX age and previous music eras. The sonoristical aspect (freely developed on vertical and horizontal plane) of the musical piece that became visible only in XX age, gaining the rank of a composer's rule, focusing on the external structure of the piece.

The result of those actions was bringing more attention to musical structure factors such as: piece chording (building chords by the quarts or development of the functions system); scale plane of the piece (pentatonic scales, heptatonic); change in perception of the tonal foundation of the piece. Such concepts as poliharmony, bitonality, polytonality, chord section or linearism emerged, being an important methodical aspect[5].

The term "sonoristics" also relates to composers' work and replaces the phrase "tonal coloristics[6]". It does in fact relate to the context of tonal color, which has three indispensable features: pitch, loudness and color, which have to exist so that the tonal color can come to life[7].

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2 I. Lindstedt, *Sonorystyka w twórczości kompozytorów polskich XX wieku,* Uniwersytet Warszawski, Warszawa 2010, pp. 27, 28.

3 Cf. H. Kostrzewska, *Sonorystyka*, Akademia Muzyczna im. I.J. Paderewskiego w Poznaniu, Poznań 2009.

4 J.M. Chomiński, *Z zagadnień techniki kompozytorskiej XX wieku*, "Muzyka" 1956, no. 3, p. 26.

5 Ibidem, pp. 26, 27.

6 Cf. W. Malinowski, *Problem sonorystyki w „Mitach" Karola Szymanowskiego*, "Muzyka" 1957, no. 4, p. 31.

7 I. Linstedt, op. cit., p. 17.

The concept of sonoristics was mostly specified by distinction of five basic workshop categories, brought by Chomiński[8]. Those categories are:

1. Sound technology category that concerns types of sound generators, articulation, dynamics, volume and penetration capability of sound.
2. Time regulation category that concerns metrum, rhythm, monochromy and polichromy.
3. Horizontal and vertical structures that exist in the context of melodic and harmonic factors transformation, clusters, roles of intensive conosances, homogenic and polygenic sounds and the subjects of synchronicity in vertical structures.
4. Transformation of sound category that concerns transmutation and transformation processes, and structural dominants.
5. Form problematics analyzed in the context of traditional systems, topofonic and aleatoric.

New sonoristic values in a piece are dependent on delivery methods that gain on meaning, thus implicating a much bigger weight of such concepts as: vocal and instrumental facture, registers, articulation, tone volume, dynamics, rhythmics, agogics, harmonics or melodics[9]. Because of that the timbre of sound comes to light and becomes what dominates over other elements of the piece. "Counterpoint and harmony rule ceases to act, which weakens the act of melodic and harmonic factor[10]".

In polish music, listed tendencies started to show up as early as in the sixties. Especially in the works of Krzysztof Penderecki[11]. Among modern composers Norbert Kuźniak is worth noting, where coexistence of sonoristics and colorful delivery is very visible[12].

Grażyna Pstrokońska-Nawratil works have a very various character. Composer uses sonoristic ways of avant garde root[13].

Eugeniusz Knapik who is considered a very talented composer of the new generation paints a slightly different picture. In his article, Krzysztof Baculewski writes that Knapik created his own style that fused the workshop-aesthetics

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8 J. Chomiński, *Muzyka Polski Ludowej*, PWN, Warszawa 1968, p. 128.

9 I. Lindstedt, op. cit., p. 31.

10 K. Baculewski, *Polska twórczość kompozytorska 1945–1984*, PWM, Kraków 1987, p. 203.

11 J. Pacewicz, *Sonoryzm*, in: M. Podhajski (ed.), *Kompozytorzy polscy 1918–2000*, vol. 1, Wydawnictwo Akademii Muzycznej im. Fryderyka Chopina w Warszawie/Akademii Muzycznej im. Stanisława Moniuszki w Gdańsku, Warszawa-Gdańsk, 2005, p. 270.

12 K. Baculewski, *In statu nascendi. O muzyce nowej generacji kompozytorów*, "Ruch Muzyczny" 1984, no 8, p. 3.

13 Ibidem, p. 4.

ways of thinking with retrospective look at the history of music. Whereas in his work he resigns of sonoristic effects. Precise noting of his cores are clean and unambiguous because of that[14].

Aleksander Lasoń works look similar. Sonoristic effects are almost non-existent, in lieu of what a trend for precision and unambiguousness of the piece[15].

Krzysztof Baculewski on the other hand uses various sonoristic effects in his works[16]. A couple of examples provided above proves that modern composers have a big interest in both using sonoristics as well as not.

Tone technology in the context of percussion instruments is tied to the sound generator, dynamics, articulation, as well as the volume and penetration capability of sound. We can highlight two basic tone generators categories: traditional – into which we have to include musical instruments and voices generated by people, and electronical that evolved tremendously in the past years. The technique of tone is influenced by the selection and ways of managing said generator[17]. It is worth noting that the traditional generators are quite tricky in explaining sonoristics topics. The effects of human voices as well as musical instruments have been mostly analyzed in the light of produced melodic and harmonic structures. Level of their perfection overcame the tonal values of the piece.

Vastness of the articulation means in the percussion pieces to produce specific sonoristic effect is humongous which is the result of using the variety of different sound generators. E.g. in the piece "Spectra" Marian Borkowski uses a wide variety of sticks other than snare sticks, hard timpani sticks or wooden, xylophone sticks (Fig. 1). We can also see usage of metal head sticks, triangle sticks, a big gong stick, tam-tam stick, bells brushes or jazz brush.

Alicjas' Gronau in her piece "Scena" beside using various drumsticks and a metal rod, uses a very popular lately superball. She also notes unusual points of contact like a tensioning screw in conga. The pull membrane of a drum is also used in its extensiveness. Starting at the center hit and ending at hitting the edges. The composer uses small metal plates as well that have to be placed in a precise time at the membrane of a conga. Describes in detail the ways of hands and fingers hitting the instrument, like: "hitting with flat hand, both hands, two fingers, four fingers, or even fingernails" (Fig. 2). Vocal part is a very interesting element of this piece. Human voice is incorporated here as singing,

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14 Ibidem.
15 Ibidem, p. 5.
16 Ibidem.
17 Cf. J. Chomiński, *Muzyka…*, p. 129.

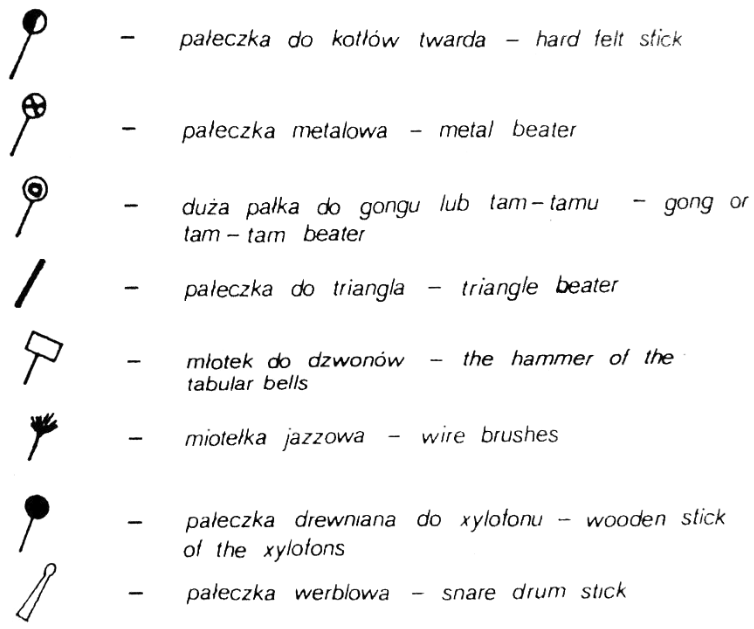

Fig. 1. Fragment of "Spectra" music score by Mariana Borkowskiego
Source: archival materials, shared by composer

whispering and screaming. Besides mormorando there are parts which should be sung in different languages on different pitches or their transpositions – in accordance with the notation. During the whisper performance it is essential for the performer to turn the head in various directions to gain a better spectrum of effects directed at the audience. The most interesting part is the glissando scream that starts at piano and ends at fortissimo, employed while playing the instrument. Piece as a whole has a character of performance with acting elements (such as moving across the stage, slow stage exit while humming the ending phrase).

Paweł Kwapiński on the other hand in his piece "Po drugiej stronie lustra" [On the other side of the mirror] uses sticks with cloth head of medium hardness, orchestral bells sticks, timpani stick of medium hardness and and a thick shaft and a brush (Fig. 3).

Thick shaft of the timpani stick has a very important articulative use in this case because in a given moment of this piece one has to quickly turn the stick and use it to play a glissando across the whole tubular bells scale.

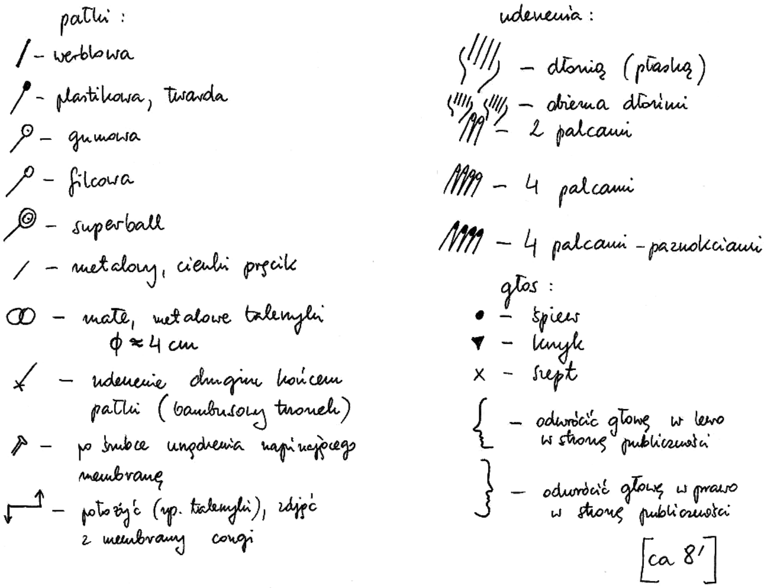

Fig. 2. Fragment of "Scena" music score by Alicji Gronau
Source: archival materials, shared by composer

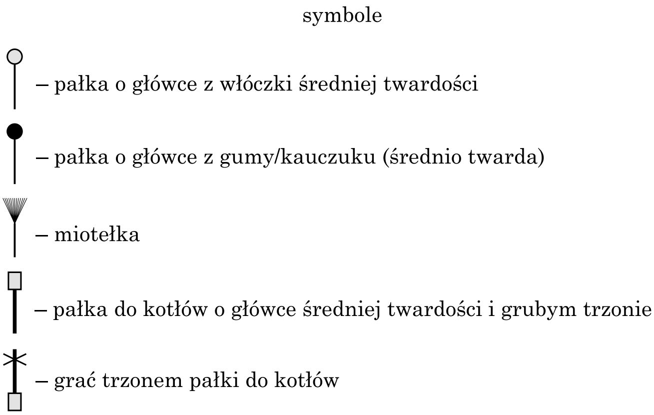

Fig. 3. Fragment of "Po drugiej stronie lustra" music score by Paweł Kwapiński
Source: archival materials, shared by composer

It is very important to note the sounds that appear in the tubular bells part. Composed suggested an unconventional setting of the bells. As seen on the schematics below some tubes have been located in a characteristic, non-standard way (Fig. 4).

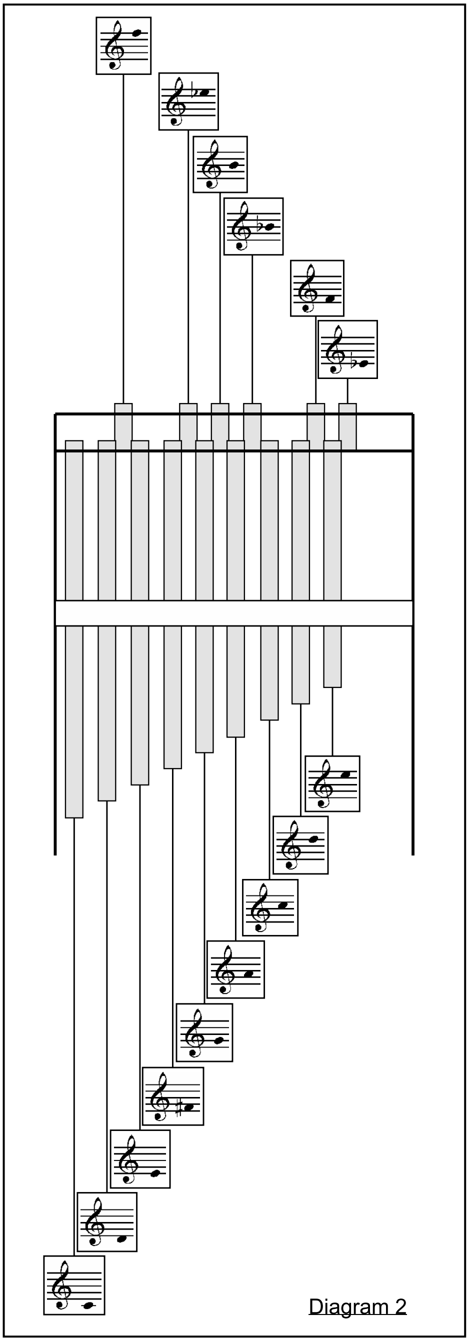

Fig. 4. Fragment of "Po drugiej stronie lustra" music score by Paweł Kwapiński
Source: archival materials, shared by composer

Dividing the melodic instruments into registers in which the performer works is also an interesting solution. Kwapiński points to three zones in the case of vibraphone and bells, and two in the case of tubular bells, which forces us to conclude that the pitch of sound is only proximately defined (Fig. 5).

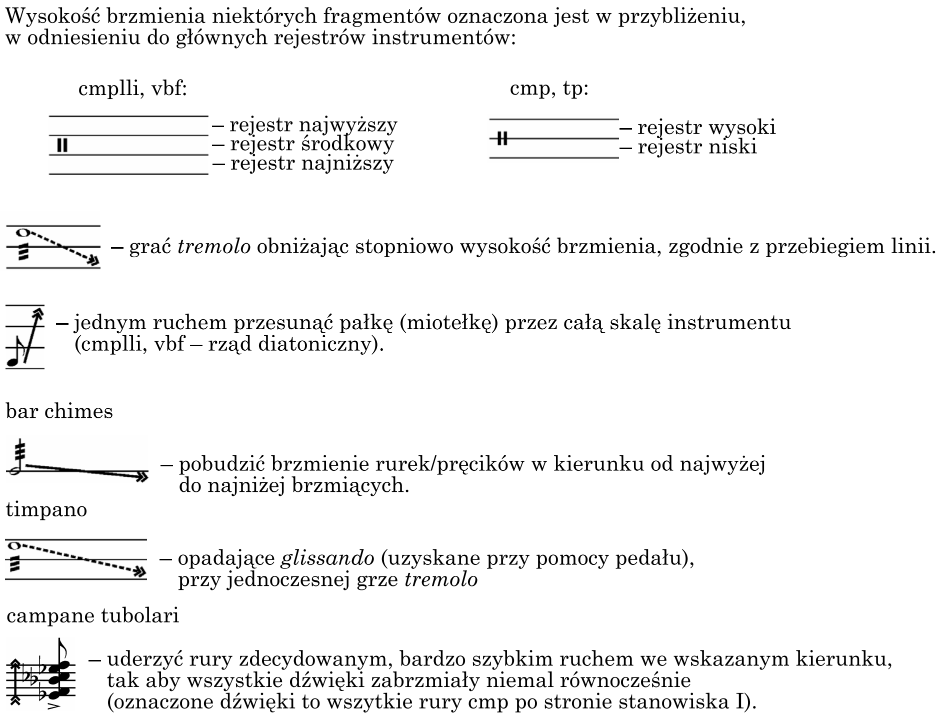

Fig. 5. Fragment of "Po drugiej stronie lustra" music score by Paweł Kwapiński
Source: archival materials, shared by composer

Time regulation category concerns metrum, rhythm, monochromatics and polychromy. Rationalization of time is one of the fundamental procedures in compository musical work that lays a fundament of every piece and its formal construction. By the Józef Chomiński[18] theory the concept of time rationalization that contains the metrical, rhythmic and agogic matters had its special place in the last century. The theorist underlines that "The movement is also, by a big factor, formed by the tone of the piece (...), increase of the movement blurs the precision of the impulses and leads to transformation

[18] Ibidem.

of the rhythmic element into dynamic or color values[19]". These are some of the causes composers pay much attention to respecting time signatures. Because of the variety of many structures, Chomiński divides them into two categories monochronical and polychronic. The first of the mentioned is based on keeping the same, stable time signature regardless of the bar division. Polychronic category is characterized by the diversity and dynamism of time signatures. Marian Borkowski in "Elementy swojego języka muzycznego" [Elements of ones musical language] distinguishes an isochronic (his original system of time division) way of time division, in which he assigned values and pauses to specific time measures, e.g.: 1 quarter note = 1 second, therefore resigning of rhythmical metrum. In Marian Borkowski's "Spectra" and Alicja Gronau "Scena" performer deals with polychronic rule of time regulation. Composers constructed their pieces using second-based calculation of specific piece fragments.

Izochronic rule of time regulation by Marian Borkowski also exists, which is visible in cadence. A whole canence should last between 1 minute and 1 : 30, according to the composer.

Specific segments as parts of the cadence do not have any assigned duration, but in the legend provided by the composer a membership of each rhythm values to the specific tempo is provided.

Another sonoristic workshop category that I would like to address are horizontal and vertical structures that exist in the context of melodic and harmonic factors transformation, clusters, intense consonances, homogenic and polygenic tones, and subjects relating to synchrony in vertical structures. "After the II world war, melodics and harmonics were subject to big transformations, they almost completely lost their primal character and meaning. Because of that it is rather advised to introduce broader concepts: horizontal and vertical structures, rather than using the old nomenclature[20]", even more because with time, in music, sounds started to appear that did not have any influence in shaping melodics and harmonics. Those sounds are generated by the percussion instruments of undefined pitch. Horizontal and vertical structures are formed depending on the tone category. According to Chomiński terminology it's structures that are: homogenous and polygenic. Employment of homogenous horizontal structures works mostly towards bringing the tone of a given solo instrument into the first plan. "Erotyki" [Erotics] by Tadeusz Bird

19 J. Chomiński, *Technika sonorystyczna jako przedmiot systematycznego szkolenia*, "Kwartalnik Instytutu Sztuki PAN" 1961, vol. 6, no. 3, p. 6.

20 Ibidem.

can be used as an example. "Utwory Orkiestrowe op. 10" by Anton Webern can provide an example of horizontal polygenic structures. "It's core is successive employment of various tones generated by various instruments. Interaction of pitched and unpitched sounds is an especially varying factor of modern music[21]". Vertical structures are created because of clearly interacting sounds, where two or more tone plans of defined or non-defined pitch are at play[22]. "As a general rule of thumb the set of phenomenons contained in the vertical structures should be divided into two categories: homogeneous structures that form singular sound plane in the light of sonoristics, and heterogeneous structures that are of selective character, because they are consisted of two or more layers. Structure can be heterogeneous when the set of pitched and unpitched instruments create two different layers[23]".

"Spectra" by Marian Borkowski consists mostly of polygenic horizontal structures. Homogenous vertical structures on the other hand are very rare in this piece. "Scena" by Alicja Gronau is constructed mostly of homogenous horizontal structures. Author leads one, main horizontal line, in which conga is the lead instrument. Sometimes accompanied by the voice of the performer. In "Scena" homogenic horizontal structures are dominant. The second and last type of structures in "Scena" are heterogenous vertical ones. They are achieved by coexistence of conga and the voice of the performer or, as in the end of the piece – accompanied by metal chimes, bamboo chimes, shell chimes, glass chimes or mark trees. "Po drugiej stronie lustra" by Paweł Kwapiński similarly "Spectra'' by Marian Borkowski is built mostly on polygenic horizontal structures, although there are both vertical and homogenic structures in different configurations in the piece as well. Tone transformation concerns transmutation and transformation processes as well as structural dominants. Musical elements transformation such as harmony, melody, tempo or rhythmics is that they no longer serve their traditional function, and in lieu are used as means to achieve specific tonal qualities. In other words melody and harmony generators are becoming tools to excite murmurs and timbre[24]. An example of such tonal transformation is maximal speed-up of the rhythmical run which leads to tonally irreducible mass, and the increase in movement itself blurs the clarity of impulses and leads in consequence to transformation of the rhythmic elements into dynamic or timbre values.

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21 Ibidem, p. 158
22 Cf. J. Chomiński, *Technika sonorystyczna…*, p. 160.
23 J. Chomiński, *Technika sonorystyczna…*, pp. 7, 8.
24 Cf. J. Chomiński, *Muzyka…*, p. 164.

We can also speak of specific element transformation also when we deal with a completely opposite situation, which is the isolation of phrases or singular sounds, that is exercised to expose and bring their sonoristic[25] values into the first plane. Transformation is also using instruments in ways alternative to their original intent, which is mentioned among others by Baculewski[26], indicating the fact the the most important novum in this context is the change of destination and function of some traditional generators, that in the end result loose their melodic or harmonic values, becoming merely emitters of timbre or murmurs. In the discussed pieces such transformations occurred, both in the cases of irreducible timbre masses and isolation of sounds, as well as in using instruments alternatively to their intended design. In Marian Borkowski piece we can easily observe transformation based on compaction of leading material until final achievement of irreducible sound mass. Transformations with which we are dealing with in “Scena” are: isolation of singular sound, as well as very characteristic vocal part. Isolation is visible already in the fourth bar of the first system of the second page of the piece. Singular conga hits visibly separated by pause causes fortification of sound features. Definitely the most interesting transformation in Gronaus' piece is the vocal part, that not only serves to sing but also to provide a wide sonoristics qualities palette. In Kwapiński's piece we are dealing with transformation based on compaction of sound material, also with specific glissandos performed on bells, vibraphone or timpani. Those transformations have characteristics of alternative use of the instrument. Below I attach examples of glissandos on bells and vibraphone in bars 3,5 i 7 of the II part of the piece (Fig. 6).

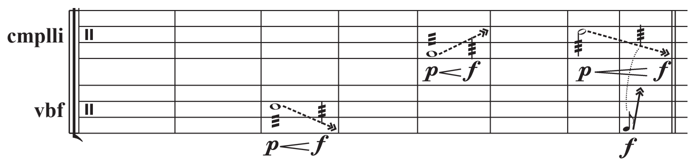

Fig. 6. Fragment of “Po drugiej stronie lustra” music score by Paweł Kwapiński
Source: archival materials, shared by composer

Compaction of the sound material is characteristic for transformation that leads to achieving irreductible tone mass can be observed already in part one of the piece, in bar 10. Besides accents that are bringing order to the fragment,

25 Ibidem, p. 7.
26 K. Baculewski, *Polska twórczość…*, p. 210.

performing possibly fast tom-toms parts blur the clarity and in the end cause rhythmic transformation resulting in homogenous tonal mass (Fig. 7).

Problematics of the form of discussed pieces is analyzed in the context of traditional systems, topofonic and aleatoric. Musical form is shaped by multiple factors – starting with tonal ordering of the material until complicated architectonic creations[27]. In this case we should take a look at modern, typical formal solutions assigned by Józef Chomiński[28] to sonoristic music. Crucial roles are played here by various experiments connected with aleatorism that can be divided into material permutation (e.g. montage aleatorism) and regulated improvisation. Incidentalism in artistic acts is the leading motive of aleatorism.

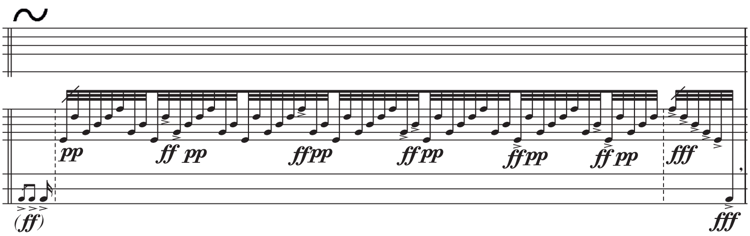

Fig. 7. Fragment of "Po drugiej stronie lustra" music score by Paweł Kwapiński
Source: archival materials, shared by composer

This kind of randomness can have a big impact on the final shape of the composition, as well as its execution. "The way of random actions in the work of a composer is perfectly described by Włodzimierz Kotoński in a commentary included in the preface to the Aelia music score (throwing the dice, picking a card, etc.). In Polish works such actions are rare though. Chance is usually seen in the execution zone. It doesn't give the performer full freedom of the execution, although such experiments were uptaken (e.g. John Cage). Aleatorism therefore brings back active participation of the artist-performer into the execution of the piece. Co-creative participation in shaping of the piece must assume high artistic level of the instrumentalist, exact knowledge of modern music as well as its technical and compository capabilities. Otherwise participation of the performer loses its sense[29]. Montage variant should be especially considered, which plays a very important role in shaping the aleatoric technique[30].

27 Cf. J. Chomiński, *Muzyka…,* p. 165.
28 J. Chomiński, *Technika sonorystyczna…*, p. 10.
29 K. Baculewski, *Polska twórczość…*, p. 237.
30 Ibidem.

The technique of montage aleatorism relies on composer creating components that the performer can later interlace, format and incorporate at any way[31]. "Often the composer sets only the duration of the piece. Not always demanding that all the groups were used by the performer to construct the end form. Rule of scheduling leads then to leaving an open form that can be realized in almost infinite ways[32]". We can see montage aleatorism in "Spectra" by Marian Borkowski. Creator of this piece leaves full freedom in selection of segments, amounts of repetitions or order they will be performed at. The only limitation left by the composer is the duration of the cadence, which should be contained between 1 and 1 : 30 min.

In the piece "Scena" by Alicja Gronau the performer stands before a regulated improvisation challenge. In the fragment in which the voice is used the improvisation framing is limited by the interval material. Composer draws our attention to the fact that the main motive should be executed on pitches c, as, g in any transposition. In the next repetition Gronau allows employment of improvised variants. Whispered or sung text is an example to this case.

An interesting aspect of Alicja Gronau piece is that it is almost parateatheatrical, which the composer herself describes in text added to the music score intended to make easier for the performer to execute the piece and understand the intention that the author wanted to capture. In this text she writes: "The drummer sits by the conga in complete darkness. After the first pause the light slightly brightens up – one point line from the top or two from the sides, alternatively a small lamp or a candle – then it should be turned on/lit up during the first pause and turned off/extinguished before the last hit on a japanese cup gong. All types of chimes should be hung on stands or strings close to the dummer at first (metal and bamboo chimes), then along the way that he will taking out of the room, japanese cup gong should be carried by the drummer (then he walks with it) or should be close by the entrance door[33]". A very important element that requires exercise is setting of the instruments in such a manner, so that the execution of the piece is comfortable for the performer. It is worth taking time to set the instruments in such a way that it's also attractive to the viewer in visual context. Composers often suggest their own schematics as we can see in the case of Marian Borkowski or Paweł

31 Cf. J. Chomiński, *Muzyka…*, p. 169.

32 J. Chomiński, K. Wilkowska-Chomińska, *Teoria formy. Małe formy instrumentalne*, PWM, Kraków 1983, p. 229.

33 Description of drummer behavious contained in music score "Scena" by Alicja Gronau, handwritten by author.

Kwapiński music scores. Question arises – are they working? It varies case to case. Every artist performer has their own individual predispositions, skills, physical and artistic capabilities, so there is no one answer to that question. From my own perspective schematics proposed by both composers give comfortable conditions to perform the pieces and allowed me to attempt to fully realize my artistic ideas and execute the pieces in accordance with the composer's notes.

What is interesting to note, Alicja Gronau's piece did not have such schematic attached. Author allowed the performer to fully take control of that matter, setting the instruments in such a way that would be adequate to their capabilities and preferences. It is also an interesting approach because it shows a lot of trust to the artist. In "Spectra" Professor Marian Borkowski employed a very vast instrumentarium. Efficient operation of all its elements is not an easy task for the performer, as it requires a lot of concentration and smart planning of actions during the performance. The composer employed 2 bongos, a conga, 2 timbales, 4 different tom-toms, 2 timpani, marakas, tubi di bambu, 2 triangles, 3 crashes, 2 blocchi di metallo sospesi, 3 different gongs, tam-mta and tubular bells. He also described in detail types of sticks that should be used by the performer. What is interesting is the use of two blocchi di metallo sospesi by the composer, which are suspended metal blocks. Their precise size is not clearly defined. Composer does not provide detailed information about its size, thickness nor shape. He leaves those decisions to make for the performer. Performing the "Spectra" I used metal dishes hung on a wooden box. That idea inspired me for further artistic work as I decided to employ them in "Mobile" by Marta Ptaszyńska, in part C, where metale tutti term is also used.

Alicja Gronau in her piece suggests a very compact instrumentarium that consists of only a few elements. It includes conga, metal places, bamboo chimes, shell chimes, metal chimes, glass chimes, japanese cup gong and a mark tree. What seems very interesting is that the chimes dictate the way of performer movement on the stage. While walking away at the end of the piece artists slightly moves the chimes of different kinds that accompany them until the end of the work, when they hit the japanese cup gong and extinguish the candle. In the music score the composer also cites a legend that brings the performer closer to the techniques that allows to achieve desired sound effect. It also contains information about gesturing and other non-musical elements used in the song. They are extremely valuable for the artist, since the piece being paratheatrical means it is supposed to be attractive for the viewer not only sound-wise but also visually.

Thanks to that kind of description it is easier for the performer to get closer to the intention of the author.

An interesting problem regarding instrumentarium, especially in regards to the setting of its elements comes from "Po drugiej stronie lustra" by Paweł Kwapiński. The Composer's proposition is very helpful for the performer since the set contains two positions in which specific parts of the piece are executed, thanks to which change of instruments position is not necessary and the execution of the composition is much more comfortable for the artist. Furthermore interesting is the fact that the way the instruments are set in the Paweł Kwapiński piece is related to the title "Po drugiej stronie lustra" [On the other side of the mirror]. Both positions are set separately and between them stand the tubular bells symbolizing the mirror. They are not a perfect reflection of each other since instruments used in both installations differ from each other. The Composer's idea was the juxtaposition of tom-toms, timpani, crashes or tam-tam, with such melodic instruments as vibraphone or bells.

All the pieces described by me in this publication have many common elements. Not only workshop-wise but also in the context of composition field – teachers and their ways of education. Alicja Gronau's piece is my intentional choice presented to underline the fact that today's musician should be able to employ a full scale of technical methods unnecessary to perform a piece, but also has to be ready for challenges reaching beyond their classical way of operating instruments (e.g. using human voice and gestures). In Paweł Kwapiński score influences of composer Marian Borkowski are noticeable, both in the terms of notation as in used instrumentarium. What is interesting is the fact that Gronau and Kwapiński were mentored by the same person, which didn't stop them in creating individual styles. I have noticed their tonal features that are inherent characteristics of sonoristic technique, which is an important element of my deliberations. Use of multi percussion is very much justified through elasticity in instruments selection and performance means – their number is infinite and fully available to the performer. It is the right way, giving space for sonoristic techniques development. Sonoristics together with multi percussion provide opportunity to research the field of innovative conceptions and unseen before composition and performance techniques.

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Abstract

The article is written about the sonorism as an element of acoustic. Works which are used as examples are composed by Alicja Gronau, Marian Borkowski and Paweł Kwapiński. The therm of sonorism and the technics of composing and performing this kind of music are described in the beginning. Next are presented technologies of sound and accessories which are used to generating sound during the performance. There are described systems of music notation in this works. In article are quotet advices, which composers gave the musicans to make performance easier and clear. Here are presented specific instruments and way how to use them. In the article are used fragments of the music sheet to make the content more interesting and close. The whole of article is closed by the summary, where are shown conclusions and most important topics.

Key words: sonorism, acoustics, percussion, composition.

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Acoustic mediation in parrots

Characteristics of the Order of Parrots

Parrots are classified as ornamental birds. In the bird flock (*Aves*), which numbers 9,000 species, they occupy a significant place, including the order of the parrots (*Psittaciformes*), numbering over 300 species. Currently, not all birds of the parrot order have been fully described by scientists, however, they have been divided into subfamilies, the most numerous of which are:

– lory (*Loriidae*) – 55 species,
– cockatoo (*Cacatuidae*) – 18 species,
– parrots (*Psittacidae*) – 257 species[1].

Parrots in their natural habitat can be found in the temperate and warm zones and on most continents of the world (except Europe and Antarctica). These birds are very sensitive, which means that a large number of species are threatened with extinction and have been intended for closed breeding in specialized centers or in zoos[2].

Parrots with an anatomical structure are famous for their large head and hooked beak. When eating, they are assisted by the tongue, which is strongly

1 Cf. R. Baumgartner, J.E. Cooper, G.M. Dorrestein, M. Fehr, K. Gabrisch, H. Gass, D. Giebler, J. Hatt, C. Herweg, S. Herzberger, E. Isenbügel, M. Karmer, R. Korbel, W. Küpper, N. Kummerfeld, H. Moorman-Roest, F. Mutschmann, P. Sandmeier, L. Sassenburg, E. Saupe, H. Schall, M. Schicht-Tinbergen, B. Schildger, A. Treiber, C.J.M. Visser, E. Wasel, C. Wenker, A. Wijnbergen, J. Wolter, P. Zwart, *Praktyka kliniczna. Zwierzęta egzotyczne. Ssaki, ptaki i zwierzęta zmiennocieplne*, Wydawnictwo Galaktyka, Łódź 2009.

2 L. Joseph, A. Toon, E.E. Schirtzinger, T.F. Wright, R. Schodde, *A Revised Nomenclature And Classification for Family-Group Taxa of Parrots (Psittaciformes),* Zootaxa, Nowa Zelandia 2012, no. 3205, pp. 26–40.

muscled and has many taste receptor endings. In some cases, there is also cornified layer the *Statum corneum* (the exfoliating outer layer of the epidermis) on the tongue. Parrots are also characterized by a large range of body weight – they can count from 10 grams to several kilograms. In order to communicate with each other, they make noises ranging from grinding screeching, whistling to singing full phrases of songs[3]. This is also why people became interested in these animals, because they were impressed by the intelligence of parrots – how they were able to remember and recreate a given number of words and to relate certain phrases, even with the time of day[4]. At home, parrots are usually kept in garden or indoor aviaries. These are rooms built especially for parrots in order to create the necessary space and living conditions for them[5].

Characteristics of the anatomical structure of the brain of parrots

Scientists, especially ornithologists, have discovered that the brain of parrots is very interesting as a research object. This is mainly due to its size, which is the largest organ compared to the rest of the bird's body.

Central parts of the parrot's brain are isolated, whose task is to connect the memory process with the subsequent acoustic communication (vocalization). These parts are located in the forebrain (prosencephalon) and are called the vocal nucleus. In parrots, at least nine vocal testicles are involved in learning voice and communication. They are completely surrounded by a sheath with nerve endings, which is more common in parrots with a greater propensity to mimic sounds. This organ is very important for the process of vocalization. The vocal testicles of parrots have a very similar meaning to the parts of the human brain that are responsible for the movement of the larynx and the control of the language. The parrot's noticeable attachment to music is due to the fact that the part of the brain that is responsible for learning vocalization sits next to the part that is responsible for the parrot's movement.

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3 C.A. Toft, T.F. Wright, *Parrots of the Wild. A Natural History of the World's Most Captivating Birds,* University of California Press, Oakland 2015, pp. 13, 14.

4 Cf. J. Hanzák, *Wielki atlas ptaków,* second edition, Państwowe Wydawnictwo Rolnicze i Leśne, Warszawa 1976.

5 S. Chvapil, *Ptaki ozdobne*, Państwowe Wydawnictwo Rolnicze i Leśne, Warszawa 1985, pp. 9–11.

Moreover, parrots' striated area in the brain have a very similar structure to the human species, with the difference that it is responsible for acoustic communication in parrots and is used for speech in humans. Another similarity is the genes responsible for the development, connectivity and functionality of brain circuits in both species (parrots and humans) (these circuits are responsible for memory and learning of acoustic sounds).

Like people, parrots differ from other animals in that they have independently developed parts in the brain tract (connections created from nerve tissue to adapt the brain). These similarities include learning processes involving the production of sounds, language, and even singing[6].

Birds do not have vocal cords, but they still make sounds[7]. This is caused by the vibrations of the membrane in the larynx. This vibration partly moves the tracheal-bronchial connection[8]. Memorizing acoustic stimuli or reacting to music is an activity acquired by imitating a pattern[9].

Acoustic mediation in parrots and the meaning of sounds

Scientists – ornithologists, specializing in ornamental and exotic birds, very often conducted research on singing. They found that parrots use language in the same way as humans. Thanks to it, they are able to precisely modulate the frequency and amplitude at the time of copying the heard sound. They use such a scheme to create their own dialects (acoustic mediation). Each parrot is able to separate a given dialect that it has learned and communicates with a given individual, hence each individual who has arrived in a flock or group causes the creation of a new dialect. There were indications and all sorts of guidelines that allowed people to distinguish between a call and songs

6 C.A. Toft, T.F. Wright, op. cit., pp. 94–97.

7 G.J.L. Beckers, B.S. Nelson, R.A. Suthers, *Vocal-Tract Filtering by Lingual Articulation in a Parrot*, "Current Biology" 2004, 14(17), pp. 1592–1597.

8 A.R. Pfenning, E. Hara, O. Whitney, M.V. Rivas, R. Wang, P.L. Roulhac, J.T. Howard, M. Wirthlin, P.V. Lovell, G. Ganapathy, J. Mountcastle, M.A. Moseley, J.W. Thompson, E. J. Soderblom, A. Iriki, M. Kato, M.T.P. Gilbert, G. Zhang, T. Bakken, A. Bongaarts, A. Bernard, E. Lein, C.V. Mello, A.J. Hartemink, E.D. Jarvis, *Convergent Transcriptional Specializations in the Brains of Humans and Song-Learning Birds*, "American Association for the Advancement of Science" 2004, 346(6215), pp. 1333–1344.

9 M. Chakraborty, S. Walløe, S. Nedergaard, E.E. Fridel, T. Dabelsteen, B. Pakkenberg, M.F. Bertelsen, G.M. Dorrestein, S.E. Brauth, S.E. Durand, E.D. Jarvis*, Core and Shell Song Systems Unique to the Parrot Brain,* "PLoS ONE" 2015, 10(6), no. e0118496, p. 96.

in parrots. The main difference was that the parrots, creating a relatively short vocalization, conveyed specific information, while making long, melodic sounds – they sang. Songs in parrots have a specific character. This is usually related to the given territory in which a particular individual is located or the solicitation of a partner for breeding time[10].

Parrots use acoustic mediation to communicate. The sound from the vibrating membrane of the larynx is short, but has many frequency changes between 500 Hz and 6 kHz and the amplitude (dB)[11]. In wild parrots there are 12 to 24 very different tones, each of which has a different meaning. The communication of the parrots with each other is considered on several levels, each of which may have two or more incantations. Five main types of communication are distinguished. The first is the call for food, which refers mainly to the sphere of the chicks. Usually it comes in the form of pleading The next call has a social nature, aims to maintain contact between the parrots in the partnership, in the family, in related or unrelated species, when hiding on the branches of the trees and during flight. It is very clear what the aim of it is. Next, you can highlight a flirty reputation. It mainly concerns partnerships and aims to build a closer relationship between parrots. In most cases it is a duet of males and females of a certain species. Provocative calling, refers to the breeding season. A pair of parrots during the breeding season, use the call to maintain the territory where they have built a nest. The last call distinguished is the alarm call – it concerns an individual. Its purpose is to communicate to other birds that one is in danger, when direct harm is done to the individual or when the parrot is frightened[12].

Some species have a rather specific calling style. In small parrots, acoustic mediation involves a narrow range of frequencies and sounds in a given tone or pitch. In larger parrots the call often has a much wider range (of frequencies). Acoustic mediation in the form of a vocalization spreads over several bands, characterized by different frequencies creating a so-called "harmonic pattern". This type of vocalization is definitely louder and characterized by more higher pitched tones than the rest of the sounds[13].

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10 C.A. Toft, T.F. Wright, op. cit., pp. 97–120.

11 J.W. Bradbury, *Vocal Communication of Wild Parrots*, "The Journal of the Acoustical Society of America" 2001, 115(5), pp. 2373–2374.

12 C.A. Toft, T.F. Wright, op. cit., pp. 97–116.

13 R.C. Beason, *What Can Birds Hear? USDA Wildlife Services*, National Wildlife Research Center, 2004, 78, pp. 92–95.

The vocalization of the parrots is in the frequency range from 2 kHz to 5 kHz (with more accurate measurements from 500 Hz to 6 kHz). Compared to humans, these frequencies are between 2 and 4 kHz. Frequencies that go beyond the high bands are frequency modulated and changed during the entire vocalization period. Despite the high switching frequency of parrots, these birds do not respond to infrasound in the range below 20 Hz or ultrasound above 20 kHz[14].

Path of sound in parrots

As a unique species among birds, parrots have an unusual pathway for sound. At first, the parrot brain registers and receives information from the environment and processes it. Thus, by obtaining information from the environment and translating it into a nerve impulse transported to the muscles, the parrot is able to react. Figure 1 shows a diagram of the location of brain areas in the parakeet *Melopsittacus undulatus*. These areas are involved in the process of learning vocalization and acoustic mediation.

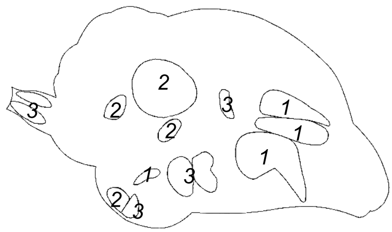

Fig. 1. Diagram of the location of brain areas in the parakeet *Melopsittacus undulatus*
Source: graphic by Kamil Dargiel

The areas marked with the number *1*, correspond to the areas in the brain assigned to learning new vocalizations, the number *2* delineates the zone that is activated during auditory perception. The last area marked with a *3*, is assigned to the places that control the motility and the process of sound production in the larynx as part of membrane vibration.

