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The kinematic potential of music and the perception of musical motion

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Abstract: The article aims to explore the mechanisms by which perceived kinematic properties of music are transformed into specific motor representations. The objectives of this study involve identifying the causes behind the emergence of motor representations that arise during the perception of music. This enables an examination of the physiological, psychological, and pedagogical prerequisites for the formation of motor representations during music performance or listening. Existing research was examined through analytical methods, including contextual, structural, and comparative analysis. The study is based on the method of bibliometric analysis as a general scientific method and the method of interpretology. A comprehensive approach to the problem was employed, incorporating an analysis of interdisciplinary studies. A systems approach was also utilized to establish connections and functions among various types of perception of music's kinematic potential. Musicological methodology was applied in the study of specific means of musical expression and their influence on the perception of motion. The kinematic potential of music stems from the way the human brain absorbs auditory stimuli. The current integrative approach to performing emphasizes natural sound-movement links, demonstrating them both during practice and on stage. The novelty of this study lies in its departure from the associative paradigm in the perception of musical motion and its emphasis on psychophysiological regularities of kinematic experiences that occur during music performance and listening.

Keywords: *Artistic time, Choralography, Conducting, Interpretation, Kinesthetic, Musical art, Musical motion, Musical perception, Musical sound, Musical space, Musical time, Performance, Pitch perception.*

1. Introduction

The question of the kinematic potential of music has long intrigued not only musicologists but also specialists from various other fields. Psychologists, cultural theorists, physicists, and acousticians have all attempted to comprehend the reasons why certain musical structures elicit similar motor responses in individuals - both internal, unexpressed through overt physical movement, and external, manifested plastically through gestures, dance, or other forms of physical activity.

It is assumed that the close connection between the perception of various sonic properties and movement played a vitally important functional role in the early stages of human development. This connection enabled individuals to distinguish the distance of objects by sound, assess their size and energy, as well as estimate their speed and trajectory of movement - all of which were crucial for survival.

The most evident - and perhaps earliest - manifestation of the kinematic perception of musical sound is the widely established scale of "high" and "low" tones found across most cultures. These terms are intentionally placed in quotation marks, as the scale itself has no direct physical basis: what is commonly

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referred to as "pitch" is, in fact, determined by the wavelength of a sound wave. Thus, the classification of sounds into high and low is largely associative in nature. However, tracing the origin of this association proves to be exceptionally challenging. It is possible that the association stems from sensations involved in vocal sound production, where the generation of higher sounds engages the “upper” head resonators, while lower sounds rely more heavily on lower-lying chest resonators. Yet, an even more plausible explanation lies in the role of the kinesthetic (proprioceptive) analyzer, which, according to neurophysiology, provides information about the body’s position in space, the relative arrangement of limbs, and the functioning of muscles, tendons, and joints. Furthermore, it is the kinesthetic analyzer that communicates a wide array of spatial information to the brain, including the directional force of gravity. Namely this force gives rise to the sensation of increasing tension when moving upward, and a corresponding decrease in tension when moving downward. In this way, the production of sound that requires greater effort (greater tension in the vocal apparatus or tighter string or membrane tension) became associated with “high” sounds.

Wanderley, et al. [1] discovered that supplementary gestures are common in musical performances, despite the fact that they are not required. Furthermore, they vary greatly amongst performers but are more stable within them. The findings revealed that these motions are not done at random, but rather as an intrinsic element of the performance process. Chaffin and Lisboa [2] demonstrated that as musicians learn a new musical composition, their performance cues go from fundamental and effective to expressive, in a more holistic way. However, body motions have an impact on performance interpretation. Dahl and Friberg [3] shown that video sequences of marimba players featuring simply the upper body clearly support emotional objectives. Vines, et al. [4] discovered that visual perception of musical performance interacts with auditory perception in a multi-modal study in which subjects either saw, heard, or saw and heard musicians playing. They also demonstrated a relationship between accessory motions and musical structural elements such as phrase borders or longer notes. Furthermore, Davidson [5] discovered that whether the stimuli were presented in either visual, auditory, or multimodal formats, the musicians' gestures provided a stronger indicator of expressive intent than the sound. This demonstrated that visual signals appear to have a significant impact on music perception.

