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Article

Human motion and musical expression: Exploring the link between physical movement and emotional resonance in performance

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Abstract: Musical performance has traditionally been understood as an auditory experience, with emotions conveyed primarily through sound. However, emerging research highlights the role of physical movement—gestures, posture, and body language—in enhancing emotional expression and creating a deeper connection between performers and their audiences. While existing studies have explored some aspects of this relationship, there is limited understanding of how specific movements modulate emotional responses across different musical genres. This study addresses these gaps by investigating the interaction between human motion and musical expression, focusing on the emotional resonance experienced by performers and audience members. The need for this study arises from the lack of comprehensive data on the correlation between movement and emotional engagement during musical performances, particularly concerning different genres. Using motion capture, biometric sensors, and facial recognition technology, the research analyzed the performances of professional and amateur musicians across classical, jazz, and contemporary music. Audience members' emotional responses were captured through physiological data and post-performance surveys. One limitation of this study is that it focused solely on live performance environments, leaving digital or virtual performances unexplored. Key findings reveal that expressive movements increased emotional intensity ratings by 1.6 points ($p < 0.001$), with heart rate rising by 6.9 BPM ($p < 0.0012$) and electrodermal activity increasing by 1.6 µS ($p < 0.0008$). Movement synchronization with musical elements, especially during climaxes, strongly correlated with heightened emotional responses ($r = 0.85$, $p < 0.01$). Classical performances exhibited the highest synchronization between movement and emotion, with audience emotional intensity peaking at 8.3 on a Likert scale.

Keywords: biomechanical analysis; human motion; emotion; biometric sensors; motion capture; electrodermal activity

1. Introduction

Musical performance is frequently perceived as an auditory experience, where sound and music take center stage. However, recent studies have increasingly recognized the importance of visual and physical elements in enhancing musical expression [1,2]. Physical Movement (PM)—whether it be the sweeping gestures of a conductor, the fluid arm motions of a pianist, or the subtle shifts in posture of a vocalist—plays an integral role in how emotions are conveyed during a performance [3]. This intersection between motion and emotion is essential for performers in expressing their emotional intent and for the audience in their perception and Emotional Engagement (EE) with the music [4,5].

Historically, musical performance research has focused on the sonic aspects of music, such as melody, rhythm, harmony, and dynamics [6]. However, as performance spaces have evolved to be more immersive and visual, there has been an increasing interest in understanding how PM can amplify or modulate emotional expression [7]. Recent technological advances, such as Motion Capture (MC), biomechanical analysis, and facial recognition, have enabled a more precise examination of this relationship [8,9]. These tools offer insights into how specific movements—such as expansive arm gestures, sharp hand motions, or even subtle facial expressions—affect the performer's emotional expression and the audience's emotional resonance [10].

Despite these advancements, a gap remains in understanding how different types of PMs correlate with varying emotional states during a performance [11]. While there is growing evidence that movement enhances emotional communication in performance, few studies have systematically explored how specific gestures, movements, and physical cues align with the emotional trajectory of a musical piece [12]. Additionally, the influence of these movements on the emotional connection between the performer and the audience has yet to be thoroughly examined across different musical genres.

This study aims to address these gaps by analyzing the role of human motion in musical performance and its impact on emotional resonance. By utilizing MC technology and biometric analysis, the research seeks to identify the specific movements that enhance or modulate emotional expression during live performances. Furthermore, the study explores the varying impact of movement across musical genres—classical, jazz, and contemporary—and examines how the synchronization between music and movement affects EE for both performers and audience members. The findings from this research are expected to contribute to a deeper understanding of the embodied nature of musical performance, where both sound and movement combine to create a holistic emotional experience. By shedding light on the physical aspects of performance, this study aims to broaden the discourse on musical expression, offering performers new insights into how their body language and gestures can elevate the emotional impact of their music.

The paper is organized as follows: Section 2 presents the theoretical framework, Section 3 presents the methodology, Section 4 presents the analysis, and Section 5 concludes the paper.