In the study of parrots, similarities were found in the molecular layout of the brain of parrots, as songbirds, and mammals (people) as shown in Figure 2. The brain circuits responsible for learned vocalisation in both species (mammals

14 C.A. Toft, T.F. Wright op. cit., pp. 100–105.

and birds) are marked with consecutive numbers. The counterparts of these circuits in humans as in parrots are arranged in special hierarchical "trees". Number *1* covers the area of the cerebral cortex *Pallium/Cortex cerebri*. The cingulate area Telencephalon, or more precisely the so-called striatum, is made up of the caudate nucleus *Nucleus caudatus*, marked with the number *2* on the graphic, which influences behaviour and mood to a large extent, and the *Putamen* shell marked with the number *3*, which plays a large role in limb movements. The last number marks the location of the smaller nuclei, the so-called *Lower Nuclei* the medial-dorsal nucleus *Dorsal-Medial nucleus* (showing emotion), the dorsolateral-medial nucleus *DML* (sound localization, word repetition) and part of the sublingual nucleus *nXII (*nXIIts; 12th tracheosynringeal nucleus) (tounge movement).

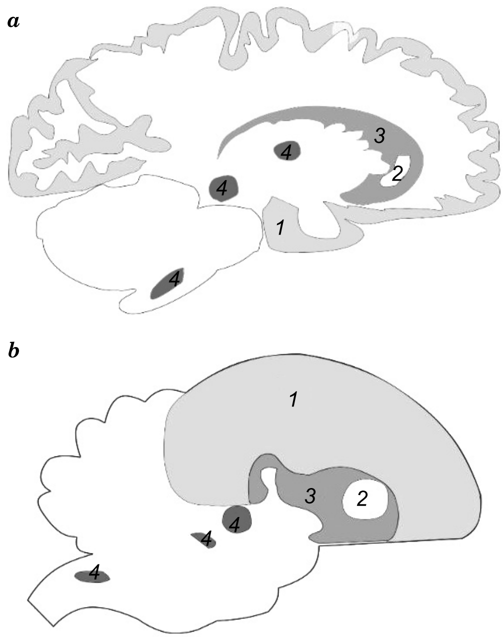

Fig. 2. Similarity in the molecular arrangement of the brain of parrots as songbirds (*a*) and people (*b*)
Source: graphic by Kamil Dargiel

The sensorimotor pathway plays a major role in the flow of sound. Initially, the sound stimulus received in the inner ear by the cochlea in the form of a bony structure is transmitted as pressure wave information to the auditory cells (sensory cells otherwise known as cilia or hair cells). Neurons are located at the border of the hair cells. They are activated by an acoustic pressure wave, which converts them (by increasing pressure) and translates them into a mechanical pressure wave. Mechanical pressure waves cause stimulation and activation of the basal warts. This process generates a vibration that becomes a signal that triggers a series of interconnected neuronal synapses (connections). This triggers the release of neurotransmitters that transport the signal from the ear to the central nervous system and more specifically to a part called the hindbrain (*Rhombencephalon*), to the cochlear nucleus (a structure found only in birds). The signal passes through the midbrain (*Mesencephalon)* during transmission to the hindbrain. Here, the mechanical pressure wave is converted into information from the sound stimulus by intermediate structures in the back of the brain. This information, after passing into the midbrain, is transported to the central coordinating part of the dorsolateral nucleus, which directs the sound information to the thalamus (*Thalamus*). The thalamus is responsible for collecting and grouping all the stimuli heard and the information coming from the other senses. From here, data is transported to the forebrain *(Prosencephalon)*, responsible for separating sound information and directing it to the cognitive centres. In the final stage, the meaning of the sound heard is interpreted by transporting the information to the consortium of cognitive processing nuclei[15].

Experiment description

The research was conducted from July to September 2020 at the Parrot House in Olsztyn. The facility has been a private business since July 2017, based at 29 C Lubelska Street. The parrot house consisted of several rooms: waiting room, service rooms and bird rooms. The waiting room contained a cash register and a gift shop. Next to the waiting room was the staff area with a separate work room. This fenced off area contained all the parrot equipment, i.e. bowls, food, containers, medical preparations, first aid kit, etc. There the workers prepared bowls of bird food and vitamin preparations with water. In order to enter the aviary (room) with the parrots, it was necessary each time to disinfect hands with a special agent located at the entrance and to pass through a shoe disinfecting mat and hanging acrylic glass mats.

The main aviary consisted of 220 square metres of floor space for the parrots and was 4 metres high. The animals had complete freedom of movement there.

15 C.A. Toft, T.F. Wright, op. cit., pp. 98–101.

The walls inside the aviary were almost entirely clad in wood, the rest was completed with a special hardened grating made to order so that the parrots would not be able to break it. It was necessary to separate the parrots from windows, lamps, radiators and ventilation. In the corners of the main aviary were: a fountain with water for drinking and a wooden sandbox for sand bathing. In the main aviary there were two side aviaries for birds that needed extra care, diet or observation. In the aviary were attached trees, branches, thick ropes and all kinds of wooden toys. There were two levels of perches in the facility: the lower level was used for human contact and to attach food and water bowls, while the higher level allowed the birds to rest, as they were out of reach of visitors.

The experiment involved 51 three-year-old parrot birds of different species:

- The blue-and-yellow macaw (*Ara ararauna*): 3 units,
- The blue-winged macaw (*Primolius maracana*): 2 units,
- The grey parrot (*Psittacus erithacus*): 3 units,
- The monk parakeet (*Myiopsitta monachus*): 1 unit,
- The green-cheeked parakeet (*Pyrrhura molinae*): 6 units,
- The galah (The pink cockatoo)(*Eolophus roseicapilla*): 10 units,
- The rose-ringed parakeet (*Psittacula krameri*): 1 unit,
- The Alexandrine parakeet (*Psittacula eupatria*): 8 units,
- The vinaceous-breasted amazon (*Amazona vinacea*): 3 units,
- The turquoise-fronted amazon (*Amazona aestiva*): 4 units,
- The yellow-naped amazon (*Amazona ochrocephala auropalliata*): 2 units,
- The southern mealy amazon (*Amazona farinosa*): 2 units,
- The regent parrot (*Polytelis anthopeplus*): 3 units,
- Meyer's parrot (*Poicephalus meyeri*): 2 units,
- The eclectus parrot (Great Lora)(*Electus roratus*): 1 unit.

The whole experiment was divided into several stages. The first stage was aimed at introducing specific sound stimuli in the main aviary. The sound stimuli (Table 1) were played/presented on consecutive days. From each type of sound stimulus, between 5 and 10 pieces of stylistically diverse music were considered. Depending on the type of music, it was played for 10 minutes to 1 hour to observe the change in parrot behaviour. After all songs, melodies and sounds were presented, the whole cycle was repeated twice in random order. In total, the experiment consisted of three cycles.

The whole course of the experiment was recorded. The music was played at the same time after the morning feeding (starting at 10.00 am), at a time when there were few visitors in the aviary. The speakers from which the sounds were heard were located in two different places in the aviary, at a height of 4 m. The sounds of guitar, violin and bells with ‘c’ and ‘g’ in the double octave at 523.3 Hz (c^2) and 784.0 Hz (g^2) were presented live from the same location in the aviary.

Table 1. List of sound stimuli and their duration

Sound stimuli	Used soundtracks	Duration of cycle [min]		
		1	2	3
1	2	3	4	5
Fairy tale music	“I Can Go the Distance” – Hercules			
	“You Can’t Take Me” – Spirit: Stallion of the Cimarron			
	“Circle of Life” – Lion King			
	“Will the Sun Ever Shine Again” – Home on the Range			
	“I Will Always Return” – Spirit: Stallion of the Cimarron	60	48	42
	“No Way Out” – Brother Bear			
	“Written in Your Heart” – Barbie as the Princess and the Pauper			
	“Strangers Like Me” – Tarzan			
	“Let It Go” – Frozen			
	“Try Everything” – Zootopia			
Jazz music	“Smooth Jazz Chillout Lounge” – Dr. SaxLove	60	60	60
Pop music	“The Lazy Song” – Bruno Mars			
	“The Greatest Show” – The Greatest Showman			
	“The Other Side” – Zac Efron, Hugh Jackman			
	“No Way” – Six			
	“Szampan” – Sanah	60	56	60
	“My Heart Will Go One” – Céline Dion			
	“Angel” – Sarah McLachlan			
	“Never Enough” – Loren Allred			
	“Oceans (Where Feet May Fail)” – Hillsong United			
	“Kilka pytań” – Patrycja Markowska			

Cont. Table 1

1	2	3	4	5
Classical music	“Violin Sonata No. 5 in F Major, Op. 24, Spring: I. Allegro” – L. van Beethoven	60	60	60
	“Renesmee’s Song” – Twilight			
	“River Flows in You” – Yirumi			
	“Kiss the Rain” – Yirumi			
	“Violin Concerto No. 5 in A Minor, Op. 7: I. Vivace” – J.M. Leclair			
	“The Well-Tempered Clavier: Book 1, BWV 846-869: Prelude and Fugue in C Major, BWV 846” – J.S. Bach			
	“Symphony No. 5 in D Major: 1. Allegro ma non troppo – Allegro assai” – W. Boyce			
	“Time Forgets…” – Yiruma			
	“One Last Time” – Jurrivh			
	“Into the Mist” – G. Maroney			
Ringtone 784.0 Hz (g^2) and 523.3 Hz (c^2)	–	5 min 13 sec	2 min 15 sec	4
Playing violin	“Ave Maria” – F. Schubert	34	25	27
	“Ave Maria” – J.S. Bach – Ch. Gounod			
	“Aria” ze Suity D – J.S. Bach			
	“Šest snadnŷch duet” violino I. – I. Pleyel			
	“My Heart Will Go One” – Céline Dion			
	“Horyzont” – P. Wojciuk			
	“Zawsze szansę masz” – Barbie Księżniczka i Żebraczka			
	“He’s a Pirate” – Patrik Pietschmann			
Playing guitar + vocal	“Seether” – Broken ft. A. Lee	23	14	16
	“Agnieszka” – Łzy			
	“Małe rzeczy” – S. Grzeszczak			
	“Wstawaj i walcz” – P. Wojciuk			
	“Żyj swoim życiem” – P. Wojciuk			
	“O Tobie” – Bajm			
	“Młodość” – Sami			
	“Joy” – P. Wojciuk (wersja gitarowa)			
	“He’s a Pirate” – Pirates of the Caribbean (guitar version)			

Source: own elaboration

The next step was to analyse the recordings and determine how many birds were receptive to the sound stimuli and showed the expected responses (calming, excitation, interest, flight or arrival). From the data obtained in the above analysis, those songs to which the animals were most responsive were taken into account and the passages that caused the greatest changes in parrot behaviour were searched for.

In the third stage, these excerpts were presented to the birds vocally by the author of the study. This trial was designed to test whether parrots respond better to human voice or music.

The next step was based on controlling the music in the main aviary with the assistance of a member of the Parrot House staff, playing selected fragments of songs, humming the melody and attempting to calm and mediate with a selected individual from the flock. These actions were performed on randomly selected parrots, choosing one bird of each species. The above procedure was repeated on the same birds in a separate room, without other parrots, to eliminate external stimuli. All results obtained are presented in tables.

In the first stage of the study, when specific sound stimuli were played or presented in the main aviary, different bird responses were observed (Table 2–4).

The parrots were most responsive to a ringing sound of 784.0 Hz i.e. a ‘g’ sound in the double octave. This result was repeated in every cycle. The birds were clearly calm. On the other hand, they did not respond at all to a bell with the sound “c” in the colon octave at a frequency of 523.3 Hz. Fairy tale music caused significant arousal and interest in the parrots, while jazz calmed

Table 2. Number of parrots responding to music in cycle 1 [pcs]

Type of music	Attention	Calm	Agitation	Flying away	Arrival	Lack of reaction
Fairy tale music	14	1	32	0	4	0
Jazz music	4	38	1	0	2	6
Pop music	6	3	30	0	5	3
Classical music	7	35	2	0	0	7
Ringtone 784.0 Hz (g^2)	17	33	0	0	1	0
Ringtone 523.3 Hz (c^2)	3	0	0	0	0	48
Playing violin	16	17	4	2	12	0
Playing guitar	7	6	27	3	2	6

Source: own elaboration

them down. Classical music had a calming effect on the birds, which was particularly evident in the third observation cycle. On the other hand, guitar playing stimulated the parrots. At first, the sound of the violin attracted the birds, but with subsequent cycles the animals began to relax. With the sound of pop music, a significant agitation of the parrots was observed.

Table 3. Number of parrots responding to music in cycle 2 [pcs]

Type of music	Attention	Calm	Agitation	Flying away	Arrival	Lack of reaction
Fairy tale music	12	1	36	0	1	1
Jazz music	2	39	3	0	0	7
Pop music	6	1	41	0	1	2
Classical music	4	43	1	0	0	3
Ringtone 784.0 Hz (g^2)	9	40	0	0	2	0
Ringtone 523.3 Hz (c^2)	2	0	0	0	0	49
Playing violin	10	24	1	5	7	4
Playing guitar	12	4	25	7	1	2

Source: own elaboration

Table 4. Number of parrots responding to music in cycle 3 [pcs]

Type of music	Attention	Calm	Agitation	Flying away	Arrival	Lack of reaction
Fairy tale music	6	2	40	0	2	1
Jazz music	5	41	3	0	0	2
Pop music	7	3	38	0	2	1
Classical music	3	45	0	0	1	2
Ringtone 784.0 Hz (g^2)	12	38	0	0	1	0
Ringtone 523.3 Hz (c^2)	0	0	0	1	0	50
Playing violin	4	35	9	0	1	2
Playing guitar	5	9	31	4	1	1

Source: own elaboration

Tables 5–19 show the responses of parrots of different species to musical stimuli, where an 'X' indicates at least one observed response.

Common Ar (*Ara ararauna*) showed interest and arousal to fairy tale and pop music and calmed down to jazz, classical, ringtone (784.0 Hz) and violin music, while the smaller Ar maracana (*Primolius maracana*) showed an adherence to sound sources and in most cases calmed down, mainly to instrumental music.

Table 5. Response to sound stimuli of the common *Ara ararauna*

Type of music	Attention	Calm	Agitation	Flying away	Arrival
Fairy tale music	X	-	X	-	X
Jazz music	-	X	-	-	-
Pop music	X	-	X	-	-
Classical music	-	X	-	-	-
Ringtone 784.0 Hz (g^2)	X	X	-	-	-
Ringtone 523.3 Hz (c^2)	-	-	-	-	-
Playing violin	-	X	-	X	X
Playing guitar	X	-	X	-	-

Source: own elaboration

Table 6. Response to sound stimuli of Ara maracana (*Primolius maracana*)

Type of music	Attention	Calm	Agitation	Flying away	Arrival
Fairy tale music	X	-	X	-	-
Jazz music	X	-	X	-	X
Pop music	-	X	-	-	X
Classical music	-	X	-	-	X
Ringtone 784.0 Hz (g^2)	X	X	-	-	-
Ringtone 523.3 Hz (c^2)	-	-	-	-	-
Playing violin	X	X	-	X	-
Playing guitar	-	X	-	-	X

Source: own elabration

Table 7. Responsiveness to auditory stimuli of the Grey parrot (*Psittacus erithacus*)

Type of music	Attention	Calm	Agitation	Flying away	Arrival
Fairy tale music	-	-	X	-	-
Jazz music	-	X	-	-	-
Pop music	-	-	X	-	-
Classical music	-	-	X	-	-
Ringtone 784.0 Hz (g^2)	X	-	-	-	-
Ringtone 523.3 Hz (c^2)	X	-	-	-	-
Playing violin	-	-	X	-	-
Playing guitar	-	-	X	X	-

Source: own elaboration

The Grey parrot's (*Psittacus erithacus*) showed interest to both stimuli from the bells and were often agitated at this time. Monk parakeet (*Myiopsitta monachus*) and Green-cheeked parakeet (*Pyrrhura molinae*) as representatives of small parrots were interested in almost every kind of sound, they flocked to fairy tale, jazz and pop music, and no escape from the presented stimuli was observed.

Table 8. Response to auditory stimuli monk parakeet (*Myiopsitta monachus*)

Type of music	Attention	Calm	Agitation	Flying away	Arrival
Fairy tale music	X	X	-	-	X
Jazz music	X	-	-	-	X
Pop music	X	-	X	-	X
Classical music	X	X	-	-	-
Ringtone 784.0 Hz (g^2)	X	X	-	-	-
Ringtone 523.3 Hz (c^2)	-	-	-	-	-
Playing violin	X	-	-	X	-
Playing guitar	X	-	-	X	-

Source: own elaboration

Table 9. Response to auditory stimuli of the green-cheeked parakeet (*Pyrrhura molinae*)

Type of music	Attention	Calm	Agitation	Flying away	Arrival
Fairy tale music	X	X	-	-	X
Jazz music	X	-	-	-	X
Pop music	X	-	-	-	X
Classical music	X	X	-	-	-
Ringtone 784.0 Hz (g^2)	X	-	-	-	-
Ringtone 523.3 Hz (c^2)	-	-	-	-	-
Playing violin	X	-	-	-	-
Playing guitar	X	-	-	-	-

Source: own elaboration

Table 10. Response to auditory stimuli Pink cockatoo (Galah) (*Eolophus roseicapilla*)

Type of music	Attention	Calm	Agitation	Flying away	Arrival
Fairy tale music	-	-	X	-	X
Jazz music	-	X	-	-	-
Pop music	-	-	X	-	-
Classical music	-	X	-	-	-
Ringtone 784.0 Hz (g^2)	X	X	-	-	-
Ringtone 523.3 Hz (c^2)	-	-	-	-	-
Playing violin	-	X	-	-	-
Playing guitar	-	-	X	X	-

Source: own elaboration

Pink cockatoos (*Eolophus roseicapilla*) often calmed down to the sound of a melody and only arrived to fairy tale music. Rose-ringed parakeet (*Psittacula krameri*) was hardly interested in stimuli at all, but was nevertheless observed to calm down considerably and did not fly or flee when different types of music were played. Alexandrine parakeet (*Psittacula eupatria*) only fled at the sound of the violin, and was often agitated at other types of music.

Table 11. Responsiveness to auditory stimuli of rose-ringed parakeet (*Psittacula krameri*)

Type of music	Attention	Calm	Agitation	Flying away	Arrival
Fairy tale music	X	-	X	-	X
Jazz music	-	X	-	-	-
Pop music	X	-	X	-	-
Clasical music	X	X	-	-	-
Ringtone 784.0 Hz (g^2)	X	X	-	-	-
Ringtone 523.3 Hz (c^2)	-	-	-	-	-
Playing violin	X	X	-	-	-
Playing guitar	X	X	-	-	-

Source: own elabotarion

Table 12. Response to auditory stimuli Alexandrine parakeet (*Psittacula eupatria*)

Type of music	Attention	Calm	Agitation	Flying away	Arrival
Fairy tale music	X	-	X	-	-
Jazz music	-	X	-	-	-
Pop music	X	-	X	-	-
Classical music	X	X	-	-	-
Ringtone 784.0 Hz (g^2)	-	X	-	-	-
Ringtone 523.3 Hz (c^2)	-	-	-	-	-
Playing violin	-	X	-	X	-
Playing guitar	-	-	X	-	-

Source: own elaboration

The vinaceous-breasted amazon (*Amazona vinacea*) did not fly to the sound of any auditory stimulus, calming only at the sound of a bell at 784.0 Hz, and were one of the species that was most aroused and interested in the experiment. The turquoise-fronted amazon (*Amazona aestiva*) did not show much interest in sounds, did not fly or run away when different types of music were played, were aroused by classical, jazz and violin music, calmed down by pop, fairy tale music and guitar sounds. The yellow-naped amazon (*Amazona ochrocephala auropalliata*) was of great interest to the music, the vast majority of the charms depicted stimulated them, calmed down only to the sound of the bell with a frequency of 784. 0 Hz, while they fled at a frequency of 523.3 Hz and flew towards the melody of fairytale and pop music. The southern mealy amazon (*Amazona farinosa*) were most interested in the sound of bells, calming was mainly induced by the sound of a g^2 bell (784.0 Hz) and by playing instruments, they were agiteted by pop and fairy tale songs.

Table 13. Response to sound stimuli of the vinaceous-breasted amazon (*Amazona vinacea*)

Type of music	Attention	Calm	Agitation	Flying away	Arrival
Fairy tale music	-	-	X	-	-
Jazz music	X	-	X	-	-
Pop music	X	-	X	-	-
Classical music	X	-	X	-	-
Ringtone 784.0 Hz (g^2)	X	X	-	-	-
Ringtone 523.3 Hz (c^2)	-	-	-	-	-
Playing violin	X	-	X	-	-
Playing guitar	X	-	X	-	-

Source: own elaboration

Table 14. Response to sound stimuli of the turquoise-fronted amazon (*Amazona aestiva*)

Type of music	Attention	Calm	Agitation	Flying away	Arrival
Fairy tale music	X	X	-	-	-
Jazz music	-	-	X	-	-
Pop music	-	X	-	-	-
Classical music	-	-	X	-	-
Ringtone 784.0 Hz (g^2)	-	X	-	-	-
Ringtone 523.3 Hz (c^2)	-	-	-	-	-
Playing violin	-	-	X	-	-
Playing guitar	-	X	-	-	-

Source: own elaboration

Table 15. Reaction to sound stimuli of the yellow-naped amazon (*Amazona ochrocephala auropalliata*)

Type of music	Attention	Calm	Agitation	Flying away	Arrival
Fairy tale music	X	-	X	-	X
Jazz music	X	-	X	-	-
Pop music	X	-	X	-	X
Classical music	X	-	X	-	-
Ringtone 784.0 Hz (g^2)	X	X	-	-	-
Ringtone 523.3 Hz (c^2)	-	-	-	X	-
Playing violin	X	-	X	-	-
Playing guitar	X	-	X	-	-

Source: own elaboration

Table 16. Response to auditory stimuli of the southern mealy amazon (*Amazona farinosa*)

Type of music	Attention	Calm	Agitation	Flying away	Arrival
Fairy tale music	X	-	X	-	X
Jazz music	-	X	-	-	-
Pop music	-	-	X	-	X
Classical music	-	X	-	-	-
Ringtone 784.0 Hz (g^2)	X	X	-	-	-
Ringtone 523.3 Hz (c^2)	X	-	-	-	-
Playing violin	X	X	-	-	-
Playing guitar	-	X	-	-	-

Source: own elaboration

The regent parrots (*Polytelis anthopeplus*) were only interested in the sound of a bell at 784.0 Hz, calmed down in the presence of pop and fairy tale music, were aroused in the presence of jazz music and instruments, the sound of which they fled from, but did not fly to any sound source. Meyer's parrots (*Poicephalus meyeri*) were not interested in classical music or guitar sounds, ran away from the sound of the violin, calmed down only at 784.0 Hz, fairy tale and pop music, while jazz stirred them. Eclectus parrot (*Eclectus roratus*) calmed down at the vast majority of the stimuli presented, only arriving at the sound of fairy tale music.

Table 17. Response to sound stimuli of the regent parrot (*Polytelis anthopeplus*)

Type of music	Attention	Calm	Agitation	Flying away	Arrival
Fairy tale music	-	X	-	-	-
Jazz music	-	-	X	-	-
Pop music	-	X	-	-	-
Classical music	-	-	-	-	-
Ringtone 784.0 Hz (g^2)	X	-	-	-	-
Ringtone 523.3 Hz (c^2)	-	-	-	-	-
Playing violin	-	-	X	X	-
Playing guitar	-	-	X	X	-

Source: own elaboration

Table 18. Response to auditory stimuli of the Meyer's parrot (*Poicephalus meyeri*)

Type of music	Attention	Calm	Agitation	Flying away	Arrival
Fairy tale music	-	X	-	-	-
Jazz music	X	-	X	-	-
Pop music	X	X	-	-	-
Classical music	-	-	-	-	-
Ringtone 784.0 Hz (g^2)	-	X	-	-	-
Ringtone 523.3 Hz (c^2)	X	-	-	-	-
Playing violin	-	-	-	X	-
Playing guitar	-	-	-	-	-

Source: own elaboration

Table 19. Response to sound stimuli of Eclectus parrot (*Eclectus roratus*)

Type of music	Attention	Calm	Agitation	Flying away	Arrival
Fairy tale music	X	-	X	-	X
Jazz music	X	X	-	-	-
Pop music	-	-	X	-	
Classical music	-	X	-	-	-
Ringtone 784.0 Hz (g^2)	X	X	-	-	-
Ringtone 523.3 Hz (c^2)	-	-	-	-	-
Playing violin	-	X	-	-	-
Playing guitar	-	-	X	X	-

Source: own elaboration

Conclusions of experience

After the experiment, particular changes occurred in the behaviour of some parrot species. The greatest progress was observed in the Alexandrine parakeet (*Psittacula eupatria*). Parrots of this species started to show more interaction with people due to sound stimuli. In addition, they began to show the typical repetition of given words, but an octave higher. Parrots began to respond more audibly to their surroundings, adding an additional dialect (each flock of birds has a distinct dialect that contains a register of sounds and calls that only individuals from that flock can recognise) to their ability to communicate with people. The ensuing dialect also resulted in new dance choreographies – due to the close connection of the regions responsible for learning vocalization and movement. The created region corresponded to a new acoustic mediation created to communicate with human in combination with movement. The lowland monk parrot (*Myiopsitta monachus*) responded well to higher frequency noises in the sound range from “g^2” (784.0 Hz) to “dis^3” (1244.5 Hz), so that when its name was uttered in this sound range the animal found the source of the call and flew to the hand. Parrots in large aviaries are very problematic for learning such skills, as there are too many stimuli that can distract the animal. The blue-and-yellow macaw (*Ara ararauna*) were very susceptible to calm melodies. No external stimulus was able to disturb their daily existence, and the parrot itself often exhibited behaviour as if it were being put into a trance or as if it were half asleep. Ara's wings were often prone to bending, nevertheless the bird allowed interaction with humans near its weaknesses (places on the body sensitive to touch). The eclectus parrot (*Eclectus roratus*) was the species that was least likely to come to people. With calm classical music as well as, cheerful music from fairy tales and pop music – she began to create her own dance as a movement dialect with the human. She did not seem to make calling noises or parrot after anyone, but she tried to find another way to create a dialect with a human. After cycles of experimentation, through interaction with music this bird was more relaxed and with calm pieces of classical music it did not run away from people. The two Grey parrots (*Psittacus erithacus*), as representatives of intelligent parrots, were not interested in any interaction with humans. Instead, after the experiment, during the playback of cheerful fairy tale or jazz music, these birds started to "sing" and fly down on the shoulders of humans seeking attentions. In addition, they began to reproduce stimuli an octave higher and create new dialects with other birds. Together with the staff at the Parrot House, we noticed that the Grey parrots began to separate their sound output into the separate species present in the aviary (they used the lower sounds found in their ambitus to interact with the common Aries, and used the higher frequencies when interacting with the smaller parrots). One bird of the species Pink Cockatoo (*Eolophus roseicapilla*) was placed in a side aviary due to an accident and required constant veterinary care. This caused the parrot to become withdrawn and stressed. After the experience, the parrot began to respond positively to the human voice. A successful acoustic mediation between human and parrot was achieved using sounds between 587.3 Hz (d^2) and 1975.6 Hz (h^3). The yellow-naped amazons (*Amazona ochrocephala auropalliata*) began to show more interaction in the form of acoustic mediation with humans and other birds after the whole experiment. They began to create new "songs" and clearly expanded the ambitus of the sounds they produced. The biggest discovery was the observation that a g^2 sound (784.0 Hz) caused each parrot to freeze and stand still, while a 523.3 Hz sound (c^2) caused no change in their behaviour.

The overall conclusion is that the birds from the aviary of the Parrot House in Olsztyn are sensitive to frequencies from 587.3 Hz (d^2) to 1975.6 Hz (h^3), show no reaction to sounds below 523.3 Hz (c^2), and are significantly calmer with jazz, classical, violin and frequencies of 784.0 Hz (g^2). They are agitated by playing busy fairy tale music, pop music and playing acoustic guitar. The observed parrot behaviour reinforces the idea that parrots, when stimulated by different musical or acoustic stimuli, are able to create new acoustic mediations within their own species and in interspecies contexts (parrot-parrot and parrot-human).

A number of restrictions

However, some more far-reaching questions can be put forward. Looking at their intelligence, did these animals become accustomed to a given musical phrase after successive repetitions? The author believes that this may have been the case. It would be advisable in the future to consider the composition of new pieces based on similar harmonisation to the piece that produced the particular behaviour in the bird. In this way there would be unlimited possibilities to use different formations of a given stimulus and to extend the mediation.

Another important aspect to take into account is that during the experiment the workers on the aviary did not change. Parrots as pack animals become attached to their keepers and this develops a bond between the keeper and the bird – the animal trusts more, comes more often and is more cooperative.

Other types of difficulties were also encountered when performing the experiment. One of them was parrots' fear at the sight of the violin and the guitar when the stimuli were first presented. After talking to the keepers, it turned out that the birds in this parrot house are not afraid of large trees bolted on the aviary, but they are afraid of planks (even the smallest ones). Most likely at first they perceived the instruments as a piece of plank and ran away.

Due to the pandemic caused by COVID-19, the number of visitors to the Parrot House decreased drastically. This caused the parrots to become frustrated and marasmic. The animals demanded attention and missed their humans, which was a big obstacle because every time they entered the aviary all the parrots would get agitated and fly to the author of the study. Therefore, it is difficult to say unequivocally whether the stimulation/interest was due to the sound stimulus or to the presence of people.

Parrots are curious by nature and love to play with interesting objects – for the birds in the Parrot House such an object was a camera, which was used to record any changes in the behaviour of the charges during the experiment.

The individual characteristics of each parrot that took part in the experiment should also be taken into account, some were more receptive, more willing to fly and showed more interest, while others were more withdrawn or frightened.

Experiments have shown that the use of music in the education of parrots and the creation of acoustic mediations with them brings measurable effects. Parrots are susceptible to acoustic stimuli and this can help achieve various goals. The staff of the parrot house noticed a great change in the behaviour of their charges, which made them very happy. They plan to continue their research on musicalising their charges using the research technique and stimuli presented by the author of this paper.

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Abstract

Scientists, especially ornithologists, have discovered that the brain of parrots is very interesting as a research object. Central parts of the parrot's brain are isolated, whose task is to connect the memory process with the subsequent acoustic communication (vocalization). These parts are located in the forebrain (prosencephalon) and are called the vocal nucleus. The vocal testicles of parrots have a very similar meaning to the parts of the human brain that are responsible for the movement of the larynx and the control of the language. The research was conducted from July to September 2020 at the Parrot House in Olsztyn. The experiment involved 51 three-year-old parrot birds of different species. Experiments have shown that the use of music in the education of parrots and the creation of acoustic mediations with them brings measurable effects. Parrots are susceptible to acoustic stimuli and this can help achieve various goals.

Key words: parrot, acoustic mediation, sound, parrot anatomy.

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Computer Applications for Popular Music Composers in Creative Work and Teaching

Introduction

For more than a decade, technological progress and the associated digitalisation of virtually all spheres of life has been an accelerating and tumultuous process. The community of people using information technology in various aspects of their everyday lives has been dubbed the information society[1]. Nowadays, this population uses not only computers, but various computerised devices, allowing it to download and upload a great amount of multimedia content. This content consists of images, sound, and text in diverse inter-relations, together constituting a virtual world[2]. The ever-expanding market accessibility

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1 F. Webster, *Theories of the Information Society*, Third edition, Routledge, London/New York 2006, pp. 263–273; H.K. Nath, *The Information Society*, "Journal of the Singapore Chinese Teachers' Union" 2009, vol. 4, 2009, pp. 19–29; E. Ziemba, T. Papaj, R. Żelazny, *New perspectives on information society. The Maturity of Research on a Sustainable Information Society*, "Online Journal of Applied Knowledge Management" 2013, vol. 1, issue 1, p. 52.

2 G.A. Tsihrintzis, L.C. Jain, *Multimedia Service in Intelligent Environments. An Instroduction*, in: G.A. Tsihrintzis, L.C. Jain (ed.), *Multimedia Services in Intelligent Environments,* Springer-Verlag, Berlin/Heidelberg 2008, pp. 1, 2; J.R. Pardo, *Copyright and Multimedia*, Kluwer Law International, The Hague/London/New York 2003, pp. 5, 6; S.M. Rahman, *Multimedia Technologies. Concepts, Methodologies, Tools, and*

of computers, and their broad improvement, along with different multimedia technologies, make an impact on music-related work, which includes composition, musical arrangement and the application of digital technology in teaching at academic institutions[3].

Technological development impacts the work of a musician, since the modern composer is more and more commonly the sound engineer and the producer, which requires the use of a computer. Their expertise is thus much wider than conventional music education, extending into the fields of computer science, technology, sound engineering and recording. Composers involved in electroacoustic music, or electronic music imitating acoustic sound, commonly utilise the MIDI interface, which is a system allowing for connections between electronic devices, including computers and digital instruments. The system facilitates sending data between devices and simultaneous control of each device[4]. MIDI does not determine the quality of the generated sound. Instead, it allows for an exchange of information (such as notes on a virtual score) between different devices[5]. The use of virtual instruments which imitate traditional ones, or allow for new timbres[6] for the sound design of original

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Applications, in: S.M. Rahman (ed.), *Preface. What is Multimedia?*, Information Science Reference, Hershey/New York 2008, p. XXVIII.

3 P. Lévy, *Cyberculture*, University of Minnesota Press, Minneapolis/London 2001, p. 122, 125.

4 D.M. Huber, *The Midi Manual. A Practical Guide to MIDI in the Project Studio*, Third edition, Focal Press, Amsterdam 2007, pp. 1–13; J. Rothstein, *MIDI a Comprehensive Introduction*, Second edition, A-R Editions, Madison 1995, pp. 1–14; P.L. Alexander, *How MIDI works*, Sixth edition, Hal Leonard, Milwaukee 2001, pp. 143–148.

5 B. Enders, *From Idiophone to Touchpad. The Technological Development to the Virtual Musical Instrument*, in: T. Bovermann, A. de Campo, H. Egermann, S.I. Hardjowirogo, S. Weinzierl (ed.), *Musical Instruments in the 21st Century. Identities, Configurations, Practices*, Springer Nature, Singapore 2017, p. 49; D. Hosken, *Music Technology and the Project Studio. Synthesis and Sampling*, Routledge, London/New York 2012, pp. 38–44; Z. Shi, T. Nakano, M. Goto, *Instlistener. An Expressive Parameter Estimation System Imitating Human Performances of Monophonic Musical Instruments*, in: M. Hayes, H. Ko (ed.), *2018 IEEE International Conference on Acoustics, Speech, and Signal Processing. Proceedings*, IEEE Signal Processing Society, Danvers 2018, pp. 581–582.

6 Tanev G., Božinovski A., *Virtual Studio Technology and its Application in Digital Music Production*, in: I. Mishkovski, S. Ristov (ed.), *The 10th Conference for Informatics and Information Technology (CIIT 2013)*, Faculty of Computer Science and Engineering, Skopje 2014, pp. 182–186; A.F.B. Laguna, N.M.P. Valdez, R.C.L. Guevara, *MIDI Implementation of a Kulintang Modal Synthesizer Using the VST 2.4 Standard*,

compositions, as well as the ability to use digital workstations for recording, editing, mixing and mastering[7] served as the basis for defining the subject, the research topic and the purpose of the research presented here.

The subject of research

The subject of the research[8] presented in this paper is the use of computers, along with dedicated software, in the work of a composer-arranger, and in composition teaching for popular music. The main research topic[9] of the paper are the methods and possibilities for using computers and music software by artists in broadly understood creative work and teaching. The purpose of the research[10] is to determine whether new technologies aid and stimulate popular music composers in their creative work; whether they are used in practice; whether they are useful and become employed in teaching; whether they increase the attractiveness of works produced with hybrid methods; for what other purposes not mentioned in the questionnaire do musicians use computers and music software; and, finally, are digital technologies, when introduced into the creative process, a liability or an opportunity for further creative development?

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in: J.B. Cruz (ed.), *TENCON 2012 IEEE Region 10 Conference*, Institute of Electrical and Electronics Engineers, Inc./IEEE Press, Danvers 2012, pp. 1, 2.

7 D. Etinger, *Tools of the Trade. Digital Audio Workstation Usage Antecedents*, "Informatologia" 2016, 49(1–2), pp. 61, 62; C. Leider, *Digital Audio Workstation*, McGraw-Hill, New York 2004, p. 48; S. Langford, *Digital Audio Workstation. Correcting and Enhancing Audio in Pro Tools, Logic Pro, Cubase, and Studio One*, Focal Press, Burlington 2014, pp. 9–13.

8 J. Sztumski, *Wstęp do metod i technik badań społecznych*, PWN, Warszawa 1984, p. 20; L. Sołoma, *Metody i techniki badań socjologicznych. Wybrane zagadnienia*, Wydawnictwo Uniwersytetu Warmińsko-Mazurskiego w Olsztynie, Olsztyn 1999, p. 13.

9 J. Sztumski, op. cit., p. 20; T. Pilch, T. Baumann, *Zasady badań pedagogicznych. Strategie ilościowe i jakościowe*, Wydawnictwo Akademickie Żak, Warszawa 2001, p. 43; S. Palka, *Metodologia badania. Praktyka pedagogiczna,* Gdańskie Wydawnictwo Psychologiczne, Gdańsk 2006, p. 12; J. Pieter, *Ogólna metodologia pracy naukowej*, Zakład Narodowy im. Ossolińskich-PAN, Wrocław 1967, p. 67; M. Łobocki, *Metody i techniki badań pedagogicznych*, Oficyna Wydawnicza Impuls, Kraków 2003, p. 21.

10 W. Dutkiewicz, *Podstawy metodologii badań do pracy magisterskiej i licencjackiej z pedagogiki*, Wydawnictwo Stachurski, Kielce 2000, p. 50; T. Pilch, *Zasady badań pedagogicznych*, Wydawnictwo Akademickie Żak, Warszawa 1998, p. 8.

Research method

The present paper utilises the research method[11] of a diagnostic survey[12]. The questionnaire method has been selected from the many existing survey techniques, since it allows for extended and substantial responses on the part of the respondents[13]. The questionnaire was composed of 17 questions, which included open-ended questions, closed-ended questions and hybrid questions, meaning closed-ended questions with the option of entering the respondent's own remarks and suggestions, allowing them to share their perspective on the particular issue.

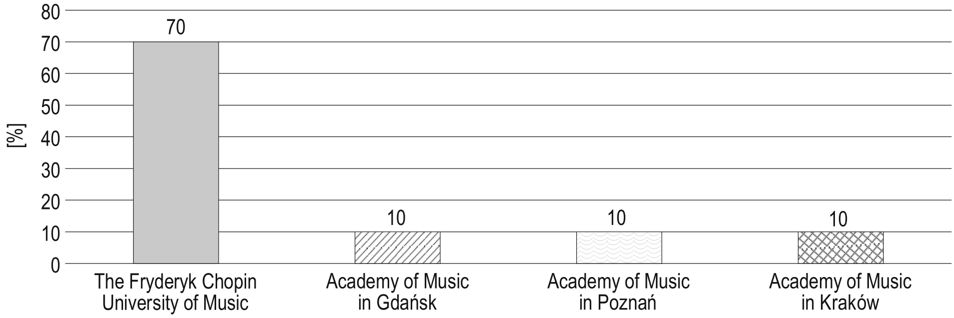

Fig. 1. Percentages of respondents to the questionnaire by institution of employment
Source: own research

The questionnaire was administered from 18 January to 5 February 2018 in four Polish academic institutions: Fryderyk Chopin University of Music in Warsaw, Stanisław Moniuszko Academy of Music in Gdańsk, Ignacy Jan Paderewski Academy of Music in Poznań, and the Academy of Music in Kraków.

Cohort characteristics

The cohort for the survey consisted of 31 people aged 32–75 (22 men and 9 women). The participants held at least a Master of Fine Arts professional degree or higher degrees and titles (including PhD in Fine Arts, Doctor habilitatus,

11 S. Nowak, *Metodologia badań socjologicznych*, PWN, Warszawa 1970, p. 237; M. Łobocki, *Metody badań pedagogicznych*, PWN, Warszawa 1982, p. 56.
12 T. Pilch, op. cit., p. 51.
13 K. Konarzewski, *Jak uprawiać badania oświatowe*, WSiP, Warszawa 2000, p. 138; T. Pilch, op. cit., pp. 86, 87.

and professor). All respondents were active artists and academic lecturers in artistic institutions of higher learning, or retired lecturers. The selection for the cohort was random, since there were no criteria for selecting the respondents or eliminating them once enrolled.

Survey results

Responses to the questionnaire regarding the use of a computer and music software in the process of composition and arrangement showed that as many as 87% of composers utilised used such technologies for that purpose (cf. Fig. 2). Music software allowed artists to listen to their compositions as they worked on them and to correct harmony or melody errors they detected. The musicians

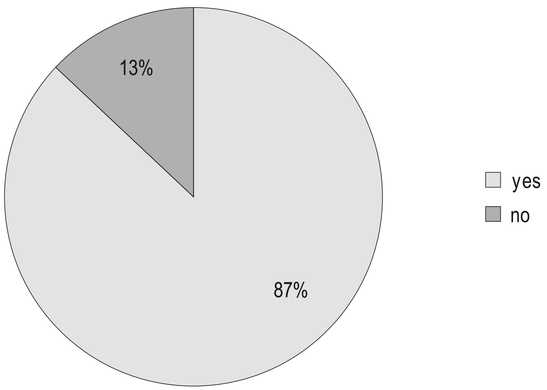

Fig. 2. Do you use a computer with music software in the process of composition and music arrangement?
Source: own research

also made use of many sound generators offered by the software and the ability to mix the generated sounds to achieve original effects in their creations. The respondents indicated that music software enables them to work faster than with traditional pen-and-paper notation, which is especially relevant with the current demand for short-term composition over the Internet.

Figure 3 shows that 71% of composers use virtual instruments in their work. The data suggests that the transformation into an information society is happening before our eyes, also impacting the creative work of composers and their output.

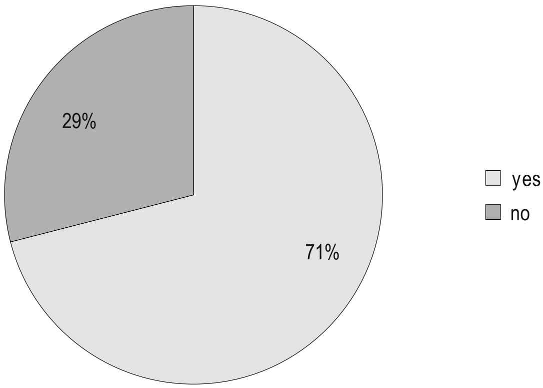

Fig. 3. Do you use virtual instruments? If so, specify the product you use
Source: own research

Figure 4 presents the percentages of responses regarding the use of virtual instruments in creative work. Apart from the software specified in the figure, musicians indicated that they use many other virtual instruments, e.g. ethnic, African, Somali and Middle-Eastern. Some respondents used virtual instrumentation software only to replay their students' work, submitted as MIDI files.