In Massie-Laberge, et al. [6] study, ten pianists performed three differing Romantic pieces in terms of technical level and character, while motion data was recorded using a passive infrared motion capture device. The authors observed pianists modulating their performances for each of the three pieces and calculated the absolute difference in percentage of length and quantity of motion (QoM) between four expressive circumstances (normal, deadpan, exaggerated, and immobility). We examined common trends in time-series location data to see if pianists express musical structure in similar ways. Pianists completed a survey to better understand how they perceive the link between bodily movements and musical structure. The results demonstrate that the change in time between the exaggerated and deadpan conditions was substantial in one measure for one of the segments, and that the level of expressiveness had a greater influence on tempo than the QoM utilized. Massie-Laberge, et al. [6] discovered that the head QoM is a crucial parameter for transmitting various expressions and structural aspects using PCA on pianist position data. Significant differences in head QoM were seen in the immobile and deadpan circumstances as compared to the usual condition, although only in certain regions of the score. Only two of the snippets showed recurrent head motions and certain structural features. Overall, these findings suggest that an examination of pianists' body movements and expressive intents should be conducted in connection to the unique musical environment, which is determined by the technical level of the works and repertory. These findings, when paired with piano teaching methods, may lead to the creation of novel ways in instrumental sessions that allow students to make independent decisions about body movements and expressiveness [7].

Mailly, et al. [8] discovered that assessing pianists' gestures is challenging since a wide range of multi-joint kinematic methods and muscular activity may be employed to generate a single piano tone.

Furthermore, pianists' gestures are expertise-dependent, with novice and expert pianists using distinct movement techniques and muscle activation when performing equivalent tasks.

A kinematic analysis of musiicians' body movements and musical timing in relation to the structural elements from various pieces of music would bring invaluable information that may help performers and music disciplines students monitor their body movements to improve their expressive communication abilities while consistently manipulating acoustical and physical parameters. These results can contribute to the design of a coherent framework that may impact both performance and music pedagogy.

2. Method

Musical art appears in this work as a subject of complex research, which determined the complex nature of the methodology of its analysis, the combination of a philosophical and aesthetic approach with specific scientific methods of studying musical art. The method of bibliometric analysis as a general scientific method and the method of interpretology as a method belonging to the field of musical art were used.

The research methodology is based, in particular, on the provision that the analysis of the interaction of scale-time levels from the standpoint of perception allows putting forward the position that the sound and compositional layers in a musical work are closed, as a result of which the actual intonational-syntactic development is relegated to the background. The intonational certainty of the musical material is, as it were, absorbed by the expressive-colorful energy of the sound stream. The idea of the substantive possibilities of sound-colorful material was formed on the basis of studying the mechanisms of perception and the associative base of sonoristics. In the diversity of impressions, common properties of comparisons and associations gradually emerge, conditioned by the flexible combination of visual-auditory and tactile sensations. Due to this, the semantic field of sonorous sounds is limited mainly by the play of sound colors and the originality of sound constructions. The increased semantic load of the phonic layer leads to a rethinking of the functions of musical means from the point of view of their embodiment of extra-musical content.

3. Results and Discussion

The spatial anchoring of auditory sensations clearly provides fertile ground for the development of an individual's perception of the shape and form of musical movement. Over time, a number of researchers have investigated these perceptions both in professional musicians and in children.

For instance, P. J. Flowers and E. Costa-Giomi found that preschool-aged children are generally not inclined to describe differences in sound frequency using the terms “high” and “low.” This finding is particularly noteworthy when compared with earlier studies on the verbalization of musical impressions in children [9, 10] where preschoolers readily used descriptors such as “fast/slow” and “loud/soft,” and demonstrated awareness of timbral and articulatory differences, describing sounds as “light/heavy.” However, only about one-third of the children referred to octave changes using the terms “high” and “low” [11].

