Efficiency of Listening to the Melody and Neural Correlates of Tonality Differentiation

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Abstract: Current knowledge suggests that the perception of music and its development may be fully described using the languages of physics, medicine, and neuroscience—including computational neuroscience. The aim of this study is to establish a methodological setting for testing the neural correlates of tonality differentiation. The procedure described in the article allows for a comparison of the outcomes of differential tonality listening in people with a certain level of stabilized musical abilities, and their neural correlations using EEG, taking into consideration the Mismatch Negativity (MMN) paradigm. The proposed methodology may constitute another step toward the assessment and objectivization of musical abilities. The hypothesis regarding the reflection of musical abilities in auditory pathways activation within CNS may prove to be true.

Keywords: listening, tonality, audiation, melody differentiation, music ability

Introduction

Although listening is a necessity for all musical activities, we are not always aware that this is not a natural ability. This common idea is a result of thinking that listening is the same as hearing—a physiological process depending on the proper working of the organ of hearing. If all parts of the ear are working properly, we hear even before we are born[1]. Listening, on the other hand, is a deliberate physiological process of recognition and differentiation of sounds, and analyzing those that are meaningful and important and those that are not. The basic cognitive conditions relating to the surrounding auditory reality are the reception of impressions, perceptional organization, and sound identification. Auditory stimulation of the organ of hearing causes a neural impulse, reflecting the internal experiences of the organism. The perceptional organization relies on the perception of external stimulus through the creation of an internal auditory representation of musical

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[1] Richard J. Gerrig and Philip G. Zimbardo, *Psychologia i życie*, trans. J. Radzicki, E. Czerniawska, A. Jaworska, J. Kowalczewska (Warszawa: PWN, 2008).

structures. Perceptual processes cover an assessment of the formal composition of the opus, its tonality, meter, harmony, and articulation or dynamics, which are based on cognitive processes. The next stage is identification and discernment, i.e. giving meaning to the observation. In this way, musical themes become units fulfilling specific functions. Audition, i.e. the activity of higher cognitive processes, is necessary to react to them properly[2].

If we are not paying particular attention, sound reception is not the same as listening. Hearing does not require training, but proper and systematic training is necessary in order to perfect a good ear for music. Listening to music also constitutes a process of communication, similar to a verbal process. Singing vocal music, like talking, is not innate. Both talking and singing require considerable instruction, repetition, and improvement with regard to strengthening proper musical patterns and their applications. Acquiring these abilities is easy in early childhood: children achieve proficiency through listening, remembering, and re-enacting. Both listening and singing are conscious, purposeful activities, which require training in order for them to be done properly.

The aim of this study is to establish a methodological setting for testing the neural correlates of tonality differentiation.

Music Listening

Review

Music constitutes the exclusive domain of humans—only humans compose, sing, and play on various instruments[3]. Even though our CUN has its own restrictions concerning sound processing (e.g. a limited range of frequencies), esthetic preferences, and methods of acquiring musical skills[4], there may be something remarkable in people embarking on musical activity simply for pleasure, and often in solitude. Instrument playing engages entire cognitive functions and influences further development. Six-month-old infants have relative hearing (the ability to recognize a melody relating to a specific reference tone, even if it is played in another tone)[5]. Infants also recognize melodies played in diverse cadence, tone, meter, groups of notes, and their duration. Two-month-old infants are able to discriminate between consonance (sound harmony) and dissonance—and prefer

[2] Ewa A. Zwolińska, "Music Education through Audiation Teaches Aesthetically", *Polskie Forum Psychologiczne* 18/2 (2013): 143–56; *Ways of Audiation. About Musical Thinking* (Bydgoszcz: Kazimierz Wielki University Press, 2014).

[3] Josh Mc Dermott and Marc D Hauser, "Thoughts on an Empirical Approach to the Evolutionary Origins of Music", *Music Perception* No. 24 (2006): 111–116.

[4] Beata Bonna, "Research on the Application of E.E. Gordon's Theory of Music Learning in the Music Education in Poland", *Culture and Education* 6 (2013): 66–87.

[5] Sandra E. Trehub, "Toward a Developmental Psychology of Music", *Annals of the New York Academy of Sciences* 999 (2003): 402–13.

consonance[6]. These abilities and preferences are probably not the product of human culture, but since there are no people who never listen to music this is hard to assess. Moreover, research on music is difficult—there is a need to take many components of the musical syntax into consideration, as well as internal (tonality, meter, etc.) and external (programs, atmosphere) meaning[7]. Music has its own structure, including recursion, joining, building, and transformation of various musical phrases that make communication through music possible, similar to the use of language[8].