Digital instruments are becoming increasingly favoured by popular and electro-acoustic music composers, since they offer a way for them to find new and innovative sounds. Such an effect can be achieved mainly by utilising digital

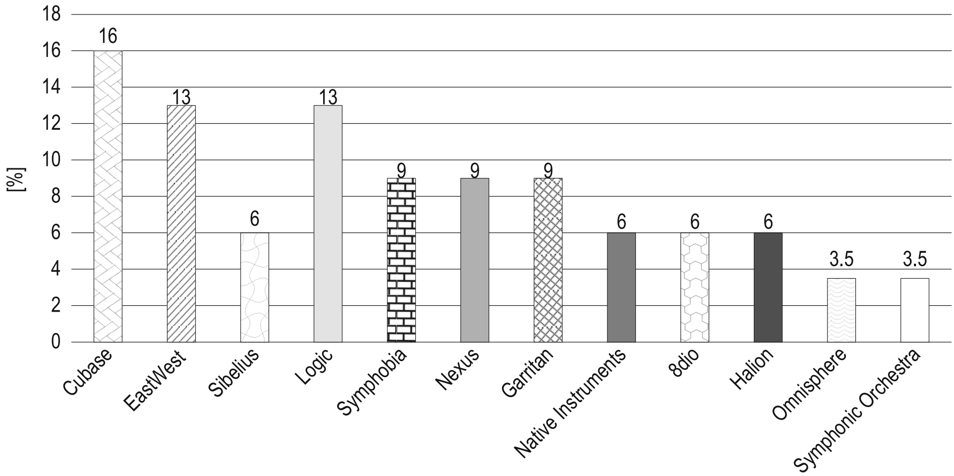

Fig. 4. Virtual instruments used by composers for composition and arrangement
Source: own research

sound simulation while processing sound with a computer and computerised devices. Virtual instruments may also be used by film music creators to supplement the orchestra in terms of sonorous effects for the cinematographic musical score, or, in the case of science fiction films, to create voices for fictional beings.

Computer games are currently the main area of development, as well as inspiration, for electronic and electroacoustic music composers. Artists create music for games which corresponds with the given game's story, generate various ambient sounds of the virtual environment and of the moving characters and creatures animated by the programmers.

Answers visualised in Figure 5 indicate that 71% of respondents believe virtual instruments to be a suitable replacement for acoustic ones, provided that they are employed skilfully. Respondents considered virtual instruments essential in education, composition and arrangement, as an aid in preserving the composer's ideas. Digital technology makes it possible for a musical piece's sound and harmony to be heard before it is preformed, e.g. by a live orchestra. Respondents agreed that virtual instrument sound can be used in the final product since they largely resemble traditional instruments in timbre, which also allows for supplementation of acoustic sound in music production.

Several times, respondents raised the issue of using virtual instruments imitating acoustic instruments which are difficult to access in Europe. European music uses characteristic instruments which are partly similar, as evidenced also by music history. Bringing in instruments from other continents often proves excessively costly or impossible, since traditional foreign instruments

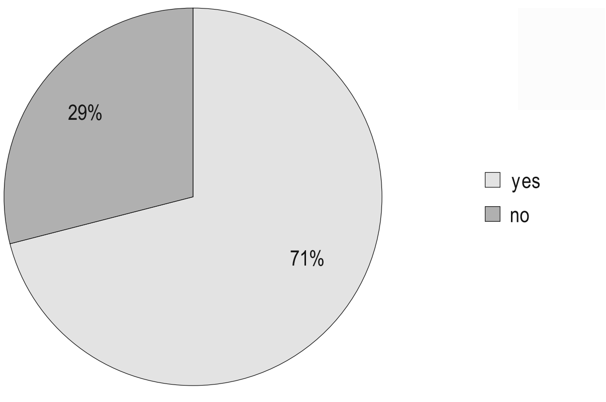

Fig. 5. Do you consider virtual instruments a viable replacement for traditional acoustic instruments? If so, specify how they can be used
Source: own research

may be protected as historical artefacts in their countries of origin. Recording an acoustic instrument *in situ* and representing its characteristics as a digital file accessible worldwide makes the timbre of an instrument located, for instance, in Zimbabwe an asset available for music creators everywhere. Digital technology can overcome certain barriers regarding the use of a varied set of instruments, or learning the sound of such geographically distant instruments in the first place, which provides composers with new sound material for their work.

It is worth noting that digital instruments require a new set of skills than a traditionally trained musician, since producing a sound is entirely different from playing acoustic instruments. A person wishing to learn how to play virtual instruments should know that they offer distinct performance possibilities compared to their acoustic counterparts[14].

Figure 6 confirms that the majority of composers (74%) were interested in broadening their knowledge about the practical applications of virtual instrumentation in their work. An analysis of survey results reveals an age limit determining the responses of the participants. Respondents aged 32–50 were interested in broadening their knowledge about digital music technology. Respondents above the age of 50 were not interested in such pursuits, which was also reflected in answers to other questions regarding similar matters.

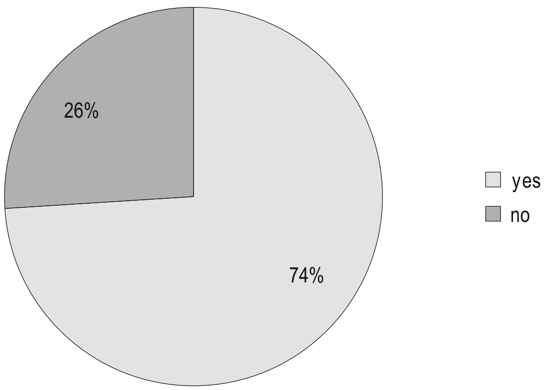

Fig. 6. Are you interested in broadening your knowledge about the practical application of virtual instruments?
Source: own research

[14] A. Pejrolo, R. DeRosa, *Acoustic and MIDI Orchestration for the Contemporary Composer. A Practical Guide to Writing and Sequencing for the Studio Orchestra*, Focal Press, Burlington 2007, pp. 1–26.

The data presented in Figure 7 regards the broadly defined use of music software in composition and arrangement. Responses to the survey reveal that the software suites most commonly used for this purpose are, i.a. Sibelius, Cubase and Finale. Grouping different software suites or using several programmes at once is a deliberate practise by the respondents, since different software may be used for distinct musical purposes.

Figure 8 presents the composers' agreement with the claim that music software improves the creative process (74%). Participants reported that music software's ability to rapidly verify the creative process is especially helpful.

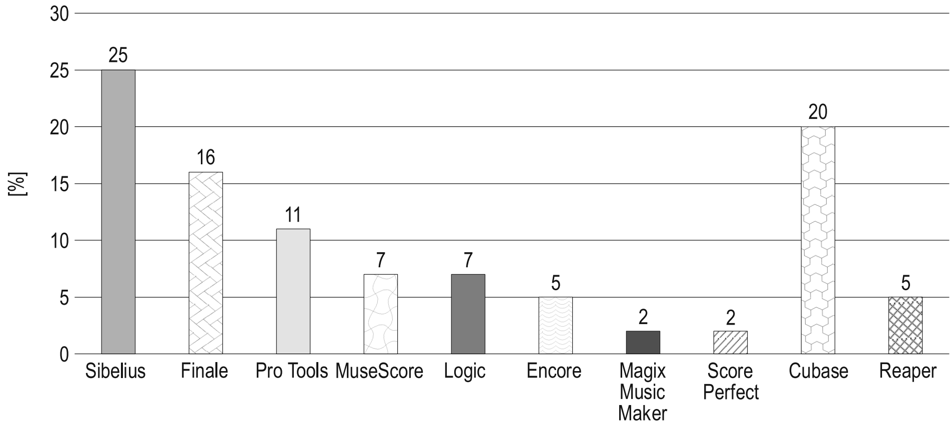

Fig. 7. What music software do you use for composing and arrangement?
Source: own research

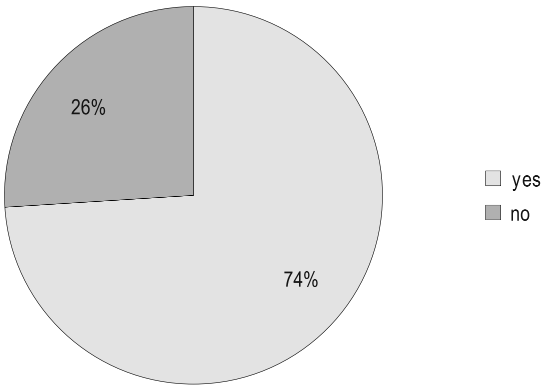

Fig. 8. Do you consider music software an aid to the creative process? If so, in what aspect (please name the software used as such a creative aid)?
Source: own research

Sounds of virtual instruments are an inspiration for creating new compositions, arrangements and experimentation with structure and sound. Programmes used for creative inspiration are presented in Figure 9.

The respondents noted in their answers that, on the one hand, composing is made much easier by the ability to listen to the work in progress with the aid of virtual instruments, and the ability to put down notes quickly. The use of a computer with music software may support a musician's artistic

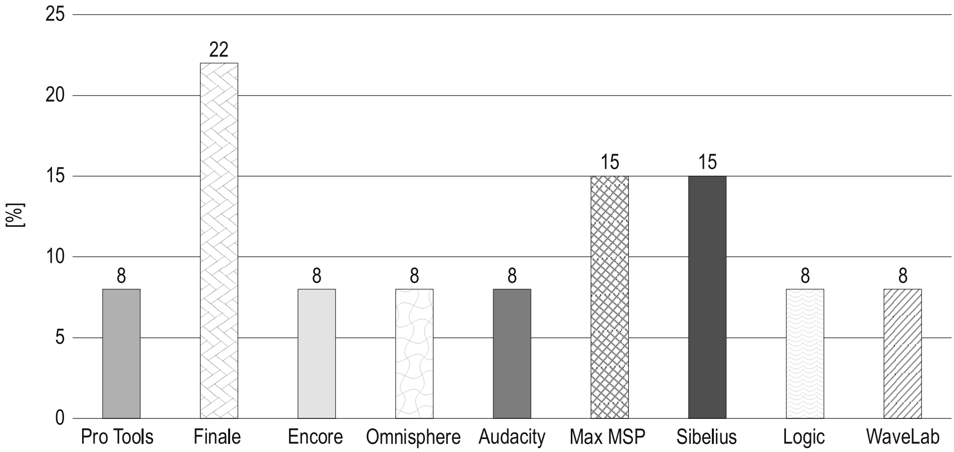

Fig. 9. Software used as aid to the creative process
Source: own research

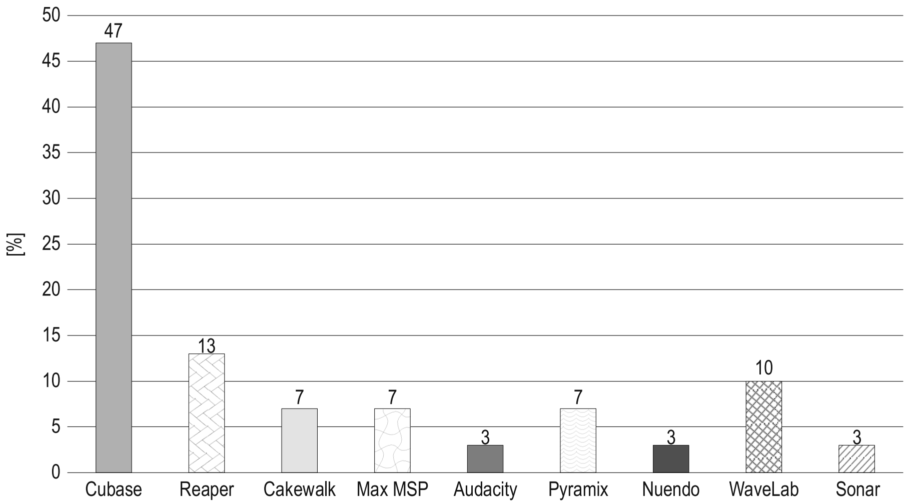

Fig. 10. What music software do you use for music production?
Source: own research

development. On the other hand, using such aids in an improper manner – one that replaces the composer's creativity – does not raise the artistic awareness but is an impediment to creative thinking.

Figure 10 presents the music software used by popular music composers in the music production. According to this data, the most popular suites are Cubase, Reaper and Wavelab.

Responses presented in Figure 11 show that most composers (84%), when asked what type of institution of higher learning they work in, named academies of music. Other respondents gave no answer to this question, as well as subsequent questions regarding teaching, which indicates that those respondents were currently uninvolved in teaching students at institutions of higher learning because they were retired lecturers.

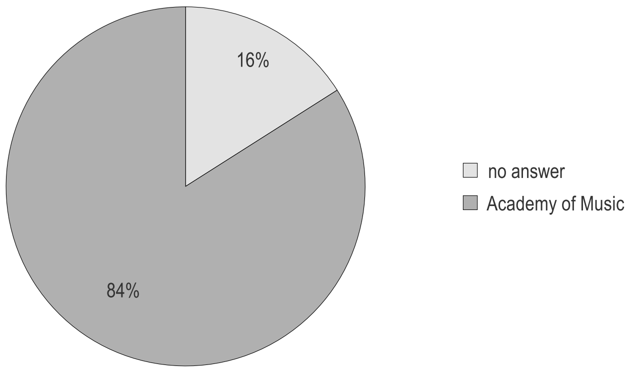

Fig. 11. What type of institution of higher learning do you work in?
Source: own research

Figure 12 presents the percentages of questionnaire responses regarding the use of a computer and music software in teaching at an academic institution. 77% of composers answered that they use a computer in instruction. Respondents indicated that using this tool, supplied with the proper music software, can make the classes more attractive and increase the students' interest in the subject matter. Respondents answering in the affirmative were also the ones who were raised in the times when technological development was a constant element of life and society was developing at a fast rate. People answering in the negative or giving no answer were the ones who did not consider a computer as a needed addition to the teaching process. This is due to the fact that in the times of the most rapid technological development those persons already held their diplomas and worked as academic lecturers and thus did not participate in the digital revolution.

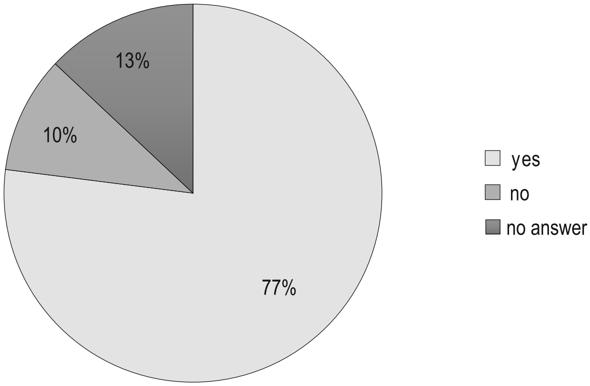

Fig. 12. Do you use a computer with music software in the teaching process?
Source: own research

Figure 13 shows how often a computer was used in the teaching process. 39% of the surveyed composers used a computer in every class. 26% used music software often, whereas 6% used it rarely, and 10% very rarely. Respondents who gave no answer to this question (19%) are persons not currently working at a music school (retired), or ones who do not use a computer at all in their teaching work.

The next question posed to composers in the questionnaire was intended to check whether the teaching aids mentioned facilitate faster acquisition of the material by the students. Respondents replied that these devices stimulate the students' creative awareness and their engagement, while the ability to introduce

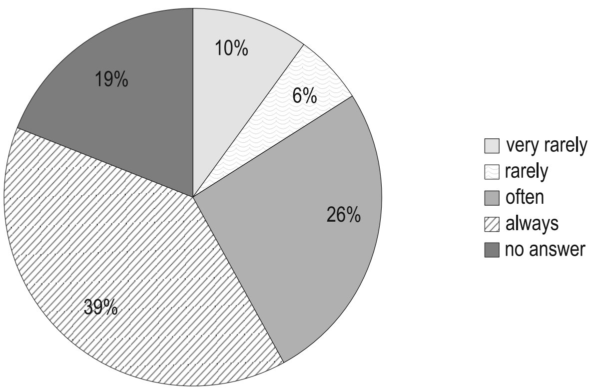

Fig. 13. How often do you use a computer with music software in the teaching process?
Source: own research

corrections live and to hear the results facilitates faster acquisition of teaching material. Students have the ability to hear their compositions and arrangements immediately and to improve their skill at writing music scores, which increases their capabilities in expressing and communicating their ideas. Lecturers also pointed out that while analysing a piece of music a computer offers the ability for slower playback, allowing the students to better analyse the hierarchical structure of the composition and to understand it.

In the case of courses such as "electroacoustics or seminar in 21st century music" it is necessary to use a computer in order to present new digital techniques in composition. The computer also serves as a teaching tool in the course "introduction to mixing and mastering", where it can be used to show the properties of a sound wave in visual form on the screen.

The next question sought to determine which courses at music schools involve music software. Respondents confirmed that computers are used in various courses, such as: "composition, orchestration, composition for film and theatre, electroacoustic composition, arrangement, instrumentation, harmony, counterpoint, introduction to mixing and mastering, seminar in 21st century music, seminar in electroacoustic music, seminar in jazz and popular music, sound engineering, music production, digital recording studio, sound laboratory, digital sound processing, digital sound analysis, musical acoustics, digital technologies in music, sound editing for visual media".

Figure 14 shows the software used by composers to digitise music notation. The main software packages mentioned by respondents are i.a. Finale, Sibelius, MuseScore.

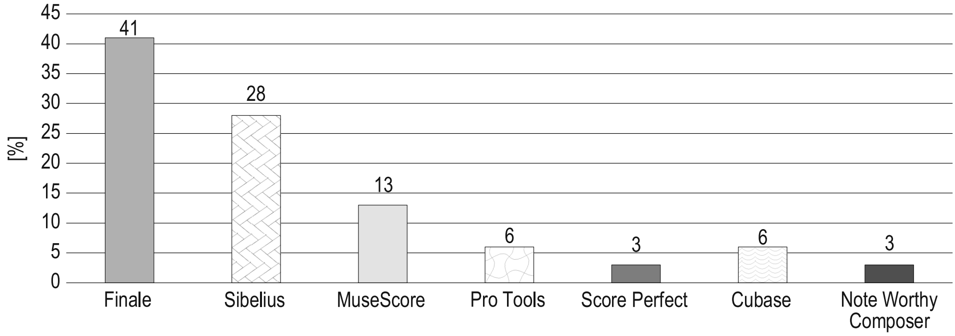

Fig. 14. Do you use music editors for digitising music notation?
If so, which editors do you use?
Source: own research

The final Figure (15) presents the musical purposes beyond composition for which respondents declared using a computer. Results show that such devices are mostly used for music post-production (21%), adding effects (19%), and mixing and mastering recordings (19% each). Respondents also mentioned other uses for music software, such as: testing and grading student work, generating sound effects, creating samples, creating audio-visual presentations, programming mixing consoles and music software development. It is also worth noting the use of a computer as a music player and as an element of live electronics for music creation in concerts.

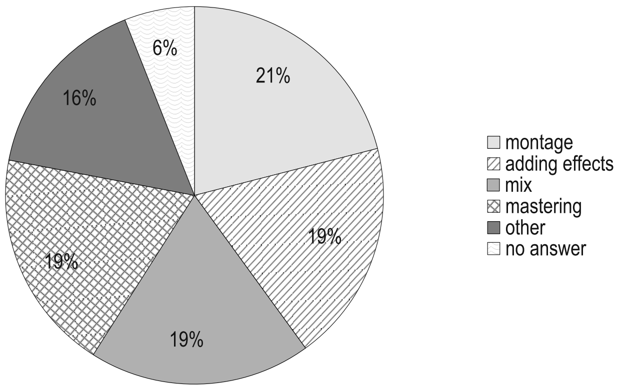

Fig. 15. For what purposes do you use a computer with appropriate music software?
Source: own research

Discussion

Is digital technology needed in music and what purpose should it serve? The need for it is hard to deny in today's technology-dominated world. Does a composer sound surprising when they admit they write their notes manually? Younger artists might ask, why make your life so much harder? Potential audiences are exposed only to the final product and they do not care whether a composer can make traditional notation on a staff. In response to audiences' expectations, composers create ever newer sounds, making their music more innovative, but also more often heeding trends and reception instead of their own compositorial ideas, which is an unfortunate turn in creative development.

An alternative to this dilemma can be found among composers who were formed before computers gained their inextricable hold on everyday life. Most of them have spent long hours imagining the sound of individual instruments or instrumental sections, ruminating, for instance, on the sound of a particular piece played by a philharmonic orchestra in the acoustic environment of a church. Relying on their mind's ear makes a composer receive the final performance as a reflection of their own thoughts. Composing a piece by relying exclusively on the mind's ear is much harder than creating it on the computer, but it also demonstrates a much higher compositorial mastery, which is bolstered by intuition and musical imagination.

Can a computer prove counterproductive in the hands of an inexperienced composer? A less mature musician might be utilising the computer as the only tool for success, which probably indicates that they have not developed musical imagination enough to make music without the aid of a computer. The personal ability to create music is also relevant, since a person who learns composition and arrangement throughout their life develops an independence of thought which is not reliant on any particular software. Probably even an experienced composer will become disaccustomed from proper work with the score if the computer offers them much quicker solutions. Should the number of such poorly trained composers increase, will music not become monotonous, clichéd and derivative from the schema present in the software? Music programmes may be able to impose a schema on the work of such a composer, which, coupled with the fact that many creators use the same software, may lead to factory-like assembly, rather than artistic creation in music.

Experienced composers will not encounter such problems with true creation, since they use the computer only as an expediency, for example, in saving their cores as music notation files so that they look legible in print. Their musical imagination is developed enough that even before writing down their work they know what they mean to achieve and what compositorial techniques they mean to employ to do it. Knowledgeable and sophisticated audiences will be able to verify and discern works which display high compositorial artistry from those created in a mechanical way enabled by digital technologies.

The acoustic space of traditional and virtual instruments

According to various researchers, acoustic space may be defined quite differently depending on the context in which a given acoustic phenomenon is considered, though it is most often associated with the generation of acoustic waves in a particular environment[15]. For the purpose of this paper, acoustic space is construed as a directional characteristic (direction of acoustic wave generation) of an acoustic musical instrument in an external environment.

Each acoustic instrument limits acoustic waves in a thoroughly distinct fashion, as this element is contingent on:

– the material from which the instrument was made,
– the construction of the instrument itself,
– the mode in which the sound is produced,
– space, i.e. the acoustic environment in which the instrument is located (the interior and its type, or whether it is an open area)
– the pitch and volume of the sound emitted by the acoustic instrument[16].

Research carried out by J. Meyer clearly demonstrates that the acoustic space generated by traditional musical instruments is indeed diverse and exceedingly variable in terms of frequency and sound intensity[17]. Acoustic waves from a single instrument can propagate in radically different directions depending on whether, for instance, the instrumentalist plays an identical melody an octave higher or lower, which indicates that:

– acoustic instruments create a specific and unique acoustic space around themselves,
– the acoustic space of traditional instruments is never homogeneous.

Contemporary microphone techniques and technologies enabling the creation of virtual acoustics rely on state-of-the-art microphone techniques and methods of reproducing sounds (samples) by means of varied speaker systems[18].

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15 R. Zawadzki, *Percepcja w przestrzeni dźwiękowej – akustyka, psychoakustyka i psychologia*, "Audiofonologia" 2003, vol. XXIV, p. 17; S. Bernat, *Słowo wstępne*, in: S. Bernat (ed.), *Dźwięk w krajobrazie jako przedmiot badań interdyscyplinarnych. Sound in Landscape as a Subject of Interdisciplinary Research*, Polihymnia, Lublin 2008, p. 7.

16 Cf. J. Meyer, *Akustik und musikalische Aufführungspraxis. Leitfaden für Akustiker, Tonmeister, Musiker, Instrumentenbauer und Architekte*, PPVMedien, Issue 6th, ext. edition, Bergkirchen 2015.

17 Ibidem.

18 Cf. B. Katz, *Mastering Audio. The Art and the Science*, second edition, Focal Press, Amsterdam, Boston 2007; Ballou G., *Audio Engineering Explained – Professional Audio Recording*, Focal Press, Burlington 2010; Cf. G.Ballou, *Electroacustic Devices. Microphones and Loudspeakres*, Focal Press, Amsterdam, Boston 2009; Cf. B. Bartlett, J. Bartlett, *Practical Recording Techniques*, 6th Edition, Focal Press/Taylor & Francis, Waltham 2013; Cf. J.C. Whitaker, B.K. Benson, *Standard Handbook of Audio and Radio Engineering*, McGraw-Hill, New York 2002; Cf. J.C. Whitaker, *Master Handbook of Audio Production*, McGraw-Hill, New York 2003.

However, current technology is not sufficiently advanced to simulate the acoustic space generated, for example, by an acoustic violin, piano or symphony orchestra in an environment such as a concert hall. The capacities of virtual instruments today are expanding as digital technology continually penetrates increasingly into the domain of music. In simulations of various interiors, the patterns of sound reverberation in a particular room can indeed be adjusted[19]; however, the reproduction of such sounds takes place via the medium of a loudspeaker system, which in itself is incapable of emitting sound exactly as a traditional instrument does. If one were to equip a concert hall with a supreme-quality PA system and reproduce a pre-recorded instrumental performance, the devices involved (from the standpoint of physics) would still not achieve the directional characteristics of the acoustic space characteristic of acoustic instruments.

It may be worthwhile to note that virtual instruments can offer an innovative sound experience thanks to digital surround reproduction systems designated as 5.1, 7.1, 10.2, 22.2, 5.1.2, 5.1.4, 7.1.2, 7.1.4, 7.1.6 etc. However, it is not an immaculately faithful emulation of the propagation of acoustic waves from traditional instruments but a kind of prosthesis which, thanks to various psychoacoustic procedures affecting the human brain, can yield various types of spatial representation (also by way of acoustic illusions).

Virtual instruments make it possible to go beyond the routine patterns, e.g. by creating new samples on the basis of recorded sounds – of a guitar, for instance – and their modulation[20]; nonetheless, the resonance of the acoustic box is completely different from the vibration of loudspeakers, which already suggests that sound simulation may be virtually perfect, but the very acoustic space that the instrument produces cannot be fully achieved through loudspeaker-mediated simulation. The digital modification and modelling of the various sound parameters of virtual instruments[21] are designed to make them sound

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19 J. Huopaniemi, M. Karjalainen, V. Välimäki, T. Huotilainen, *Virtual Instruments in Virtual Rooms – A Real-Time Binaural Room Simulation Environment for Physical Models of Musical Instruments*, in: Proceedings of the International Computer Music Conference (ICMC), 1994, pp. 455–462, https://quod.lib.umich.edu/i/icmc/bbp2372.1994?rgn=full+text [accessed: 10.02.2022].

20 Y. Yun, S.H. Cha, *Designing Virtual Instruments for Computer Music*, "International Journal of Multimedia and Ubiquitous Engineering" 2013, vol. 8, no. 5, pp. 173–178.

21 V. Välimäki, T. Takala, *Virtual Musical Instruments – Natural Sound Using Physical Models,* "Organised Sound" 1996, vol. 1, issue 2, pp. 75–86, https://www.researchgate.net/profile/Vesa-Vaelimaeki/publication/231982630_Virtual_musical_instruments_-_Natural_sound_using_physical_models/links/0fcfd50cc24e756655000000/Virtual-musical-instruments-Natural-sound-using-physical-models.pdf [accessed: 16.02.2022].

as similar to acoustic instruments as possible. Numerous composers, students and contemporary music producers take advantage of digital technologies to generate various sounds to a substantial extent and great effect as well, so that even a trained musician may not be able to distinguish the **sound** of a virtual instrument from its acoustic counterpart. However, such aspects apply to phonography (recording) and widely understood popular music, whereas electroacoustic technology today still fails to generate the **acoustic space of a given traditional instrument** (in the context of wave propagation, e.g. in a concert hall). This is an altogether different aspect that tends to be forgotten, but it is worth noting, not in terms of timbre (simulation quality) but where it concerns **acoustics**, i.e. the manner in which acoustic waves propagate in a particular environment. When developing new computer software for the simulation of sounds originating with virtual instruments, an entirely new parameter should be introduced, i.e. the acoustic space, which, as is the case with traditional instruments, should be variable depending on the frequency and intensity of sound. Sound quality (where it involves timbre) relies thoroughly on the analysis of distinct sound characteristics, which do not possess the coverage and counterpart in the analysis of a properly effected acoustic space.

Conclusions

The results of the conducted survey clearly show that a computer with music software aids composers in their creative and teaching, since it allows for a more rapid verification of the creative process. Digital tools also inspire greater interest among students in the process of music creation. A computer with the appropriate music software is employed mainly by the creators of popular and electroacoustic music, since those genres often include the sound of electronic instruments.

Nowadays, lecturers at institutions of higher learning offer classes involving the use of music software, or, in the case of certain specialised courses, teaching the use of a particular software suite. Composers taking part in the survey indicated that the presentation of musical material being discussed in class is more readily comprehended by students if this material is presented with appropriate digital tools.

The survey results clearly revealed that composers of popular music use dedicated music software for composing and arrangement. Apart from composition and arrangement, musicians named many other uses of that software. Most common uses of the computer were: mixing and mastering, postproduction and editing of the musical material and adding sound effects to recordings. Modern artists search for new sounds which can be aided by virtual instruments. Such instruments may become an inspiration for creating downright pioneering sound, works and musical arrangements.

Digital technology, like any other technical aid, brings noticeable benefits if used rationally and sparingly. The computer should not be treated as an overriding tool, but only as assistance to a qualified composer and arranger. The main application of digital technologies is streamlining the work process and making it more efficient through the use of specialised tools. These should, with proper use, contribute in the long term to the development of the user, not relieve them of the need for responsible and creative thinking.

It is not computers and technological advancement that shape the current and future condition of composition, arrangement and academic teaching of music. It is the people, being aware of the drawbacks and benefits of using digital devices, who must learn to use that technology in moderation. Computer technology, composition, arrangement and academic teaching make constant advancements, which is why we must be prepared for traditional teaching methods to be supported by modern technologies, whose purpose is to improve teaching and to stimulate composers and arrangers of popular music to develop their creative work.

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Abstract

Technology, which constantly influences society, is also significant in the work of the composers and arrangers of popular music. This work increasingly involves computers along with dedicated music software. The modern composer is also a music producer and sound engineer, using virtual instruments, music notation editors and digital workstations for music production. This article presents original studies conducted with the participation of Polish composers. The results clearly indicate that contemporary music creation is aided by digital technologies. The application of the computer and computerised devices allows for faster creation of the finished musical product, but can also be a liability to the composer when it becomes an overriding tool, replacing responsibility and creative thinking.

Key words: music, composer, digital art, composition, digital technologies in music.

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The Space of Cultural Communication in the Perspective of the New Humanities

Introduction

The unfolding discussion on the space of musical works in the context of cultural communication was inspired by the new humanities and certain areas of contemporary research addressed by Ryszard Nycz[1]. *A*rt-based research (in Polish: *humanistyka artystyczna*) has proven to be particularly interesting as it uses artworks to form humanistic cognition, transcending the boundaries of language and conceptual rationality. "The world of the new humanities [as] a world of immanence, participation, cognition from within, and participatory knowledge"[2] has prompted us to re-examine a musical work and its existence through a chain of relationships between its creator, performer, and addressee, as well as in the categories of artistic communication. In his analysis of the new humanities, Nycz argues that "engaged humanities are a form of intervention, quite invasive at times, shifting ossified attitudes, forejudgements, and behaviours of a given community or population"[3]. This type of research opposes the notion of impartial, neutral, and objective cognition and perception of artistic phenomena as existing independently of the cognitive act. This concept corresponds to many well-established studies, discoveries, and views, primarily Roman Ingarden's research on the aesthetics and existence of artworks, including works of music. The relevance of his

1 R. Nycz, *Kultura jako czasownik. Sondowanie nowej humanistyki*, Instytut Badań Literackich PAN, Warszawa 2017, p. 19.
2 R. Nycz, op. cit., p. 59.
3 Ibidem.

reflections in today's artistic domain, where the roles of the creator, performer, and addressee are intricately intertwined in the production of new cultural spaces, is impressive.

The space of musical communication – musical communication as space

A musical work in its full existence, entailing the phase of creation, followed by the phases of performance, perception, and reception, constitutes a form of communication. According to McLuhan, who famously said that "the medium is the message", the character of the medium conveys a message or information that can be received and can change culture; thus, the medium is an "extension of man" and therefore a human creation in a technical form[4]. For the purposes of this analysis, let us approach a musical work as a medium of musical communication that carries an artistic and cultural message, considering its creator (composer), performer, and addressee (listener) as participants in this act of communication.

Whenever a musical work is manifested in a sound form that is engraved into the social consciousness, a certain mental, acoustic, and temporal space is isolated and captured in which the work emerges and begins to function as the field where the creator, performer, and addressee interact with each other. These interactions were discussed by Ingarden in his studies on the identity of a musical work as an intentional object[5] that adopts a different form in each of its phases of existence: creation, communication, and reception. While these ideas are not new, I would like to recollect them and highlight their validity in today's processes of artistic communication.

The space of creation opens up a field for a musical work to exist and convey its cultural message. Comprising the conceptual phase, it determines the mysterious stage of the creative process that matures in the composer's imagination and action field. This is the space wherein the work seems the least perceptible before it adopts its material form as a score or performance, despite its idea being evident. At this point, the existence of the work is elusive and puzzling in so far as we do not know its final and comprehensive form that

4 H.M. McLuhan, *Understanding Media. The Extensions of Man*, The MIT Press, New York 1964, p. 10.

5 R. Ingarden, *Utwór muzyczny a sprawa jego tożsamości*, in: *Studia z estetyki*, vol. 2, PWN, Warszawa 1958, pp. 293–294.

is yet to manifest itself as sheet music. This prompts the following questions: Does such a work exist (or not) if it only resides in the composer's imagination? Should we recognise the existence of unfinished works or those only planned? Some of them are vividly present in the musical community where they function as incomplete or unfinished works (e.g., Zygmunt Noskowski's symphonic poem *The Steppe* intended as an introduction to a larger stage work or Franz Schubert's two-movement *Symphony No. 8 in B minor* commonly known as "Unfinished").

Although the work does not have a tangible existence at this point, it continues to adopt its most ideal form, pursuing the unattainable vision of the fanciful until it eventually materialises itself in the real world. Performances of the musical work constantly aspire to reach the composer's ideal but can only approximate it. While the concept phase may not directly represent a part of the actual act of communication (because the work hasn't yet a tangible form), it is critical for its existence. Without the act of creation, the work cannot come into being, and without the work, no communication can take place. Consequently, the space of creation, where the cultural message emerges, determines all subsequent stages of the work's existence. Each performance will necessarily enter into a dialogue with the idea presented by the work's creator. The more the performer (and the addressee) is aware of this interdependency, the more intriguing the process of communication shall be. The conceptual phase makes us reflect on the code employed throughout the message. What language is used by the creator? What are the creator's objectives? What is important for the creator's vision of the work? How do they imagine it? All these questions, albeit hardly new, become even more relevant when we explore their deeper meaning as well as our ability to understand the issues at hand. The spontaneity of the creative process and the characteristic of "unawareness" associated with it, the inspiration understood as the esoteric "lifegiving breath of the spirit"[6], and the following work on the theme represent the dimensions of the space in the work's concept, which form the background and the basis for artistic communication in its entirety.

This space of creation evolves into a creative field of performance where the work is materialised in the real world. This process happens when the work is "committed to paper" (written down as sheet music), where it is essentially still connected with the conceptual phase. However, at this stage, the work enters

6 W. Stróżewski, *O pojęciu inspiracji*, in: W. Stróżewski, *Wokół piękna. Szkice z estetyki*, Univesitas, Kraków 2002, p. 308.

a new space, that of performance, giving room to another person in this chain of communication – the performer (who is sometimes the creator themselves). The role of the performer is suspended between two phases: the creation and communication (presentation) of the message. On the one hand, the performer is a co-creator of the work that brings the message into being, and on the other, the performer conveys the message to the addressee (listener). This complicated role, merging two functions, raises many questions and doubts, but it also reveals a certain potential. The questions that arise here are primarily about the scope or "the field of free interpretation". This phrase was inspired, inter alia, by Jolanta Maćkiewicz's research on the freedom of interpretation, recently discussed not only in terms of aesthetics but also in formal and legal contexts[7]. What is the limit of the autonomy of artistic expression? Does it have limits at all? Do they depend on the performer or the audience? When certain proposals of interpretation are accepted by the audience, they can be concluded as appropriate. However, does this apply to the freedom of creative expression? How faithful should creative expression be to the tradition, and how much can it deviate from it? What do we even understand by tradition? Is it dictated by the composer's vision? If so, how can we then reconstruct the vision of artists who are long gone? Do we really follow the composer's vision in an interpretation, or is an interpretation rather a compilation of visions presented by renowned performers? And the final question is: Does something like a "right", "correct", or even "perfect" interpretation exist? The answer to this question largely depends on what is meant by "right" or "perfect". Do these terms describe the interpretation being closest to the composer's vision, expected by the audience, or pursued and recognised as satisfactory by the performer?

While burying this problem with questions may not be the best strategy, it nonetheless makes sense to ask them as they bring us closer to the essence of the matter at hand. Inasmuch as many elements of reality are relatively open to dispute, the area of interpretation can also be debatable. A lot depends on the adopted perspective, expectations, the awareness of one's choices, and the

7 M. Górski (ed.), *Problem autonomii interpretacyjnej*, in: *Swoboda wypowiedzi twórczej. Standardy krajowe i międzynarodowe*, Woltres Kluwer, Warszawa 2019, p. 247, https://static.profinfo.pl/file/core_products/2019/1/18/291ee1b0ef36afdb92b0eb48e5952246/Swoboda%20wypowiedzi%20art%20-%20profinfo.pdf?view [accessed: 22.04.2022]; J. Maćkiewicz, *Reception and Interpretation, or the (Co-)Creating of Text*, in: *Interpretacje dzieła muzycznego. Teoria i praktyka*, A. Nowak (ed.), Bydgoszcz 2016, pp. 33–56; J. Maćkiewicz, *Jak mówimy o mówieniu, czyli językowy model komunikacji werbalnej*, https://wuwr.pl/jk/article/view/665/642 [accessed: 29.04.2022].

readiness to accept novelty and bold interpretations. One can even risk and say that there are no "right" or "wrong" interpretations but only "acceptable" or "unacceptable" ones because they depend on the performer and the addressee – their knowledge, competence, experience, and creativity[8]. Nevertheless, freedom of choice, however we choose to define it, never absolves us from the responsibility of making these decisions. Following a certain interpretative path will produce certain results.

These are the doubts that artists must face and more or less become aware of. As performers, they approach a work that is "finite", "closed out", and "complete" in terms of the composer's intention, thus requiring its meaning and structure be read in a specific manner. However, this process is always influenced by the filter of the artist's and listener's sensitivity, cultural position, experience, and the situation in which the work is interpreted. These factors influence the interpretation and make the work "open", giving it a new meaning depending on the time and place of interpretation and the person who interprets it. According to Umberto Eco, the aesthetic validity of a work increases in proportion to the number of its possible interpretations, particularly depending on how many aspects it reveals to the addressee and the diversity of reactions it evokes without impairing the work's identity[9].

Performers frequently ask the following questions: How much can I, as a performer, interfere with the idea of the work (which to a certain extent already happens when I undertake to perform it)? How far can I, consciously and intentionally, follow my own ideas, and what do "my own" ideas actually mean? Typically, in classical music, performers interpret musical works by availing themselves of the performances of other artists. Consequently, one can ask how the composer's score is to be approached, particularly when it leaves a wide margin of uncertainty. Even if the score seems extremely "rigid" and unyielding to different interpretations, limited by the composer's relatively specific and precise notation, what does a "precise" notation really mean? How accurate can it be, for example, in terms of performance directions? Can we be confident that we fully understand what Fryderyk Chopin had in mind

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8 J. Maćkiewicz, *Reception and Interpretation, or the (Co-)Creating of Text*, in: *Interpretacje dzieła muzycznego. Teoria i praktyka*, A. Nowak (ed.), Bydgoszcz 2016, pp. 43, 44.

9 U. Eco, *Dzieło otwarte. Forma i nieokreśloność w poetykach* współczesnych, translated into Polish by J. Gałuszka et al., Czytelnik, Warszawa 1973 [all quotations in the text come from the English translation of the book: *The Open Work,* translated by Anna Cancogni, with an introduction by David Robey, Harvard University Press, 1989, p. 3 – translator's note].

when adding the title *Romance. Larghetto* to the second movement of his *Piano Concerto No. 1 in E minor,* Op. 11? How do we understand it today and how did Chopin conceive it? Did he intend it as a reflection of the artist's emotions or only as a performance direction dictated by the interpretation of the tempo and character of music? Or maybe he followed the trends of the period during which he created this concerto, the time of the emerging Romanticism, when the lyrical, melodic, and calm notes came to the foreground, shifting the listener's attention to what was pleasant, spiritual, personal, and intimate? In other cases, the said "field of free interpretation" grows dangerously large when the compositional notation is too sparing, too vague, or uses general terms describing the style, tradition, and convention that were well known in the performance practices of a given epoch.

While it is generally believed that this difficulty applies to early music, we must realise that it is gradually entering today's performance practices too. Pianist Hubert Rutkowski offers thorough insights and detailed knowledge when discussing the performance directions in his interpretations of Mozart's piano music, but not many people are providing answers on how to perform Witold Lutosławski's *soave* (*Chain II*) or Karol Szymanowski's *risvegliando* (in *Calypso* from *Metopes*, Op. 29). Similarly, questions about the interpretative sense of aphorism in Anton Webern's music, particularly the astonishing scale of time and space (how to achieve crescendo and diminuendo on one stationary [standing] note that lasts two seconds?), remain open. These deliberations lead us to Ingarden's concept of places of indeterminacy in a work of art, presented by the Polish philosopher in the 1930s and currently developed by Marcin Poprawski[10]. What are places of indeterminacy? To a greater or lesser extent, they concern all components of music, perhaps with the exclusion of the pitch, although in some cases, even this property cannot be precisely specified in the score (e.g., in places with the *tremolo* articulation or in *glissando* passages). On the one hand, places of indeterminacy leave room for the performer who must decide how to specify these "indetermined" or "unclear" elements during the performance; on the other hand, they reach into the territory reserved for the listener, opening yet another spectrum of possibilities in terms of music reception.