Thus, it is confirmed that the “vertical” perception of pitch develops gradually as a result of internalizing culturally accepted conventions and accumulating life experience, including kinesthetic experience. This notion is supported by research Ashley [12] in which participants were presented with melodic phrases accompanied by graphical contours. It was found that for musically trained individuals, the alignment of pitch ascent with an upward graphic trajectory enhanced melodic recall, whereas incongruent visual contours hindered the task. However, after a short period of training, the differences between congruent and incongruent conditions significantly diminished or even disappeared entirely, reinforcing the learned nature of pitch perception in a vertical framework [6].

The development of connections between music and movement is influenced by numerous factors: innate physiological flexibility, the degree of motor coordination, emotional sensitivity, and prior experience in musical performance or dance. Studies on the perception of musical motion have convincingly demonstrated, for example, that individuals who play the piano tend to perceive pitch changes not vertically, but laterally - ascending frequencies are associated with rightward movement, while descending frequencies correspond to leftward movement [13].

Another stable association can be observed between loudness and the perceived distance of a sound source. In everyday life, this correlation tends to be consistent: louder sounds are generally interpreted as closer, while quieter ones are perceived as farther away. In musical contexts, however, changes in loudness are typically not due to shifts in the perceived spatial distance of the sound source, but rather result from variations in the force applied to a musical instrument [14, 15]. "Nevertheless, a listener may metaphorically associate musical loudness with distance, based on their life experience connecting these two features in non-musical contexts" [13].

On the other hand, a comparison of experimental data between participants with and without musical training revealed differences in the intensity of connections between auditory and spatial sensations, but not in their directional tendencies. According to the researchers, this suggests *"a stronger inclination among musicians to associate specific musical and motor parameters. Thus, it appears that most aspects of musical-emotional mappings originate not from professional musical experience, but from broader, more general sources"* [13].

Several sources of musical motion have been explored within scientific discourse. Rhythm is considered one of the most prominent phenomena that evoke kinetic responses in listeners. Some researchers have pointed to the categories of tension and release, driven by tonal gravitations, as key contributors to musical motion. Harmonic conditions such as the interplay of dissonance and consonance are also regarded as sources of perceived movement. However, this model does not fully account for atonal music with non-conflictual structure and the absence of a distinct rhythmic organization. Despite lacking the aforementioned sources of movement, such music can still evoke vivid plastic imagery and kinesthetic responses in the listener [8, 16].

Shepard [17] emphasized the role of not only perception but also imagination in shaping the auditory equivalent of visible motion [17]. He argued that the human brain, accustomed to operating with real physical movement, tends to convert more metaphorical and abstract motion - whether visible or imagined - into perceived motion [18].

It should also be added that sound itself is often characterized by humans using vocabulary borrowed from entirely different sensory domains, as if the mind seeks more concrete ways to describe it. For instance, a sound may be referred to as *"sharp"*, which draws on tactile perception; *"bright"*, invoking visual imagery; or a timbre may be described as *"syrupy"*, appealing to gustatory associations. In fact, it is nearly impossible to find an adjective that is specific solely to the description of sound, apart from perhaps *"loud"* or *"soft"*. This suggests that even when attempting to define the qualities of sound, the human brain tends to interpret and describe its subtle texture through more physically grounded phenomena.

When discussing movement, it is impossible to avoid questions concerning the relationship between space and time. In art, they exist simultaneously in two forms: the real and the artistic. The real duration of an opera does not coincide with its artistic time. The real space in which a symphony is performed may not match its artistic location (for example, the actual placement of the orchestra during the performance of Dvořák [19] symphony *From the New World* does not have to align with the geographical origin of the music). Moreover, space and time possess the property of mutual transition, where static elements of space contain artistic movement, and the dynamic flow of time is "fixed" within the concept of "musical form." For instance, a sculpture of a running dog is static, not changing over time, yet to human consciousness, it represents movement through time. Conversely, a chord played by an orchestra, though unchanging, may last for a significant amount of time and occupy a specific period, but it will be perceived as a static object.