Several cortical areas are shared by music and language. Areas of the frontal lobe associated with language processing are also active when listening to music without vocals[9]. Moreover, listening to an unexpected sound may activate the lateral-inferior frontal lobe (Broadmann area 44) and the respective area in the left frontal lobe (Broca's area and anterior temporal lobe)[10]. Broca's area and the anterior temporal lobe are also active when listening to a musical phrase with unpredictable structure. "Processes of language and music processing" within the left hemisphere overlap[11]. People like melodies with parameters of noise—partly random, and partly predictable: variations of the amplitude and tone are similar to natural, e.g. flowing water, rain, or wind[12].

Music listening relies on learning new timbres, checking them in earlier known contexts, dividing sounds into significant and non-significant, seeking categories that contain them, and making predictions concerning the further development of the sound. When listening to music, the brain actively reconstitutes transfer from the performer, and overlaps it with an additional meaning arising from the brain's own context and experiences. Thus, understanding of music is either subjective (different for each person), or objective (providing components allowing for a common impression).

This knowledge suggests that we may fully describe music perception and its development using the language of physics, medicine, and neuroscience, including computational neuroscience. Thus, a more objective assessment of brain-derived processes relating to listening to music is within reach. Other questions may arise. How can music

[6] Gagnon, R., C. Hunse, L. Carmichael, F. Fellows, and J. Patrick, "Human Fetal Responses to Vibratory Acoustic Stimulation from Twenty-six Weeks to Term." *American Journal of Obstetrics and Gynecology* No. 157 (1987): 1375–84.

[7] Caroline Palmer, "Listening, Imagining, Performing: Melody as a Life Cycle of Musical Thought", *Music Perception* No. 33 (2015): 3–11.

[8] W. Tecumseh Fitch, and Marc D. Hauser, "Computational Constraints on Syntactic Processing in a Nonhuman primate", *Science* No. 303 (2004): 377–80.

[9] Daniel J. Levitin and Vinod Menon, "Musical Structure is Processed in 'Language' Areas of the Brain: A Possible Role for Brodmann Area 47 in Temporal Coherence", *NeuroImage* No. 20:4 (Dec., 2003): 2142–52.

[10] Barbara Tillman, Petr Janata and Jamshed Bharucha, "Activation of the Inferior Frontal Cortex in Musical Priming", *Cognitive Brain Research* No. 16 (2003): 145–61; Stefan Koelsch, Thomas C. Gunter, D. Yves von Cramon, Stefan Zysset, Gabriele Lohmann, and Angela D. Friederici., "Bach Speaks: A Cortical "Language-network" Serves the Processing of Music", *NeuroImage* No. 17 (2002): 956–66.

[11] Michael S. Gazzaniga, *Human: The Science behind what Makes us Unique* (Sopot: Smak Słowa, 2011).

[12] Richard F. Voss, and John Clarke, "1/f Noise in Music and Speech", *Nature* Vol. 258 No. 5533 (Nov. 1975): 317–318; De Coensel, B., D. Botterdooren and T. De Muer, "1/f Noise in Rural and Urban Soundscapes", *Acta Acoustica* No. 89 (2003): 287–95.

foster the development of the brain? How may music lessons support the learning of math or biology? How can we shape this process in newborns, infants, and pre-school children?

We take into consideration the stimulus (the performance of a piece of music), its perception, and cerebral representation in terms of a response (psychic and artistic experience)[13]. Such an impression requires reasoning based on an understanding of listened to and audited music. It may be far beyond traditional cognitive and emotional spheres[14].

Complexity of Listening to Modified Tonality versus Audiation Analysis

The particular dimension of listening to music is the Mismatch Negativity (MMN) mechanism. MMN is specific to measurement of the deviations of the tonal components within auditory Event Related Potential (ERP). Electroencephalogram (EEG)-registered events concern music and perception of its tonal components. Studies on MMN have showed relationships between various sound features such as pitch, tone, source location—but also dynamics, and rhythm[15]. Current studies on MMN phenomena cover a wide area, from analysis of simple sound detection to complex music perception. We wish to emphasize the fact that, from the point of view of the audiation theory, we focus on the analysis of listening: features of single events (e.g. central sounds), intervals, diatonic series, metric events, and tone.