10 R. Ingarden, *Formy poznawania dzieła literackiego*, "Pamiętnik Literacki" 1936, 1/4(33), pp. 163–192), p. 176; M. Poprawski, *Miejsca niedookreślenia dzieła muzycznego*, PTPN, Poznań 2009.

Continuing this discussion on the space of artistic communication, one may wonder whether the performer's task is to merely convey the message. In my opinion, that is not the case. The performer also leaves a mark on the message, fashioning it together with the creator. At this point, the personality of the latter merges with that of the former, producing a unique artistic blend for the listener. As a result, the listener can be puzzled or even at a loss because sometimes the composer and the performer may compete with each other (Who is more important: Ludwig van Beethoven or Anne Sophie Mutter playing his violin concerto? Could it be Herbert von Karajan leading the orchestra?[11] Or maybe Arthur Rubinstein when he plays Beethoven's piano concerto as if conducting it from his position at the piano while looking down, self-importantly and decidedly, on young Bernard Haitink?)[12]. Sometimes the performer is completely devoted to the creator's original vision and blends in entirely, wishing not so much to mark their presence but present the work perfectly and faithfully to the creator's idea and time (e.g., Jordi Savall with Hespèrion XXI[13], Giuliano Carmignola and Sonatori de la Gioiosa Marca[14], and Marcin Świątkiewicz[15]). While listeners may find themselves entangled in the performer's interpretation, their opinions on it may differ. Given their own expectations or even prejudice, they can be guided by critical or hermeneutic reviews. This again prompts a question: How open are they in their reception of the work? How capable are they of perceiving and understanding music as a phenomenon, and how firmly do they stand by their fixed beliefs, rejecting, on principle, everything that is new and preferring to be guided by what they know, like, enjoy, and what they are used to.

11 H. von Karajan, *Ludwig van Beethoven – Violin Concerto DVD 1990*/ Berliner Philharmoniker – Anne-Sophie Mutter/ Recorded 18–24 February 1984/ SVD 46385.

12 *Ludwig van Beethoven, Piano Concerto No. 3 in C minor, Op. 37*, Artur Rubinstein, Concertgebouw Orchestra, Bernard Haitink, 1973, https://www.youtube.com/watch?v=44a2kZ72RzY [accessed: 22.04.2022].

13 Jordi Savall, *Lachrimae Caravaggio (Hespèrion XXI)*, Maguelone Festival 2012, https://www.youtube.com/watch?v=LoK8eTqHzak [accessed: 29.04.2022].

14 *Vivaldi. Concerti della Natura*, Sonatori de la Gioiosa Marca, Giuliano Carmignola, Recorded 11–14 April 1999, Abbazia di Rosazzo, Italy, 2000 Erato Disques, Paris, Warner Music Europe.

15 This is how I remembered Marcin Świątkiewicz's words: "You just have to be a faithful agent [intermediary – translator's note] of music and let it resonate properly", regarding the performance of Johann Sebastian Bach's *The Art of the Fugue* (German: *Die Kunst der Fuge*) at the Actus Humanus Nativitas Festival, Gdańsk, 8 December 2021.

This brief discussion reveals a space that encompasses several fields (zones) of artistic communication: (1) the origin of the message – its formation, creation, and materialisation; (2) the communication (conveyance) of the message, which includes co-creation or even creation; and (3) the reception of the message, related to the other zones through the aspect of co-creation as part of reception and participation based on one's own meanings, feelings, conclusions, and opinions. The aspects of the message creation, co-creation, and reception seem to prevail and are already evident at the stage of composition.

Musical works and communication in the perspective of the new humanities

In his book *Culture as a Verb: Fathoming the New Humanities*, Nycz presents an approach slightly different than the "traditional" or generally accepted approach to art where artworks are perceived as finite creations existing in the ideal world presented to the "unfazed" or detached audience that is of little significance to the work as a historically fixed, never-to-be-altered construct. Nycz proposes to look at art as a phenomenon happening here and now, around us, both within ourselves and outside of us, but never without us – always with us as active co-creators of all artistic communication. This involves taking on and being aware of our shared roles of creators, performers, and addressees. At times, we are more of creators, and other times, more of performers, audiences, or art critics. The meaning of "culture as a verb" cannot be overstated in the present world – it refers to culture as a social phenomenon and a platform for artistic communication, continuously refined both in form and content. It addresses matters crucial for the humankind and stirs imagination as well as a sense of beauty and other senses (sometimes also the nerves). Serving as a reflection of contemporary humans and our emotionality, it speaks to us and about us, frequently using our own language, which it constructs from elements of our everyday life, community, technology, and pace of life. While our own, the language used by contemporary culture can be intricate, disguised in the meanders of the spontaneously created new means of expression. The art of our times speaks our language, yet we, as the audience, frequently see it as foreign. We ask: What is it? What is this piece, painting, or play about? We are surprised, but we should not be. It is our language even if we are not always able to understand it. In his book *Orality and Literacy*, Walter Ong shows how the language of artistic communication changes along with the development and popularisation of new forms of universal communication – the written word, print, and digital technology[16]. Our sensitivity is increasingly becoming intellectual and less emotional. Art is experienced through associations and symbolism of verbal texts. While we are capable of receiving, and most likely also decoding, large quantities of data simultaneously, our ancestors from the Renaissance or Baroque period would not be able to do the same.

Art-based research. Inclusive culture

Artistic communication plays a critical role in the study of the human condition. Nycz highlights the emergence of the new branches in the contemporary humanities. In addition to digital humanities (and digital humanities laboratories), engaged humanities (engaged socially, politically, and economically), cognitive humanities (knowledge exchange with natural science and exact sciences), and posthumanism (the study of human relationships with natural and cultural environments), he distinguishes art-based research "covering both the humanities of the artistic tools and practices, as well as art as a research-based cultural practice"[17]. According to this approach, fine arts, literature, and other artistic practices are no longer just subjects of humanistic research but are emerging as its components and turning into research areas themselves. Art-based research, or research using art as its narrative, includes humanistic explorations "through art" and studies of relationships between different research fields and cultural practices. As Nycz observes, "it combines […] approaches based on engagement in social problems with action-oriented research in social sciences and various forms of art (narrative, performative, visual). Artistic experiments are treated as a way towards humanistic cognition – one that extends beyond the boundaries of the language and conceptual rationality"[18]. Nycz argues that art-based research provides an opportunity to broaden the boundaries of cognition and deepen our knowledge about the human forms of understanding, feeling, acting, and "the affective foundations of the community ties"[19]. The affective orientation of art-based research was also

16 W.J. Ong, *Oralność i piśmienność. Słowo poddane technologii*, Communicare, Wydawnictwa Uniwersytetu Warszawskiego, Warszawa 2011, p. 131.
17 R. Nycz, op. cit., p. 43.
18 R. Nycz, op. cit., p. 50.
19 Ibidem.

addressed by Susan Langer in *Feeling and Form. A Theory of Art*[20]. Although published many years ago, her pioneering work remains valid to this day and discusses extremely resonant issues such as the musical matrix, image of time, living works, and the measure of ideas. They can inspire this sphere of research, guiding it towards the vision of art as a phenomenon that exists and functions in the specific dimensions of time and space.

Shifting priorities: Artwork as a construct open to new interpretations

How can a work of art be defined in the context of the new humanities? To answer this, we must change our priorities and shift the emphasis from the artwork as such to its presence and materialisation – as discussed at great length by Eco in relation to his concept of the open work[21]. According to him, the openness of artworks lies within their very nature. Whenever an artwork is released into the cultural community, it goes through its subsequent presentations and is reviewed upon each reception, gaining new meanings, complementing the previous ones, defining and redefining them, and transforming itself into a representation of new values. While certain artworks are more open at the time of their execution, according to Eco, all artworks are open. This observation applies, for example, to aleatoric music where certain components can be controlled by the performer or even the listener, e.g., Stockhausen's *Klavierstück XI*, known for its mobile or polyvalent structure, in which the performer can determine the order in which the 19 fragments of the composition are to be played, or Serocki's *A piacere*, which uses a similar idea and introduces the concept of open form by instructing the performer to proceed with the work's segments and structures *a piacere* (Italian for "as preferred" or "at one's own discretion").

The openness of a work can be defined by the diversity of meanings it carries – their multitude, multidimensionality, timeliness, and freshness. It is not dependent on the type of composition but on interpretation proposals for the cultural text. Rather than serving as finite or specific messages, artworks provide an opportunity to create different forms, depending on the performer's initiative and vision. Certain types of art promote active contact with it. Dynamic forms,

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20 Ibidem.

21 U. Eco, op. cit., pp. 23–27.

seeking indeterminacy and escaping explicit definitions particularly stand up to this challenge, offering many options of interpretations. Baroque forms, based on the contrast between solid and void, light and darkness, etc., with the crossing musical planes (vocal *versus* instrumental), flexible melodic lines, and rapidly changing rhythm and harmonics, encourage musical freedom and the opening or dilation of the sound space. New forms are discovered by focusing on the action and polysemy of works, with emphasis shifted from the creator – work relationship to the work – addressee relationship. According to Eco, "if Baroque spirituality is to be seen as the first clear manifestation of modern culture and sensitivity, it is because here, for the first time, man opts out of the canon of authorised responses and finds that he is faced (both in art and in science) by a world in a fluid state which requires corresponding creativity on his part"[22].

Discovering various interpretation options for each cultural text seems to be our obligation. Listeners are waiting for new approaches to musical works, which become possible as performance styles evolve – through modifications, new meanings, and creative definitions and redefinitions of the musical text. Given the multitude of possible sound concretisations, the work can be constantly made anew in the action-oriented context of "culture as a verb", where it is treated as an ever-evolving construct inscribed in the process of action. Eco argues that the validity of a work is determined by its openness, which to a large extent depends on listeners who apply their new understanding to the work, determine its reception, accept or reject the work, and consequently create a specific space for its existence: "This is all the more true of poetic works that are deliberately based on suggestiveness, since the text sets out to stimulate the private world of the addressee so that he can draw from inside himself some deeper response that mirrors the subtler resonances underlying the text"[23].

The subsequent interpretations of a work add new meanings to its reception and reveal its new contents. As already mentioned, there are works that encourage such activity. Using illusion, intrinsically dynamic and suggestive of secrets and other-than-reality content, they seem to be naturally open to different meanings. These are frequently the features of the Baroque and Romantic music, which make the works conducive to various interpretations. Following Eco's inspiring voice, we can find many relevant

22 U. Eco, op. cit., p. 8.
23 Ibidem, p. 9.

examples. The vision of the poetry of indefinite or vague meaning (Novalis), characteristic of Romanticism, resulted in many interpretation options, adding multidimensionality to works from that period. The symbolism in Stéphane Mallarmé's poetry, the mysterious prose of Franz Kafka and James Joyce, the plays of Stanisław Wyspiański and Stanisław Ignacy Witkiewicz (Witkacy), based on the interplay of symbols and multidimensional meanings, have particularly triggered works to open themselves to multiple interpretations. Eco uses the concept of "works in motion" or "works in movement" (Italian: *opere in movimento*) to denote music whose compositional foundations shift from what is finite and definite. This idea is anticipated in Mallarmé's *The Book* (French: *Livre*), aspiring to the vision of a total work that seeks to capture the infinite. It is also employed in Julio Cortázar's *Hopscotch* (Spanish: *Rayuela*), whose readers are presented with "blocks" that they need to assemble, thus co-creating the novel with the author. The concept may also be found in visual arts, for example, in Alexander Calder's *mobiles*, innovative type of sculptures propelled into motion by the movements of air (kinetic art).

Finally, it can be found in musical compositions inspired by the already mentioned aleatorism such as Henri Pousseur's *Scambi*[24], where there is an explicit invitation to exercise choice as certain segments of the work are to be linked by the performer, and possibly by the listener too, in their preferred order. This results in the shape of the work constantly changing and produces a different sound image with each performance. *Scambi* is an electronic work with a mobile structure. In fact, the listener and the performer do not as much determine the order of the respective sections, but they essentially create their own musical version of the piece. The composition consists of 16 pairs of segments referred to as "layers" by the composer. The layers form the basic links of the composition and can be assembled in various ways. Pousseur's original idea was to provide listeners with the layers recorded separately (when the work was completed in the 1950s, they would be released as separate reels of tape) so that they could "assemble" their own version of the composition. Each listener would also become a performer of the work as well as its creator, collaborating with the composer in the making of music based on the previously supplied ready-made layers.

The poetics of the open work pertains to the inspiration of "acts of conscious freedom" in performers who are placed "at the focal point of a network

[24] U. Eco, op. cit., p. 12.

of limitless interrelations”[25], to which they give the shape of their own choosing. A similar focus on the subjectivity of interpretations emerged much earlier in history. For example, Vitruvius made a distinction between “symmetry” and “eurythmy” defined as “an adjustment of objective proportions to the requirements of a subjective vision”[26]. These ideas were further pursued by Leonardo da Vinci in his research on the aerial and colour perspective. The Baroque inspired interest not so much in the essence as in the sphere of the phenomenon while setting the future directions for the development of sensualism and empiricism. The ambiguity of perception was also postulated by phenomenology. According to Edmund Husserl, “each state of consciousness implies the existence of a horizon which varies with the modification of its connections together with other states”[27]. According to Eco, the most perfect example of how the poetics of the open work encourages “acts of conscious freedom” is *Ulysses* by James Joyce. It is “an image of the ontological and existential situation of the contemporary world”; it has “all the richness of the cosmos itself” as “the author intends his book to imply the totality of space and time, of all spaces and all times that are possible”[28].

Similar tendencies can be observed in the music by certain contemporary artists. Their intention is to create a specific sound space of a musical work, free from any familiar logical sequences. They enable listeners to move freely in the sound sphere of such music, allowing them to pursue their preferred trajectory of sounds during their listening experience and without imposing the composer’s logic on their perception of music. Examples of this compositional approach include works by Aleksander Kościów (*Lithaniae*) and Andrzej Karałow (*Trajectory of Green*). They encourage us to consciously create our own sound image and be mindful of certain aspects of the composition while listening, depending on individual preferences. Some will say that the reception of a work always includes, to a greater or lesser extent, the individual interpretation of its form, structure, and sound; however, in this case, it is the composer’s intention to strive, consciously and consistently, to create a work of such form and arrangement that will enable free perception and perhaps even liberate listeners otherwise unfamiliar with this type of music reception.

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25 U. Eco, op. cit., p. 4.

26 Ibidem, p. 5.

27 E. Husserl, *Méditations cartésiennes*, Librairie Vrin, Paris 1953, in: U. Eco, op. cit., p. 16.

28 U. Eco, op. cit., p. 10.

Extension of the interpretation field

While it is hardly a formal rule, interpretation is generally expected to be insightful and original. This approach has been instilled into us by practitioners of the historically informed performance (HIP). The creativity of historical performers in their constant pursuit of new, undiscovered, and fascinating works is extraordinary, if not fearless at times. The features of the increasingly popular HIP movement include sensitivity to the quality of the performance, faithfulness to the tenet and the creative and performance style of the musical era in which a work was originally conceived, incorporation of the contemporary spirit, and the placing of oneself behind the music that has the leading voice. They are evident in the spontaneous and colourful interpretations of Jean Rondeau (Baroque harpsichord music), Agnieszka Budzińska-Bennett (music of the early Middle Ages), and Philippe Jaroussky (unknown Baroque arias). Numerous festivals of early music, dynamically gaining recognition in recent years also in Poland, such as the Misteria Paschalia Festival in Cracow, Actus Humanus in Gdańsk, and Music in Paradise Festival in Paradyż, artistic ensembles like Och! Orkiestra, bold performance ideas combining Baroque music with jazz improvisations (L'Arpeggiata founded and led by Christina Pluhar), and recordings of forgotten music (Philippe Jaroussky's albums with Antonio Vivaldi's sacred works[29] and the forgotten works by the opera and oratorio master Antonio Caldara[30]) build a fascinating interpretation field that encourages an ambitious dialogue. In fact, everyone who undertakes to perform early music tries to develop, in the most informed manner possible, their own interpretation strategy to ensure that what they communicate remains valuable and in line with the expectations of connoisseurs of such music.

The experiences of historical performers have undoubtedly had a significant effect on other performance areas and on the broadly defined interpretative awareness. This is largely due to the advancement of mass media and increasing access to digital technology, both of which drive this relationship of mutual influences. They proved to be even more important during the COVID-19 pandemic, when culture, including music, became more accessible online, with many performances recorded and shared by internet users. Previously, works

29 *Vivaldi. Pietà. Sacred Works for Alto*, Philippe Jaroussky, *Ensemble Artaserse*, Erato Paris 2014, CD.

30 *Caldara in Vienna (Forgotten Castrato Arias)*, Philippe Jaroussky, Emmanuelle Haim, Concerto Köln, Virgin Classic 2010, CD.

performed during festivals and concerts would typically disappear without a trace and were accessible almost exclusively to those who physically attended the concert or performance.

The extension of the interpretation field involves putting more emphasis on the role of the addressee participating in the work's execution and reception. More experienced, liberated from the shackles of customs, habits, and prejudices telling them to accept only well-known works and familiar performances, the new audiences are emerging, filled with new expectations from performers and the anticipation of novel artistic message. In this context, performers play a critical role as those responsible for the development (build-up) of listeners' expectations through ambitious projects.

The key to interpretation as the essence of communication

Each proposal for the execution of a work essentially requires finding a key to its interpretation. It guarantees clear communication from the performer about the interpretative path they are going to pursue. Communicating this path – for example, by providing the necessary information before the concert – certainly helps better prepare the audience for its reception and creates a new environment for interpretation.

The creation and usage of the same system of values, or "a platform of common meanings", by both parties in the communication process is, according to Wiesław Łukaszewski, a guarantee of mutual understanding, and as such, it lays the foundations for effective communication. However, it is hardly an easy process because the language we use varies depending on the topic, person, and context[31]. Łukaszewski cites Herbert Paul Grice and his four principles of effective communication (Gricean maxims): (1) quantity – communicate only as much as is necessary; (2) quality – stick to the facts, make your message genuine, clear, and transparent; (3) relevance – avoid changing the meaning of communication as well as digressions; and (4) clarity – avoid redundancy, prolixity, and obscurity of expression[32].

How can these four areas be articulated in musical communication? First, the maxim of quantity may correspond to the sparing use of the execution techniques, their consistency, and similarity of structure (e.g., the articulatory precision in the performance of uniform *staccato* sounds). Second, the principle

31 W. Łukaszewski, *Niewielka suma szczęścia*, Smak Słowa, Warszawa 2020, p. 23.
32 W. Łukaszewski, op. cit., pp. 23, 24.

of quality is essentially reflected in compliance with the score and with what is communicated by the composer. Third, relevance is a condition that completes the previous point; it can be also associated with the compatibility of style. Last but not least, the maxim of clarity becomes particularly important in the case of "oversentimental", "exaggerated", "overdone" performances, stylistically and content-wise incoherent, spoilt by mannerism and incompatible with a given type of work or composer's oeuvre.

Łukaszewski points out that in the world of everyday communication, the four principles are rarely respected individually and hardly ever all at once. The problem lies not only in the communication quality or the system of meanings but also in the motivations of both the sender (originator) and receiver (addressee). One has to not only be able to communicate with another person but also want to do it, which not always goes together[33]. Striving towards effective communication and a readiness to communicate effectively resembles the construction of hermeneutic bridges – finding ways to reach out, relate to each other, and establish a rapport with the addressee. It also involves taking responsibility for this rather difficult process as well as its success or failure.

Cognition through interpretation

In the past, one of the ways to acquire knowledge and understanding of a musical work was to copy it. This is how Johann Sebastian Bach, just like many other apprentices of the trade, learnt the secrets of composing. Another invaluable source of insight into music is its performance – one needs to develop a close relationship with a piece and work with it to "permeate" its structure and internal space. It could be argued that no one knows a work better than its composer and performer, both of whom must explore the deepest layers of music. What does this interpretation-based cognition through performance look like? One can compare it to reading for the purpose of gaining knowledge about literature (in contrast, such a far-fetched symbiosis is probably impossible with paintings). Similar to musical works that can be performed, architecture also facilitates contact with the addressee by offering access to the designed space, encouraging its exploration and experiencing. The concept of active listening and mindful reception of musical works seems to correspond to concepts of reading written texts, or indeed any cultural texts, analysed by Ryszard Nycz,

33 W. Łukaszewski, op. cit., p. 24.

who emphasises the critical role of reading for the understanding of any work. He employs the term "reading" as an analytical "metacategory" that "highlights the processuality (rather than the result), partiality, and aspectivity (rather than the finality or finiteness), the activity of the subject as a condition for activating the meaning (through participation rather than contemplation or observation), as well as the relational and interactive character of the meaning (rather than the meaning as a specific sense secured or implied in the text)"[34].

This approach taps into and accentuates the creative demands long known in the world of art. For instance, Paul Valéry argued that a work does not have one "true" meaning "assigned" to it "in advance": "Il n'y a pas de vrai sens d'un texte"[35]. The poetic freedom should be able to express itself as pure poetry (Paul Verlaine) and create equivocal symbols such as those abundant, for example, in works by Mallarmé or Kafka[36]. These statements correspond to the multi-level and multi-sensory nature of many contemporary works of music. In Ignacy Zalewski's *Symphony in Memory of Dominik Połoński* (2019), one can capture the elements of the late cellist's musical and sound portrait composed of quotations from Brahms' sonatas as well as references to Połoński's cello playing technique and specific features of great symphony music (Beethoven's ideological sphere and instrumentation, Romantic narration evoking the theme of passing and death, etc.).

When studying a work through its interpretation (whether by reading a literary text or performing a musical text), both the subject and text occupy the same space. They are the agents of the work, partake in the same cultural space, and are no longer placed "on opposite sides of the cognition barricade" like in the past[37]. Reading emerges as "the carrier of the meaning and a medium of participatory cultural cognition"[38]. Reading music, defined literally as studying the score and symbolically as analysing its structures and meanings when listening to and talking about music performances, was also discussed during a series of meetings entitled "Czytanie muzyki – rozmowy otwarte" [Reading Music – Open Talks], held by the Institute of Theatre and Media Arts of the Adam Mickiewicz University in Poznań in 2021[39]. In his *Notes on*

34 R. Nycz, op. cit., p. 58.
35 U. Eco, op. cit., p. 9.
36 Ibidem, pp. 8, 9.
37 R. Nycz, op. cit., p. 58.
38 Ibidem, p. 58.
39 *Czytanie muzyki – rozmowy otwarte. Rozmowa 1 – dr hab. Szymon Paczkowski, prof. UW. Wokół pasji Bachowskich*, 30.03.2021, Instytut Teatru i Sztuki Mediów,

Chopin, André Gide invites readers to re-evaluate the meanings of Chopin's music through a mindful reflection and careful study of his compositions[40].

Among all arts, music has arguably the greatest power to connect with and include audiences as it requires, for its existence and reception, participation in an actual performance situation and a complete commitment to listening. The performance scenario is crucial for the existence of music as it determines the interactive space for the process of musical communication. It is a specific space – nowadays typically a concert hall, an entertainment venue, or simply a place where music is played and listened to – where a musical work comes into being material form, is co-created by the performer, and has its meaning created by listeners as active addressees of culture. The specificity of the space where a musical work is to exist, communicate and be communicated, along with its impact, is not without significance for creators. It shapes their artistic attitudes and inspires their composing choices. Consequently, it is this vibrant, dynamic, and energetic space enabling creative encounters, experiences, and sensations that we should appreciate as the actual stage of contemporary, inclusive culture based on action rather than impassive continuance.

Conclusion

The openness of a work inscribed in its structure from the outset of the work's existence, the freedom of reception releasing a great degree of interpretative imagination in listeners and viewers, and the cooperation of all potential participants in the artistic process, from the creator to the performer and the addressee, result in a field of possibilities where artworks of our time are realised. Immersed in the music of the past and present, we continue to experience the musical history of the past 2,000 years or so, claiming to be so familiar with it that we usurp the right to interpret very distant epochs and their perception of music through our 21st-century sensitivity and filters. We propel the processuality of art and participate in its vibrant dynamics and action, with the new humanities emerging as a world of immanence, cognition from within, and participatory knowledge. The words of Kirsten Hastrup, also

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http://dramat-itism.home.amu.edu.pl/czytanie-muzyki-rozmowy-otwarte/ [accessed: 22.04.2022].

40 A. Gide, *Notatki o Chopinie*, Astraia, Warszawa 2007, pp. 19, 20.

quoted by Nycz, can serve as a testimony to this process: "There is no way to get through to the essence of the reality without becoming a part of it"[41].

The separation of the addressee from the creator and performer appears to have taken place only in the 20th century with the emergence of the élite and individually oriented reception of art in philharmonic halls and opera houses. Previously, participation in culture and art was a natural phenomenon. Shakespeare's theatre enabled viewers to watch the actors from all sides due to a centrally located stage and a circular arena for the audience. In the 17th-century oratorios and *drammi per musica*, performers and viewers participated in the artistic event on nearly equal terms, and the creation of art involved a common exchange, experience, and celebration. The Romantic music parlour would place listeners close to performers, allowing them to create and receive music nearly simultaneously. It is only our contemporary focus on creating stars rather than art itself that has introduced this artificial divide. Accordingly, the current trends in art-based research show that it is time to abandon this privileged position and once again enjoy the beauty of art that is created through shared feelings, common understanding, and collective contribution to the artistic world.

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41 R. Nycz, op. cit., p. 59.

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Abstract

In my discussion on the space of musical communication, I refer to selected areas of the new humanities, particularly Ryszard Nycz's studies *Kultura jako czasownik.* Sondowanie nowej humanistyki [Culture as a Verb: Fathoming the New Humanities]. My reflections concentrate on art-based research that perceives artworks as objects of cognition and artistic experiments as a way to form humanistic cognition, transcending the boundaries of language and conceptual rationality. The world of the new humanities is emerging as a world of immanence, participation, cognition from within, and participatory knowledge. According to Nycz, reading, listening to music, and viewing images as processes of mediated organisation of the subject – object relationships are becoming carriers of the meaning and a medium for participatory cultural knowledge. How does it apply to music research? How can this perspective be used to study music? These are the fundamental questions that I address in my article.

Key words: communication, musical work, interpretation.

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Fixing Music: Aesthetic and Cultural Background of Recording Technologies Development

One of basic assumptions in contemporary research of culture is the integral and complementary nature of cultural systems. Considering the dynamics of processes taking place in the social space, it is more reasonable to use the neutral category of change than the evaluative concept of progress. On the other hand, breakthrough technologies, such as the popularization of printing in modern ages, entail such extensive changes that it is impossible to avoid a value-based approach[1].

Hence the interdisciplinary studies that also manifests itself in research of contemporary culture – the same phenomena should be perceived in context-evaluative or descriptive-analytical perspectives. Such cases include the invention of voice communication and sound recording, which became a breakthrough comparable to the invention of printing. It has been technologically improved in the course of over a hundred years and has taken new forms leading to global changes in culture.

Treated as a symbolic beginning of a new era in culture, the date of the invention of the phonograph by Thomas Edison is only an approximate

1 The broader analysis of this concept I presented in the paper *Dynamics of Culture*. In the same article, I treat the processing and storage of information as a result of a technological leap and the basis for further civilization changes, which I intend to refer to also in assumptions to this chapter. K.D. Szatrawski, *Dynamika kultury. Od quasi-naturalnej indywidualności do cywilizacji mas*, "Humanistyka i Przyrodoznawstwo" 2006, no. 12, 2006, pp. 180, 181.

beginning of changes. The idea of fixing the sound in its physical representation was embodied by Édouard-Léon Scott de Martinville in series of experiments with graphical tracing of various sounds in 1853 or 1854. In early 1957 he introduced first instrument recording the voice as visual trace of vibrations, called by inventor "phonoautograph". Later the same year his invention was patented. As it has been noted by Patrick Feaster, "even though Scott recorded sounds for visual apprehension rather than for playback, the subjects he chose and the ambitions he expressed bear a striking resemblance to those we associate with later phonographic practice"[2]. The idea of graphical representation of sound which was understood as vibrations paved the way for inventions of devices based on the transmission of electric vibrations.

In 1876 Alexander Graham Bell patented electromagnetic telephone based on *amplitude modulation*. This was just the first working construction of an electromagnetic telephone (gr: distant voice) but the idea of remote communication had spread decades earlier. It is worth remembering that the basic idea for both telephone and phonograph was the physical characteristics of sound waves and its history was built on attempts to improve the telegraph. The development of telephony was supported by the emerging economic and financial structures, it was an innovation accelerating the flow of information and in many situations replacing the correspondence that lasted much longer. In the last decade of the 19th century there was no audience wide enough to create appliances for music recording and reproduction.

The idea of voice communication was considered a priority to such an extent that the inventor himself treated the phonograph as a device that allows recording telephone conversations. The development of telephony was supported by the emerging economic and financial structures, it was an innovation accelerating the flow of information and in many situations replacing the correspondence that lasted much longer. Many ideas of technical solution have been met in first working phonograph patented in 1877 by Thomas Alva Edison. The recordings were made on a cylinder 4 inches in diameter and 4 inches long, in which a tin foil was applied over the prepared groove. The recording was based on a trace pressed on foil perpendicular to the cylinder (vertical-cut), which corresponded to the frequency and amplitude of the sound transmitted through the tube, diaphragm and stylus. Inventor initially treated the device as a prototype of dictating machine and the phonograph

2 P. Feaster, *Édouard-Léon Scott de Martinville. An Annotated Discography,* "RSC Journal" 2010, vol. XLI, p. 43.

was initially improved from this point of view, for example, in 1888 Edison introduced the new version with stable electric propulsion and a wax cylinder. New improvements allowing erasing the record were used. In the first decades, however, main focus was still on human speech and documentary recordings and the device was intended mainly for office use.

The first commercial successes showed that the commercial potential of audio recordings relies more on the mass audience than on the richer but less numerous business addressees. In 1890, the first nickel per play jukebox was installed at the Palais Royal Saloon in San Francisco, grossing over $ 1,000 in six months. Edison was cautious about the musical possibilities of sound recording, but in fact this was the application chosen by the users. The production of duplicate Edison rollers on a larger scale, which began in 1901, was a response to user demand. At the same time, competing companies proposed cheaper and cheaper playback devices, which increased the sales volume of rollers and discs. Marches and Tin Pan Alley songs were sold alongside classical music[3].

Recording technologies and, consequently, the recording industry from its very beginning have a double function assumption. They were created from inventions corresponding to communication needs, and only when they appeared in the social context, they begin to operate as an element consolidating collective memory. In 1888, ten years after the first phonograph recordings, Edison recorded 12-years old Polish pianist Józef Hofman. As a result, this recording was recognized as the first recording of artist known by name[4], although it did not strengthen the position of Edison's invention. In the same year, Emile Berliner introduced a new sound reproduction technology, who patented a gramophone using a flat plate with a spiral groove instead of the previous cylinder[5]. Emile Berliner's lateral-cut disc introduced to market in 1889, was first flat disc what created more space for future mass production. It was still far from standard. In 1905 brothers Pathé tried to establish their own standard with vertical cut grow resemble to cut of first cylinders of Edison's phonograph. First Berliner's disks were one-side and had 5 inches diameter with speed of rotation 30 rpm. In 1890's records had 7 inches and both sides were used.

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3 R.J. Burgess, *The History of Music Production*, Oxford University Press, Oxford 2014, p. 11.

4 M. Kominek, *Zaczęło się od fonografu…*, PWM, Kraków 1986, p. 37.

5 Edison experimented also with flat plate recording device, as this kind of media was also mentioned in patented idea, but change of relative speed as the needle approaches the center of the record were causing an audible drop in quality, so he gave up the idea.

Around 1910 most common musical production was placed on 10-inch disks which were able to fit 3 minutes of recording on every side. Various sizes and speed variants were in use to omit material limitations. Although three-minutes time limit was enough for most of popular songs, it was a serious limitation in case of classical music. The new solutions resulted in better sound quality and allowed more content and flexibility for the mass production of gramophone records, which in 20th century became basic technology for developing home listening culture. In next decades records were also main resource of music played in radio programs. Although in the first decades the radio broadcast was based mainly on live performances, the quality development of the gramophone plate led to a situation in which the record became the main source of broadcast music.

For this to happen, it has to be formed new patterns of behavior and a change in awareness about the function of music. In the era of industrialization all the cultural processes were subordinate to values accepted by wide groups of society. The lifestyle of the main social groups determined the space music was functioning. Any change in these structures could occur only when accepted by wide groups of society. In the case of the development of phonography, the shift was clear and promising further development. The only weak point was its narrow social range, which was not enough to generate social change. This become possible with next development in mass communication. As telegraph and telephone were in business use, radio based on electromagnetic waves discovered by Heinrich Hertz in 1886 and 1890's experiments with "wireless telegraph" by Guglielmo Marconi, gave new perspective for audio technologies.

New medium was called "radio" for radius propagation of electromagnetic signal. First spoken words and music sounds translation took place in Brant Rock, Massachusetts in December 1906. It started as technical solution for business applications, like one of early scheduled radio stations operated by Amsterdam Stock Exchange which was established for fast information spreading. In first years of the radio, content basis was spoken word, and music played secondary role. Bit by bit radio created new behavioral attitude of its listeners. Between the wars in 1920's and 1930's together with gramophone records, radio become new phenomenon in popular culture.

It is hard to point exact moment when recording technologies created quality change in musical culture. The process was so complex that its effects appeared not only in the interwar period, but far consequences were creating the whole current of postwar changes in musical culture and are still present in 21st

century. Along with technological advancement copies of recordings became cheaper and the quality of the sound improved this was enough for creating new labels and to expand catalogues. In last decade of 19th century classical music was already published and collected. This was just the beginning of new tendency. In 1898 Joseph Berliner (brother of Emile) launched in Hannover Gramophone Co., the first independent record pressing plant[6]. Gramophone records were produced in Europe (recording and pressing) spreading the culture of listening mechanical music for many countries – in 1899 it has operating branches in Germany, Russia, Austria, France and Spain. In 1900 catalogue of Gramophone Co. lists 5000 titles. The label put a lot of emphasis on the production of records with classical music – clearly differentiating the European market from production coming from the American companies[7].

Significant role in this success played new method of matrix production. In Berliner's Technology, zinc matrices were digested with acid, what made the walls of the grooves rough what causes high noise level. The improved Eldridge Johnson method consisted of cutting basic recording on a wax plate and then creating a copy of the matrix by galvanization. In 1900, Berliner and Johnson joined forces, founding Victor Talking Machines Co. This was first act of creating new branch of entertainment, but mass production was the flywheel of cultural changes. The next step in development of new industrial complex was its diversification, in the shadow of strong producers in first decades of 20th century appeared group of small labels specialized in various genres of music. This makes record market more susceptible to changes in the economic situation but also more sensitive to the expectations of record buyers.

The pre-war recording industry focused on qualitative and economic issues, generally aimed at profit, ignored the cultural consequences of its activities[8]. Development of a sound recording on discs available to a wide audience was not only groundbreaking turn in engineering but also revolution in musical culture. Three-minutes songs become standard not only in popular music. In classical repertoire and jazz music, where live performances were much longer, 78 rpm record was forcing a choice of shorter fragments or shortening pieces to fit them in the limits. Technologies are the main factor of cultural change, wherein the

6 This plant developed into Deutsche Grammophone AG, and then Deutsche Grammophone Geselshaft – one of main companies recording classical music.

7 M. Kominek, op. cit., p. 49, 50.

8 S. Maisonneuve, *Between History and Commodity. The Production of a Musical Patrimony Through the Record in the 1920–1930s*, "Poetics" 2001, vol. 29, Issue 2, p. 91.

spread of technology is a necessary condition and social change can occur only if capacity of technological pervasion is statistically significant. This process took place with mechanical music and culture of listening. This was the case of innovations in technological sphere leading to changes which primarily take place in the sphere of mentality, collective recognition or rejection of certain activities and values. In interwar period listeners found three-minute song is enough for aesthetic experience. This way the change of listening habits run in the sphere of new kinds of social rituals and procedures, fashion or trends and then becomes the element of social agreement and basis for creating a new context within next phase of technology improvements. International Talking Machines in Germany made series of improvements for double-sided record pressing. Their label was Odeon. In 1909 label Odeon released first official album: four double-sided records featuring recording of Tchaikovsky's Nutcracker Suite in special package[9]. Sets of records including cycles of songs, dances or classical compositions were published in closed covers called "albums". Later in 20th century, when long playing records and Compact Disc records were able to fit whole cycles of songs on one disc, the term "album" remained.

Edison's technology survived to the first decades of the 20th century as an inexpensive archiving method until it was replaced by the Dictaphone introduced by Bell's Company in 1920. Smithsonian's Institutions were still using Edison's recording machines for archival purposes, when mass production of disc recordings started career of musical record on newly established market. From this moment we can observe double nature of recording industry – as communication and as extension of social memory. The same as photography in 19th century, next century developments gave new instruments for documenting various elements of culture, and new sources for researching and educational purposes. One of the related technologies was optical sound recording. Based on principles demonstrated in 1880 in Bell's Photophone, this technology was developed for military use and only in 1920's it was reshaped to add the sound to the movies. It was based on the same idea of recording the sound as groove shaped analogously to the sound wave but in optical solutions the groove was just the image of a sound as transparent track on film and ray of light was used like stylus in traditional gramophone[10]. Since movie industry was build as silent medium, initially, the Hollywood environment

9 D. Rauf, *Recording Industry*, Ferguson, New York 2010, p. 6.

10 Beam of light going through moving track fluctuate and this is read by a photo-electric cell, amplified as electric signal and changing into sound by loud speakers. This technology

was skeptical about the idea of a sound film. The only justification seemed to include songs in the film, therefore the first feature film was musical *The Jazz Singer* featuring Al Jolson. It was premiered October 6, 1927[11]. Sound movies played an important role in spreading the patterns of the popular musical culture, paving the road for television success after II world war and general change of mass culture.

Technology alternative to mechanical or optical vibrations and giving new perspectives to sound recording was magnetic recording. In 1898 Danish constructor Valdemar Poulsen invented wire recorder. First idea of magnetic recording was examined by Thomas Edison but he planed to use magnetic ink in his Phonograph, so this was still connected with form of groove representation of vibration. Poulsen idea based on changing the magnetic field of steel wire while recording and reading these changes while reading[12]. In 1935 Radio Exhibition in Berlin group of constructors working for AEG company presented first construction based on magnetic tape – a polyester film coated with Fe_3O_4 powder. Next year tape recorder was used for first recording of full symphony. It was Mozart's 39th Symphony played by London Philharmonia Orchestra conducted by Sir Thomas Beecham. From 1946 all new recordings of Deutsche Grammophone Gesellschaft were made primarily on tape and next few years all professional recordings were made with this technology.

Magnetic tape was revolutionary improvement. It was much more flexible than etched groove, ready for various changes and manipulations, giving possibility of tape splice and edition by omiting part of recording or connecting any fragment to another one. Glenn Gould in his famous paper *The Prospects of Recording* he saw this as a threat to the integrity of the musical message:

> Of all the techniques peculiar to the studio recording, none has been the subject of such controversy as the tape splice. With due regard to the not so unusual phenomenon of a recording comprised of single-take sonata or symphony movements, the great majority of present-day recordings consist of a collection of tape segments varying in duration upwards from one twentieth of a second. Superficially, the purpose of the splice is to rectify performance mishaps. Through its use, the wayward phrase, the insecure quaver can, except when

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with various quality improvements, as Dolby Noise Reduction or stereophonic sound was in use to the end of 20th century and then replaced by digital technology.

11 D. Rauf, op. cit., p. 8.

12 The devices were expensive and uncomfortable, but this technology has been developed for decades, using, among others, in air recorders to fix voices from cabin.

> prohibited by "overhang" or similar circumstances of acoustical imbalance, be remedied by minute retakes of the offending moment, or of a splice segment of which it forms a part[13].

But the same qualities flourished with the idea of music for tape. Pierre Schaeffer in studio Radiodiffusion Française show first fruits of a new attitude to musical composition. The essential element of novelty was the sound material he was using. And what was especially significant, he used the sounds that were not intentionally musical, taken from real life soundscape and paste in new context they were creating music of reality – understanding this unusual feature he called his genre *musique concrete*. Schaeffer's manipulations with tape recordings and compositions he created as sound collages were criticized as incidental and chaotic. Schaeffer's idea of creating new music on entirely non-musical material was radical but it was recognized more as a provocative experiment than the example of fully functional musical work, which can be analyzed and understand as complete work of art and an aesthetic subject. Schaeffer understood academic music of 20th century was far from natural spontaneity. Focusing on sound qualities and extra-musical structures, he hoped to renew the formal ideas and communication ideas of music.

> Post-Schaefferian composers have adopted Schaeffer's philosophy only selectively. While Schaeffer faulted German-led electronic music for relying on synthesis to generate abstract sounds rather than using what he felt were aesthetically rich found materials, many subsequent electroacoustic composers incorporate some manner of sound synthesis into their pieces; some also avoid using concrete materials at all. And as the name electroacoustic suggests, many of these works also incorporate traditional instruments[14].

It is commonly believed that Schaeffer's *Cinq études de bruits*, recorded in 1948 are the first examples of concrete music. But before Schaeffer started to work with the prerecorded sound and its manipulations, as early as in 1944 at the University of Cairo composer and ethnomusicologist Halim El-Dabh using wire recorder created *The Expression of Zaar*. He became famous for his works made in Columbia-Princeton Electronic Music Center, especially for *Leila and the Poet* (1959) being concrete music version of old Arabic tale about

13 G. Gould, *The Prospects of Recording*, "High Fidelity" April 1966, p. 51.
14 J. Demers, *Listening Through The Noise. The Esthetics of Experimental Electronic Music*, Oxford University Press, Oxford 2010, p. 29.

Layla and Majnun[15]. After this publication this work was cited by experimental rock musicians and Halim El-Dabh became a legend of the musical avant-garde of 1960's and next generations of experimental artists.