This largely aligns with Arnheim [20] reflections on the relationship between space and time in works of art. "This transformation of sequence into simultaneity leads to a curious paradox: a musical composition, drama, novel, or dance must be perceived as a kind of visual image if they are to be understood as a structural whole. Painting and sculpture are manifestations of a contemplative attitude. They present a world of action transformed into simultaneity" [20].

Indeed, in many cases, time, understood as a measure of dynamic changes in space (or their absence), is quite conditional and changes depending on the position of the perceiver and the strategy of thought. The readiness for a holistic grasp, for simultaneous perception, characterizes the "spatial" strategy of thinking. The "temporal" strategy of thinking, on the other hand, is linked to the ability for sequential cognition.

Artistic time is manifested through pulsation, which breaks the infinite flow of time into even or uneven segments, causing movement to evoke the sensation of real passage of time. As for tempo, it rather conveys the intensity of the artistic action taking place.

Mostova [21] in her dissertation research, notes that "the unit of measurement for real time – the second – is perceived by humans as the 'golden mean' of the tempo scale. It can be assumed that the reason for this lies in the characteristic average tempo of the human heart rate, which in a calm state is 60-70 beats per minute. This is why such a tempo is perceived as calm. Accordingly, a pulsation of more than 60-70 beats per minute is perceived as fast, while fewer beats are perceived as slow" [22].

It is evident that tempo can also carry an emotional connotation, directly linked to human physiology. Fast pulsation is generally associated with states of excitement (whether joyful or anxious), fear, anticipation, or even affect, as well as with purely physical sensations when a person is moving quickly (for example, running). Conversely, a low frequency of pulsation directs our attention to states of calm, tranquility, or the physical sensations of a person at rest, ill, or moving slowly. An excessively slow pulsation or its abrupt stop evokes persistent associations with states such as powerlessness, shock, and death [22].

If we turn to more "down-to-earth" and specific categories when considering the source of musical movement, we will notice that the performer is often overlooked. The habit of thinking within the Western tradition, which tends to focus more on the abstract properties of music, hides from us one of the most immediate sources of musical movement – the performer. In turn, the movements of the performer include those directly related to their instrument and sound production, as well as those that carry the emotional concept, essentially the physical interpretation of the musical composition [23, 24].

"When analyzing performance movement, one can refer to several interconnected factors: the method of production (bow, tongue), articulation style (staccato, legato), the physical 'shaping' of a sustained sound (vibrato, lip trill), tempo of movement (tempo and meter, or agogics), character of movement (rhythm in the narrow sense), force of movement (dynamics), and even changes in pitch (musical space). All of these, some more than others, are kinetically represented in the acoustic array, and their specific extraction will shape the listener's perception of musical movement" [25].

Numerous studies show that the spatial and kinematic associations generated by various means of musical expressiveness are, first, asymmetrical, and second, cross-modal.

"Asymmetry is expressed in that crescendo and diminuendo are directed asymmetrically relative to verticality: while diminuendo is closely linked to descending spatial movement, crescendo is only slightly associated with ascents. /.../ Furthermore, crescendo and diminuendo are also asymmetrical in terms of speed: while crescendo evokes a sense of acceleration, diminuendo does not evoke a sense of deceleration. /.../ In addition, in both experiments, an increase in pitch is associated with acceleration and approaching, while a decrease in pitch is not linked to deceleration or distancing" [13].

Cross-modality is manifested in the fact that changes in the intensity of one musical property can create the illusion of corresponding changes in another. A common example in the descriptions of experiments is the fact that changes in volume create the illusion of changes in pitch, or conversely, thickening of texture or an increase in volume is perceived as acceleration, while a decrease in texture density is perceived as deceleration [13].