Studies on MMN concerning interval or contour and tonal context[16] may be particularly significant. Tonal music is based on 7-step diatonic modes with the addition of 5 chromatic alterations, which together constitute a 12-semitone scale. Edwin E. Gordon emphasizes the developmental importance of the tonal hierarchy, observed even in the most basic music rules, reflected in jazz, classical music, pop, etc. He also emphasizes the importance of particular scales, typical of modal music: Ionian, Dorian, Phrygian, Lydian,

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[13] Michael S. Gazzaniga, *Human;* Wilfried Gruhn, "Learning: On the Multiple Facets of a Colloquial Concept", *Min-Ad: Israel Studies in Musicology Online* No. 13 (2016): 227–36; Marc A. Schmuckler, "Expectation in Music: Investigation of Melodic and Harmonic Processes", *Music Perception* 7/2 (Winter, 1989): 109–50; David Temperley and Daphne Tan, "Emotional Connotations of Diatonic Modes", *Music Perception* No. 30/3 (Febr., 2013): 237–57; Daniel Shepherd and Nicola Sigg, "Music Preference, Social Identity, and Self-Esteem", *Music Perception* No. 32/5 (June, 2015): 507–514.

[14] Edwin Elias Gordon, *Learning Sequences in Music: Skill, Content, and Patterns. A Music Learning Theory* (Bydgoszcz: WSP, 1999).

[15] Xide Yu, Tao Liu, and Dingguo Gao, "The Mismatch Negativity (MMN): An Indicator of Perception of Regularities in Music", *Behavioural Neurology* 4 (Oct. 2015): 1-12. DOI: 10.1155/2015/469508; Peter Vuust, Elvira Brattico, Miia Seppänen, Risto Näätänen, and Mari Tervaniemi, "The Sound of Music: Differentiating Musicians Using a Fast, Musical Multi-feature Mismatch Negativity Paradigm", *Neuropsychologia* 50/7 (2012): 1432–43; Mari Tervaniemi, Lauri Janhunen, Stefanie Kruck, Vesa Putkinen, and Minna Huotilainen, "Auditory Profiles of Classical, Jazz, and Rock Musicians: Genre-specific Sensitivity to Musical Sound Features", *Frontiers in Psychology* 6/1900 (Jan., 2016): 1–11. DOI:10.3389/fpsyg.2015.01900.

[16] Yune-Sang Lee, Petr Janata, Carlton Frost, Michael Hanke and Richard Granger, "Investigation of Melodic Contour Processing in the Brain using Multivariate Pattern-based fMRI", *NeuroImage* 57; 1 (July, 2011): 293–300; Xide Yu, Tao Liu, and Dingguo Gao, "The Mismatch Negativity (MMN)…", 1-12; Mari Tervaniemi, Lauri Janhunen, Stefanie Kruck, Vesa Putkinen, and Minna Huotilainen, "Auditory Profiles of Classical, Jazz, and Rock Musicians…", 1-11.

etc. People may discriminate differences between frequencies 10-30 Hz[17]. Change of pitch in music should be analyzed not only in relation to the ambitus of the particular group/interval, but also the diatonic/chromatic scale. It may relate to both melodic interval (tones played subsequently) and harmonic interval (tones played simultaneously). Thus, sounds presented in a continuous and simultaneous way are characterized not only by pitch, but also by contour related to the duration, as many studies suggest[18]. This constitutes a feature of the melody, determining short sound sequences, and creating topics. Contours perception and processing is a necessary basis for melody recognition. Dowling & Fujitani have shown the role played by the interval and contour to be a key feature of melody recognition[19]. Subtle deviations between reference and test melodies were recognized in the interval profile. Some studies have recommended caution with regard to a comparison of the results of listened music processing using the MMN paradigm[20]. Koelsch et al.[21] showed that musicians (violinists) were aware of 80 percent of modified chords (harmonic sounds), whereas non-musicians were aware only of 10 percent. Thus, changed inputs may be related to MMN in musicians, while not in non-musicians.

The aforementioned results may suggest that tone discrimination within a particular tone series may play a critical role in well-educated musicians. Further studies[22] show a relationship to age: MMN enhancement was caused by earlier music education, not by earlier differences between groups. Thus, the assumption may be true that development of sensitivity to various functions of sound (time, dynamics, tone, interval, contour) is not uniform, but results from long-term education within a particular music genre. It may stimulate processes described by MMN, which may contribute to EEG registered changes in the neural generators in musical and non-musical groups[23].

Similar responses may be observed in people with developed/learned audiation. Thus, musical strategies of learning may significantly influence the abilities of the behavioral and cortical processing of the auditory features in the given tonal context. This

[17] Xide Yu, Tao Liu, and Dingguo Gao, "The Mismatch Negativity (MMN)…", 2-11.