The consequence of the introduction of a tape to a recording studio that had consequences for the entire musical culture was the use of improved recording technique. The change consisted of using a multi-track tape recorder in the 1950s, which shaped a new approach to recordings. In place of setting the microphone that corresponded to the listener's position, it became possible to save many traces at the same time and connect them in any proportions. The development of this functionality was Mixing Console. As a result, this led to the creation of virtual acoustic spaces and control over spatial effects as an additional element of the musical work. The awareness of this phenomenon played a significant role in works based on innovative sound and revolutionary recording techniques. The importance of this process was explained by Frank Zappa in his book:

> Increased sophistication of mixing consoles made it possible for any number of microphones in the room to be combined by the engineer to create new audio illusions, impossible in the acoustical world – a big difference from the mix determined by the distance between the performer and the microphone. On a multichannel mix you can put a close mike on the kick drum, a close mike on the snare drum, a close mike on the horns and so on – and then combine them. There is no place in nature where a human being could stand that would allow him to hear all those instruments that way with his ears. This artificial acoustical perspective has become the norm. (…) Digital ambience-creating devices became available. With them, record producers could build "imaginary rooms" (as I have described) for the mix to reside in. Using several of those devices, the engineer can create an array of "imaginary rooms." This allows individual voices or instruments in the mix to exist in separate and distinct imaginary acoustical environments simultaneously [16].

Magnetic recording written and read by magnetic heads was much more sophisticated than mechanical imaging of sound vibration. Magnetic tape, and even Compact Cassette served as a carrier in the early period of IT

15 This is the story of 7th century Bedouin poet Qays ibn al-Mulawwah who was obsessed with his love to Layla. Halim El-Dabh created narrative form basing on concrete music techniques. This composition was premiered as first work on Columbia-Princeton Electronic Music Center album published by Columbia Masterworks (MS 6566) in 1964.

16 F. Zappa, P. Occhiogrosso, *The Real Frank Zappa Book*, Picador, London 1990, p. 157, 158.

development. Later, their function was taken over by floppy disks, and later Flash memory. It should be remembered that the historical rewrite, as well as current digital techniques, are based on the processing and storage of data (also musical) data, which takes place in the form of a magnetic recording on computer disks or electromagnetic in computer memory. Some technological solutions of digital recordings like DAT (digital audio tape) introduced by SONY in 1987 or DCC (digital compact cassette) introduced by Philips and Matsushita Electric in 1992 are also based on magnetic tape recoding.

Analog Compact Cassette Introduced by Philips in 1963 was primarily intended for use with dictaphone. Later quality of sound was improved and cassette became alternative for home audio systems. The small size and miniaturization of the equipment meant that the 1970s became a period of portable music playback devices and cassette players on car radios, and from 1979 produced by Sony Walkman and similar players of other companies in combination with specially designed light headphones revolutionized the way listening to music. The classical music market was still based on traditional and later digital record recordings and stationary players. However, popular, usually dynamic music found the right medium in this technology.

Communication in musical terms meant possibility to listen performances of artists distant in space and in time. And this seems to be the point of no return. Whole history of musical culture was based on live performances – in early music professional performances were generally limited to court (aristocratic) circles or church music, but the rest was musically active. After industrial revolution new society received public music institutions and the only alternative was more or less unprofessional home music or still alive traditional folk music. The popularization of recorded music, initially on anonymous disks, but starting from the second half of 1890s more and more often signed by recognizable artists meant that the exchange of musical information began to accelerate. It was just the beginning of the process. The development of recording technology and strengthening of the music market led to a situation where the catalogs of record companies became the mainstream of musical culture. Horace Silver in many fragments of his autobiography points the position of records in jazz education. He was collecting, listening with friends, analyzing playing with lower speed and copying. As he remembered "on one of the gigs I played with Hawk, I quoted an old Fletcher Henderson song in my solo. Hawk was quite surprised that a young man in his early twenties would know that song. What he didn't know was that I was an avid listener of all the older jazz recordings and had a pile of old tunes stored in my head"[17]. Artists focused their attention on the record market and in consequence number of stores with sheet music was decreasing while this place has been taken by record stores.

Selling millions of records music industry changed the shape of musical business. In some genres of popular music, concerts have become a secondary form of artistic activity. The same time decreased the number of people who were able to read notes or who have experience in singing. Also the culture of general society has been significantly changed. Comparing the quality of performances registered at the beginning of the 20th century and contemporary phonographic production, the shocking difference of quality can be seen. Producer Rick Rubin in an interview for "Music Angle" famous for his versatility and perfection pointed higher quality of recorded music as effect of ideal: "I feel like – I don't want to say 'perfection' but there's an ideal that's reached in recorded music that I very rarely see live.(...) I don't go out to see a lot of music live because I'm always so disappointed. I'd rather stay home and listen to my cds"[18]. Obviously, it is the result of technical capabilities of contemporary music production, but it is not important how such great precision is achieved, but what effects it has on society. Listening to more and more perfect recordings is a factor intimidating many people who could actively participate in traditional culture and even fulfill themselves as musicians amateurs, just if their standards were lower. On the other hand, the acceleration of musical communication, which at the turn of the 20th and 21st centuries increased the availability of all media, both notes, and recordings, caused that young generations gain experience and skills faster. In past centuries, one had to spend many years to achieve them. This basic musical education is done so quickly that it does not blur children's creativity and, as a result, the young generation of musicians goes out on stage with decisive, which was previously a feature of unique personalities.

The improvement of musical communication, the accelerated exchange of patterns and attitudes led to the democratization of musical culture. Starting from 1920, when within a month 75,000 discs of *Crazy Blues* was sold the history of hits begins. Recorded August 10, 1920 by Mamie Smith and Her Jazz Hounds, the so-called "race music" became one of the trends changing aesthetic approach but in longer perspective also the social attitude. Stereotypes regarding

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17 H. Silver, *Let's Get to the Nitty Gritty. The Autobiography of Horace Silver*, University of California Press, Berkeley 2006, p. 47.

18 J. Brown, *Rick Rubin in the Studio*, ECW Press, Toronto 2009, p. 13, 14.

breed or nationality were only part of the problem. The same mechanism concerned social position, sex or age. In Mamie Smith's *Crazy Blues* listeners found picture of vaudeville artist singing song written by bandleader Perry Bedford. The lyrics are about the singer, who was abandoned by her man, gets crazy. She get high and shoot the policeman. It was composed in the style of a popular song with blues expression. Over a million copies of *Crazy Blues* were sold during the year. From the perspective of the managers of the record companies, the production and marketing of high-volume hits required proven rules. And this excluded creative freedom in advance.

> Other record companies, all of them based in or near New York, followed the lead of Mamie Smith's company, Okeh, and signed up blues talent for recording. *Crazy Blues* established something of a formula that would be used for the next few years: a female star drawn from the northern vaudeville or cabaret scene or working in a current stage show, performing a song by a male professional songwriter (who might also be her pianist, band leader, manager, or husband), accompanied by a five- to eight-piece jazz band. Many of the songs contained multiple strains, not all of them in a blues form, and most were complaints about no-good men. These singers (the most important being Mamie Smith, Lucille Hegamin, Trixie Smith, Alberta Hunter, Ethel Waters, Lizzie Miles, and Edith Wilson) were professional entertainers, some of them dancers and actresses as well, for whom blues was just part of their repertoire. Few wrote many of their own songs. In the early 1920s most blues records by black artists were released in the regular popular series by such companies as Okeh, Columbia, Arto, Bell, Pathe, Paramount, and the black-owned Black Swan[19].

This process continued for many decades. But already in the interwar period, significant changes can be seen. Social context of recording technology augmented memory and identity experience, "the specific content of popular musical memories varied with, among other things, the experience of ethnic, racial, gender, and regional identities"[20]. The volume of sold production gave blues and jazz strong position in popular culture. In the south of the United States, many hillbilly musicians under the sign of commercializing Country Music used the experience of blues and often recorded together, such

[19] D. Evans, *The Development of the Blues*, in: A. Moore (ed.), *Blues and Gospel Music*, Cambridge University Press, Cambridge 2002, p. 29.

[20] W.H. Kenney, *Recorded Music in American Life. The Phonograph and Popular Memory 1890–1945*, Oxford University Press, New York 1999, p. 182.

practice "reflects the great impact of black culture on country performers"[21]. Such cultural tendencies created new social sensitivity and awareness, and as a consequence, led to significant changes in laws and a widely accepted system of values. The role of music in the process of social change was subject of numerous studies, but it is worth mentioning that the genre of protest song owed his position to recordings, including million copies sold records or television recordings, and the great figures of the folk music like Pete Seeger or Joan Baez were introduced into Rock & Roll Hall of Fame.

Every element of new technology was playing its own role, even material of which records were pressed had an impact on musical culture. At the beginning records were pressed of various materials. First Berliner's records were made of ebonite (vulcanized rubber). Around 1895 shellac records became standard for the next half of the century. In 1946 RCA-Victor Company used new material for record production – vinyl which shortly become standard in production of gramophone records. Vinyl gave better quality and new possibilities of precision pressing. Two years later, June 1948 Columbia Records, Incorporated show in New York new standard for vinyl records Long Playing Microgroove Record with higher density of grooves and speed of 33 rpm every side of 12-inch disc was able to fit 25 minutes of recording. This improvement made possible production of recordings comprising bigger symphonic works and operas. For the juke-boxes, radio and hits oriented segment of music market production of one song records (singles) was continued. Microgroove technology, improved quality of vinyl and speed of 45 rpm gave these records very good quality of sound. In 1980s some popularity gained 45rpm 12-inch maxi-single, with capacity was usually 7–10 minutes on every side.

Also jazz musicians reacted to this possibility including longer improvisations and expanding the time of modern jazz pieces. But what should be taken into account, artists have increasingly independent of the temporary framework set by technological restrictions. In next decades it was rising process. For example Miles Davis' groundbreaking album *Kind of Blue* consists of 5 compositions recorded in 1959 and average timing of every piece is about 9 minutes long. John Coltrane's masterpiece *A Love Supreme* recorded in 1964 is four part composition where shortest part has 7'02" and longest one has 10'42" and whole time of this album is 32'49" on both sides. And Miles Davis' double

21 A. Harkins, *Hillbilly. A Cultural History of an American Icon*, Oxford University Press, Oxford 2004, p. 75.

LP album *Bitches Brew* recorded in 1969 main composition placed on B-side of first LP is 27'00" long. This way, with new standard of record, new forms appeared in jazz and in rock music.

In late sixties rock bands playing progressive rock were recording complex musical works called "rock suites". Average timing was more than 20 minutes on one side of the LP. Such groups as Genesis, King Crimson, Mothers of Invention, Pink Floyd and Yes were known for such attitude. Radio stations playing long pieces were loosing positions, while popular music stations playing typical three-minutes songs were taking more and more listeners. The more ambitious artistic projects were, the more listeners were turning to simplest forms of popular music. In 1973 Pink Floyd album *The Dark Side of the Moon*, started new trend of concept album comprising short songs connected by one artistic idea. Sold in 45 millions copies this is one of groundbreaking album in the history of popular music. In consequence many artists, including Pink Floyd itself, tried to repeat this success. This met the tendency called AOR – album oriented radio. Unlike most radio stations playing hits from singles, some stations played music from albums, presenting a more diverse style.

This phenomenon was related to the development of a 12-inch vinyl LP record as a medium. On the one hand, artists playing progressive or experimental rock like Frank Zappa, Captain Beefheart, The West Coast Pop Art Experimental Band and many others, were placing songs on longplay album that, due to the length, could not fit in the single. In turn, typical rock bands, playing classic songs, some of which were published in parallel on the singles, took care of the diversity of the album program, so that is why, in a typical album program many artists were including stylistically and formally heterogeneous songs. This meant that the album usually containing about 40–45 minutes of music gained the position of a complementary artistic statement. The formative importance of this medium can be demonstrated by the fact that the overwhelming majority of musicians recorded their albums in standard long play length also after the introduction in 1981 of the digital record in the Compact Disc standard, when the capacity of the recording allowed timing almost twice as long as on the LP. After introduction digital formats to the cloud and selling access through the internet length of musical track become practically unlimited and independent of any format, but in most cases it is still 40–50 minutes long.

Multimedia developers will be group professionally creating the "storyline" for the music and connected elements. They will decide where does listener start, where does he wind up, and what does he learn, giving him all the necessary information in one logical data flow[22].

Along with the development of the quality of media and the appropriate progress of technical implementation of studio and concert recordings, the division of music business into zones was formed. In the eighties, sales were more and more systematic, including not only music media or tickets, but also souvenirs related to events, small items and advertising gadgets, criticism in press, radio and television. Each element was important in the overall reception of the artistic phenomenon[23].

The digitization of the recording process was the result of the pursuit of sound quality improvement and definitive noise reduction. The consequences of digitization become numerous improvements reaching deep into the processes of creation the sound and its features. Devices, and over time plugins for recording programs or controlling the course of performance have become part of technological processes that affect aesthetic decisions. Some of them i.e. auto-tuners, initially treated as gadgets, have become part of the compulsory equipment in many types of popular music, similarly to the rhythmic adaptation procedures, and then quantizing rhythmic patterns to make them like "living" performances. But the most changing area under the influence of new technologies was the distribution of music on the Internet. On the one hand, the digital environment gives unprecedented ease of reaching to any resources of world music culture, and on the other, an individual listener or artist turns out to be defenseless in relation to the activities of organizations referring to the protection of copyright and blocking access to resources[24].

Digital era and internet made created new space for recorded music. It is potentially present but we need to know what we want to hear. Educational and information services are part of the social context of music. In this respect, new technologies have similarly significant achievements as new technologies in the field of music. These qualities made 20th century revolution in music possible. Reaching global radius of reception, music once more confirmed

22 D. Rauf, op. cit., p. 54.

23 A. Lieberman, *The Entertainment Marketing Revolution. Bringing the Moguls, the Media, and the Magic to the World*, Financial Times Prentice Hall, Upper Saddle River 2002, p. 176.

24 Without entering the discussion here, I would like to notice that musical culture is not served by neither complete blockage nor a complete lack of copyright protection. Therefore, the sooner will be developed and disseminated the scope of freedom like the fair use, the faster music culture will be able to free itself from legal complexities.

that it is what always been – the element of identity in individual, national, cultural, human and universal denotation. Career of World Music, striving for a specific convergence of styles and achieving universalism in diversity proves how far music remains unity.

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Abstract

Invention of voice transmition and sound recording with development of recording devices created revolutionary changes of culture and social mechanisms. The first recording devices were built for office use as a device that allows recording telephone conversations or for fixation of agreements and spoken information. Improved devices allowed to record music and this function has become the main reason for the interest in new technology. The invention of the radio became an element supporting the development of phonography, which in the interwar period was a popular medium. In the interwar period, the purchasing power of various social groups contributed to the democratization of new media, and the repertoire reflected social diversity. The next significant invention was a sound film, which strengthened the potential of musical culture. The development of the radio and invention of television significantly raised the attractiveness of the recorded music and its social importance. 3 minute songs played from 78 rpm records in interwar period and long playing records on 33 rpm introduced after the was became standard for other musical genres. Invention of magnetic tape recorder have impact on studio recording, creating new consciousness of sound and musical proportions. This improvement was also used for creative experiments. Compact Cassette, digital recording and compact disc created new space for individual and social activity. Internet was next revolution giving new possibilities of development.

Key words: phonograph, gramophone, tape recorder, music, culture.

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Influence of Music Education and Pitch Scales on the Grouping of the AB-AB Sequence Sounds

Introduction

Sound perception is related to two types of processes in the human auditory system – sensory and cognitive processes. Sensory processes refer to the set of phenomena associated with the reception of acoustic waves from the environment, the processing of acoustic waves into nerve impulses in the auditory organ, the encoding in the form of impulses of data about the physical characteristics of the received sounds and the transmission of nerve impulses to the hearing centres in the cerebral cortex. The effectiveness of sensory processes related to hearing is determined by the physiological state of the human auditory system. Research in the field of psychoacoustics, which examines the relationship between the physical characteristics of sound and auditory sensation, usually assumes that there are no major differences in the mechanisms of these phenomena between people with physiologically normal hearing.

Cognitive processes, on the contrary, are related to the processing by the mind of information coming from the organ of hearing and other senses. Processing occurs in the central nervous system and involves receiving information from the environment, storing and transforming it, and reintroducing it into the environment in the form of a response-behaviour. Cognitive processes include, among others, attention, awareness, perception, memory, thinking and reasoning[1]. The resulting cognitive structures are used by the individual to form a mental image of the stimuli received.

1 E. Nęcka, J. Orzechowski, B. Szymura, *Psychologia poznawcza*, Academica Wydawnictwo SWPS, PWN, Warszawa 2006, pp. 178, 278, 320, 420.

Cognitive processes depend on various factors related to the past experiences of the person receiving sensory stimuli. For this reason, people with a similar physiological state of hearing but with different experiences of sound perception, may differ in, for example, their sensitivity to sound changes and perceive auditory images with different properties and structure when their hearing organ is stimulated by the same acoustic signal. Experiences acquired as a result of musical education and gained in professional music practice, among others, have a significant impact on the formation of cognitive processes in sound perception.

As a result of the hearing process, a variety of perceptual elements and structures can arise in the mind of the hearer. When listening to a sound, it is possible to identify sound sources, the acoustic properties of the environment in which the sources are located and to differentiate sounds in terms of their elementary sensory attributes, which include loudness, pitch, timbre and perceived duration. Traditional research into the principles of sound perception uses specialised methods of auditory evaluation to obtain a description of the relationship between the physical characteristics of sound and the qualities of the impression received by the hearer.

Research studies in psychoacoustics and music acoustics employ the concept of a perceptual stream. A perceptual stream (or an auditory or acoustic stream) is a sequence or a set of auditory impressions arranged in such a manner that the hearer perceives a given acoustic event as an entity. This means that the recipient can, for instance, recognise and distinguish individual sounds as voices in polyphonic works or harmonic structures (distinguishing different perceptual streams) through their ability to find elements with similar characteristics, coherence or regularity. The essence of the perceptual stream is to extract distinctive characteristics of sounds from their entirety in order to obtain an overall picture or a complete auditory description of a given acoustic event.

The literature provides evidence that the cognitive processes involved in sound perception are developed in musicians in a specific manner, which makes musicians different from non-musicians in sound perception situations not specifically related to music. Based on the results of published research, it can be concluded that musical education affects sound perception in situations where cognitive processes play a predominant role in sound perception. A phenomenon in which cognitive processes play a particularly important role is combining sounds into perceptual streams.

The research presented in this study was conducted in order to determine whether the processes of grouping sounds into perceptual streams demonstrate different characteristics in musicians and non-musicians. The nature of the research is experimental and its essential part is the psychoacoustic experiment conducted by the author.

Experimental assumptions and aim

Experiment aimed to investigate what influence on perceptual stream grouping is exerted by the pitch differences of sound pairs played in sequence in different pitch ranges. The experiment was based on those described by Miller and Heise[2], Dowling[3], Bregman and Campbell[4], Bregman[5], and van Noorden[6]. It investigated the phenomenon of sound grouping into perceptual streams based on the pitch difference between two sounds, depending on the tempo of sequence playback[7]. The sound pairs were played in different octaves. In addition, previous pilot experiments conducted by this author[8] with two cohorts of participants, i.e. musicians and non-musicians, demonstrate that the two groups display certain noticeable and simultaneously evident differences in the perception of the same sound stimuli, which inspired further and much more in-depth research concerned with the analysis of auditory imaging in the context of perceptual streaming.

2 G.A. Miller, G.A. Heise, *The Trill Threshold*, "Journal of Acoustical Society of America" 1950, vol. 22, issue 1, pp. 637, 638.

3 W.J. Dowling, *Rhythmic Fission and Perceptual Organization*, "Journal of Acoustical Society of America" 1968, vol. 44, issue 1, p. 369.

4 A.S. Bregman, J. Campbell, *Primary Auditory Stream Segregation and Perception of Order in Rapid Sequences of Tones*, "Journal of Experimental Psychology" 1971, vol. 89, no. 2, pp. 244–249.

5 A.S. Bregman, *Auditory Scene Analysis. The Perceptual Organization of Sound*, The MIT Press, Cambridge, Massachusetts 1990, pp. 65–67, 157–163.

6 L.P.A.S. van Noorden, *Minimum Differences of Level and Frequency for Perceptual Fission of Tone Sequences ABAB*, "Journal of Acoustical Society of America" 1977, vol. 61, no. 4, pp. 1041–1045; idem, *Temporal Coherence in the Perception of Tones Sequences* (unpublished dissertation), Technical University Eindhoven, Eindhoven 1975, pp. 1–4, 7–10, 18–20, 28–32.

7 A.S. Bregman, *Audio Demonstrations of Auditory Scene Analysis*, http://webpages.mcgill.ca/staff/Group2/abregm1/web/downloadstoc.htm [accessed: on 12.12.2022].

8 A. Rosiński, *Wpływ wykształcenia muzycznego na grupowanie dźwięków sekwencji ABA–ABA w rytm galopujący*, in: *Przestrzenie akustyki. Professional Acoustics*, A. Rosiński (ed.), Wydawnictwo Uniwersytetu Warmińsko-Mazurskiego w Olsztynie, Olsztyn 2021, pp. 53–70.

Sound material

The experiment used repeated sequences comprised of two sounds separated by a perfect fifth. This interval was played in three octaves: great, one-line, and three-line. Sound frequencies were set according to equal-temperament tuning:

– in the great octave: D = 73.416 Hz, A = 110.000 Hz,
– in the one-line octave: d^1 = 293.666 Hz, a^1 = 440.000 Hz,
– in the three-line octave: d^3 = 1174.700 Hz, a^3 = 1760.000 Hz.

The time plot of stimulus replay is depicted in Figure 1. Sounds were played in sequence: low sound and high sound in each series. The time between the beginning of one sound and the beginning of the neighbouring sound was taken as the basic measurement time step. A single time series in this experiment were two sounds played alternately, without intermissions, similar to the experiment conducted by Shonle and Horan[9].

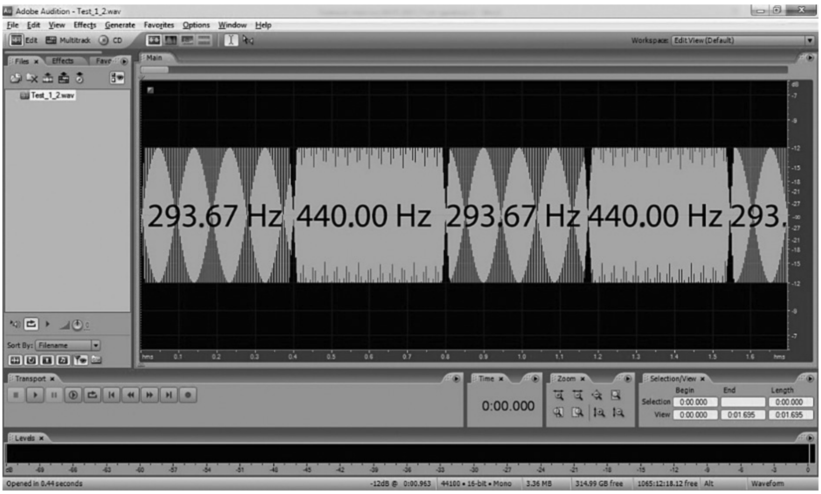

Fig. 1. Screen capture – an analysis by *Adobe Audition* software depicting a time paradigm of a sound sequence played in the experiment. Frequencies shown in the interface window relate to the interval played in one-line octave
Source: own research

9 J.I. Shonle, K.E. Horan, *Trill Threshold Revisited*, "Journal of Acoustical Society of America" 1976, vol. 59, issue 2, pp. 469–471.

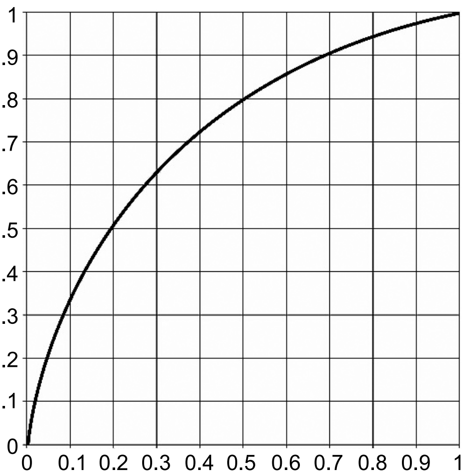

Fig. 2. Duration of sounds in AB sequences as a function of time elapsed from task start
Source: own study, software-generated analysis from: *Matemaks.pl. Matematyka maksymalnie prosta. Program do rysowania wykresów funkcji*, https://www.matemaks.pl/program-do-rysowania-wykresow-funkcji.html [accessed on: 9.02.2021]

The duration of each sound was computer-generated and lasted from 400 ms to 40 ms[10]. In order to avoid crackling in audio replay, the amplitude envelope of each sound was given a linear attack and release of 10 ms[11]. The temporal sequence of sounds was regulated and analysed by software on the WPF.NET platform.

Time control of sound duration was modelled after the sound material used in the experiment described by Bregman and Campbell[12]. The duration

10 A.S. Bregman, *Auditory Scene Analysis. The Perceptual Organization of Sound*, The MIT Press, Cambridge, Massachusetts 1990, pp. 157–158; ibidem, p. 50; L.P.A.S. van Noorden, op. cit., p. 1041; G.L. Dannenbring, A. S. Bregman, *Effect of Silence Between Tones on Auditory Stream Segregation*, "Journal of Acoustical Society of America" 1976, vol. 59, no. 4, p. 987.

11 G.L. Dannenbring, A.S. Bregman, *Stream Segregation and the Illusion of Overlap*, "Journal of Experimental Psychology. Human Perception and Performance" 1976, vol. 2, no. 4, pp. 546, 568.

12 A.S. Bregman, J. Campbell, *Primary Auditory Stream Segregation and Perception of Order in Rapid Sequences of Tones*, "Journal of Experimental Psychology" 1971, vol. 89, no. 2, pp. 244–249; A.S. Bregman, *Audio Demonstrations of Auditory Scene Analysis,* http://webpages.mcgill.ca/staff/Group2/abregm1/web/downloadstoc.htm [accessed: on 12.12.2022].

of sounds gradually decreased over the course of the task, following a hyperbolic function (illustrated in Fig. 2), according to the formula:

$$t = ((-1/(3x+1))+1) * (4/3)$$

where t signifies the duration of a single sample, and x signifies the time elapsed since the sequence start.

The series of sounds was presented a maximum of 207 times, which gives 414 sounds replayed in a single presentation. The task was conducted three times.

Hardware and software employed in listening sessions

Listening sessions were held in computer room 120 of the Gdańsk Academy of Fine Arts, and in chamber music hall S2 of the Gdańsk Academy of Music. The listening station comprised the following elements:

- *Asus M51VA-AP117* portable computer with *Windows 7 Ultimate 64-bit* operating system, and the *Microsoft* programming platform *Windows Presentation Foundation* (WPF.NET). The application was developed in the *Microsoft Visual Studio 2013* programming environment.
- *Beyerdynamic DT 770 pro* closed headset with 80-ohm impedance. The volume of the stimuli was determined in a previous pilot study involving three musicians and three non-musicians with no prior experience with auditory experiments. These individuals established a level of audio path amplification that supplied the volume of maximum comfort during the listening experiment. The established loudness level was approximately 70 phons. All audio samples were generated on the WPF.NET software platform with the *Microsoft Visual Studio 2013* development environment, using a mono system with a 44.1 kHz sampling rate and a resolution of 16 bits. All analyses and statistical calculations were carried out using *IBM SPSS Statistics V23.0 software*.

Subjects

The experiment involved 48 subjects, aged 21 to 27, including 24 students or graduates of the Gdańsk Academy of Music and 24 students or graduates of the Gdańsk Academy of Fine Arts. The group of 48 subjects was comprised of 40 women and 8 men. Candidates for the groups were recruited at random.

The study was designed as a series of experimental sessions, all of which involved two groups of subjects: students and young graduates of the Academy of Music, and students and young graduates of the Academy of Fine Arts who were non-musicians. For the purposes of this paper, students of the Gdańsk Academy of Music and young professional musicians are jointly referred to as "musicians", while "non-musicians" are the students of the Academy of Fine Arts, including individuals with some experience in amateur music. Detailed data of participants' education, professional speciality and music experience are presented below.

Data concerning musicians

1. Subjects began their education between the ages of 5 and 10, and graduated from primary and secondary music school.
2. They continuously practiced playing musical instruments over the last 13–22 years.
3. Professional education of three subjects was temporarily interrupted for incidental reasons.
4. The subjects did not possess absolute pitch.
5. The subjects mostly performed classical music.
6. All subjects were right-handed.

Data concerning non-musicians

1. Five subjects had attended a music centre, primary music school, or private lessons in singing or instrumental music. Those individuals received a few years of music education, and some of them were involved in amateur music performance.
2. Other subjects received no instrumental or singing instruction, nor performed music as amateurs.
3. The majority of non-musicians listened to general popular music.
4. All were right-handed.

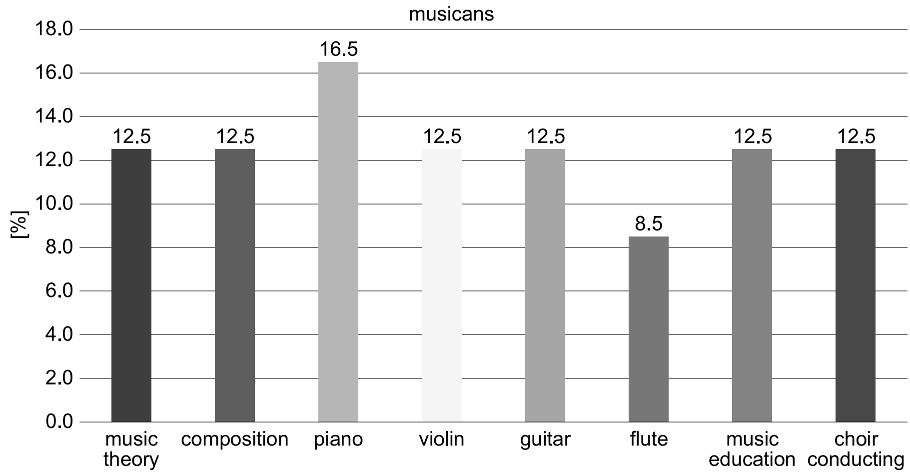

Fig. 3 . Percentage of subjects among musicians by academic focus or professional specialty
Source: own research

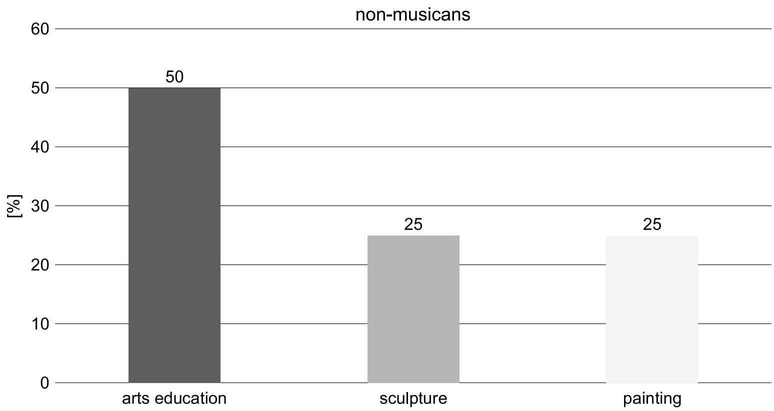

Fig. 4. Percentages of non-musicians by academic focus or professional specialty
Source: own research

Listening sessions

The study was conducted in listening sessions separate for each participant. The subjects were instructed to indicate the moment that they heard the sounds separate in two perceptual streams. At the beginning of the session, a demonstration series was played, taken from the work by Bregman[13],

13 Ibidem.

in order to familiarise the listener with the phenomenon of perceptual fission and to explain the experimental task.

Results

Table 1 presents group results of the experiment – mean sample duration at each group's indication of perceptual stream fission, as well as standard deviation and standard error of each value set. The values shown in Table 1 are displayed in graphical form in Figure 5.

Table 1. Group results of experiment – mean sample durations (in ms) at which each listener group indicated sounds separating into two perceptual streams, as well as standard deviation and standard error of each value set. Results are divided by octave: great, one-line and three-line

Specification	Group	*N*	Mean	Standard deviation	Mean standard error
Great octave	musicians	24	114.25	27.355	5.584
	non-musicians	24	169.13	45.431	9.273
One-line octave	musicians	24	94.83	27.747	5.664
	non-musicians	24	179.29	49.849	10.175
Three-line octave	musicians	24	79.21	28.152	5.746
	non-musicians	24	172.00	56.083	11.448

Source: own research

Figure 5 presents responses given by musicians and non-musicians as to the duration of sample sounds (threshold) at which they experience fission of perceptual sound streams. The graph shows mean values and standard deviations of the sets of 24 responses in the musician group and non-musician group, divided by octaves: great, one-line, and three-line.

To investigate whether differences in the mean results between the groups of musicians and non-musicians carry statistical significance, a Student's t-test for independent samples was performed. The calculated t values and the associated p likelihood values are shown in Table 2. p values, shown in the rightmost column, are ($p < 0.001$), which is grounds for rejecting the null hypothesis that the average results in the two groups are not statistically different.

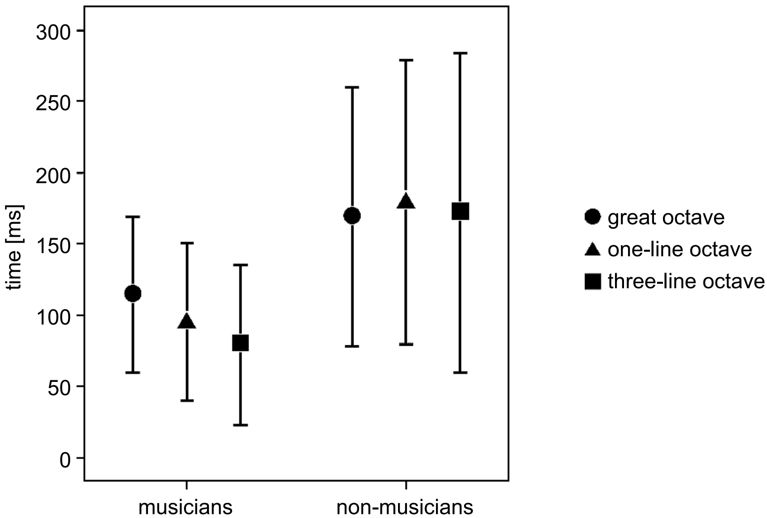

Fig. 5. Duration of samples [ms], at which sounds separated by a perfect fifth fissioned in two perceptual streams. Mean values and standard deviations of results by octave: great, one-line, three-line
Source: own research

Table 2. Results of Student's *t*-test for independent variables – experiment

Specification	*t*-test for equality of means		
	t	*df*	significance (two-tailed)
Great octave	-5.069	23	$p < 0.00001$
One-line octave	-7.252	23	$p < 0.000$
Three-line octave	-7.244	23	$p < 0.000$

Source: own research

Figures 6–8 show histograms of subject responses in tests regarding auditory stream fission in two perceptual streams. The set of 24 responses in the group of musicians and non-musicians was segregated in discrete time intervals. The *x*-axis shows the number of subjects whose responses fell in a particular interval. Subsequent figures show graphs relating to sequences played in great, one-line and three-line octaves, respectively.

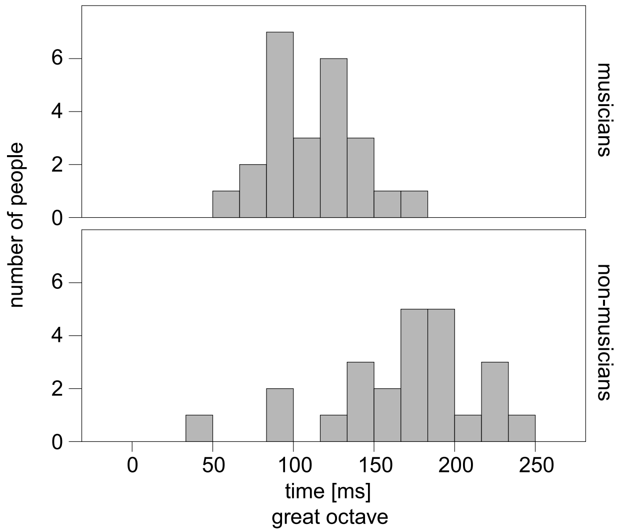

Fig. 6. Number of subjects – musicians and non-musicians whose responses fell in particular time intervals plotted on the *x*-axis.
Results for sound sequences played in the great octave
Source: own research

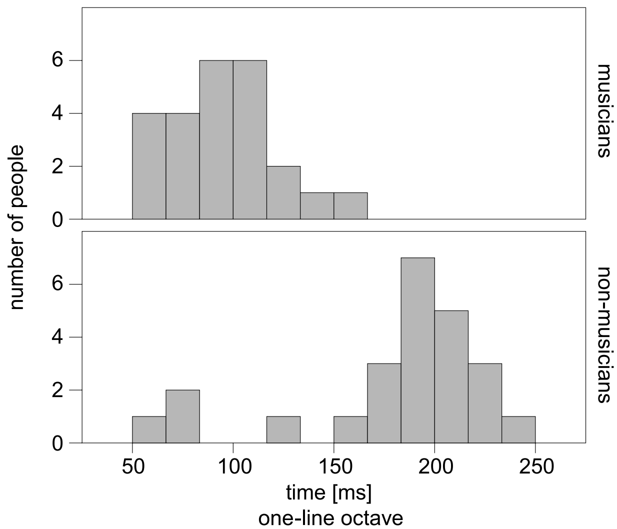

Fig. 7. Number of subjects – musicians and non-musicians whose responses fell in particular time intervals plotted on the *x*-axis.
Results for sound sequences played in the one-line octave
Source: own research

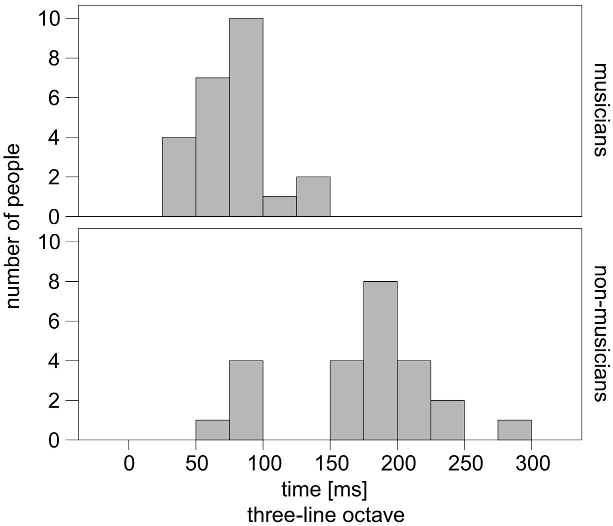

Fig. 8. Number of subjects – musicians and non-musicians whose responses fell in particular time intervals plotted on the *x*-axis.
Results for sound sequences played in the three-line octave
Source: own research

Table 3 shows the values of the Pearson correlation coefficient describing the level of linear correlation between variables in experiment, in the group of musicians, including years of continuous practice, age when instrument lessons began, results in the great octave, one-line octave, and three-line octave.

Data presented in Table 3 show that there is a statistically negative correlation between the number of years of continuous practice of music and the duration of sound at which sequences fissioned in two perceptual streams in great, one-line, and three-line octaves. There is also a positive statistical correlation between listener age and the above variable (sound duration).

Figure 9 presents scatter plots of the correlations observed in experiment in the group of musicians among the following variables: age, years of continuous practice, age at first instrumental lessons, great octave, one-line octave, and three-line octave.

For a better understanding and elucidation of the obtained experimental data within the musician and non-musician cohorts, as well as to appreciate their significance, it was determined that one more statistical test needs to be performed. A one-way ANOVA analysis of variance, which was opted for in this case, is a statistical method that enables one to examine the observations

Table 3. Values of the Pearson correlation coefficient between variables in the group of musicians, and their statistical significance – experiment

Specification		Years of continuous practice	Age at first instrumental lessons	Great octave	One-line octave	Three-line octave
Years of continuous practice	Pearson correlation coefficient	1	-0.839	-0.599	-0.520	-0.486
	significance (two-tailed)	–	0.000	0.002	0.009	0.016
	N	24	24	24	24	24
Age at first instrumental lessons	Pearson correlation coefficient	-0.839	1	0.727	0.667	0.653
	significance (two-tailed)	0.000	–	0.000	0.000	0.001
	N	24	24	24	24	24
Great octave	Pearson correlation coefficient	-0.599	0.727	1	0.957	0.918
	significance (two-tailed)	0.002	0.000	–	0.000	0.000
	N	24	24	24	24	24
One-line octave	Pearson correlation coefficient	-0.520	0.667	0.957	1	0.981
	significance (two-tailed)	0.009	0.000	0.000	–	0.000
	N	24	24	24	24	24
Three-line octave	Pearson correlation coefficient	-0.486	0.653	0.918	0.981	1
	Significance (two-tailed)	0.016	0.001	0.000	0.000	–
	N	24	24	24	24	24

Source: own research

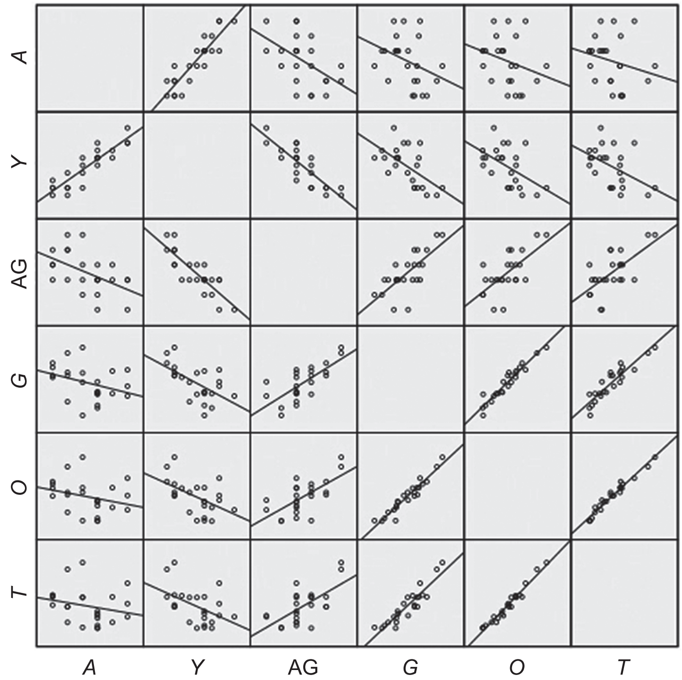

Fig. 9. Scatter plots of correlations observed in experiment in the group of musicians (explanation: *A* – age, *Y* – years of continuous practice, AG – age at first instrumental lessons, *G* – great octave, *O* – one-line octave, *T* – three-line octave)
Source: own research

made in the course of the experiment. With the use of this method, one is able to estimate the probability with which isolated and, at the same time, differentiating factors (results) that actually occur can result in differences between the observed averages in given cohorts. In addition, a univariate analysis examines the influence of each factor in turn, with the latter being considered completely separately during statistical analysis.