The assessment of musical movement is a rather complex mental operation (which, however, occurs subconsciously). The formation of the concept of musical movement can take place through visual representation, motor sensation (kinesthesia), as well as vestibular and kinesthetic components of perception.

Musical movement (like any movement in general) is assessed according to several parameters: direction, intensity, amplitude, and form. Most often, the direction of movement is evaluated as smooth, ascending, descending, approaching, or distancing. The intensity and amplitude of musical movement are assessed in terms of their increase or decrease, as well as the uniformity of these changes [21].

Between-conductor variability analysis examined whether each conductor had similar or different kinematic features compared to the other conductors. Analysis of between conductor kinematic variability is demonstrated in Figure 1. Time-points with high between-conductor kinematic variability are identified in Figure 2.

According to Huang, et al. [26] directors employ body gestures to express their interpretations of musical works through performance instructions that focus on certain musical characteristics. Huang, et al. [26] investigated how the kinematic aspects of conducting motions connect to compositional components such as rhythmic patterns, melodic peaks, dynamic shifts, and conductors' own interpretational remarks. Six conductors with four to 29 years of experience were interviewed and asked to annotate a musical score (W. A. Mozart's Eine Kleine Nachtmusik, No. 13, K. 525, first movement, mm. 1-55) based on a variety of interpretational intents. Kinematic metrics such as baton speed, acceleration, and jerk were retrieved using Visual 3D and Matlab software applications. Crosscorrelation indicated that, as predicted, intra-conductor movement kinematic patterns were more comparable than inter-conductor patterns.

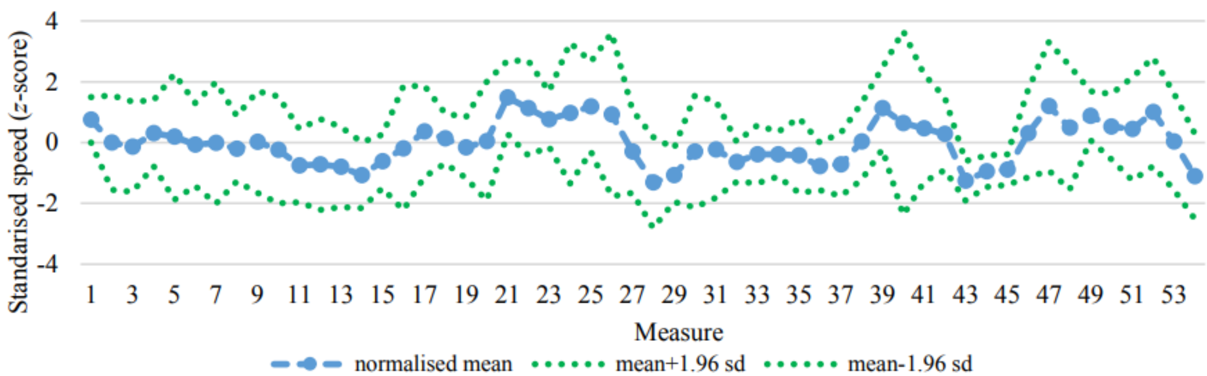

Figure 1.
Mozart Mean Speed ± 1.96 x SD (All Conductors).
Source: Huang, et al. [26].