2. Theoretical framework

2.1. Concept of musical expression

Musical expression, whether vocal or instrumental, has long been regarded as a fundamental means by which musicians communicate emotions. The expressive qualities of music, such as dynamics, tempo, articulation, and phrasing, serve as vehicles through which performers can convey emotional content to listeners [13]. Vocal music, often paired with lyrics, allows for a direct representation of emotion, but the nuanced delivery—tone, pitch variation, vibrato, and breath control—adds layers of emotional depth. Scholars have explored how these vocal techniques enable performers to evoke specific emotions such as joy, sorrow, or anger in the listener [14]. Instrumental music, devoid of lyrics, relies on a more abstract form of emotional communication. The emotional impact of instrumental performance is mediated by factors such as the choice of instrument, the register in which it is played, and the manipulation of musical elements like melody, harmony, rhythm, and timbre [15]. For example, a slow, minor-key melody played on a cello can evoke melancholy, while a fast-paced, major-key piece on the violin might convey excitement or happiness. Studies have examined how performers use variations in volume (crescendo and decrescendo), tempo (accelerando and ritardando), and articulation (legato, staccato) to shape the emotional narrative of a portion [16].

Researchers in the field of music cognition have also explored how musicians personalize their expression, going beyond mere technical execution to imbue their performances with their emotional states and intentions [17]. This subjective interpretation is shaped by factors such as cultural context, personal experience, and the performer's emotional connection to the music. In this method, musical expression echoes the composer's intent and an interactive process between the performer and the audience [18]. In recent years, technological advances have enabled a more precise analysis of musical expression [19]. Studies using MC, facial recognition, and biometric feedback have provided new insights into the physical gestures and physiological changes accompanying emotional expression in music performance [20]. These technological tools have allowed researchers to identify correlations between certain expressive gestures—like hand movements or facial expressions—and the emotions they convey in vocal and instrumental contexts.

2.2. PM in performance

The role of PM in musical performance has been the subject of growing interest in recent years, with numerous studies highlighting how body language, posture, and gestures significantly contribute to the performer's expressive capacity and the audience's perception of the music. Traditionally, musical performance was viewed as primarily an auditory experience, but modern research has shown that visual elements—mainly the performer's PMs—enhance the communication of emotions and musical intent [4].

Body language, which includes gestures, facial expressions, and subtle movements, is a non-verbal expression that complements the sound being produced. Several studies have found that the visual aspect of performance often enhances the audience's emotional experience, as they can interpret the performer's physical cues as representations of the music's emotional content [21,22]. For instance, a pianist's sweeping arm movements or a violinist's bowing gestures can amplify the intensity or serenity of a musical passage. Researchers have identified a close connection between specific gestures and the emotions they convey, such as expansive movements correlating with feelings of excitement or enthusiasm, while more restrained gestures tend to evoke calmness or introspection.

Posture, too, plays a pivotal role in performance, influencing not only the technical aspects of sound production but also the overall emotional delivery. A performer's stance can reflect confidence, poise, or tension, affecting how the audience perceives the performance [23]. Research has demonstrated that musicians who maintain an open, upright posture tend to project more powerful and emotionally engaging performances than those with closed or slouched body positions. This is particularly relevant for instrumentalists like singers, wind players, and pianists, where posture directly impacts breath control, resonance, and overall sound quality [24].

Gestural communication is especially significant in ensemble performances, where musicians rely on one another's physical cues to synchronize and interpret the emotional nuances of the music. Conductors, for example, use their hands and facial expressions to guide the emotional trajectory of an orchestra, while smaller chamber groups often communicate through subtle gestures, such as head nods or eye contact. Studies have shown that even slight variations in gesture can change the emotional perception of a musical performance, suggesting that movement is not merely supplementary but integral to the act of making music.

In addition, research on mirror neurons and embodied cognition has provided insight into why audiences respond so strongly to PMs in performance [25]. These studies suggest that observers often subconsciously mimic the movements they see, leading to a shared emotional experience between the performer and the audience. In this way, the physical aspect of performance becomes a crucial factor in how emotion is both expressed by the performer and experienced by the audience.