Following analysis, the averaged data for both groups of subjects (musicians and non-musicians) compiled in Table 5, and the collated results indicate a high level of statistical significance. This means that the experiment demonstrated tangible and realistically occurring differences in sound perception between the two cohorts for each of the variants. For the great octave, the level of statistical significance was $p < 10^{-5}$, while for the one- and three-line octaves, the level of statistical significance was computed as $p < 10^{-6}$.

Table 4. Results of a one-way analysis of variance ANOVA test performed for the experiment described in this study

Specification		Sum of squares	*df*	Mean square	*F*	Significance level
Experiment						
Great octave	between cohorts	36135.188	1	36135.188	25.699	$p < 10^{-5}$
	within cohorts	64681.125	23	1406.111	–	–
	total	100816.313	24	–	–	–
One-line octave	between cohorts	85598.521	1	85598.521	52.598	$p < 10^{-6}$
	within cohorts	74860.292	23	1627.398	–	–
	total	160458.813	24	–	–	–
Three-line octave	between cohorts	103323.521	1	103323.521	52.477	$p < 10^{-6}$
	within cohorts	90569.958	23	1968.912	–	–
	total	193893.479	24	–	–	–

Source: own research

Discussion of results

The frequency difference between two sounds at which their sequence is perceived as separated in two perceptual streams was named the *trill threshold* by Miller and Heise[14]. Since the sounds played in the present experiment were separated by an interval of a perfect fifth, the accurate name for their relationship, in terms of music theory, is *tremolando threshold*, since trill refers to a quick repetition of sounds separated by a second.

Experiment demonstrated that the tempo of replay at which the perfect fifth tremolando is fissioned by musicians in two perceptual streams is dependent on the octave to which the sounds belong (cf. Fig. 5). The higher the octave (great, one-line, three-line), the shorter the sample duration at which musicians indicated the fission threshold (the faster tempo of the tremolando). The dispersion of the results, expressed by the value of standard deviation, was similar in the group of musicians, independent of the octave in which the sequence was played.

In the group of non-musicians, the perceptual fission occurred at a slower tempo of the tremolando (longer sample duration). In this group, the average

[14] G.A. Miller, G.A. Heise, op. cit., pp. 637, 638.

sample duration at the threshold was characterised by a small difference from octave to octave. This means that the pitch of the octave containing the fifth in question in many cases had no bearing on the fission threshold, or did so to a much lesser extent than in the case of musicians. The two groups of listeners also differed in the dispersal of responses, which was much greater in the group of non-musicians than musicians.

It also should be noted that the group of musicians exhibited a statistically significant correlation between the age of musical initiation and the tremolando threshold perceived. This correlation is consistent with reports that cognitive processes concerning pitch perception are especially stimulated during music education in childhood. An example of the influence of childhood music education on perceptual processes is the fact that among musicians possessing absolute pitch, a great majority are individuals who started music education in kindergarten[15].

In the conditions created in the experiment, the deciding factors influencing sound fission in two perceptual streams were the interval between the sounds and the tempo of the sound sequence. In order to achieve fission, one of those parameters must be increased – the interval or the tempo. The values of the tremolando threshold established in experiment can therefore be qualitatively compared to data published by Miller and Heise[16], and by Shonle and Horan[17], while taking into consideration that the above-mentioned authors played their sequences of intervals at a constant tempo, while the variable was the size of the interval, as the listener regulated the frequency of the lower sound. In the work of Miller and Heise, the frequency difference at which the trill threshold occurred was roughly proportional to the frequency of the sequence's lower sound. Thus, the perceptual threshold was found at a similar interval, irrespective of the frequency range in which the sounds were played. Data obtained in the group of non-musicians qualitatively confirm this observation, since they show the tremolando threshold (in the interval of fifth) as unchanging as it is transposed to other octaves.

15 D. Deutsch, T. Henthorn, E. Marvin, H.S. Xu, *Absolute Pitch Among American and Chinese Conservatory Students. Prevalence Differences, and Evidence for a Speech-Related Critical Period*, "Journal of Acoustical Society of America" 2006, vol. 119, Issue 2, pp. 719–722.

16 Ibidem.

17 J.I. Shonle, K.E. Horan, *Trill Threshold Revisited*, "Journal of Acoustical Society of America" 1976, vol. 59, Issue 2, pp. 469–471.

In the work of Shonle and Horan, the trill threshold had a similar value on a linear scale, as the lower sound was changed in a range from 250 to 1000 Hz, which indicated that the threshold interval was diminished in sequences played at higher therefore frequencies. These results are not consistent with the data described by Miller and Heise, nor with the observations made in the present experiment.

The most likely reason for the difference observed between the results of musicians and non-musicians in assessing tremolando threshold is the fact that music education and practice renders the hearing of musicians especially attuned to changes in pitch, and gives them better ability to recognise sounds in fast sequences than non-musicians[18]. As the tempo of the tremolando increases, a musician's perception is able to keep up longer with the changes in sound pitch. For this reason, the tremolando threshold occurs in musicians at a faster tempo than in non-musicians.

Data regarding amateur instrumental music experience on the tremolando threshold may be treated only as preliminary observations. The group of five subjects with amateur music experience exhibited a significant dispersion of results, and the sample size is too small to allow reliable conclusions regarding perceptual fission of the sound stream in this group of listeners.

Conclusion

Routine audiometric tests, conducted while recruiting subjects participating in psychoacoustic tests to check whether the respondents' hearing is otologically normal, are insufficient for this type of research, as they should be extended to include eligibility criteria regarding musical education. The fact that musical education and practice may affect cognitive processes in sound perception should be taken into account when recruiting listeners for psychoacoustic studies, because often identical psychoacoustic experiments repeated on different groups of subjects show that they respond quite differently[19]. In many cases, musical education can be a factor considerably influencing the outcome

18 L.S. Jacobson, L.L. Cuddy, A.R. Kilgour, *Time Tagging. A Key to Musician's Superior Memory*, "Music Perception" 2003, vol. 20, no. 3, pp. 307–313.

19 J.I. Shonle, K.E. Horan, *Trill Threshold Revisited*, "Journal of Acoustical Society of America" 1976, 59, issue 2, pp. 469–471; G.A. Miller, G.A. Heise, *The Thrill Threshold*, "Journal of Acoustical Society of America" 1950, 22, pp. 637, 638.

of an experiment, which should be recorded as important information, as this fact is not taken into account at all when researchers plan psychoacoustic experiments.

The results of psychoacoustic experiments clearly demonstrate that many years of musical education bring substantial benefits, which can be used by musically educated people, unconsciously, throughout their lives in tasks not only strictly related to music. Broadly understood analysis and processing of sounds in the mind, reaching a person from the external environment, indicates that in the case of musicians there is a different type of interpretation of the sounds incoming to the listener. Musicians can group and isolate sounds differently, paying attention to their different characteristics as compared to non-musicians. Thus music education, when practiced universally, can produce very interesting results when used outside of music, during everyday contact with sounds.

In the experiment conducted, the same sound grouping phenomena in terms of quality were observed in musicians and non-musicians. When the sounds were shortened and a certain limit (threshold) of the playback speed was exceeded, the AB–AB sequence was split into two perceptual streams, consisting of a higher (A) and a lower (B) sound.

With the qualitative similarity of the phenomena investigated, significant differences occurred between the groups of musicians and non-musicians as to the threshold value of the rate at which the sequence was split into two streams. In the group of musicians, this threshold occurred at a faster speed of playing the sequence than in the non-musicians.

In most sequences presented to listeners for evaluation in these experiments, the speed of sound reproduction at which the sequence split into two streams was about twice as high in the musician group as in the non-musician group.

The fact that the range of speed at which a sequence of sounds of different pitch is perceived as a single stream is wider in musicians than in non-musicians and includes faster speeds indicates that musicians are able to keep up with faster pitch changes in a sequence than non-musicians. The existence of such a difference is an expected observation, since musicians have extensive analytical pitch listening skills developed as a result of practice in playing instruments and the exercises they participate in ear training classes during their education in music schools and music studies. In addition to the speed at which the sequence was played, the variables in the experiments also included the octave in which the sounds were arranged. Adjustment of these variables significantly affected the results obtained in the group of musicians, while it had no significant effect on the responses provided by non-musicians. Most probably, the ability to perceptually follow the faster pitch changes in the sequence of sounds performed by the tremolando when transposing the interval to a higher octave results from differences in auditory sensitivity to pitch changes within the range of the musical scale. In the examined pitch range, from the great octave to the three-line octave, the hearing sensitivity to pitch changes increases along with the pitch[20]. The effect of the octave in which the sounds are played is presumably revealed when the sequence is played quickly and it is more difficult for the listener to perceptually follow pitch changes in a single stream. In the non-musician group, when the sequences were played at a slower speed, differences in auditory sensitivity to changes in pitch had no effect on the tremolando perception threshold.

It should be emphasised that the differences between the results obtained in the group of musicians and non-musicians were in most cases significant and showed a high level of statistical significance, which is reflected in the analyses presented in the description of the results in the individual chapters, as well as in the summary presented in the appendix.

The fact that individual results in the groups of musicians and non-musicians were significantly spread in all experiments is very important in the interpretation of the results obtained, with the spread being greater in the non-musicians than in the musicians. In analysing the results of the experiments, it is important to remember that the research referred to phenomena related to cognitive processes, which greatly depend on a given person's experience in sound perception, as well as on many other personal characteristics. Reports published by various authors reveal that the grouping of sounds into streams is determined, among other things, by the functional symmetry of the motor and sensory organs and the lateral dominance (laterality) of these organs[21]. These features occur in the population in different configurations.

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20 A. Miśkiewicz, A. Rakowski, P. Rogoziński, M. Kocańda, *Progi różnicowe częstości a progi różnicowe wysokości dźwięków muzycznych*, in: A. Rakowski (ed.), Kształtowanie i percepcja sekwencji dźwięków muzycznych, Wydawnictwo Akademii Muzycznej im. Fryderyka Chopina, Warszawa 2001, pp. 125–154; C.C. Wier, W. Jesteadt, D.M. Green, *Frequency Discrimination as a Function of Frequency and Sensation Level*, "Journal of the Acoustical Society of America" 1977, vol. 61, issue 1, pp. 179–184.

21 D. Deutsch, *Two Channel Listening to Musical Scales*, "Journal of the Acoustical Society of America" 1975, vol. 57, issue 5, pp. 1156, 1157; idem, *Ear Dominance and Sequential Interactions*, "Journal of the Acoustical Society of America" 1980, vol. 67, issue 1, pp. 225–227; idem, *The Octave Illusion in Relation to Handedness and Familial Handedness Background*, "Neuropsychologia" 1983, vol. 21, issue 3, pp. 290–292; idem,

The complexity of the phenomena affecting the grouping of sounds into perceptual streams makes it difficult to obtain data that could be normative for a specific type of group of listeners. Therefore, when analysing the results of the experiments, it is important to bear in mind that the results for individuals may differ significantly from the data averaged over a group of listeners.

The conducted research also yields a conclusion relating to the recruitment of listeners participating in experiments on psychoacoustic aspects. If the experiments do not address hearing pathology, the eligibility criteria for listeners in the experimental group usually include the fact that the person has otologically normal hearing, which is checked by routine audiometric testing, and, in some cases, the age of the listener. Contemporary psychoacoustic research is paying increasing attention to issues relating to cognitive processes in sound perception. The results obtained in this study show that in this type of research, it may be very important to consider whether the listeners participating in the research have a musical background.

The experiments conducted in this study can be classified as basic research and were concerned with the perception of elementary sound sequences which may be components of larger sound structures in musical works. The results may also be of practical importance for musicians, as they broaden their knowledge of the principles of sound perception occurring in situations relevant to technical issues faced by composers of electroacoustic music in their work on the realization of works and by sound directors. At the same time, it should be noted that the experiments described in this paper concerned elementary perceptual phenomena occurring during the reproduction of artificially generated test sound sequences to listeners. In musical works, the perception

Auditory Illusions, Handedness, and the Spatial Environment, "Journal of the Audio Engineering Society" 1983, vol. 31, pp. 610–612; idem, *Reply to Reconsidering Evidence for the Suppression Model of the Octave Illusion*, by C.D. Chambers, J.B. Mattingley, S.A. Moss, "Psychonomic Bulletin & Review" 2004, vol. 11, issue 4, pp. 671, 672; idem, *An Auditory Illusion*, "Journal of the Acoustical Society of America" 1974, vol. 55, S18–S19; idem, *The Octave Illusion Revisited Again*, "Journal of Experimental Psychology. Human Perception and Performance" 2004, vol. 30, pp. 359–363; idem, *Illusions for Stereo Headphones*, "Audio Magazine" 1987, March, pp. 43–45; idem, *The Octave Illusion and The What-Where Connection*, in: R.S. Nickerson, R.W. Pew (ed.), *Attention and Performance*, Hillsdale, NJ, Erlbaum 1980, pp. 578–580; D. Deutsch, *Musical Illusions*, "Scientific American" 1975, vol. 233, no. 4, pp. 93–95; D. Deutsch, *An Auditory Illusion*, "Nature" 1974, 251, pp. 307–309.

of sounds as being grouped into streams, for example, as individual voices in a polyphonic work, is the effect of the coexistence of a number of complex processes with underlying interdisciplinary issues, as described in research papers.

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Abstract

This paper discusses an experiment conducted with two groups of participants, composed of musicians and non-musicians, in order to investigate the impact that the speed of a sound sequence and the pitch at which selected sounds are played on the grouping of sounds into perceptual streams. Significant differences were observed between musicians and non-musicians with respect to the threshold sequence speed at which the sequence was split into two streams. In modern psychoacoustic studies, the qualifying criteria for listeners usually include otologically normal hearing (verified by audiometric test) and age. The differences in the results for the two groups suggest that the musical background of the participating listeners may be a vital factor. The criterion of musical education should be taken into account during experiments so that the results obtained are reliable, uniform and free from interpretive errors.

Key words: hearing, psychoacoustics, musical acoustics, music education.

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Identification of Environmental Sounds: Auditory Abilities of Musicians and Non-Musicians

Introduction

In listening conditions encountered in the environment individual sounds are usually heard in an ambient auditory scene. In psychoacoustic laboratory experiments background sounds are often considered as maskers which impair the audibility of the target sounds. However, regardless of its masking effect, the acoustic background against which sounds are heard in the environment provides the listener with contextual information for auditory orientation in the surrounding space.

Auditory context effects in sound identification have been most extensively explored in relation to speech perception and language comprehension. A substantial body of research has demonstrated that the comprehension of spoken language may be affected by various phonetic, lexical and sentential effects[1]. The effect of auditory context on the identification of environmental sound sources has been much less studied than the contextual effects in language comprehension. The experiments have shown that, depending on whether a sound is heard in a congruent or incongruent context, the listener's ability of recognizing the sound source may be facilitated or inhibited[2]. The context in which a sound is heard – a background auditory scene or a sequence of preceding or following sounds – is congruent when it may be encountered in real situations in the environment; for example, street traffic noise is congruent with the sound of a passing car.

Two published experiments[3] studied the listener's accuracy of recognizing the sources of target sounds mixed in short samples of auditory scenes. The results have shown that identification accuracy worsened when the sounds were mixed in a congruent scene and improved when they were contextually incongruent with the background.

The inferences regarding the influence of contextual congruency on sound identification were based on a comparison of the percentage of correct identifications obtained for target sounds presented at the same *S/N* ratio in a congruent and in an incongruent scene[4]. Presumably, in addition to the effect of the background scene's congruency, the variability of identification scores obtained for sounds mixed in different auditory scenes was caused, to some degree, by the acoustic, spectral and temporal characteristics of the scenes.

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1 e.g. W.D. Marslen-Wilson, *Functional Parallelism in Spoken-Word Recognition*, "Cognition" 1987, vol. 25, no. 1–2, pp. 71–102; K. Moll, C. Cardillo, U.J. Aydelott, *Effects of Competing Speech on Sentence-Word Priming: Semantic, Perceptual, and Attentional Factors*, in: J.D. Moore and K. Stennig (eds), *Cognitive Science*, Lawrence Erlbaum Associates, Edinburgh 2001, pp. 651–656.

2 J.A. Ballas, T. Mullins, *Effects of Context on the Identification of Everyday Sounds*, "Human Performance" 1991, vol. 4, no. 3, pp. 199–219; R. Leech, B. Gygi, J. Aydelott, F. Dick, *Informational Factors in Identifying Environmental Sounds in Natural Auditory Scenes*, "Journal of the Acoustical Society of America", vol. 126, no. 6, pp. 3147–3155; B. Gygi, V. Shafiro, *The Incongruency Advantage for Environmental Sounds Presented in Natural Auditory Scenes*, "Journal of Experimental Psychology. Human Perception and Performance", vol. 37, no. 2, 2011, pp. 551–565.

3 R. Leech, B. Gygi, J. Aydelott, F. Dick, op. cit.; B. Gygi, V. Shafiro, op. cit.

4 Ibidem.

More insight into the perceptual mechanisms of sound identification in natural auditory scenes might be gained if the listeners' response reaction time was also measured during the sound identification tasks in the experiments. The time interval elapsing from the sound's onset to the beginning of the listener's response, called identification response time in this paper, might be longer for sounds that are difficult to identify in a given context than for those that are identified more easily.

Listener response time in the identification of environmental sounds was studied so far only for sounds presented in quiet. Ballas reported that identification response time was largely variable and ranged from 1.25 to nearly 7 s, depending on the sound[5]. Guillame et al. had their listeners identify environmental sounds in a gated paradigm consisting in presenting step-by-step segments of each sound, increasing in duration[6]. The shortest duration of the segment after which the first correct identification was obtained ranged, for various sounds, from 50 to nearly 700 ms in their experiment.

The experiments mentioned above have demonstrated that the measurement of sound identification response time is fraught with methodological problems as it is difficult to determine exactly the moment at which the listener actually identifies the sound source. In Ballas' experiment[7] the listeners pressed the space bar on a computer keyboard to initiate the presentation of a sound and pressed it again, as soon as they had – as the author put it – "a reasonable idea about the cause of the sound." The listeners then typed a noun and a verb that represented their identification of the sound. On each trial the time that elapsed between the onset of the sound and the space-bar press was recorded. A disadvantage of such a procedure was that the listener could press the space bar after having only a vague idea of what might have been the source of the sound and formulate the exact response during the time interval between pressing the space bar and typing the response. The duration of that interval was not measured in the experiment but one may presume that it could be comparable or even longer than the interval taken as the response time.

5 J.A. Ballas, *Common Factors in the Identification of an Assortment of Brief Everyday Sounds*, "Journal of Experimental Psychology. Human Perception and Performance" 1993, vol. 19, no. 2, pp. 250–267.

6 A. Guillame, L. Pellieux, V. Chastres, C. Blancard, C. Drake, *How Long Does it Take to Identify Everyday Sounds?*, "Proceedings of the 10th International Conference on Auditory Displays", Sydney 2004, pp. 1–4.

7 J.A. Ballas, op. cit.

Guillame et al.[8] avoided some of the disadvantages of Ballas' response time measurement procedure by using short segments of sounds, increasing in duration. Such a method had, however, another drawback: the presentation of incomplete sounds created an artificial listening scenery, very different from natural conditions when full-duration sounds are heard. In fact, the information obtained from the responses in such a task was that the listener was able to recognize a sound after hearing its segment of a given duration but the actual response time of the listener was unknown.

The present experiment was sought to assess the listeners' ability of recognizing environmental sounds in various auditory scenes in a way that enabled to reliably measure the identification response time. To avoid, at least in part, the methodological problems encountered in the studies discussed above a novel procedure was used in which the listeners were required to give their responses orally, immediately as soon as they identified the sound source in a trial.

The experiment was conducted on a group of musicians and a group of non-musicians. The two groups of subjects were employed to verify the main working hypothesis of the study which postulated that musicians possess more refined sound identification abilities than non-musicians and such a perceptual enhancement manifests itself in more accurate and faster identification of environmental sounds embedded in natural auditory scenes. The experiment was also intended to examine whether the sound identification response time depends on the target sound's contextual congruency or incongruency with the background scene.

The above working hypothesis was inferred from the reports of the so-called musician hearing enhancement effect which indicate that musical training and professional musical experience develop not only strictly musical hearing but also enhance various auditory abilities not directly related to music. For example, musicians, compared to non-musicians, demonstrate better ability of understanding speech in noise[9], better discriminate the timbre of voices in speech[10], have better ability of hearing out individual components in tone complexes[11],

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8 A. Guillame, L. Pellieux, V. Chastres, C. Blancard, C. Drake, op. cit.

9 A. Parbery-Clark, E. Skoe, C. Lam, N. Kraus, *Musician Enhancement for Speech-in-Noise*, "Ear and Hearing" 2009, vol. 30, no. 6, pp. 653–661.

10 J.-P. Chartrand, P. Belin, *Superior Voice Timbre Processing in Musicians*, "Neuroscience Letters" 2006, vol. 405, no. 3, pp. 164–167.

11 P.A. Fine, B.C.J. Moore, *Frequency Analysis and Musical Ability*, "Music Perception" 1993, vol. 11, no. 1, pp. 39–53.

possess enhanced auditory working memory[12], manifest superior auditory attention selectivity[13], faster react to sounds[14], and are less susceptible to backward masking[15] and informational masking[16]. The findings of enhanced auditory abilities of musicians observed in behavioural, psychoacoustic experiments have recently been supported by a growing evidence from neurophysiological studies of functional brain imaging[17]. Overall, the findings of the studies cited above suggest that musicianship may benefit in enhanced auditory orientation in the environment and prompt a more accurate and more readily identification of environmental sounds.

Method

Target sounds and auditory scenes

The target sounds and the auditory scenes were recorded with a dummy head (Neumann KU 100) and digitally stored in two-channel (16 bit/44100 Hz) wave format. The set of target sounds comprised 12 items which had either a form of a single homogenous sound or consisted of a series of brief sounds forming an acoustic event. The sounds were exemplars of three categories distinguished in a taxonomy of environmental sounds based on their acoustic

12 A.S. Chan, Y.C. Ho, M.C. Cheung, *Music Training Improves Verbal Memory*, "Nature" 1998, vol. 396 (Issue 6707, 12 November 1998), p. 128.

13 Y. Lee, M. Lu, H. Ko, *Effects of Skill Training on Working Memory Capacity*, "Learning and Instruction" 2007, vol. 17, no. 3, pp. 336–344.

14 D.L. Strait, N. Kraus, A. Parbery-Clark, R. Ashley, *Musical Experience Shapes Top-Down Auditory Mechanisms: Evidence from Masking and Auditory Attention Performance*, "Hearing Research" 2010, vol. 261, no. 1–2, pp. 22–29.

15 Ibidem.

16 A.J. Oxenham, B.J. Fligor, C.R. Mason, G.Jr. Kidd, *Informational Masking and Musical Training*, "Journal of the Acoustical Society of America" 2003, vol. 114, no. 3, pp. 1543–1549.

17 e.g. G. Musacchia, M. Sams, E. Skoe, N. Kraus, *Musicians Have Enhanced Subcortical Auditory and Audiovisual Processing of Speech and Music*, "Proceedings of the National Academy of Sciences" 2007, vol. 104, no. 40, pp. 15894–15898; C. Pantev, B. Ross, T. Fujioka, L.J. Trainor, M. Schutte, M. Schulz, *Music and Learning-Induced Cortical Plasticity*, "Annals of the New York Academy of Sciences" 2007, vol. 999, pp. 438–450; S.C. Herholz, B. Boh, C. Pantev, *Musical Training Modulates Encoding of Higher-Order Regularities in the Auditory Cortex,* "European Journal of Neuroscience" 2011, vol. 34, no. 3, pp. 524–529.

characteristics: (1) harmonic sounds (H), (2) impulsive sounds (I), (3) non-harmonic sounds (NH)[18]. Table 1 lists the target sounds and shows their durations, waveforms and rough, ongoing amplitude spectra. The waveforms and spectra of the target sounds are presented for the sum of the left and right channel signals. The pictograms shown in the first column were displayed in colour, on the computer screen, on a list of target sounds in each trial.

The target sounds were mixed in a continuous recording of an ongoing auditory scene. The auditory scenes used in the experiment were the following: (1) street traffic, (2) an indoor swimming pool, (3) a student cafeteria, (4) a large shopping hall. The spectra of the auditory scenes, measured for the sum of the left and the right channel signals, are shown in Figure 1. The scenes were played back at a loudness level of about 65 phons. The loudness level was chosen in a pilot experiment such as to obtain, to the best possible degree, an impression that the listener was immersed in a natural, environmental atmosphere. The scenes varied in the degree of signal variability over time, represented by the crest factor. The crest factor values are given in individual panels for each auditory scene, in Figure 1.

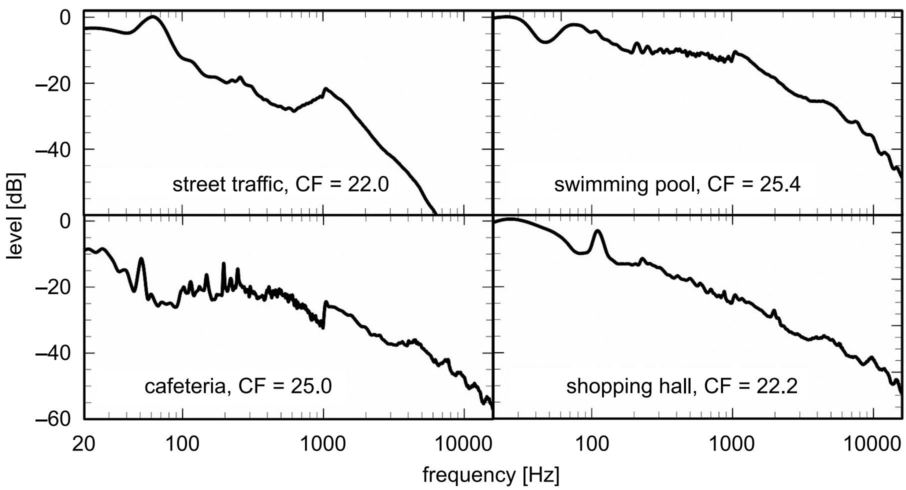
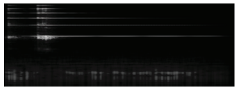
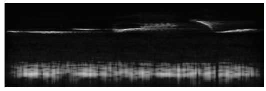
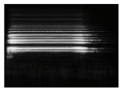
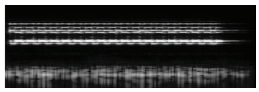
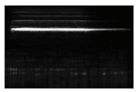
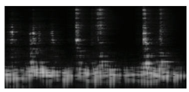
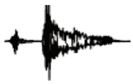
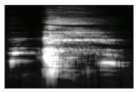
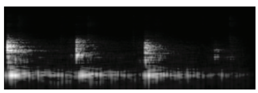
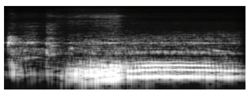
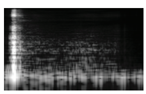
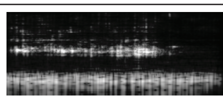
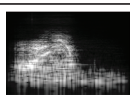


Fig. 1. Sound spectra and crest factor values (CF) measured for individual auditory scenes
Source: authors' own data

18 B. Gygi, G.R. Kidd, C.S. Watson, *Similarity and Categorization of Environmental Sounds*, "Perception and Psychophysics" 2007, vol. 69, no. 6, pp. 839–855.

Table 1. Duration, waveforms, and rough, ongoing spectra of the target sounds. The abscissa on each spectrogram is sound duration represented on a linear scale and the ordinate shows the frequency on a logarithmic scale, in a 20–20000 Hz range. The acronyms in the second column indicate: H – harmonic sounds, I – impulsive sounds, NH – non-harmonic sounds

Pictogram	Sound source/event	Duration [ms]	Waveform	Ongoing sound spectrum
	bicycle bell (H)	1296		
	bird calling (H)	1442		
	car horn (H)	637		
	telephone ring (H)	1376		
	whistle blow (H)	738		
	computer keyboard (I)	1049		
	coughing (I)	724		
	footsteps (I)	1445		
	car starter (NH)	1368		
	match lighting (NH)	809		
	water pouring (NH)	1245		
	zipper (NH)	702		

Source: authors' own data. The pictograms shown in column 1 were designed by Bartłomiej Drejewicz

Each target sound was mixed at three signal levels in an auditory scene. The lowest signal level was roughly determined in a pilot experiment and set for each target sound and each auditory scene such that the sound was just audible in the scene background. Three recording engineers adjusted each target sound to a just-audible level in each scene and the median of their adjustments was taken as the lowest signal level for a given target sound in a given scene. The two other signal levels of each target sound were by 3 and 6 dB higher than the lowest level. For each auditory scene, a block of trials comprised 36 target sounds (12 sounds × three signal levels) mixed in the given scene. Table 2 shows the crest factor for each target sound and the signal-to-noise ratio (*S*/*N*) at the lowest signal level in each scene. The values given in the table are means of two values measured for the left and the right channel.

Table 2. Crest factor for each target sound and the signal-to-noise ratio (*S*/*N*) at the lowest signal level in each auditory scene

Target sound	Target sound crest factor	*S*/*N* [dB], street traffic	*S*/*N* [dB], swimming pool	*S*/*N* [dB], cafeteria	*S*/*N* [dB], shopping hall
Bicycle bell	19.8	–33.8	–16.3	–15.7	–15.7
Bird calling	13.3	–27.0	–9.5	–10.9	–10.9
Car horn	12.9	–10.8	–4.3	–9.7	–9.7
Telephone ring	11.0	–15.5	–7.0	–8.4	–8.4
Whistle blow	16.0	–26.4	–14.9	–14.3	–14.3
Computer keyboard	24.6	–30.8	–10.3	–12.7	–12.7
Coughing	22.8	–22.8	–7.3	–6.7	–6.7
Footsteps	22.5	–11.5	0.0	–0.4	0.4
Car starter	15.2	–16.5	–1.0	1.6	1.6
Match lighting	31.3	–28.4	–10.9	–8.3	–8.3
Water pouring	19.1	–24.1	–2.6	–7.0	–7.0
Zipper	19.1	–13.0	–4.5	–6.9	–6.9

Source: authors' own data

Apparatus

The experiment was conducted in a sound-attenuating booth. The apparatus set-up was built around two computers: a PC with an M-Audio Audiophile 2946 sound card and an iMac with an RME Fireface 400 audio interface.

The PC monitor and the keyboard were placed in the booth and served as the listener's communication interface. The target sound files were read from the PC hard disk, sent in S/PDIF format to the RME Fireface 400 interface and mixed with the recordings of auditory scenes played back from the IMac's hard disk. The mix of the target sounds and the auditory scene was then sent to a Beyerdynamic DT 990 headset. The listener's oral responses captured with a microphone in the booth and the target sound audio signals delivered to the headset were synchronously recorded on separate audio tracks and stored on the iMac's hard disk.

Listening sessions

The listener was seated in front of a computer monitor in the booth and activated the presentation of a series of trials by pressing the space bar on the keyboard. The observation intervals within which the target sounds appeared in a continuous auditory scene were marked by a visual sign on the computer screen. Each observation interval lasted 10 s, regardless of the target sound duration. The moment at which the target sound was presented within the observation interval was chosen at random, with a restriction that the sound should terminate before the end of the interval. The listeners were informed that the purpose of the experiment was to measure the response time in sound identification and were instructed to speak out the sound source immediately, as soon as they recognized it, and click with the mouse on the respective pictogram on a list of 12 target sound sources displayed on the computer screen. The pictograms were displayed in different order in each trial. Clicking on a pictogram activated the presentation of a next test trial. When the listener was unable to recognize the sound source, they gave a guessed answer.

Measurement of response time

Identification response time was determined by measuring the duration of the time interval between the onset of the target sound and the beginning of the listener's oral response. The response time was read off for each trial after the listening session from a screen display of two waveforms synchronously recorded on two audio tracks during the session: a track with the target sounds presented to the listener and a track with the listener's oral responses. Within the procedure of the current experiment identification response time is equivalent to "choice reaction time", a term used in psychophysics for the subject's reaction time measured in a multi-choice response paradigm, when there are multiple stimuli and each stimulus requires a different response.

Listeners

The experiment was conducted on a group of 10 musicians (six men and four women, 18–23 years old) and 10 non-musicians (four men and six women, 20–28 years old). All listeners had pure-tone audiometric thresholds at 15 dB HL or less, at octave frequencies between 0.25 and 8 kHz. The musicians were students at the Chopin University of Music and the non-musicians were students from various non-musical academic schools. None of the non-musician listeners had any experience in amateur musical activity. The listeners were paid for their participation in the experiment.

Each listener completed six repetitions of a series of 36 target sounds mixed in each of the four auditory scenes. The first series conducted for each scene was a practice test and was not included in the calculations of results.

Results

The pairs of panels placed side-by-side in Figure 2 present, for individual target sounds, a comparison of sound identification scores and identification response time, for the non-musician and musician groups. The abscissa of each point is the result obtained for non-musicians and the ordinate is the respective result for the musician group. The sound identification scores are the group mean percentages of correct responses, shown separately for each of the three target sound levels and four auditory scenes. The identification response time values were calculated by taking the median of individual medians of sound identification response time determined for each listener in the group. The data points located above the broken diagonal line in a panel are those for which the result, *i.e.* the identification score or the response time, was higher for musicians than for non-musicians; the data points below the diagonal line are those for which the result was higher for non-musicians. The different symbols on the graphs indicate the auditory scenes in which the target sounds were mixed.

Identification response time was read off only for the trials in which the listener had correctly recognized the sound source therefore the individual medians were calculated for five or less responses, depending on how many correct responses were obtained for a given data point. Two listeners – a musician and a non-musician – made considerably more mistakes in sound identification than all the other listeners in their groups so in some cases the individual sound identification response time medians had to be determined from only one or two responses for those listeners. In cases when all responses were wrong the calculation of the individual median was not at all possible. Due to a large number of wrong identifications of the sounds the responses of those two listeners have been excluded from the calculation of group results and the data shown in Figure 2 and Figure 3 are based on the responses of nine listeners in each group.

The group medians of sound identification response time, shown in Figure 2, are replotted in a different manner in Figure 3 to allow a clearer comparison of response time for musicians (closed symbols) and non-musicians (open symbols) at three target sound levels, in each auditory scene. The successive symbols plotted for a given auditory scene along the ordinate axis show the data for each of the three target sound levels, in ascending order. The error bars indicate the interquartile ranges around the medians.

A four-way ANOVA (listeners' musicianship × auditory scene × target sound × target sound's signal level) applied to the identification scores has shown no statistically significant main effects of musicianship ($F(1, 16) = 2.066$, $p = 0.17$, $\eta_p^2 = 0.114$) and auditory scene ($F(3, 48) = 1.156$, $p = 0.336$, $\eta_p^2 = 0.067$). Statistically significant main effects were those of the target sound ($F(4.037, 64.591) = 22.373$, $p < 0.001$, $\eta_p^2 = 0.583$) and the target sound's signal level ($F(1.215, 19.444) = 148.272$, $p < 0.001$, $\eta_p^2 = 0.903$). No significant interactions were found between the listeners' musicianship and the other effects: auditory scene × musicianship ($F(3, 48) = 0.908$, $p = 0,444$, $\eta_p^2 = 0.054$), target sound × musicianship ($F(4.037, 64.591) = 1.006$, $p = 0.412$, $\eta_p^2 = 0.059$), target sound's signal level × musicianship ($F(1.215, 19.444) = 1.543$, $p = 0.234$, $\eta_p^2 = 0.088$).

As the response time was determined only for correct listener responses the number of collected samples was small and not the same for all data points. The central trends of the data sets were therefore determined by calculating the medians so it was not possible to estimate the statistical significance of the results with the use of ANOVA. The medians plotted in Figure 2 and Figure 3 should be therefore considered as results of a pilot experiment which may give some general insight into the studied effects but does not meet the statistical requirements of reliable scientific inference.

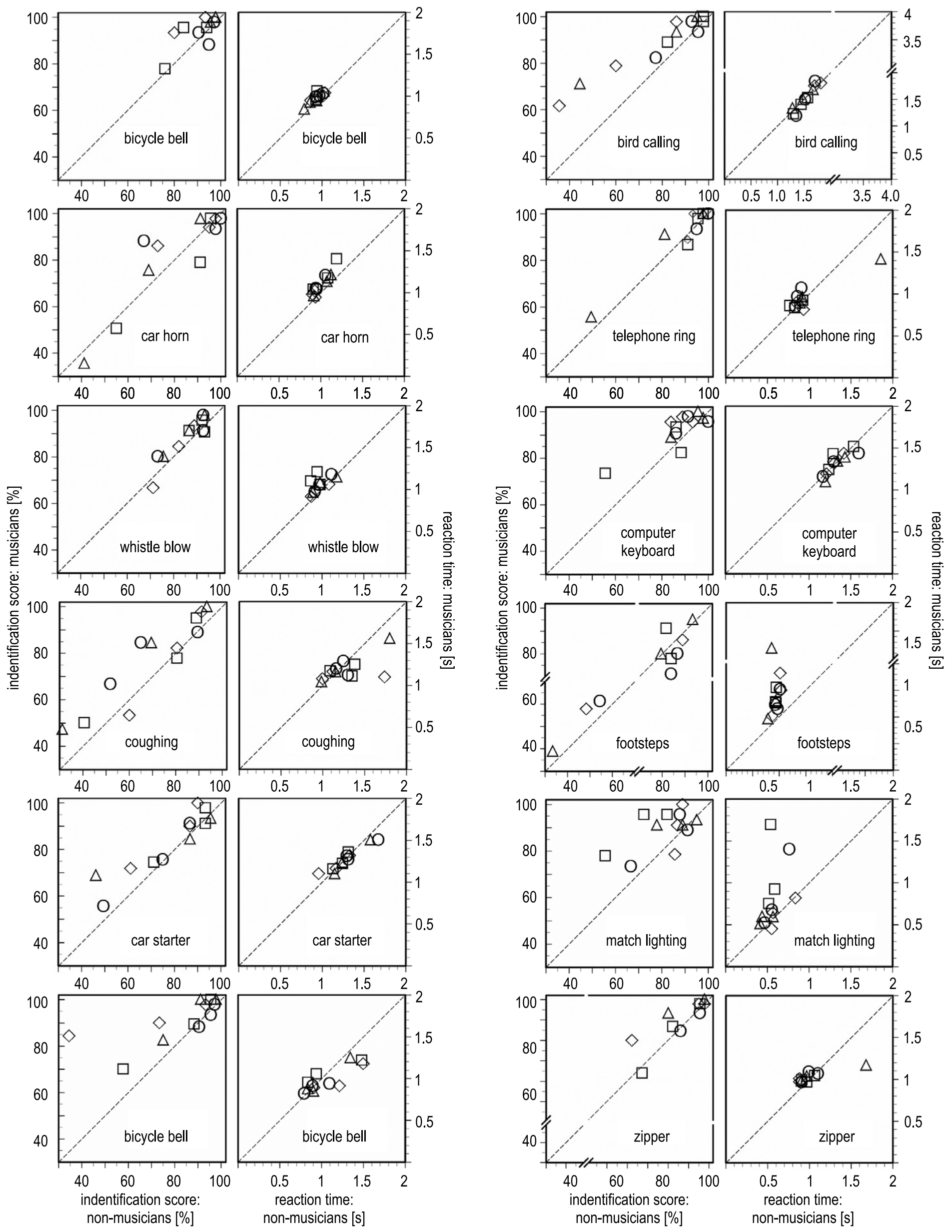


Fig. 2. Group sound identification scores and group median sound identification response time for musicians plotted against the respective group means for non-musicians. Individual panels present the data obtained for one target sound at three target sound levels in four auditory scenes. The symbols indicate: street noise (diamonds), swimming pool (triangles), cafeteria (circles), shopping hall (squares)

Source: authors' own data

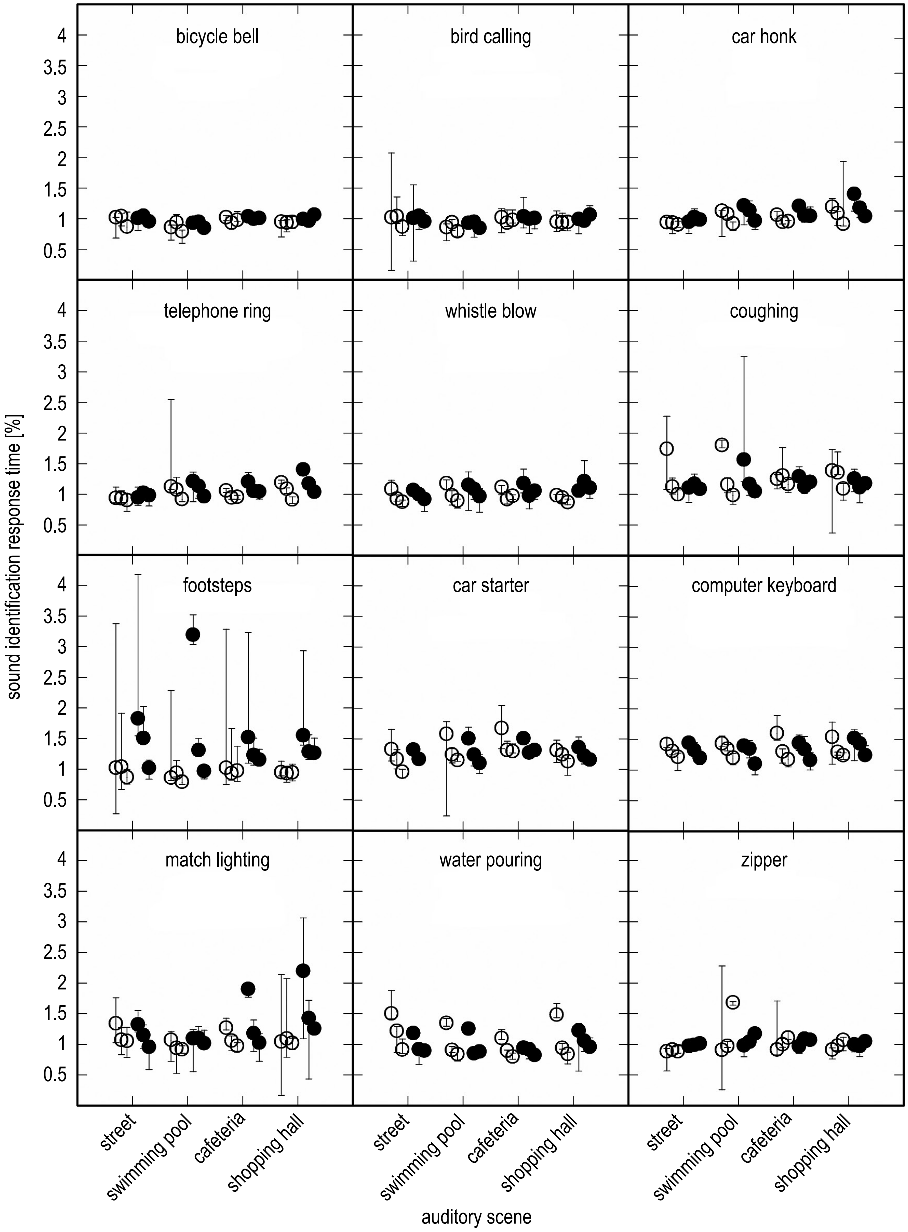


Fig. 3. Sound identification response time for 12 target sounds mixed in four auditory scenes. The data are group medians calculated for non-musicians (open symbols) and musicians (closed symbols). The successive symbols grouped along the abscissa in each triad cluster show the data for three signal levels, in ascending order. The error bars indicate the interquartile ranges around the medians

Source: authors' own data

Discussion

It is apparent in Figure 2 that most identification scores plotted in individual panels for the target sounds lie above the diagonal broken line which means that the scores were generally higher for musicians than for non-musicians. The advantage of musicians over non-musicians in sound identification accuracy is most evident for the sounds of bird calling, coughing, car starter, match lighting, water pouring and zipper. For other sounds the data points are clustered in closer proximity to the diagonal line, on its both sides. Overall, 72% of group identification scores shown in Figure 2 are higher for musicians than for non-musicians.