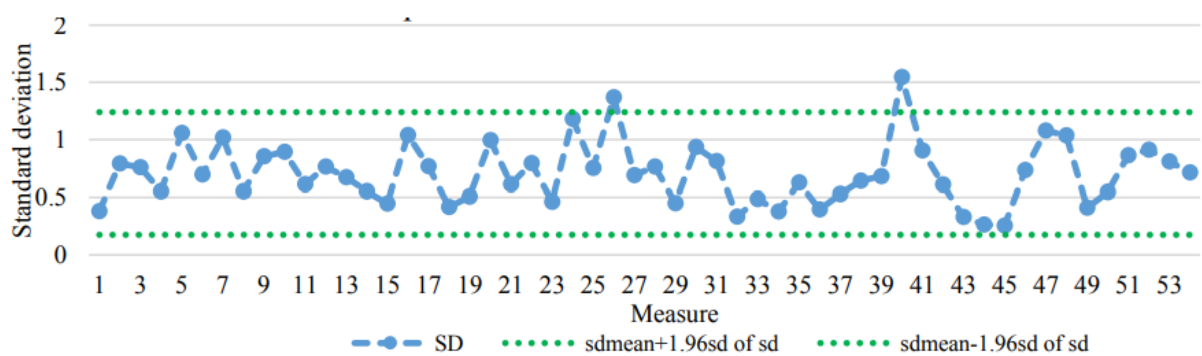

Figure 2.
Mozart Speed Between-conductor Standard Deviation.
Source: Huang, et al. [26].

The form of movement is the most complex parameter, as its variety is unlimited and quite ambiguous. However, certain basic types of movement can be identified. It should be noted that these are characteristics of simple structures of a lower order, which, in turn, at the intersection of direction and form, create new, more complex structures.

It seems well-established that the listener's body acts as a kind of converter of musical movement, which it perceives from various sources.

Clarke [27] distinguished three types of events conveyed by musical sound [27]. The first type consists of performance events, that is, the actual movements made by the performer. These are accessible to the listener with any thesaurus, and the experience of observing the performer strengthens the ability to mentally reproduce these impressions when listening to a recording. The second type is abstract and more closely related to professional training. Clarke [27] refers to this as a structural event. According to him, hearing structural events means perceiving the syntactic division of music, sensing its harmonic development, and registering articulation, phrasing, etc. The third type of event is also abstract; it is related to the emotional content of the music, the use of movement patterns that resemble bodily movements through which human emotions are expressed. These are expressive events.

The perception of musical movement reflects the listener's position in relation to the music. The listener may hear the sound object rather than the performer. They may experience the actual movements of the performer and/or instrument. This is confirmed, for example, by the fact that a listener who is a teacher is more likely to experience the real movement of the student-performer than the kinetic reactions to the audible musical texture. On the other hand, a listener who is engrossed in the musical structure itself will draw motor associations from the spatial perception of the form of the composition, while a listener with an emotionally active stance is more likely to pick up on movement forms characteristic of human gesticulation.

However, this concept raises the following question: how does a spectator-listener perceive movement originating from the performer when their instrument and sound production mechanisms are largely hidden, as in vocal and choral music?

The instrument of the vocalists is their body. The degree to which the mechanisms of sound production are visible to an outside observer in this activity depends on various factors: the character and tempo of the sound, the type of vocal technique used, and the performer's intention to either reveal or conceal certain technical (physiological) aspects of it. For example, a piece in a fast tempo, requiring active articulation, is unlikely to hide the bodily technical elements. However, the performer's facial expressions and gestures while singing can be consciously controlled. Depending on the artistic goals, the amplitude of their expressiveness can vary significantly. Vocal works provoke motor associations in the listener just as much (if not more) than instrumental ones. The most likely reason for this is the human ability for emotional and motor synchronization, developed as a tool for establishing social connections in early societies. The inability of humans to survive alone made this brain function absolutely essential.

Cox [28] believes that the listener kinesthetically responds not so much to the sounds themselves, but to their perception of the physical effort that produces that sound Cox [28]. Galbreath and Thatcher [29] emphasize that "when we perceive sound, we (empathetically, embodied) draw conclusions about the interpretation of the creator of that sound" [29]. Studying the feedback of musicians' interpretation in relation to the conductor's perception, Galbreath and Thatcher [29] suggest focusing on a new approach to conducting, where this feedback is used not only for the conductor's reflection and performance correction but also as a "receiver" and accumulator of collective interpretation. This idea is interesting because it flips the traditional view of conducting as a process of imposing the conductor's will and interpretation on performers through musical-physical movement. The value and viability of this idea still need to be evaluated, although it undoubtedly could contribute to the development of conducting pedagogy.