[18] Yune-Sang Lee, Petr Janata, Carlton Frost, Michael Hanke and Richard Granger, "Investigation of Melodic Contour …", 293–300.

[19] Walter J. Dowling and Diane S. Fujitani, "Contour, interval, and pitch recognition in memory for melodies", *Journal of the Acoustical Society of America, 49* (2), (1971): 524-531; Walter J. Dowling, "Scale and contour: Two components of a theory of memory for melodies", *Psychological Review*, Vol. 85 (4) (July 1978): 341-348. DOI. 10.1037/0033-295X.85.4.341.

[20] Xide Yu, Tao Liu, and Dingguo Gao, "The Mismatch Negativity (MMN)…", 2-11; Katja N. Goydke, Eckart Altenmüller, Jürn Möller and Thomas F. Münte, "Changes in Emotional Tone and Instrumental Timbre are Reflected by the Mismatch Negativity", *Cognitive Brain Research* 21:3 (Nov. 2004): 351–59. DOI: 10.1016/j.cogbrainres.2004.06.009; Peter Vuust, Elvira Brattico, Miia Seppänen, Risto Näätänen, and Mari Tervaniemi, "The Sound of Music…", 1442.

[21] Stefan Koelsch, Erich Schröger and Mari Tervaniemi, "Superior Pre-attentive Auditory Processing in Musicians." *NeuroReport* Vol. 26, No. 10/6 (Apr., 1999): 1309–13.

[22] Vesa Putkinen, Mari Tervaniemi, Katri Saarikivi, Nathalie R. de Vent and Minna Huotilainen, "Investigating the Effects of Musical Training on Functional Brain Development with a Novel Melodic MMN Paradigm", *Neurobiology of Learning & Memory* 110 (April, 2014): 8–15. DOI: 10.1016/j.nlm.2014.01.007.

[23] Mari Tervaniemi, Lauri Janhunen, Stefanie Kruck, Vesa Putkinen, and Minna Huotilainen, "Auditory Profiles of Classical, Jazz, and Rock Musicians…", 10.

might suggest that brain development in the aforementioned area is sensitive to the specificity of the training and experiences related to listening. The training proposed within the model of the Gordon's Theory of Music Learning thus seems to be so systemic and coherent, that it could cause the required status of the audiation development.

The Concept of the Study

The described concept of research is based on Edwin E. Gordon's theory of music learning, which enables analysis of the audition-based cognitive processes. Donald Norman[24] distinguished three levels of beauty:

1) superficial (universal, biological) beauty, common for all people, means immediate response to stimuli;
2) beauty of action/behavior, which needs to focus on musical activity;
3) deep beauty, hidden in meaning and implication, conscious reflection taking into consideration culture, education, memory, and experience.

Development of audition as a skill shapes a sense of beauty in the second and third levels above. Assessment of melodies is done based on a series of sounds (intervals, contours), not a single sound. The source of musical impressions is the relationship among musical themes, composed from joined tonal and rhythmic patterns. Such an ability to assess aesthetic value is key for an audition (thinking by sounds). Edwin E. Gordon[25] described the constant stages of audition development (audition changes according to the constant sequence of cognitive development). Each stage of an audition shapes cognitive sound structures. They decide the course of the musical development of the particular person as a result of mind maturation and cumulation of musical experiences[26].

Neuroscience tries to explain the cognitive processing of musical sounds, taking into consideration the dynamics of processed information. There is an assumption that more fluent processing of information concerning perceived stimuli leads to a more efficient aesthetic response[27]. The dynamics of sound processing was analyzed based on evoked potentials (event-related potentials—ERP). There were analyzed changes within electroencephalograms (EEG) in response to listening to the same instrumental melody recorded in eight diverse musical scales. The analysis relied on multiple repeating of the auditory stimuli in diverse modes, and overlapping parts of EEG recorded with and without the stimulus. The most interesting of these may be the nature and level of neural and behavioral activity in people with different musical abilities. Current studies show that E.E.

[24] Donald A. Norman, "Introduction to this Special Section on Beauty, Goodness, and Usability", *Human-Computer Interaction* Vol. 19 (2004): 311–318.
[25] Edwin E. Gordon, *Learning Sequences in Music ...* .
[26] Beata Bonna, "Research on the Application of E.E. Gordon's Theory … ", 66-87; Ewa A. Zwolińska, *Audiation. Study of Music Learning Theory by Edwin E. Gordon* (Bydgoszcz: Kazimierz Wielki University Press, 2011).
[27] Michael S. Gazzaniga, *Human.*

Gordon's AMMA tool application is suitable for this purpose[28]. Average ERP is used to avoid variation of latency[29].