Although the group means suggest that there is an appreciable effect of musicianship on sound identification accuracy, the results of ANOVA indicate that the differences between the means of identification scores calculated for musicians and non-musicians are not statistically significant. The lack of statistical significance resulted from a relatively large dispersion of data across the listeners in each group.

It should be noted here that, prior to the current experiment, a pilot study of sound identification was conducted on a group of musicians and a group of non-musicians with the use of the same target sounds and auditory scenes as those employed in the current study . In that study the listener's response time was not measured so the listeners did not have to respond immediately at the moment when they recognized the sound source and the results did not show any significant difference between the scores of musicians and non-musicians. The finding that such a difference, although not statistically significant, was observed when the subjects had to respond as quickly as possible after hearing a sound suggests that the musician hearing enhancement effect may reveal itself when the identification task requires more listening effort and engages a broader range of the listener's cognitive resources.

No difference between musicians and non-musicians in sound identification acuity was also observed in an experiment conducted to determine recognition-detection threshold gaps for environmental sound samples[19]. The term recognition-detection threshold gap (RDTG) denotes the sound level difference between the recognition threshold and the detection threshold determined for

19 A. Miśkiewicz, T. Rościszewska, J. Żera, J. Majer, B. Okoń-Makowska, *Detection and Recognition Thresholds of Environmental Sounds by Musicians and Non-Musicians*, “Archives of Acoustics” 2018, vol. 43, no. 4, pp. 581–592.

a sound[20]. The experiment of Miśkiewicz et al. has shown that the RDTGs are different for different types of environmental sounds but do not differ for musicians and non-musicians[21].

The data in Figure 2 also show that musicians and non-musicians did not appreciably differ in the response time in the identification of most target sounds. Two exceptions were the sounds of match lighting and footsteps for which the response time was much longer in the musician group than in the group of non-musicians. It should also be noted that the identification scores and the response time values obtained for the match lighting sound demonstrate an effect known as the "speed-accuracy tradeoff". The term "speed-accuracy tradeoff" refers to the observation that subjects are inclined to trade increases in speed for decreases in accuracy in choice reaction time experiments[22]. In the case of the match lighting sound the data show that non-musicians responded faster than musicians but musicians obtained a higher percentage of correct identifications (Fig. 2).

When trying to analyze the results of response time measurement compiled in individual panels in Figure 2 it should be noted that there is a constraint in the interpretation of those results. Due to the small number of data samples and lack of statistical significance of the studied effects the response time data are not much more than rough estimates that can serve as guidelines for further research.

The results plotted in individual panels in Figure 3 show that the listeners' response time slightly decreased with increasing level of the target sounds. It has long been known that human response time decreases in stimulus detection tasks as a power function of stimulus intensity. This relationship, reported by numerous researchers, has been known as Piéron's Law[23]. Over the past century, Piéron's Law had been studied in relation to various sensory modalities,

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20 K. Abouchacra, T. Letowski, L. Gothie, *Detection and Recognition of Natural Sounds*, "Archives of Acoustics" 2007, vol. 32, no. 3, pp. 603–616.

21 A. Miśkiewicz, T. Rościszewska, J. Żera, J. Majer, B. Okoń-Makowska, op. cit.

22 G.R. Grice, A. Spiker, *Speed-Accuracy Tradeoff in Choice Reaction Time: Within Conditions, Between Conditions, and Between Subjects*, "Perception and Psychophysics" 1979, vol. 26, no. 2, pp. 118–126; R.P. Heitz, *The Speed-Accuracy Tradeoff: History, Physiology, Methodology, and Behavior*, "Frontiers in Neuroscience" 2014, vol. 8, article 150.

23 H. Piéron, *Recherches sur les lois de variation des temps de latence sensorielle en fonction des intensités excitatrices*, "L'Année Psychologique" 1913, vol. 20, pp. 17–96; H. Piéron, *Nouvelles recherches sur l'analyse du temps de latence sensorielle et sur la loi qui relie ce temps à l'intensité d'excitation*, "L'Année Psychologique" 1920, vol. 22, pp. 58–142.

including the auditory modality[24]. More recent studies of visual perception have shown that Piéron's Law also holds in choice tasks and seems to be a general phenomenon in psychophysics[25]. The present findings of the effect of signal level on the speed of sound identification are in general agreement with Piéron's Law and suggest that Piéron's Law also applies to stimulus identification in the auditory modality.

An important issue in the discussion of the results is whether the identification response time differs across the target sounds and the auditory scenes. The data shown in Figure 3 indicate that sound identification response time depends, to some degree, on the acoustic class to which a given sound belongs. Most of the group response time medians calculated for harmonic sounds (bicycle bell, bird calling, car honk, telephone ring, and whistle blow) are within a range of 0.8–1.1 s, with only a few slightly higher values at the lowest signal levels; for most impulse and non-harmonic sounds the response time is somewhat longer. For those sounds, almost all of the group medians fall into a range of 0.8–2.0 s, with an exception of two results obtained for the match lighting and footstep sounds which exceed 2 s at the lowest signal levels.

The finding that harmonic sounds were recognized slightly faster than non-harmonic sounds may be explained by the nature of different auditory cues used for sound identification. For harmonic sounds, the most likely identification cue was their timbre resulting from the sound spectrum characteristics whereas the main cue for the identification of other classes of sounds was presumably the temporal structure of sound. When a sound is recognized upon its temporal structure more time may be needed for extracting such a type of information from the stimulus than when the identification cue is based on the stationary sound spectrum. Longer identification response time may be therefore an effect of the sound's distinctive acoustic temporal structure and not always indicate that the cognitive processing of sensory information was prolonged.

It should also be noted that the sound identification response time values determined in the current experiment were generally lower than in Ballas'

24 e.g. R. Chocholle, *Variation des temps de réaction auditifs en fonction de l'intensite à diverses fréquences*, "L'Année Psychologique" 1940, vol. 41, no. 1, pp. 65–124.

25 J. Palmer, A.C. Huk, M.N. Shadlen, *The Effect of Stimulus Strength on the Speed and Accuracy of a Perceptual Decision*, "Journal of Vision" 2005, vol. 5, no. 5, pp. 376–404; T. Stafford, L. Ingram, K.N. Gurney, *Piéron's Law Holds During Stroop Conflict: Insights Into the Architecture of Decision Making*, "Cognitive Science" 2011, vol. 35, no. 8, pp. 1553–1566.

study[26] who reported a range from 1.25 to nearly 7 s for environmental sounds presented in quiet. This difference could be largely due to the differences in the methods used for the estimation of identification response time in Ballas' study and in the current experiment.

Another important problem that needs to be discussed in relation to the objectives of the present study is the effect of contextual congruency of target sounds and background auditory scenes on sound identification. This effect was explored in published studies by comparing the percentage of correct identification responses obtained for the same target sounds mixed with different background scenes at the same signal-to-noise ratio[27]. A shortcoming of such a procedure is that identification scores obtained for a sound at the same *S/N* ratio in different background scenes depend not only on the contextual congruency of the target sound and the background but also on the amount of masking of the target perceptual cues by the background scene. The amount of masking depends on a complexity of spectral and temporal interrelations between the target sound and the background and may therefore vary at the same *S/N* ratio for different combinations of sounds and backgrounds.

An alternative way of assessing the influence of the background cognitive content on sound identification is to compare the identification response time measured for the same sounds embedded in different scenes. Such a method was used by Gordon for the assessment of contextual effects in the identification of visual objects[28]. Gordon reported that contextually inconsistent objects yielded shorter identification response times than consistent objects.

The present data do not demonstrate any evidence of the contextual congruency/incongruency of auditory scenes on sound identification response time. It is apparent in Figure 3 that identification response time measured for the same sounds in different auditory scenes is not appreciably different which means that the present data do not support the reports of a facilitation effect of contextually incongruent scenes on sound identification[29].

One may hypothesize that the lack of such an effect in the current study was a result of mixing the target sounds in continuous recordings of auditory scenes. During a continuous presentation of an auditory scene the listeners

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[26] J.A. Ballas, op. cit.

[27] R. Leech, B. Gygi, J. Aydelott, F. Dick, op. cit.; B. Gygi, V. Shafiro, op. cit.

[28] R.D. Gordon, *Attentional Allocation During the Perception of Scenes*, "Journal of Experimental Psychology. Human Perception and Performance" 2004, vol. 30, no. 4, pp. 60–777.

[29] R. Leech, B. Gygi, J. Aydelott, F. Dick, op. cit.; B. Gygi, V. Shafiro, op. cit.

became immersed in its acoustic ambience and adapted themselves to a constant background. The reported findings of the incongruence advantage for environmental sounds were obtained in experiments conducted with the use of target sounds mixed with very short excerpts of auditory scenes and the scenes were changed within a trial series[30].

A fundamental issue in summing up this discussion is to offer an explanation for the fact that the current study, as well as our previous experiments[31], did not reveal any pronounced hearing advantage of musicians over non-musicians in the identification of environmental sounds, although enhanced auditory abilities of musicians were observed in a variety of other kind of non-musical auditory tasks. Such an explanation, which can also be applied to the findings of the current study, was proposed by Miśkiewicz et al., who suggested that the phenomenon known as "musician hearing enhancement" may be observed only in certain modes of listening[32]. The term "mode of listening" refers to a specific listening strategy used by the listener in an auditory task[33]. Usually, three basic categories are distinguished in the taxonomy of listening modes: "causal listening", "semantic listening", and "reduced listening"[34]. Causal listening, also termed "everyday listening"[35] is focused on auditory orientation in the listener's environment: on the identification of sound sources as well as on acquisition and processing of the information about the environmental events reflected by the sounds. The focus of "semantic listening" is to extract the information conveyed by the sounds by means of a certain code or language. The objective of "reduced listening" is to perceive the inherent sonic characteristics of the sounds with no connotations to any sound sources or events that might produce the sounds. The term "reduced listening" was coined by Pierre Schaeffer in a treatise on the

30 Ibidem.

31 A. Miśkiewicz, T. Rościszewska, J. Żera, J. Majer, B. Okoń-Makowska, op. cit.

32 Ibidem.

33 W.W. Gaver, *What in the World Do We Hear? An Ecological Approach to Auditory Event Perception*, "Ecological Psychology" 1993, vol. 5, no. 1, pp. 1–29; idem, *How Do We Hear in the World? Explorations in Ecological Acoustics*, "Ecological Psychology" 1993, vol. 5, no. 4, pp. 285–313; M. Chion, *Audio-Vision. Sound on Screen*, University Press, New York, Columbia 1994; A. Preis, A. Klawiter, *The Audition of Natural Sounds – Its Levels and Relevant Experiments,* "Proceedings of Forum Acusticum", Kraków 2005, pp. 1595–1599; K. Tuuri, M.-S. Mustonen, A. Pirhonen, *Same Sound – Different Meanings: A Novel Scheme for Modes of Listening,* "Proceedings of Audio Mostly", Fraunhofer Institute for Digital Media Technology IDMT, 2007, pp. 13–18.

34 M. Chion, op. cit.

35 W.W. Gaver, *What in the World*…; idem, *How Do We Hear*…

phenomenology of musical and auditory objects[36]. "Reduced listening" has also been called "musical listening"[37].

The published findings of the musician hearing enhancement effect, discussed in the Introduction, were obtained in experiments which required the subjects to listen to the test sounds either in the semantic mode or in the reduced mode whereas the identification of environmental sounds is an auditory task belonging to the causal listening category. The current study, as well as our previous experiments[38] have demonstrated that the skill of listening in causal mode, needed for efficient auditory orientation in the environment, is only very little, if at all, enhanced by musical education and musical practice.

Conclusions

Within the observations collected in the current study and the methodological constraints of our experimental design the following conclusions emerge regarding the identification of environmental sounds by musicians and non-musicians.

1. Musicians and non-musicians do not differ in the ability of identifying environmental sound sources in natural auditory scenes.
2. The finding of no appreciable effect of musicianship on sound identification acuity is in contrast to what might be expected from published reports of enhanced hearing abilities of musicians. The lack of evidence for such a hearing enhancement effect in the current study may result from the nature of the sound identification task performed in the experiment which required the subjects to listen to the sounds in the causal mode, focused on auditory orientation in the environment. The reported findings of a hearing advantage of musicians over non-musicians were observed in non-musical auditory tasks that required the subjects to listen to the sounds either in the reduced mode, focused on purely sonic characteristics of the sounds, or in the semantic mode, aimed at extracting linguistic messages conveyed by the sounds. The three listening modes, distinguished in the literature engage different listener cognitive resources and activate different cognitive processes.

36 P. Schaeffer, *Traité des objets musicaux,* Editions du Seuil, Paris 1966.
37 W.W. Gaver, *What in the World*…; idem, *How Do We Hear…*
38 A. Miśkiewicz, T. Rościszewska, J. Żera, J. Majer, B. Okoń-Makowska, op. cit.

3. The speed of sound identification, reflected by the sound identification response time, depends on the sound's acoustic characteristics and is shortest for harmonic sounds which are recognized predominantly upon their perceived characteristics associated with the stationary sound spectrum. Sounds which are recognized upon their temporal characteristics yield somewhat longer identification response time.
4. Sound identification response time does not change when a sound is embedded in different auditory scenes which implies that the sound identification speed and the listener response readiness are not influenced by the cognitive, contextual content of the acoustic ambience in which a sound is heard.
5. Identification of environmental sounds is a complex process involving a variety of sensory and cognitive phenomena. In many cases, the observations made in an experiment may be therefore confined to specific stimulus sets and listening conditions. Due to the methodological constraints of the current study the findings reported in this paper can be interpreted only as guidelines for future research. The musician hearing enhancement phenomenon, explored in relation to the identification of environmental sounds and to other instances of causal listening, needs further studies conducted with the use of a broader corpus of target sounds and auditory scenes, presented in a variety of listening conditions.

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Abstract

The study was aimed to compare the auditory abilities of musicians and non-musicians in the identification of environmental sounds embedded in the recordings of natural auditory scenes. The subjects were instructed to respond immediately as soon as they identified the sound source. It was found that the percentage of correct identification responses was slightly higher in the group of musicians but the differences between the two groups of subjects were not statistically significant. Musicians and non-musician did not differ in the response time in sound identification. It also was found that the sound identification response time did not depend on whether or not the target sound was congruent with the background auditory scene. The lack of significant evidence for the superiority of musicians over non-musicians in the accuracy and speed of sound identification is in contrast to what was expected from the reports of the so-called musician hearing enhancement effect.

Key words: environmental sounds, sound identification, sound identification speed.

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Anatomy and Physiology of the Voice Organ in Computed Tomography in the Executive Context

Introduction

The formation of voice in the form of speech and singing is a uniquely human characteristic. The peripheral part of the voice organ, the glottis, which is a part of the larynx, is the primary generation of sound, and all body structures are directly or indirectly related to the acoustic wave produced during phonation.

The peripheral part (effector) forms a single unit with the central analyser of the central nervous system thanks to the neural connections[1]. The cortical voice analyser is located in the frontal lobes of the cerebral cortex. The medulla oblongata contains centres for the nerves that supply the larynx. The activity of the voice and speech organ is controlled by the nervous system via proprioception[2]

1 Z. Pawłowski, *Foniatryczna diagnostyka*, OW "Impuls", Kraków, 2005, p. 27.

2 Proprioception (kinaesthesia) is a medical term. It is a sensory input from the joint and muscle receptors that informs the brain about the position of a particular part of the body,

by compensating for the elastic properties and tensions of the muscles of the respiratory, phonatory and articulatory systems[3].

The voice production process is possible thanks to the coordinated interaction of many organs. Some of them (the trachea, the bronchi, and the lungs), by generating a stream of expiratory air, act as a bellows pumping air to the sound generator, i.e. the larynx. Others (the laryngeal vestibule, the pharynx, the oral cavity, the nasal cavity and the paranasal sinuses) form the timbre of the voice and create the speech sounds. Another very important component of the peripheral effector is the muscular system of the chest, the abdomen, the neck, and the back, as the breathing process is dependent on it. This is because breathing cannot be separated from speaking or singing. The diaphragm is the major muscle of respiration (Fig. 1, Fig. 2). In the correct vocal emission, it is important to become aware of the inspiration and expiration at the anatomical level.

While inhaling, the most important role is attributed to the action of the diaphragm resulting in the relaxation of the abdominal muscles, the elevation of the ribs and, slightly, of the sternum, due to the elongation of the thoracic part of vertebral column. In contrast, exhalation takes place thanks to the action of the abdominal prelum with the simultaneous relaxation of the diaphragm, lowering of the ribs and the sternum, and a forward stooping of the thoracic vertebrae[4]. It is worth mentioning that the term 'abdominal prelum' is understood as a system of muscles, i.e. the rectus abdominis muscle, the external abdominal oblique muscle, the internal abdominal oblique muscle, and the transversus abdominis muscle, which form the abdominal wall.

As a result of the thickening and thinning of the expiratory air (due to an increase and decrease of pressure), the fundamental (or laryngeal) tone is produced on vocal folds. Overall, however, both the inspiration and expiration are unconditioned reflexes, i.e. they are independent of our will. Nevertheless, one can minimally shape and influence the respiratory volumes and the action of the muscles in the process of methodical training in singing.

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needed to maintain balance. Usually, these stimuli remain outside our consciousness.

3 Z. Pawłowski, op. cit., p. 27.

4 Z. Madej, H. Zajączkiewicz, *Głos jako przestrzeń akustyczno-fizjologiczna. Podstawowe założenia anatomiczne jako punkt wyjścia do interpretacji głosu w perspektywie wykonawczej*, in: A. Rosiński (ed.), *Przestrzenie akustyki (Professional Acoustics)*, Wydawnictwo Uniwersytetu Warmińsko-Mazurskiego w Olsztynie, Olsztyn 2021, pp. 166–167.

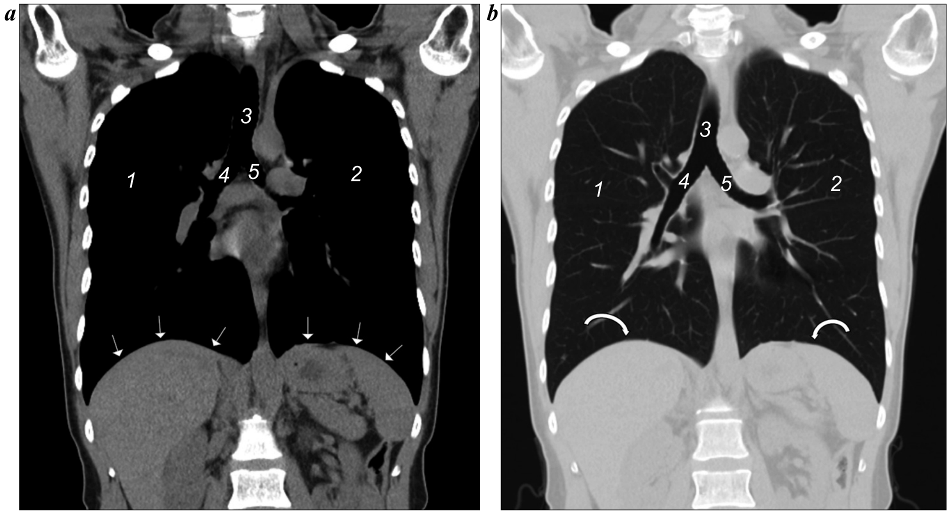

Fig. 1. The CT images of the chest – a frontal section: *a* – soft tissue window; *b* – lung window. The diaphragm: the right and left hemidiaphragm – straight and curved arrows, *1* – right lung; *2* – left lung; *3* – trachea; *4* – right main bronchus; *5* – left main bronchus
Source: the CT images from authors' collection

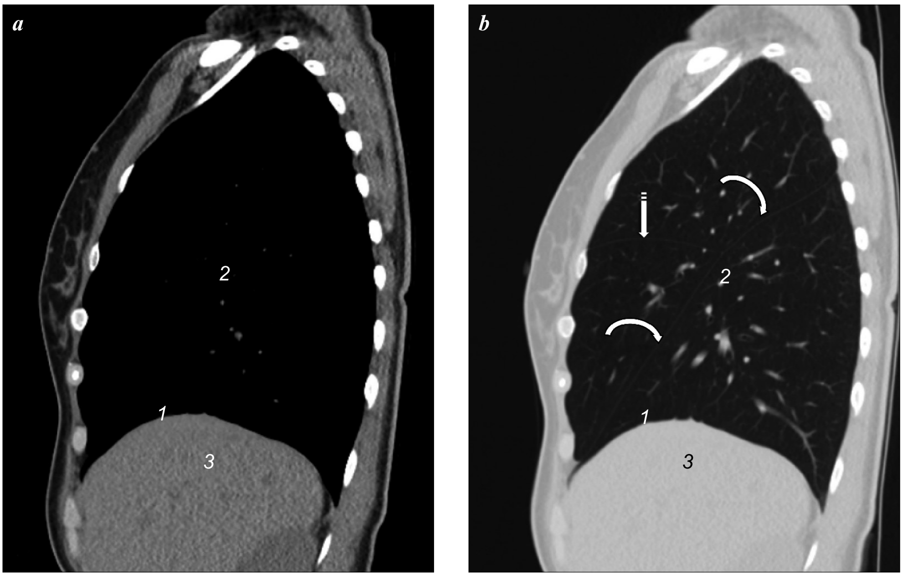

Fig. 2. The CT images of the chest: a sagittal section: *a* – soft tissue window; *b* – lung window; *1* – the right hemidiaphragm seen from the side; *2* – right lung; *3* – liver. Oblique fissure of right lung – curved arrows. Horizontal fissure of right lung – straight arrow
Source: the CT images from authors' collection

The central analyser is made up of the brain centres located in different parts of the cerebral cortex. They are connected to the organ of hearing, which is responsible for receiving appropriate speech signals and sending them to the cerebral cortex. The larynx is only part of a larger whole, and its function is to generate sounds. Speech and singing are produced through the interaction of different components, the most important of which is the nervous system. This is confirmed by the fact that children who are born deaf will never speak and will remain mute. They will never learn to sing, even though their speech organ (the peripheral effector) is properly developed[5]. Therefore, the following statement is true: "with his larynx, man is able to make noises; he speaks and he sings with his brain[6]".

The development of the human voice

The human voice develops from the moment the first sound, namely a scream, is emitted, i.e. from birth. The cry of a newborn allows the airways to be cleared and helps expand the lung tissue and oxygenate the baby. The very first sound made by a human being is unconditional, and each subsequent one, whether it be weeping, moaning, or whimpering, expresses his or her emotional state. This is the only way a newborn or an infant can communicate with its environment and signal hunger, pain or contentment. The cry, characteristic of a very young child, disappears after a few months. It is a high-pitched sound with a frequency of 600 Hz and an intensity of approx. 110 dB, is rather piercing and unpleasant (alarming).

As ontogeny continues, the child's voice pitch decreases while its modulation capabilities increase[7]. The most significant development of the voice occurs during puberty. At this time, the timbre (tone colour) of girls' and boys' voices begins to be clearly distinguishable. This is the so-called mutation resulting from the changing structure of the larynx, which changes the scale and timbre of the voice.

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5 Cf. R.T. Sataloff, *Professional Voice. The Science and Art of Clinical Care*, Raven Press, New York 1991.

6 J. Krassowski, *Higiena głosu śpiewaczego*, Wydawnictwo Akademii Muzycznej im. Stanisława Moniuszki w Gdańsku, Gdańsk 1990, p. 8.

7 M. Zalesska-Kręcicka, *Głos i jego zaburzenia*, Akademia Muzyczna im. Karola Lipińskiego we Wrocławiu, Wrocław 2004, p. 55.

The mutation process begins at approx. 12–15 years of age. The larynx belongs to the tertiary sex organs, which means that this organ is directly affected by sex hormones, primarily testosterone. Voice mutation involves a change in the sound of the voice in both boys and girls during adolescence due to physiological changes within the voice organs. This process lasts for approx. three years. The laryngeal cartilages expand, the vocal cords elongate considerably, and the trachea and the supralaryngeal spaces enlarge. During mutation, hoarseness and voice disruptions are frequent: due to disorders in the coordination of laryngeal muscles, congestion of the mucous membrane and increased mucus secretion, high and low sounds are produced alternately. In boys, the voice pitch decreases on average by one octave, while in girls, by a third or even less. Testosterone causes the enlargement of the larynx and the vocal cords, which become thicker and longer, and that changes their sound. The mutation in girls is not as noticeable as in boys; however, it is equally important in terms of vocal pedagogy.

During mutation, the vocal folds become thicker and grow longer: in boys by approx. 10 mm while in girls by approx. 4 mm, which increases their blood supply and weight. In boys, the average voice pitch decreases to approx. 128 Hz, while in girls to approx. 256 Hz. In boys, the so-called "mutational triangle", i.e. the incomplete phonatory closure of the vocal folds in the posterior parts, is often noted during mutation. During this period, it is very important not to strain the voice, as the occurring changes reduce its efficiency.

At the same time, as the larynx develops, the whole body matures as well, as the chest and the body posture develop. After the mutation period, the voice already has a developed timbre and scale.

During sexual maturity, the voice stabilises and undergoes no changes. However, a properly trained, professionally managed voice can change as required. Its scale can be increased, and its timbre can be rounded off.

In females, the turning point is the menopausal period, with the changing hormonal balance causing changes in the voice organ. This is due to an increase in the weight of the vocal folds, resulting from the thickening of the epithelium and a tendency to the formation of oedemas.

In the eighth decade of the age, the average female voice pitch decreases to a level of approx. 195 Hz, i.e. changes by approx. 61 Hz. In contrast, in males, the average voice pitch decreases until the fifth decade of life and then increases as the weight and elasticity of the vocal folds decreases. Such a voice is often described as "senile" or "squeaky". Voice changes in males are considerably more noticeable than those in females.

At an old age, the muscle mass and the flexibility of the chest decrease. Changes in the pitch and strength of the voice are also associated with the degeneration of laryngeal muscles and a change in elastic fibres in the submucosal region. The mucous membrane is atrophic, and its moisture level decreases as the number of salivary glands decreases.

Methods of voice testing

The very first observation of one's own larynx was carried out in 1854 by the Spanish singer Manuel Garcia.

The voice organ is assessed in a phoniatric examination by an otolaryngologist or a phoniatrist. For people using their voice professionally, this examination should always be preceded by a carefully taken medical history. This should include, e.g. the information on previous voice disorders and their treatment, co-morbidities, medications taken, addictions, and the current mental state. This is followed by a laryngological examination (an assessment of the nose, the pharynx, the ears, and the larynx). After viewing the larynx under either indirect laryngoscopy (using a laryngeal mirror with a diameter of approx. 25–30 mm) – Figure 15 or telelaryngoscopy (with magnification), a voice assessment is carried out. The following parameters are assessed: the character

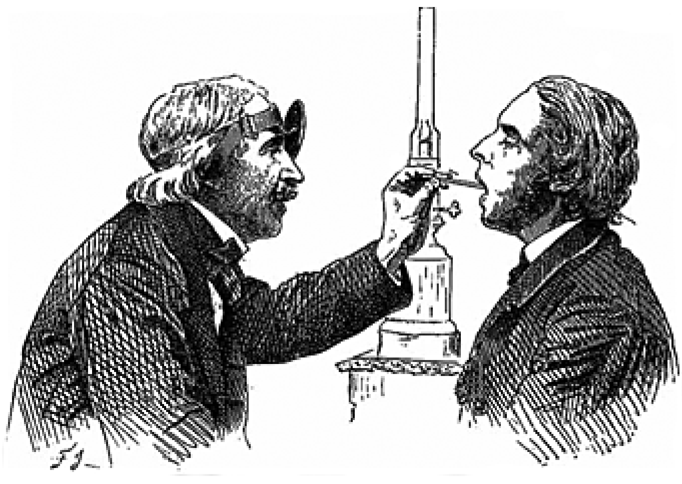

Fig. 3. First attempts to view the larynx
Source: M. Garcia, *Traité complet de l'art du chant*, 8 ed. Paris 1884, Heugel et Cie; *Laryngoscopy*, https://en.wikipedia.org/wiki/Laryngoscopy [accessed: 12.04.2022]

of the voice, the breathing pattern, phonation time, the activation of resonators, the average voice pitch and its range, and the compensatory capacity of the larynx.

A voice can be described as resonant, matt, raspy, hoarse, or completely silent (aphonia). In a subjective evaluation, a correct voice should be resonant, clear, devoid of a noise component, not tiring, rich in resonance, produced with a soft vocal onset, without internal tension, and without tensing the neck muscles[8]. Its pitch should correspond to gender and age. The visible widening of the neck veins during phonation is indicative of an improper, strained method of voice production. The movements of the chest during breathing help answer the question as to what breathing pattern is used by the subject: the upper or thoracic, the middle or thoracoabdominal (diaphragmatic-costal), or the lower or abdominal pattern.

The phonation time is determined by instructing the subject to pronounce a vowel, for example "a", during a single full exhalation. It lasts on average from 20 to 25 seconds[9], while in singers, it lasts considerably longer, i.e. 40–60 seconds. A value below 10 seconds indicates a pathological condition. What is important for strengthening the voice and obtaining its individual timbre is the activation of the vocal tract resonators, i.e. the appropriate use of the resonating cavities of the nose, oral cavity, the pharynx, and the paranasal sinuses while they "convey" the transported air to the so-called open timbre. In order to assess the (use of) resonators, a simple test is applied, which involves placing the middle finger on the lateral, bony wall of the nosal cavity while pronouncing the sounds ma-me-mi. During a correct phonation, vibrations can be felt under the fingertips. It should be noted, however, that the same vibration should be felt at the back of the head at the level of the mastoid processes. Otherwise, the sound of the voice will be considerably poorer in terms of overtones. The average voice pitch and the voice range are determined using a frequency meter. The average voice pitch is 128 Hz (c) for males, and 256 Hz (c^1) for females. The average voice range covers from 1.5 to 2 octaves. In singers, the scale of the voice ranges from 2 to 3 octaves[10].

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8 M. Śliwońska-Kowalska, E. Nielubek-Bogusz, *Rehabilitacja zawodowych zaburzeń głosu*, Instytut Medycyny Pracy im. prof. J. Nofera, Łódź 2009.

9 Cf. A. Pruszewicz, *Foniatria kliniczna*, PZWL, Warszawa 1992.

10 Cf. J. Chaciński, K. Chacińska, *Podstawy emisji głosu w procesie kształcenia nauczycieli muzyki*, Słupsk, Wyższa Szkoła Pedagogiczna, Słupsk 1999.

The scales for different voice types are as follows:

– the coloratura soprano scale – v.f. length[11]: up to 14 mm; v.f. width[12]: 2–2.5 mm;
– this is the highest female voice characterised by the scale ranging from c^1 to f^3, and great fluency;
– the soprano scale – from c^1 to c^3, sometimes e^3, v.f. length of up to 14–19 mm; v.f. width of 2–3 mm; this voice is characterised by a light timbre, medium strength, and the mobility being lower than that in the coloratura soprano but higher than that in the mezzo-soprano;
– the mezzo-soprano scale – from a to g^2 (lyrical), from g to c^3 (dramatic), v.f. length: up to 18–21 mm, v.f. width: 2.5–3 mm; a type of a human voice with the vocal range lying between the soprano and the alto voice types, partially encompassing both the voices;
– the alto scale – g (sometimes f) – g^2;
– the contralto scale – from c to c^2;
– the tenor scale – from c to c^2 (sometimes d^2), v.f. length of 18–23 mm; v.f. width of 2.5–3 mm; tenor is the highest male voice that can be produced using the chest register;
– the baritone scale – from G/A to g1, v.f. length of 22–24 mm; v.f. width of 3–4 mm; a male voice falling in the middle range of the voice scale, usually between G and A up to g^1, or from 110 to 390 Hz;
– the bass scale – from E to d^1 (bas profondo from C), v.f. length of 24–25 mm; v.f. width of 3–5 mm; the lowest male voice; in a choir, it usually covers the scale ranging from F to c^1 or e^1, while in solo singing, the C scale (from D to e^1).

The compensatory capacity of the larynx is examined by pressing down on the thyroid cartilage laminae during phonation, which should raise the laryngeal tone, while pressing down on the thyroid cartilage notch posteriorly and inferiorly should lower it. Another important parameter is the vocal onset, i.e. the way the vocal folds transition from the respiratory to the phonatory position. A few types can be distinguished: soft (or physiological); hard – with a strong stop; and breathing, or aspiratory, where a gap is created in the posterior part of the glottis, and a portion of the air is turned into a murmur. The maximum voice intensity is the ability to increase this intensity (dynamic modulation). They are estimated subjectively as low, medium, and high, or using

[11] The length of vocal folds.
[12] The width of vocal folds.

a microphone located at a fixed distance from the mouth (approx. 30 cm) and an intensity level meter. The maximum intensity for a whisper is 50 dB, for everyday speech it is 65 dB, and for a shout, 80 dB (up to 115 dB).

The basic specialist examination of the larynx, which enables the qualitative assessment of the vocal fold vibrations, is laryngostroboscopy.

The examination uses the stroboscopic effect, i.e. an optical illusion resulting from the fact that light impressions last longer in our eye than the stimulus is active. The vibrations of vocal folds are very rapid. When using intermittent (stroboscopic) light to illuminate the larynx with a frequency of vibrations different from that of the vocal fold vibrations, movements of the vocal folds can be observed in slow motion. Based on the image thus obtained, the action of the vocal folds can be assessed. In people with an excessively strong gag reflex, a laryngostroboscopic examination should be carried out under surface anaesthesia (lignocaine 10%), which will allow it to be performed smoothly. The examination is carried out by observing movements of the vocal folds at the same voice intensity over the entire voice scale, starting from the middle register.

The examination results are recorded on computer disks and archived to provide a comparative scale for subsequent examinations. A stroboscopic examination can also be performed using a flexible laryngo-fiberscope. A fiberscope inserted through the nose to the level of the laryngeal inlet enables the observation of the larynx under physiological phonation conditions (which helps avoid the rather unpleasant pulling out of the tongue which is required when using rigid laryngostroboscopes).

A laryngostroboscopic examination allows functional and organic lesions to be differentiated, which is very useful in the early diagnosis of neoplastic lesions. An image of the laryngeal structures and functions can also be obtained by computed tomography diagnostic examination, i.e. multi-layerd and multi-sectional images of the larynx[13].

A non-invasive and relatively objective method of voice examination is the acoustic analysis of recorded voice samples. What is analysed is a digital recording sample of the “a” sound phonated in a stable manner, lasting for at least one second.

[13] A. Pruszewicz, *Metody badania narządu głosu*, “Postępy w Chirurgii Głowy i Szyi” 2002, vol. 2, no. 2, pp. 3–25.

Phoniatric evaluation of an opera singer's voice organ

A person aspiring to become a professional singer should meet the following criteria in addition to having strong motivation, physical aptitude, and mental resilience:

1. A properly developed voice organ (without anatomical defects).
2. Proper respiratory and phonatory coordination.
3. Proper phonation time.
4. Normal physiological hearing and a good ear for music.
5. No speech impediments, a correct diction.
6. A voice scale falling within the limits of an untrained voice.
7. No chronic diseases or lesions within the upper and lower respiratory tract (e.g. chronic inflammation of the mucous membrane of the upper respiratory tract or allergies causing the nasal obstruction)[14].

Computed tomography

One of the examinations that can objectively show the entire vocal tract and the related anatomical areas is computed tomography (CT). It is a recognised and widely used method that enables spatial imaging of the different tissues of the entire body. A computed tomography examination very clearly reveals the bone structures and less cartilaginous tissue, e.g. the laryngeal cartilages and soft tissues 16, 17.

The larynx

The larynx (Latin: *larynx*) is the upper part of the respiratory tract. Its anlage emerges in the fourth week of the foetal life[15]. The larynx is an organ made of cartilages, ligaments and muscles, which connects the pharynx with the trachea. The larynx is composed of several structures, i.e. cartilages that are classified as paired (arytenoid, corniculate, cuneiform and tritiated cartilages) or single (epiglottic, cricoid and thyroid cartilages). Further components include

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14 E. Sielska-Badurek, E. Kazanecka, E. Osuch-Wójcikiewicz, A. Domeracka-Kołodziej, *Rola foniatry w multidyscyplinarnej opiece nad wokalista*, “Otoralyngologia” 2012, 11(3), 2012, pp. 87–94.

15 A. Pruszewicz, *Foniatria kliniczna*…, p. 29.

the epiglottis, the intrinsic and extrinsic laryngeal muscles, ligaments and soft tissues. The tissues include the epithelium and the subepithelial tissue. In children, the larynx is located at the level between the second and the fourth cervical vertebra, in adults between the fourth and the fifth cervical vertebra in females, and between the fifth and the sixth vertebra in males. The differences in the position of the larynx are due to the individual maturation (between 6 and 8 months of gestation, the laryngeal descent occurs, in a 5-month-old foetus, the epiglottis may still be in contact with the soft palate) and sexual maturation in boys (between 13 and 14 years of age). At an older age, senile descent of the larynx occurs due to the weakening of the muscles supporting the larynx and the stretching of the laryngeal ligamentous apparatus. The position of the larynx also changes due to the movements that alter the position of the neck. For example, when the head is bent forward and the chest is stationary, the larynx is located just above the manubrium of the sternum, and when the head is tilted back as far as possible, the larynx rises significantly.

The thyroid cartilage is the largest laryngeal cartilage. Its two symmetrical laminae join at an angle of approx. 90° in males, and 120° in females and children. The laryngeal prominence characteristic of males, commonly referred to as the Adam's apple, is found in the anterosuperior part of the cartilage with the superior thyroid notch. Muscular attachments are located on both sides of the cartilage. The oblique line on the external surface of the lamina gives

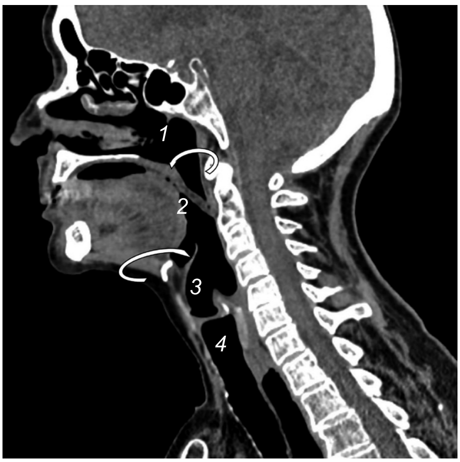

Fig. 4. The CT image of the neck: a soft tissue window in a sagittal section.
A pharynx and larynx in a sagittal view: *1* – nasopharynx; *2* – oropharynx;
3 – laryngopharynx; *4* – trachea. Soft palate and epiglottis marked by curved arrows
Source: the CT images from authors' collection

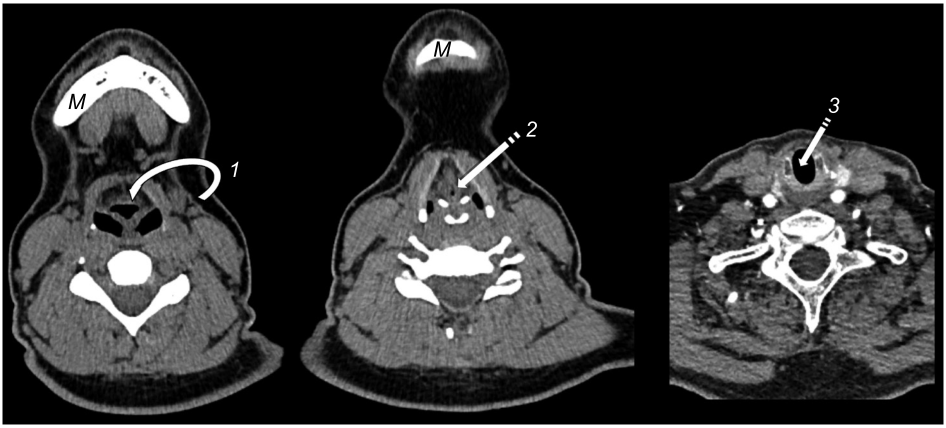

Fig. 5. The CT images of the neck: a soft tissue window in a transverse (axial) section:
1 – larynx, a transverse section on the level of epiglottis;
2 – glottis; *3* – subglottic part; *M* – mandible
Source: the CT images from authors' collection

attachments for the part of inferior pharyngeal constrictor (thyropharyngeus muscle), and for the sternothyroid and thyrohyoid. As well as in the angle between the laminae on the internal surface of the lamina there are the ligamentous (thyroepiglottic, vestibular and vocal ligament) and muscular attachements (the thyroarytenoid, thyroepiglottic and vocalis muscles, and the stalk of the epiglottis).