Recent technological advancements, such as MC and biomechanical analysis, have enabled a more precise study of the relationship between movement and music [26]. These tools allow researchers to track the kinematic data of musicians' movements, offering insights into how different motion patterns correspond with various emotional states or musical dynamics. Findings from such studies have revealed that even micro-movements—like subtle shifts in finger placement or minute facial expressions—can significantly affect the emotional quality of a performance.

2.3. Emotional resonance: Defining and theorizing emotion in music

Emotional resonance refers to the profound, shared experience of emotion between the performer and the audience during a musical performance. It is the connection formed when a performer's emotional expression aligns with the audience's emotional response, creating a reciprocal bond that deepens the overall impact of the performance. Emotional resonance is not simply about the conveyance of emotion but the internalization and reflection of that emotion, simultaneously making music a profoundly personal and collective experience.

For the performer, emotional resonance is the ability to channel personal emotions into their music, making their performance feel authentic and emotionally charged. This resonance often comes from a personal connection to the piece of music, past experiences, or emotional states. Performers who can embody the emotion behind the music entirely can create an emotionally immersive experience for their audience. Through nuances in timing, dynamics, phrasing, and movement, they evoke emotional responses that align with their own internal feelings, resonating with the audience more viscerally.

From the audience's perspective, emotional resonance occurs when listeners experience emotional reactions that mirror or complement the performer's expression. This can happen consciously, as when listeners recognize a piece's mood or emotional tone, or unconsciously, as emotional cues in the music trigger psychological and physiological responses. The process of emotional resonance in the audience is deeply rooted in psychological mechanisms, such as empathy, where listeners may "feel" the emotions expressed by the performer through auditory and visual stimuli. The interplay of sound, motion, and expression fosters an emotional connection that transcends the musical notes.

Psychological theories provide valuable insights into the mechanisms behind emotional resonance in music. One prominent theory is the Appraisal Theory of Emotion (**Figure 1**), which posits that emotions are elicited based on an individual's assessment or interpretation of a stimulus—in this case, music. As listeners perceive different elements of a musical performance, such as melody, rhythm, and dynamics, they appraise the emotional significance of these components based on their own experiences and context. For instance, a listener might interpret a slow, minor-key passage as sad, whereas another might find it soothing, leading to different emotional responses.

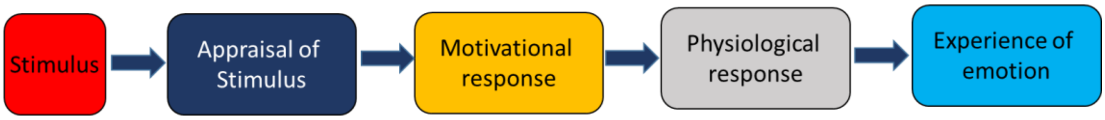

Figure 1. Appraisal theory of emotion.

Another influential theory is Embodied Cognition (**Figure 2**), which suggests that emotions are processed in the brain and experienced through the body. In this context, the PMs of the performer—such as their gestures, posture, and facial expressions—contribute to emotional resonance by allowing the audience to "feel" the music physically. Audiences may subconsciously mimic the movements or emotions of the performer through processes like mirror neuron activation, further enhancing the emotional connection. The audience's physiological responses—such as changes in heart rate, skin conductance, or even tears—are tangible manifestations of emotional resonance.

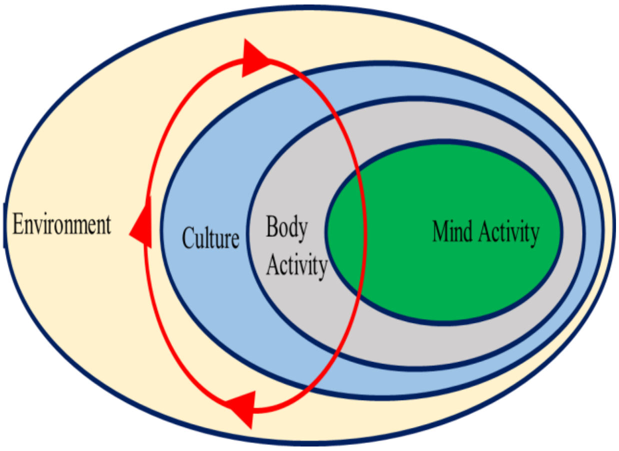

Figure 2. Embodied cognition.