Methodology

The starting point for the test of abilities (E.E. Gordon's AMMA test) comprises material based on tonal and rhythmic content presented electronically during the study. Such a procedure allows for a comparison of the outcomes of tonality listening in people with a certain level of stabilized musical abilities.

People differ from each other in the area of listening abilities[30]. This may be proved by empirical testing: the pairing of a listened short melody to the tonality (scale). Outcomes may show:

- quality of listening;
- possibility of music memorization;
- average efficiency of listening;
- people with the highest efficiency of music memorization;
- relation between the efficiency of memorization and the level of musical abilities.

The true outcome of the assessment of listening ability is the ability to understand how particular versions of the melodies are understood, memorized, and qualified to the particular tonalities.

The key role may be played by the individual musical potential of each participant. Currently, there is a limited understanding of the fluency of processing of the experience-based tonal content[31] associated with the level of musical abilities and preferences[32], and the ability of "musical syntax audiation"[33].

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[28] Peter Vuust, Elvira Brattico, Miia Seppänen, Risto Näätänen, and Mari Tervaniemi, "The Sound of Music…", 1432-1443.

[29] Piotr Jaśkowski, *Neuronauka poznawcza. Jak mózg tworzy umysł*, (Warszawa: Vizja Press & IT, 2009).

[30] David Temperley and Daphne Tan, "Emotional Connotations of Diatonic Modes", 237–257; Mark A. Schmuckler, "Expectation in Music: Investigation of Melodic and Harmonic Processes", *Music Perception* 7/2 (1989): 109–150.

[31] John Tobby and Leda Cosmides, "Does Beauty Build Adapted Minds? Toward an Evolutionary Theory of Aesthetics, Fiction and the Arts", *Substance* #94/95 (2001): 6–27; David Temperley and Daphne Tan, "Emotional Connotations of Diatonic Modes", 237–257.

[32] Rolf Reber, Norbert Schwartz and Piotr Winkielman, "Processing Fluency and Aesthetic Pleasure: Is Beauty in the Perceiver's Processing Experience?" *Personality and Social Psychology Review* Vol. 8, No. 4 (2004): 364–382; Beata Bonna, "Research on the Application of E.E. Gordon's Theory … ", 66-87; Hasan G. Tekman, *Music Preferences as Signs of Who we are: Personality and Social Factors*. Proceedings of the 7th Triennial Conference of European Society for the Cognitive Sciences of Music ed. J. Louhivuori, T. Eerola, S. Saarikallio, T. Himberg, and P.S. Eerola (ESCOM, 2009): 592–595; Roger A Kendall and Edward C. Carterette, "Verbal Attributes of Simultaneous Wind Instrument Timbres: I. von Bismarck's Adjectives", *Music Perception* 10 (1993): 445–468; Daniel Shepherd and Nicola Sigg, "Music Preference…" 507–514.

[33] Edwin E. Gordon, *Manual for the Advanced Measures of Music Audiation*. (Chicago: GIA Publications, Inc., 1989).

The syntax described above constitutes:

- tonality: relation of sound pitch and motives to the final sound;
- rhythm: relation of rhythmical values and motives to "macrobites" and "microbites"[34].

Syntax understanding is associated with what a particular person may perceive using audition. Thus, outcomes depend on individual abilities of recognizing and understanding tonality and meter, and the process may be more important than the stimuli itself [35].

The Aim of the Experiment

The study began in 2017, and its second stage is now being carried out in the Creativity Development Laboratory of the Department of Music Pedagogy at Kazimierz Wielki University in Bydgoszcz (Poland)—the only Polish research team with experience in studies on audiation. The study also engaged specialists from the Collegium Medicom of the Nicolaus Copernicus University in Toruń (Poland), the Neurocognitive Laboratory, Center of Modern Interdisciplinary Technologies, Nicolaus Copernicus University in Toruń, and also the Institute of Mechanics and Applied Computer Science, Kazimierz Wielki University.

The main aim of our experiment was to seek an answer to the following questions: What happens within CNS during differentiation of the melody presented in various modal scales (tonalities)? Which neural and behavioral responses are caused by the location of the central sound in intervals and contour of the melody within the given modal tone?

Material

Group under study: 186 adults, students of pedagogy at the Kazimierz Wielki University were checked prior to AMMA and AS assessment. A further (EEG; test Mod_1) 15 people showing various levels of musical ability (described as high, moderate, low) were classified as musicians (at the least, having attended musical school, N=7) and non-musicians (only basic musical education, N=8). Age: 19-22, gender: 12 female, 3 male, convenience sample based on the agreement of the proper local bioethical committee. Freely given and written informed consent was obtained from every student prior to the study.