Below thyroid cartilage lies the cricoid cartilage, i.e. the only cartilage that forms a closed ring resembling a signet ring. Cricoid cartilage connects to the thyroid cartilage by the median (anterior) cricothyroid ligament, the thickened medial portion of the conus elasticus. Within the arch of this cartilage, there are attachments for the cricothyroid muscle and behind it the cricopharyngeus (part of the inferior pharyngeal constrictor). The lamina of cartilage gives attachement for lateral and posterior cricoarytenoid muscle. The lower edge of the cricoid cartilage is connected to the trachea with a cricotracheal ligament. The arytenoid cartilages are found on the posterior upper edge of the cricoid cartilage. The arytenoid cartilages are small in size, which enables the rapid abduction and adduction of the vocal cords[16]. Their shape resembles pyramids or an inverted letter T. They are the site of attachment for the lateral and posterior cricoarytenoid muscles, the thyro-arytenoid muscle, interarytenoid muscle (transverse and oblique parts) and, primarily, the vocal ligament and

16 M. Zalesska-Kręcicka, *Atlas chorób krtani*, Volumed, Wrocław 1995, p. 6.

vocalis muscle. The epiglottic cartilage is a single structure that provides scaffolding for the epiglottis. It is shaped like a small, curved leaf and forms the anterior wall of the laryngeal entrance (Fig. 6). The epiglottis diverts liquids and food away from the laryngeal inlet however it is not essential for respiration or phonation and safe swallowing is still possible without an epiglottis.

Fig. 6. The place of cricothyrotomy performance – marked by arrow.
The CT image of the neck: a soft tissue window in a sagittal section
Source: the CT images from authors' collection

The cartilaginous skeleton of the larynx is almost completely calcified in males around the age of approx. 50 years, and in females around the age of approx. 76 years, although significant deviations have been noted[17].

The laryngeal skeleton is connected by connective tissue elements, i.e. membranes and ligaments. The external and internal membranes and ligaments connect the cartilages together. The external membranes and ligaments connect the larynx to the surrounding anatomical structures. The most important membranes include the thyrohyoid membrane, cricothyroid membrane with median cricothyroid ligament and conus elasticus, and the cricotracheal ligament, which connects the larynx with the trachea. It should be noted that the cricothyroid membrane is where the respiratory tract runs the closest to the skin, which is why the life-saving procedure of cricothyrotomy is performed

[17] A. Obrębowski, *Narząd głosu i jego znaczenie w komunikacji społecznej*, Uniwersytet Medyczny w Poznaniu, Poznań 2008, p. 10.

at that site[18]. Additionally, the intrinsic, quadrangular membrane passes from the epiglottis to the ipsilateral arytenoid cartilage and its lower border forms the vestibular ligament.

Two groups of muscles, i.e. the intrinsic and extrinsic muscles, serve a significant role in the biomechanics of the larynx. In illustrative terms, we can say that the extrinsic muscles, along with the system of membranes and ligaments, suspend the larynx in the neck. With regard to their function, they can be divided into the larynx-elevating and larynx-lowering muscles.

1. The extrinsic laryngeal muscles that elevate the larynx and shorten the vocal tract:
   a) inferior pharyngeal constrictor (Latin: *musculus constrictor pharyngis inferior*)
   b) the suprahyoid muscles:
      – digastric muscle (Latin: *musculus digastricus*),
      – geniohyoid muscle (Latin: *musculus geniohyoideus*),
      – mylohyoid muscle (Latin: *musculus mylohyoideus*),
      – stylohyoid muscle (Latin: *musculus stylohyoideus*).
2. The extrinsic laryngeal muscles that lower the larynx and increases the length of the laryngopharynx and reduce supraglottal pressure:
   a) the infrahyoid muscles:
      – sternohyoid muscle (Latin: *musculus sternohyoideus*),
      – sternothyroid muscle (Latin: *musculus sternothyroideus*),
      – thyrohyoid muscle (Latin: *musculus thyrohyoideus*),
      – omohyoid muscle (Latin: *musculus omohyoideus*).

The extrinsic laryngeal muscles by raising or lowering the larynx can affect the quality and the pitch of the voice. The geniohyoid additionally elevates and anteriorly displaces the larynx, particularly during deglutition. Laryngeal elevation reduces the length and caliber of the laryngopharynx and thus shortens the entire vocal tract.

18 Cricothyrotomy – a life-saving laryngological surgery that involves the cutting of the cricothyroid ligament located between the lower edge of the laryngeal thyroid cartilage lamina and the upper edge of the laryngeal cricoid cartilage arch. It is used as a quick and emergency way to open the airways that have become blocked at the level or above the true glottis.

On the other hand, the intrinsic muscles of the neck ensure the movement of the laryngeal cartilages and control the width of the glottis and the tension of the vocal folds as well as the vestibular folds[19].

The intrinsic laryngeal muscles can also be divided in terms of their function.

1. Vocal fold sphincter muscles vary the degree of abduction and adduction of the vocal folds and hence changed rima glottidis dimensions and the degree of opening (which close the true glottis):
   a) lateral cricoarytenoid muscle (Latin: *musculus cricoarytenoideus lateralis*) is responsible for adduction during phonation (speaking) together with thyroarytenoid and interarytenoid,
   b) posterior cricoarytenoid muscle (Latin: *musculus cricoarytenoideus posterior*) responsible for abduction during respiration (breathing)) interarytenoid muscle (Latin: *musculus interarytenoideus*) oblique and transverse part. The oblique arytenoids together with aryepiglottic muscles act as a sphincter of the laryngeal inlet by adducting the aryepiglottic folds. They are also weak adductors of the vocal folds. The transverse interarytenoid pulls the arytenoid cartilages towards each other and closing the rima glottidis (its posterior, intercartilaginous, part).
2. Vocal fold retractor muscle, regulate the length of the vocal folds:
   a) posterior cricoarytenoid muscle (Latin: *musculus cricoarytenoideus posterior*) – its dysfunction leads to dyspnoea, since the glottis cannot be opened,
   b) thyroarytenoid muscle (Latin: *musculus thyroarytenoideus*),
   c) cricothyroid muscle (Latin: *musculus cricothyroideus*),
   d) vocal muscle (Latin: *musculus vocalis*).
3. The muscles above regulate the tension, tightening the vocal folds. When the vocal folds do not operate properly, they are bilaterally flaccid
4. The muscles modified and closing the laryngeal inlet:
   a) thyroepiglottic muscle (Latin: *musculus thyroepiglotticus*),
   b) aryepiglottic muscle (Latin: *musculus aryepiglotticus*),
   c) oblique arytenoid muscle (Latin: *musculus arythenoideus pars pbliqua*).

These muscles pull the epiglottis posteriorly and inferiorly.

19 A. Obrębowski, op. cit., p. 12.

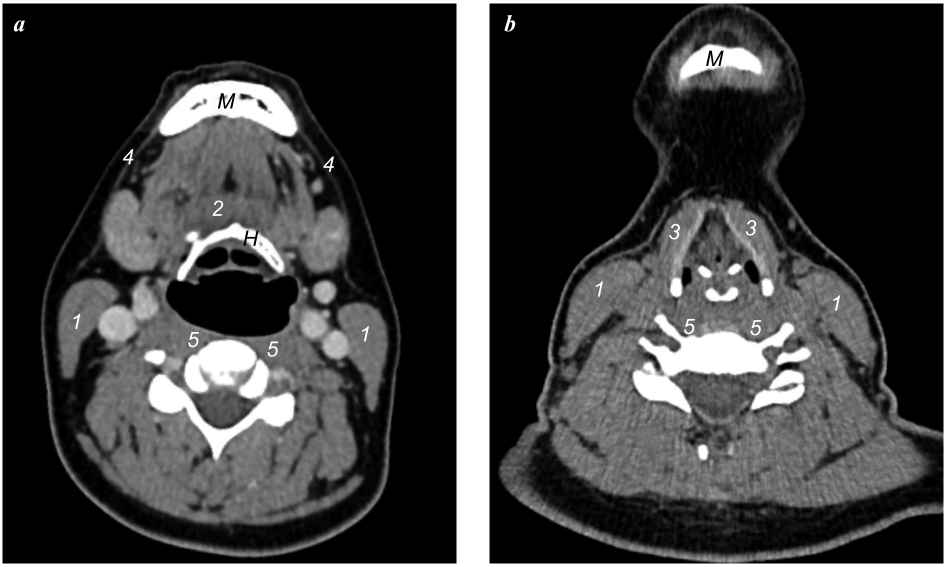

Fig. 7. The CT images of the neck: a soft tissue window in a transverse (axial) section; *a* – section at the level of hyoid bone; *b* – section at the level of thyroid cartilage. The neck muscles: *1* – sternocleidomastoid; *2* – suprahyoid group muscle; *3* – infrahyoid group muscle; *4* – platysma; *5* – longus colli and longus capitis; *M* – mandible; *H* – hyoid bone
Source: the CT images from authors' collection

The laryngeal cavity

The laryngeal cavity is made up of cartilages that form the anterior wall (the epiglottic cartilage, the thyroid cartilage angle, the thyroepiglottic ligament, the arch of cricoid cartilage and the cricothyroid ligament), the lateral wall (arch of cricoid cartilage and the arytenoid cartilages, and cuneiform and corniculate cartilages), and the posterior wall (the lamina of cricoid cartilage and the interarytenoid muscle). It is divided into the laryngeal inlet, laryngeal vestibule, rima vestibuli, laryngeal ventricle, rima glottidis with the glottis, i.e. the laryngeal cavity proper, and the infraglottic cavity, which terminates between the cricoid cartilage and the first tracheal cartilage. The upper part, of laryngeal cavity is formed by the laryngeal inlet, the aryepiglottic fold and the laryngeal vestibule. The laryngeal vestibule is limited by laryngeal inlet superiorly and vestibular fold inferiorly, anteriorly by the epiglottis and posteriorly by the interarytenoid mucosa, and laterally by the aryepiglottic folds.

The smallest, middle part of the laryngeal cavity is made up of rima vestibuli, vestibular folds, ventricle and saccule up to rima glottidis. The rima glottidis is located between two vocal folds that limit the so-called true glottis and the medial surfaces of the arytenoid cartilages. The glottis is a generator of the fundamental tone referred to as the laryngeal tone. This is because the energy expressed by the subglottal pressure vector is transformed into acoustic energy within the glottis[20]. In 1975, a Japanese physician Minoru Hirano distinguished five layers of this structure. The differences in the mechanical properties of the individual layers enable the proper propagation of tensions, which is a prerequisite for the normal vibration of the folds[21]. During phonation, the vocal cords perform complex oscillatory movements that allow a sound of a high frequency, amplitude and phase to be generated[22].

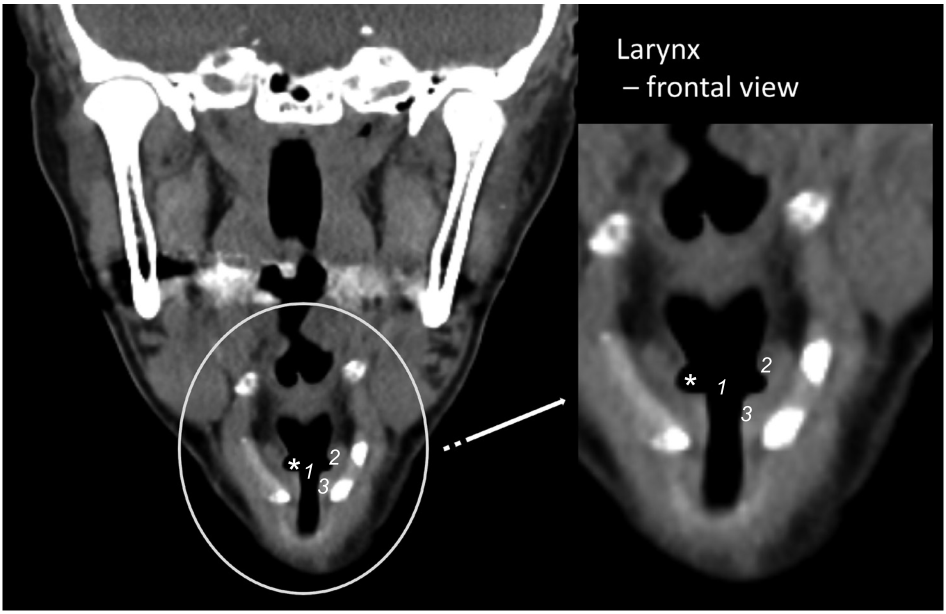

Fig. 8. The CT image of the larynx: a soft tissue window in a frontal section on the level of glottis. The glottic part of larynx: *1* – glottis; *2* – vestibular fold; *3* – vocal fold; * – laryngeal ventricle
Source: the CT images from authors' collection

20 A. Obrębowski, op. cit., p. 15.
21 Z. Pawłowski, op. cit., p. 29.
22 M. Hirano, *Morphological Structure of the Vocal Cord as a Vibrator and its Variations*, "Folia Phoniatrica et Logopaedica" 1974, 26, pp. 89–94.

The mucous membrane of the larynx is made up of the areolar tissue, which is the reason why oedemas form there and, in dangerous situations, interrupt the air supply. The larynx is lined by the stratified or pseudostratified ciliated epithelium except in the area such as the epiglottis, the vocal folds, and the medial surface of the arytenoid cartilages, where the non-keratenising squamous epithelium is found.

Innervation and vascularisation of the larynx

The larynx is innervated by the branches of the vagus nerve: the superior laryngeal nerve, whose external branch (mostly motor) innervates the cricothyroid muscle, while the internal branch (mostly sensory) innervates the mucous membrane that lines the upper and middle part of the larynx up to the vocal cords level. The recurrent laryngeal nerve (mixed, mostly motor and sensory) innervates all the other muscles of the larynx as well as the mucous membrane of the lower part of the larynx, below the vocal cords. The larynx has also the autonomic innervation, the sympathetic and parasympathetic fibers. The superior laryngeal nerve receives communication from the superior cervical ganglion (sympathetic). The parasympathetic fibers run with superior and recurrent laryngeal nerves (secretomotor fibers).

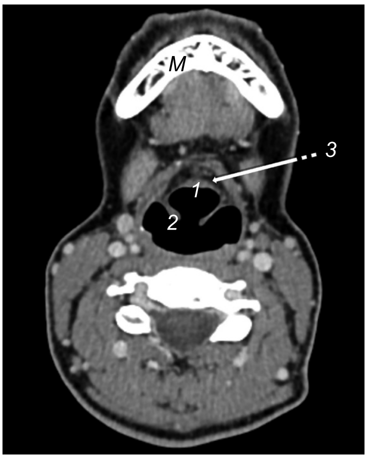

Fig. 9. The CT image of the neck: a soft tissue window in a transverse (axial) section:
1 – the supraglottic part of larynx – an axial section on the level of epiglottis;
2 – aryepiglottic fold; *3* – pre-epiglottic fat tissue in pre-epiglottic space
and epiglottic vallecula; *M* – mandible
Source: the CT images from authors' collection

The larynx is supplied by the superior laryngeal artery, which diverges from the superior thyroid artery, the cricothyroid branch also diverging from the superior thyroid arteries, and the inferior laryngeal artery diverging from the inferior thyroid artery. Within the larynx, the lymph is drained through the superior deep lateral cervical lymph nodes, and the inferior deep lateral cervical lymph nodes as well as deep anterior cervical lymph nodes (prelaryngeal or *Delphian* lymph node, pretracheal, paratracheal cervical lymph nodes) to the lymphatic trunk.

Physiology of the larynx

The larynx serves three essential functions:

1. breathing – as it is part of the respiratory tract;
2. phonation – as it is an organ in which the vocal folds vibrating under the influence of vocal pressure are the source of sound.
3. protective – to the lower respiratory tract by closing the glottis via the epiglottis when swallowing or vomiting.

During breathing, the vocal folds are in the respiratory position, and the glottis is open.

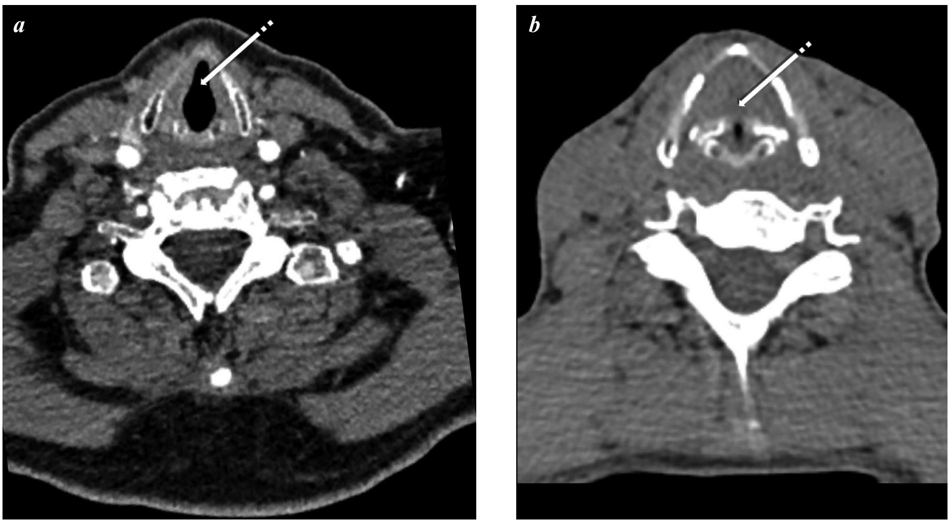

Fig. 10. The CT images of the neck: a soft tissue window in a transverse (axial) section The respiratory tract, the larynx on the level of arytenoid cartilages: *a* – the glottis during breathing, the glottis is open; *b* – the glottis during phonation, the glottis is closed *Source*: the CT images from authors' collection

During swallowing, a reflex mechanism controlled by the glossopharyngeal nerve causes a contraction of the aryepiglottic folds as well as the vocal and vestibular folds (Fig. 10). At the same time, the epiglottis tilts due to the contraction of the thyroepiglottic muscle.

The nose

The internal nose, i.e. the nasal cavity with the adjacent paranasal sinuses, is terminated on both sides by the anterior and posterior nostrils. The anterior nostril, the piriform aperture allow the air to reach the respiratory system and are the first section of the airways. The posterior nostrils, the choana of cranium lead to the upper, nasal part of pharynx, also referred to as the nasopharynx. The nasal septum, which runs the length of the nose internally, divides it into two parts, the right and left part of the nasal cavity. In the nasal cavity, bilaterally, the inferior, middle, superior and highest nasal concha are located.

In terms of the functions served by the nasal cavity, the vestibule of the nose, the respiratory part, and the olfactory parts are distinguished in it.

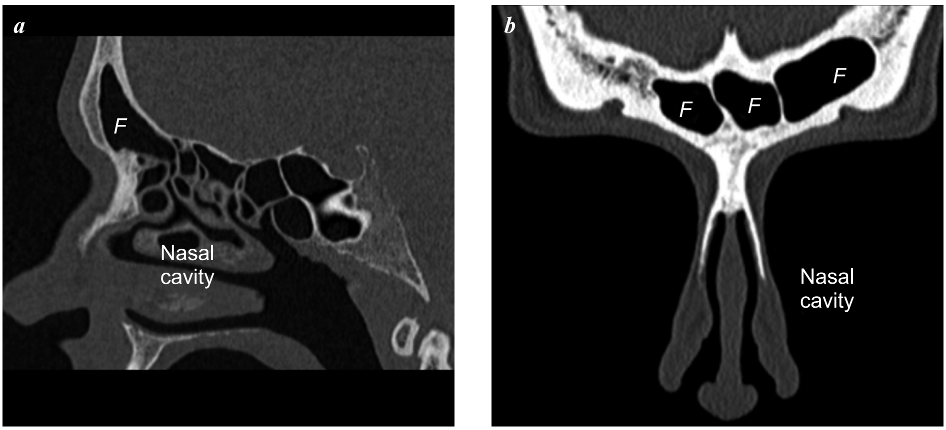

Fig. 11. The CT images of the paranasal sinuses: a bony window in a midsaggital section through the nasal cavity and frontal sinus – *a)* and a frontal section on the level of nasal bone – *b*). The nasal cavity and the frontal sinus (*F*)
Source: the CT images from authors' collection

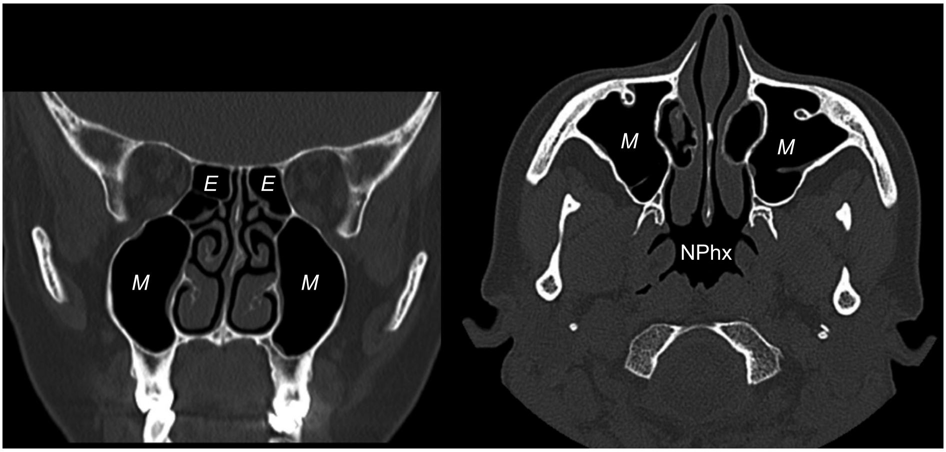

Fig. 12. The CT images of the paranasal sinuses: a bony window in a frontal section on the level of maxillary sinus and a transverse (axial) section on the level of maxillary sinus and nasopharynx. The nasal cavity and the paranasal sinuses: *M* – maxillary sinus; *E* – ethmoidal air cells; NPhx – nasopharynx
Source: the CT images from authors' collection

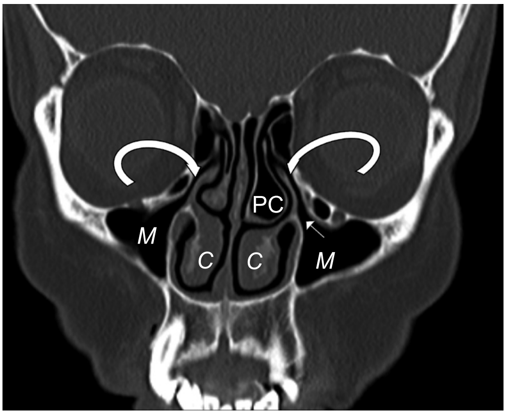

Fig. 13. The CT image of the paranasal sinuses: a bony window in a frontal section on the level of maxillary sinus. The nasal cavity and the paranasal sinuses: *M* – maxillary sinus; *C* – inferior nasal concha; PC – pneumatized middle nasal concha on the left, the ethmoidal infundibulum – curved arrows and the ostium of maxillary sinus – the small arrow
Source: the CT images from authors' collection

The oral cavity and the pharynx (throat)

The oral cavity is the first section of the digestive tract. It is in contact with the outside world through the gap in the mouth, limited by the upper and lower lips, which is the vestibule of the oral cavity and leads to the oral cavity proper. The posterior border of the oral cavity is the pharynx.

The vestibule of the oral cavity is a space located between the inside of the lips and the cheeks, the outside of the teeth and the alveolar processes covered by the gingivae (gums). An important anatomical part is the frenula of the lower and upper lips, which are significant element involved in the mouth arrangement when speaking or singing.

The oral cavity proper is found posteriorly to the alveolar processes of the jaw and the alveolar part of the mandible. It passes posteriorly into another section of the digestive tract, i.e. the pharynx. The oral cavity proper is limited superiorly by the hard palate and the soft palate and inferiorly by the floor of the mouth on which the tongue is located. The posterior border between the oral cavity and the pharynx is the isthmus of fauces.

The tongue, located inside the oral cavity proper, is made up of striated muscles covered with a mucous membrane. The tongue is one of the most important muscles which, in a way, form sounds. Moreover, the tongue

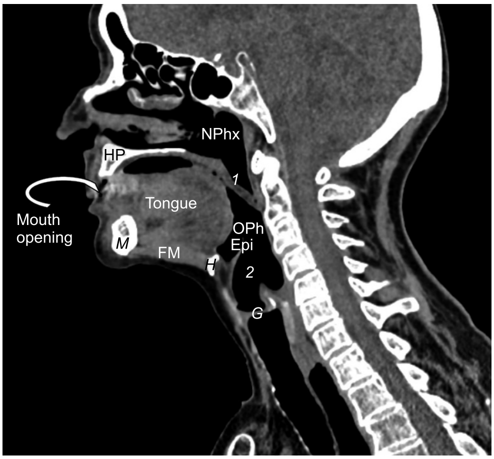

Fig. 14. The CT image of the neck: a soft tissue window in a sagittal section
The oral cavity proper, the pharynx, and the larynx in a relaxed position:
OPh – oropharynx; NPhx – nasopharynx; Epi – epiglottis; *G* – glottis;
FM – muscles of the floor of the mouth; *M* – mandible; *H* – hyoid bone;
HP – hard palate; *1* – soft palate and uvula; *2* – laryngopharynx
Source: the CT images from authors' collection

is involved in the process of chewing food and moving broken down food to the further sections of the gastrointestinal tract. The tissues located beneath the tongue form the so-called floor of the mouth, which is made up of muscles covered with a mucous membrane. Under the tongue, the submandibular and sublingual gland duct openings are located, which are essential for the moistening of the mucous membranes and keeping them properly tensioned and hydrated.

The interior of the oral cavity is lined with a mucous membrane, which plays an important role in the passage of the sound wave. It is important that the membrane is properly moistened while singing, which is associated with a better reflection and the "internal" feeling of the sound.

The teeth located in the alveolar process of maxilla and the mandible are also important components of the oral cavity, which are indirectly involved in the emission process by providing a certain acoustic framework felt by the singer[23]. The adult set of teeth comprises 28–32 permanent teeth arranged in two (upper and lower) dental arches and include incisors, canines, premolars and molars.

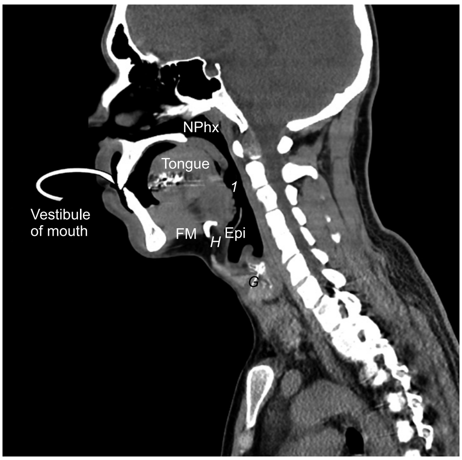

Fig. 15. The CT image of the neck: a soft tissue window in a sagittal section. The oral cavity proper, the pharynx, and the larynx during inspiration: NPhx – nasopharynx; Epi – epiglottis; *G* – glottis; FM – muscles of the floor of the mouth; *H* – hyoid bone; *1* – oropharynx
Source: the CT images from authors' collection

[23] A. Kosmowska, E. Sielska-Badurek, K. Niemczyk, *Wpływ tremy na czynności i odczucia w obrębie traktu głosowego*, "Polski Przegląd Otorynolaryngologiczny" 2017, vol. 6, no. 3, pp. 1–9.

The pharynx is an organ that connects the oral cavity, the nasal cavity, the larynx, and the oesophagus. It is at the level of the pharynx that the digestive and respiratory tracts cross, which results in the pharynx being, in functional terms, part of both the digestive and respiratory systems.

In anatomical terms, the pharynx should be considered as three interconnected parts.

1. The nasopharynx as the upper part of pharynx.
2. The oropharynx as the middle part of pharynx.
3. The laryngopharynx as the lower part of pharynx.

Fig. 16. The CT image of the head and neck: a soft tissue window in a sagittal section. The nasal cavity, nasopharynx, oropharynx and laryngopharynx
Source: the CT images from authors' collection

From a singer's point of view, the nasopharynx, i.e. the upper part of the pharynx, is one of the principal anatomical structures.

Its superior wall is formed by the vault of the pharynx, which passes into the posterior wall. At the point of transition of the vault into the posterior wall, the pharyngeal tonsil is located, which becomes atrophy with age.

The anterior wall of the nasopharynx is open forward and made up of the posterior nostrils, which connect the nasal part of the pharynx with the nasal cavity. On the lateral wall of the nasopharynx is the pharyngeal opening of auditory (Eustachian) tube, which is directed inferiorly and medially by a prominence formed by the bulging cartilaginous part of the auditory tube. The torus tubarius is located immediately posterior to the pharyngeal opening of auditory tube with its salpinopharyngeal and salpingopalatine folds

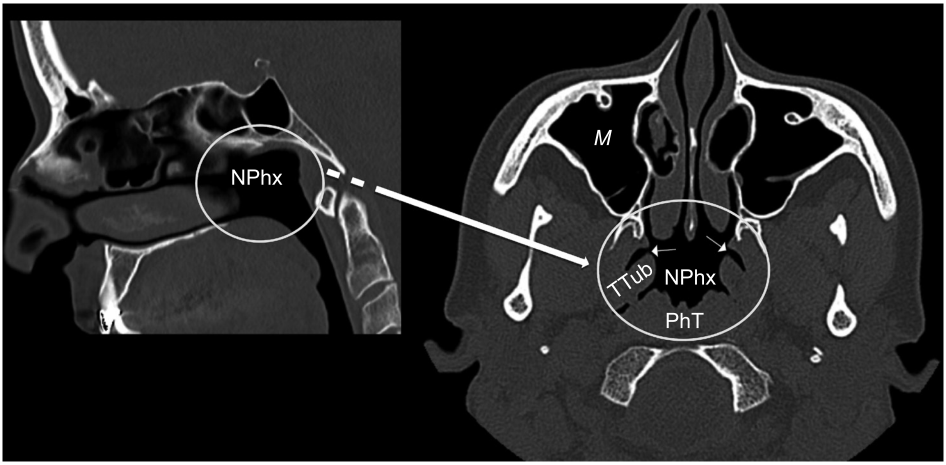

Fig. 17. The CT images of the nasopharynx: a bony window, a sagittal section on the level of nasopharynx and a transverse (axial) section on the level of nasopharynx and maxillary sinus. The nasopharynx: NPhx – nasopharynx; TTub – torus tubarius; PhT – pharyngeal tonsil; *M* – maxillary sinus. Pharyngeal opening of auditory (Eustachian) tube – small arrows
Source: the CT images from authors' collection

Fig. 18. The nasopharynx: *1* – nasopharynx; *2* – right chamber of sphenoid sinus; *3* – left chamber of sphenoid sinus. The CT image of the nasopharynx: a bony window in a frontal section on the level of nasopharynx
Source: the CT images from authors' collection

and tubal tonsil. A cluster of lymphatic tissue called the tubal tonsil is located on top of that. The torus tubarius extends inferiorly to form the salpingopharyngeal fold. From below, the pharyngeal opening of auditory tube is narrowed by a protrusion of the levator veli palatini muscle covered by the mucous membrane. Behind the pharyngeal opening of auditory tube, between the torus tubarius and the posterior pharyngeal wall, there is a small, depressed space known as the pharyngeal recess[24]. The auditory (Eustachian) tube leads into the middle ear, and connects to the tympanic cavity and mastoid process, i.e. a pneumatised and aerated space. In terms of acoustics, thanks to the concept of the mask understood as the entire head in singing, this is a site of the significant reverberation of the acoustic wave.

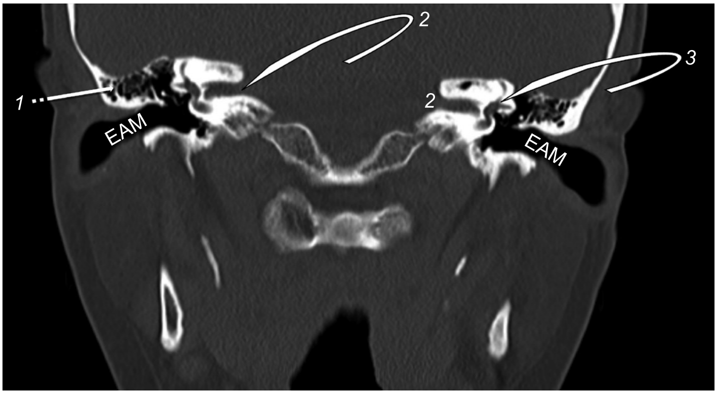

Fig. 19. The CT image of the temporal bone: a bony window in frontal section on the level of external acustic meatus. The external acustic meatus (EAM); *1* – the mastoid air cells; *2* – internal acustic meatus; *3* – vestibule and semicircular canals
Source: the CT images from authors' collection

The border of the lower part of the nasopharynx is also the border of the upper part of the soft palate, which causes the so-called nasopharyngeal stop and enabling proper phonation through the correct arrangement of the muscles. This is also an important site in the methodology of voice management, as it is here that the formation of the so-called "aerial palatum", i.e. an anatomically internally unlimited air space which is prepared to freely take over the laryngeal tone and transfer it further into the subsequent structures of the vocal tract, is shaped[25].

24 J. Sokołowska-Pituchowa, *Anatomia człowieka. Podręcznik dla studentów medycyny*, PZWL, Warszawa 1989, pp. 521–523, 851–852.

25 Z. Madej, H. Zajączkiewicz, op. cit., p. 161.

Fig. 20. The CT image of the temporal bone: a bony window in transverse (axial) section on the level of external acustic meatus (on the right) and tympanic cavity (on the left). The temporal bones: EAM – external acustic meatus; *1* – the mastoid air cells; *2* – sphenoid sinus; *3* – cochlea; *4* – tympanic cavity with auditory ossicles; *5* – mastoid air cells
Source: the CT images from authors' collection

Theories of voice production

Phonation is a function of the larynx, which continues to be intensively studied. Many hypotheses about the mechanism of phonation have been put forward in recent years. There are two theories that are of significance. The neurochronaxic (clonic) theory proposed by a French phoniatrist and neurophysiologist Raoul Husson deals with the neurophysiological nature of the phenomenon of vocal cord vibration. Husson believed that the vibrations of the vocal cords were not determined by the wave of exhaled or inhaled air but by the operation of the cerebral cortex. In his opinion, vocal cord vibrations were triggered by nerve impulses sent by the central nervous system. A nerve impulse that reaches the larynx causes a contraction which opens the glottis, while a decontraction closes it, and the frequency of vocal cord vibrations corresponds to the frequency of nerve impulses. The exhaled air is only the medium of wave propagation. Husson supported his theory by stating that even though both humans and animals have a similarly constructed larynx, only the human kind has been capable of developing speech. An argument that undermined Husson's theory of the neurophysiological nature of the vocal cord vibration phenomenon has been the experimental acquisition of a fundamental tone from a larynx cut out of a dead body.

The (modern) aerodynamic theory. The subglottal pressure passively opens and closes the glottis while irritating the nerve endings that transmit stimuli to the brain. The central nervous system sends impulses to the laryngeal nerves, which coordinate the action of the larynx. The vibrations of the vocal cords are the result of the competition between the subglottal pressure (which moves the cords apart) and the muscle contraction controlled by the nervous system. The advancing column of air is divided by the vibrating vocal cords into a series of rhythmical blasts[26]. There are two parallel pathways to control voice production, the motor laryngeal pathway and the limbic pathway. The motor laryngeal part controls cortical connections responsible for regulating voluntary voice production. The limbic part controls non-verbal, innate and emotional vocalizations.

Sound formation

The human voice is, in its essence, a complex instrument. The ability to make sounds, speak and sing is given to almost every human being. A healthy user of the vocal apparatus is capable of using it irrespective of their vocal skills or the innate scale. Rarely, however, there are people who use their voice intuitively in a natural, free and effortless manner in almost every register.

Most people use their voice in an ineffective and incorrect manner because they believe they are "condemned" to its unchanging sound once and for all. Although they are partially right, they do not realise that the appropriate exercises may help the voice sound fuller and be more sonorous, resonant, and attractive. A particular form of using the voice is singing as an "extension of speech". Singing at a high, professional level requires a lot of regular practice under the guidance of a teacher who helps the student become aware of how a sound is produced, and find the right way to produce the voice and standardise the sound.

The ability to produce the voice correctly using one's own vocal apparatus is possible thanks to the phonatory and articulatory organs, namely the larynx and the vocal cords, the pharynx, the resonators (sinuses), the cheeks, the tongue, and the lips.

Each sound is made up of 16 harmonics which are called overtones[27].

A sound is produced when the glottis periodically lets the air pass through, negative subglottal pressure is created, and the vocal cords close the glottis while

[26] A. Obrębowski, op. cit., p. 28.

[27] Overtones (Latin: *aliquot* – several) – harmonic tones (overtones), accompanying sounds, component tones of a sound. They are a multiple of the fundamental frequency of the sound.

they are vibrating. The vibrations of the ligaments are similar to the vibrating strings of musical instruments, and the human body can be metaphorically compared to the body of a guitar, piano or double bass. The vibrating ligaments also vibrate the remaining surroundings, namely the bones, the trachea, the bronchi, and all the spaces.

The timbre of the voice is determined by the type of structure of the nasal resonance cavities, the larynx, and the oral cavity, as well as by the age, gender, and physique. In terms of their position in relation to the vocal folds, the resonators can be divided into the upper resonators, also referred to as the vocal tract, and the lower resonators. The vocal tract is made up of the laryngeal ventricle, the pharynx, the oral cavity, the nasal cavity and the paranasal sinuses, while the lower resonators include the subglottic region, the trachea, the bronchi and the chest.

When discussing resonators, it is important to mention the registers. In vocalism, we recognise the chest register, the head register, and the combination of both, i.e. the mixed register. A vocal register can therefore be defined as a series of sounds having the same timbre and produced in the same manner[28]. However, in order for a proper register to be formed, the proper methodology for the production or the formation of sound (and its appropriate management) is required.

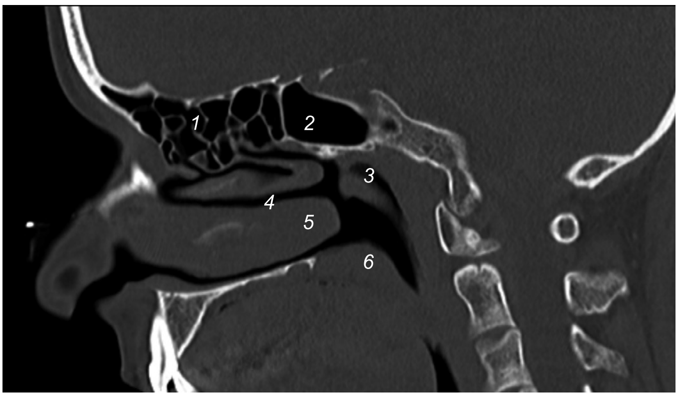

Fig. 21. The CT image of the nasal cavity and nasopharynx:
a bony window in parasagittal section, the vocal tract resonators: *1* – ethmoidal air cells; *2* – the sphenoid sinus; *3* – pharyngeal ostium of auditory tube; *4* – middle nasal meatus; *5* – inferior nasal concha; *6* – soft pallate
Source: the CT images from authors' collection

28 M. Zalesska-Kręcicka, *Głos i jego zaburzenia…*, p. 55.

Fig. 22. The CT image of the larynx: a soft tissue window, a frontal section on the level of glottis, Airspaces in the laryngeal region
Source: the CT images from authors' collection

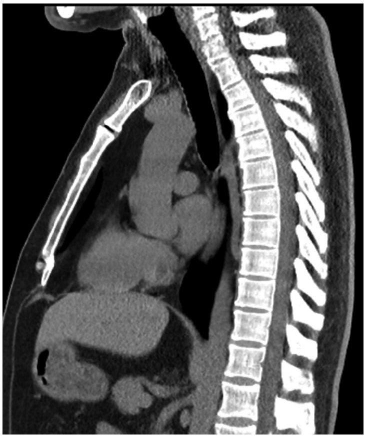

Fig. 23. The CT image of the chest: a soft tissue window, a sagittal section on the level of trachea. The chest resonators
Source: the CT images from authors' collection

Halina Sobierajska[29] distinguishes two vocal registers, i.e. the chest and the head register. In the chest register (otherwise known as the overall register), the vibrations cover their entire mass. In the head register (otherwise known as marginal register), mainly the fold edges vibrate. Thanks to the use of the resonators in the training process, efforts are made to ensure a smooth transition

[29] Cf. H. Sobierajska, *Uczymy się śpiewać*, Państwowe Zakłady Wydawnictw Szkolnych, Warszawa 1972.

from one register into another. It is worth noting that when we ask several people to sing the "f[1]" sound, e.g. using the word "do", we will hear that for each person, the sound has a different timbre, which means that every singer produces it and prepares for singing differently. It appears that a sound is not equal to another sound. As far back as ancient Greece, singers used methods allowing them to focus on one particular sound to make it as perfect as possible. An ancient singer would go to the quarry, stand facing the rock wall, and practice singing a particular sound long enough for his/her master to be satisfied. A good sound is one that has its depth and is freely produced, i.e. not constricted. It should be properly conveyed to the so-called open timbre, which is associated with the overtone richness and the sonority of the sound. So, what should be done in order to sing well? The correct production of a good sound involves numerous exercises for articulation, breathing, body posture, and emotional control under stress, which requires up to several years of training. However, it is worth becoming involved in working on this natural instrument because learning to sing makes us more aware of both our body and the ability to use the voice.

Considering our body and psyche as a single entity will allow the desired goal to be achieved. It is important, however, to combine methodological skills with strengthening the anatomical and physiological knowledge of the vocal tract.

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Abstract

The voice is a uniquely human characteristic. The larynx is the primary sound generator, and all body structures are directly or indirectly related to the acoustic wave produced during phonation. The voice production process is possible thanks to the coordinated interaction of many organs. As a result of the thickening and thinning of the expiratory air (due to an increase and decrease of pressure), the fundamental (laryngeal) tone is produced on vocal folds. The diaphragm is the major muscle of respiration and, in combination with the muscular and skeletal systems of the thorax, the abdominal cavity, the neck, and the back, it serves an important role in the respiratory process. An examination that can objectively show the entire vocal tract and the related anatomical regions active in the process of singing is computed tomography (CT) scanning.

Key words: larynx, vocal tract, classical singing, opera singing, acoustic, tomography.

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