The Theory of Musical Expectation (**Figure 3**) also plays a key role in emotional resonance. According to this theory, listeners expect how music should progress based on familiar musical patterns, such as harmonic resolutions or rhythmic structures. When a performance either meets or defies these expectations, it triggers emotional reactions like surprise, joy, or tension. Skilled performers often manipulate these expectations to heighten emotional resonance, creating moments of anticipation or release that align with the emotional arc of the music.

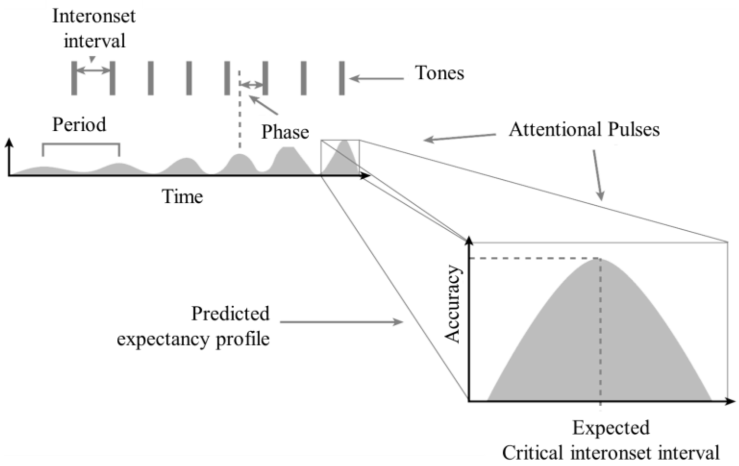

Figure 3. Theory of musical expectation.

Lastly, the Aesthetic Theory of Emotion in Music emphasizes the listener's aesthetic appreciation of music as a vehicle for emotional experience. This theory argues that music serves as an abstract form of emotional communication, where the structure and form of the composition—rather than explicit verbal content—evoke emotional states. In this view, emotional resonance is achieved when the audience appreciates the performance's beauty, complexity, or emotional depth, connecting on both an intellectual and emotional level.

2.4. Integration of motion and emotion

The integration of motion and emotion in musical performance has been widely studied as a key factor in amplifying or modulating emotional expression. PM—whether it is intentional gestures, posture, or subtle body language—serves as a complementary medium through which performers enhance the emotional impact of their music. The way performers move during a piece often aligns with their emotional intent, providing visual cues that resonate with the music and the audience's emotional response. This symbiotic relationship between motion and sound creates a more immersive and expressive performance, deepening the emotional experience for the performer and the audience. Research has shown that movement acts as an extension of emotional expression by allowing performers to embody the music physically. Gestures, such as a pianist's flowing hand motions or a violinist's bowing technique, often correspond to the emotional tone of the piece. For example, sharp, staccato movements may reflect tension or excitement, while smooth, fluid motions can evoke calmness or melancholy. These gestures influence the performer's ability to express emotion and provide the audience with a visual representation of the emotional content. Studies have found that audience members often perceive performances as more emotionally charged when they can observe these PMs, as they serve as non-verbal cues that clarify and intensify the emotional narrative of the music.

Moreover, the synchronization between motion and music helps modulate the intensity of emotional expression. For instance, exaggerated or expansive movements during a dramatic or climactic performance can amplify the perceived Emotional Intensity (EI). In contrast, more restrained or minimal movements during slower or more introspective passages can create a sense of subtlety and emotional depth. This modulation through movement allows performers to dynamically adjust the emotional arc of a piece, engaging the audience on multiple sensory levels—auditory, visual, and emotional. Several studies in the field of music performance and embodied cognition have examined how movement affects the performer's emotional expression. These studies suggest that PM enhances the audience's experience and influences the performer's emotional state. By engaging the body in expressive motion, performers may intensify their emotional connection to the music, creating a feedback loop where physical gestures deepen their EE. This process, often called "embodied performance," allows musicians to feel the music more fully, leading to more authentic and assertive emotional expression.