[34] Edwin E. Gordon, *Learning Sequences in Music ...*
[35] Michael S. Gazzaniga, *Human.*

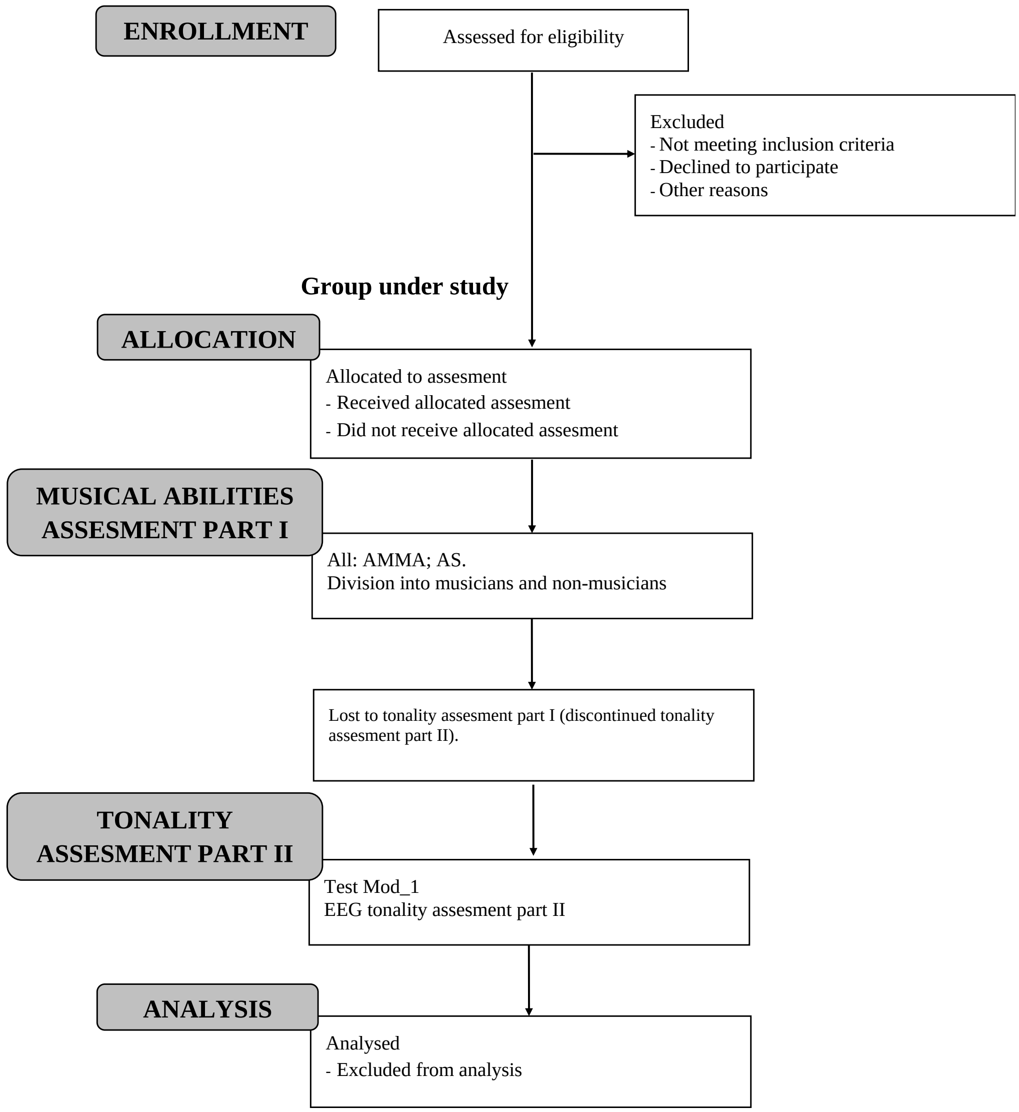

Figure 1. Proposed students' flow diagram

Methods

Test of Musical Abilities

The basis of the test of abilities (E.E. Gordon's AMMA test) comprised material produced based on tonal and rhythmic content presented electronically during the study. Such a procedure allows for a comparison of outcomes of tonality listening in people having a certain level of stabilized musical abilities[36].

[36] Edwin E. Gordon, *Manual for the Advanced Measures of Music Audiation*.