Returning to the psychophysiological foundations of the kinematic perception of music, it is important to note that research in the field of neurophysiology demonstrates the presence of so-called "mirror" neurons in humans [30] which are equally activated both during actual action and while observing the actions of others. This means that the brain does not distinguish much between the action itself and the observation of that action. This experience is well known to vocalists who have ever had issues with their vocal cords. When it is necessary to reduce or eliminate vocal strain, they not only have to stop singing but also stop listening to others singing, as this activates their own vocal cords even in the process of silence. Conversely, in the rehabilitation of patients after vocal cord surgeries, phoniatricians may recommend that the patient listen to recordings of specific vocalists in order to gently activate the vocal cords without engaging them in active work. This neurological mechanism is defined by specialists as "the tendency to automatically imitate and synchronize facial expressions, vocalizations, postures, and movements with those of another person..." [31].

Thus, the functions of mirror neurons, combined with the functions of the kinesthetic analyzer, determine the human ability to transform auditory impressions into motor ones, and motor ones into auditory. The accuracy and speed of this process are influenced, among other things, by the actual physical (rather than just mental) experience of the performer or listener. While we cannot influence the listener's experience, the performer’s kinetic experience is increasingly drawing the attention of educators. This trend has been particularly prominent in the field of choral music, finding expression in the so-called choralography.

In a general sense, choralography refers to the movements and gestures performed by choristers during a musical performance to enhance the artistic impression. Essentially, it is one of the forms of theatricalization of musical performance. Choralography can express the meaning of the text of the piece, illustrate it to some extent, and also amplify the expression of emotions. The main purpose of choralography is the execution of movements by the performers themselves, rather than by a special choreographic group.

The use of movement during choral performance has several limitations. First, there are physiological limitations: the movements must be compatible with singing, and the physical load must be proportionate to the capabilities and training of the singers. The movement should not negatively affect the sound. Secondly, a balance must be maintained between music and movement. Choralography should complement the performance, not overshadow the music itself. Thirdly, the visual and plastic solution should correspond to the musical material according to specific criteria.

Choralographic composition, as a form of artistic interpretation, should align with the composer’s intent or complement it. Therefore, in order to preserve the integrity of the performance, the movements must correspond to the composition stylistically, maintaining (or even better, highlighting) its genre specificity and structure. The movements should be organized according to the tempo-rhythm of the piece, take into account its internal spatial intentions, and adequately express the ideological and emotional meaning of the intonations through plasticity.

At the same time, choralography is beginning to be used as a methodological tool for training choristers and conductors. An interesting approach is offered by Panda van Proosdij, a Dutch coach of choral movement, whom she refers to as “choireography”. Her goal is not only the chorographic staging of choral numbers but also the exploration of the interrelationship between movement and sound. In her master classes, Panda van Proosdij demonstrates and explains which movements influence vocal sound production and how they contribute to the natural improvement of tone formation. Her choral staging is characterized by a focus not only on the plastic expression of the musical work but also on the ergonomics of sound. However, even more significantly, her work with movement presents an intriguing system of collective vocal work, which deserves separate study.

4. Conclusion

The kinematic potential of music is rooted in the way the human brain processes auditory impressions. Thanks to mirror neurons and the work of the kinesthetic analyzer, the motor associations that arise under the influence of music share a common nature among most people. The modern integrative approach to performance increasingly brings these natural sound-movement connections to the forefront, revealing them both in the rehearsal process and in stage performances. A harmonious combination of the performer's plasticity and the sound texture can significantly enhance the impact of a musical piece on the listener's consciousness. For this reason, further exploration of these patterns appears both valuable and worthwhile.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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