Musical Stimuli

The background effect was experimental material based on a variation of modality (test Mod_1). The tonal background for the test was a major version of a 23-bar melody[37] in a dichotomic derived from a school repertoire (composer: M. Gawryłkiewicz). Tonal ambitus of this construction was fitted between *h* and c^2. Every version was constructed based on diverse tonality: 1. Major/Ionian, 2. Dorian, 3. Phrygian, 4. Lydian, 5. Mixolydian, 6. Aeolian, 7. Minor harmonic, and 8. Locrian. All melodies were performed on a Solton Ketron synthesizer to control possible associations of presented melodies with a particular (favorable or unfavorable) timbre of selected musical instruments[38]. All eight versions of the melody were presented in six series (A–F). Each series presented the unique sequence of melodies. The material was well-known to the students.

Test Mod_1 was applied once. Every series lasted for 5 minutes and 50 seconds (total time for each person: 35 minutes). Every session consisted of stimuli repeated in the unique sequence. The musical content of melodies, their duration, the method of reproduction, and of measurement were the same for each participant. Participants made decisions while listening carefully. Identification of each version listened to was made using a keyboard. Analysis of the decisions made by students (including errors) excluded random events. The interval between two subsequent expositions was always the same (3,6 seconds). The duration of the tests led to them being divided into two parts within one week. Figure 2 shows the scheme of application of the test Mod_1. Success is described by the proper pairing of subsequent versions.

To sum up: procedure allows for a comparison of the musical attention paid by students through an assessment of aspects of stimuli reception (listening to the interval and contour of the melodic line), and the exact moment at which they make a decision (response). The procedure was processed in a controlled environment, and exposure to stimuli was continued for as long as the participants focused their attention. Musical stimuli were prepared to enable differences to be measured among people with musical abilities at many levels [39].

[37] David Temperley and Daphne Tan, "Emotional Connotations of Diatonic Modes", 237–257.

[38] Edwin E. Gordon, *Manual for the Instrument Timbre Preference Test* (Chicago: GIA Publications, Inc., 1984); Paweł A. Trzos, "The Level of Musical Aptitudes and Instrumental Timbre Preferences as Determinants of Music Achievements (according to the Author's own educational research):, *Mūzikas zinātne šodien: pāstavīgais un mainīgais. Zinātnisko rakstu krājums* Vol. IV (2011): 221–231; Roger A Kendall and Edward C. Carterette, "Verbal Attributes of Simultaneous Wind Instrument Timbres…", 445–468; Asterios Zacharakis, Konstantinos Pastiadis and Joshua D. Reiss, "An Interlanguage Study of Musical Timbre Semantic Dimensions and their Acoustic Correlates", *Music Perception* 31 (4) (2014): 337–356.

[39] Edwin E. Gordon, *Rating Scales and Their Uses for Measuring and Evaluating Achievment in Music Performance*, (Chicago: GIA Publications, Inc., 2002).

The main melody (major)

	Tonalities →	
The first serie (A)	**Variability of tonalities**	**Next series:**
1. **Major/Ionian (main melody)** 2. **Dorian** 3. **Phrygian** 4. **Lydian** 5. **Mixolydian** 6. **Aeolian** 7. **Minor harmonic** 8. **Locrian**	Time: 5,50 min. Pause between: 3,6 sek.	**B - F**

Figure 2. Scheme of application of the test Mod_1

EEG Procedure

EEG assessment covered all series in each participant. Registered signals were processed using band pass EEG digital filters (0.2-50 Hz) and Notch filters (blocking 50 Hz). Sensitivity of the EEG channels was set to 100 µV. EEG sample rate was set to 120 Hz. Data sets were registered and analyzed for subsequent elements (duration: 30 seconds). Computational artifact analysis was provided taking only clear recordings into consideration. Aforementioned data sets were further analyzed using Fast Fourier Transform (FFT). Features of analysis: frequency: 0.2-25 Hz, resolution 0.2 Hz, filtration: Hann window, waves: delta (0.2-3.6 Hz), theta (3.8-7.6 Hz), alpha (7.8-12 Hz), sigma (12.2-14 Hz), beta (14.2-25 Hz).

Outcomes of the EEG energy spectrum were averaged and calculated as values reflecting energy of the signal in the spectrum of 1 Hz [µV2 /Hz]. Spectrums of the energy in the left and right hemispheres were compared using signals from electrodes C3 and C4, P3 and P4, O1 and O2 for particular EEG waves.

Result Analysis

Outcomes of the EEG-based study will be analyzed using both traditional statistical methods and also advanced computational methods (principal components analysis—PCA, multidimensional scaling—MDS, etc.), including imaging of the results and possible differences between them. We anticipate that our results will show statistically significant differences among students' response to presented musical stimuli. Results of those students with higher musical abilities may be statistically and significantly different from results of students with moderate or low abilities.

The complexity of the studies and analysis of results require additional computational elements and dedicated tools, which are currently being developed—thus our results may be preliminary.

Discussion

Limitations of Previous Studies

There is a lack of advanced previous studies with which to compare our research. Roslau et al. recently described perception of songs by professional singers and actors as reflected in a magnetoencephalography (MEG)[41]. Lily Law and Marcel Zentner[42] described construction of music perception skills, and Hubbard (2010) reviewed literature relating to auditory imagery.

Limitations of our Studies

We regard our research as preliminary due to the following limitations:

- a limited sample;
- a convenience sample;
- a lack of randomization and procedures according to CONSORT 2010;
- a relatively novel methodology;
- a relatively novel analysis and interpretation of the outcomes needed for careful assessment and visualization.

[41] Ken Rosslau, Sibylle C. Herholz, Arne Knief, Magdalene Ortmann, Dirk Deuster, Claus-Michael M. Schmidt, Antoinetteam Zehnhoff - Dinnesen, Christo Pantev and Christian Dobel, "Song Perception by Professional Singers and Actors: An MEG Study." *PLoS One* 11/2 (Febr. 2016): 1–18.

[42] Lily N. Law and Marcel Zentner, "Assessing Musical Abilities Objectively: Construction and Validation of the Profile of Music Perception Skills", *PLoS One* 7/12 (Dec. 2012): 15–33. DOI.org/10.1371/journal.pone.0052508.

We are aware that the latency of auditory evoked potentials (AEPs) may influence results; thus short- (0–10ms), middle- (10–100ms), and long- (100–1000ms) latency AEPs should be taken into consideration. This may engage a huge computational workload, and be more time-consuming compared with the traditional approach.

Thus, our research requires preliminary studies and refinement based on the results. We are still seeking an optimal solution based on our current research.

The most interesting seems to be research on typical areas of MMN while listening to the intervals and contours of the melodies in people with good audiation in the following cases: 1. one tonality, 2. one tone of the instrument [43].

Directions for Further Studies

Our results will be replicated in subsequent studies on larger samples. There is a need for more advanced analysis tools.

From the practical point of view: described analysis, if confirmed by subsequent studies, might constitute an additional objective tool for assessment of musical abilities in students. This may imply changes in selection and preparation of pupils and students, including simplified and quicker procedures. It may encourage us to seek musical talents, even hidden, and look for prognostic signs. Our knowledge concerning neural correlates of certain levels of musical abilities may significantly influence knowledge and experience in the area of AEP and sound processing within subsequent levels of the auditory paths in central nervous systems (CUN). The ultimate goal will be research using semi-simultaneous EEG (better temporal resolution) and functional magnetic resonance imaging (fMRI, providing better spatial resolution).

Another, purely scientific, application may be computational models of physiological and pathological music processing, including developmental and neurodegenerative changes. Such an approach may provide a possibly deeper understanding of the mechanism underlying the proper development of hearing to the music and evidence-based control in these processes, including new assessment and teaching methods [44].

The clinical application may be found in assessment of changes in the musical abilities of professional musicians during aging, after physical damage (e.g. traumatic brain injury—TBI) or cerebrovascular accidents (CVA, e.g. stroke).

[43] Xide Yu, Tao Liu, and Dingguo Gao, "The Mismatch Negativity (MMN)…", 2-11; Katja N. Goydke, Eckart Altenmüller, Jürn Möller and Thomas F. Münte, "Changes in Emotional Tone and Instrumental Timbre …" 351–59; Peter Vuust, Elvira Brattico, Miia Seppänen, Risto Näätänen, and Mari Tervaniemi, "The Sound of Music…", 1432-1443; Mari Tervaniemi, Lauri Janhunen, Stefanie Kruck, Vesa Putkinen, and Minna Huotilainen, "Auditory Profiles of Classical, Jazz, and Rock Musicians…", 1-11.

[44] Meenakshy K. Aiyer and Josephine L. Dorsch, "The Transformation of an EBM Curriculum: A 10-year Experience", *Medical Teacher* 4 (July 2008): 377–383; Wilfried Gruhn, "Learning: On the Multiple Facets of a Colloquial Concept...", 227–236.

Conclusions

The proposed methodology may constitute another step toward assessment and objectivization of musical abilities. The hypothesis concerning the reflection of musical abilities in auditory pathways activation within CNS may prove to be true. Our future efforts will focus on research on audiation influence taking into consideration the latest research, including the role of MMN.

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