Technological advances, such as MC and biomechanical analysis, have provided new insights into how specific movements correlate with emotional expression. These tools have allowed researchers to map performers' precise gestures and postures when conveying different emotional states. For example, a study using MC technology might analyze the hand movements of a pianist playing a joyful, fast-paced piece versus a slow, mournful one. The data from these studies show that even subtle differences in motion—such as the speed, size, or fluidity of gestures—can significantly alter the emotional perception of a performance.

Furthermore, movement can bridge the performer's emotions and the audience's response, creating a shared emotional experience. Audience members often subconsciously mimic or internalize the performer's movements through processes like mirror neuron activation, which helps them emotionally resonate with the music. This physical synchronization between performer and audience reinforces the emotional connection, making the music feel more emotionally impactful. In live performance settings, the visual spectacle of a performer's movement enhances the emotional experience, making the performance more engaging and immersive. In ensemble performances, motion is crucial in coordinating emotional expression among musicians. Musicians often use gestures and body language to communicate subtle emotional cues to one another, ensuring that the emotional tone of the piece is cohesive and unified. This non-verbal communication enhances the emotional resonance of the performance, as each member of the ensemble contributes to a shared emotional goal through synchronized motion.

3. Research methodology

3.1. Student participants

A total of 97 students were initially enrolled in the study, comprising both performers and audience members, to explore the intricate relationship between human motion, musical expression, and emotional resonance. Students were divided into two groups—performers and audience members—each meeting specific eligibility criteria designed to ensure the reliability of the findings. For performers, the criteria required at least 1.5 years of formal training for amateurs and 4 years for professionals, with students coming from various musical backgrounds, including classical, jazz, and contemporary genres. On the other hand, audience members were selected based on the absence of formal musical training to ensure unbiased emotional responses to the performances. After the initial screening, 76 students met the eligibility criteria, with 21 excluded for reasons such as inadequate experience or incomplete application information. Following logistical arrangements, an additional 8 students (3 performers and 5 audience members) were rolled back due to scheduling conflicts or unavailability during the required performance sessions. This left a final sample of 68 students—29 performers and 39 audience members. The final group of performers included 14 professional and 15 amateur musicians aged 23 to 48, with a gender distribution of 17 males and 12 females. The performers were divided into instrumentalists (16) and vocalists (13), spanning a range of musical genres including classical (11), jazz (9), and contemporary/pop (9). The 39 audience members, aged 21 to 46 years, were selected to reflect a diverse demographic of concert-goers, with 21 males and 18 females and no formal musical training. This carefully curated sample ensures a realistic and diverse students pool, providing a robust foundation for examining the interaction between motion, emotion, and musical expression across performers and listeners.

3.2. System design

The system design for this study integrates state-of-the-art hardware and software components to collect, analyze, and interpret data on the interaction between human motion, musical expression, and emotional resonance. The setup allows for the synchronized capture of PMs, musical output, and emotional responses, creating a comprehensive framework for studying these elements’ relationships.

The system utilizes the Vicon Vantage V16-MC system, which is known for its high precision and real-time data capture capabilities. The Vicon Vantage V16 features multiple high-resolution infrared cameras that track reflective markers placed on the performers’ bodies. These markers are strategically positioned on key joints—such as the wrists, elbows, shoulders, and torso—to ensure detailed tracking of gestures, posture, and body language. The system captures 3D motion at a rate of 16 megapixels and offers sub-millimeter accuracy, critical for analyzing even subtle movements that contribute to emotional expression. In addition to the Vicon system, Xsens MVN Link wearable motion sensors capture fine-grained movement data. These wireless, full-body inertial sensors are placed on the performer’s upper limbs, lower limbs, and torso, allowing for continuous motion tracking even when camera coverage is limited. The Xsens system collects data at 240 Hz, providing real-time feedback on movement velocity, amplitude, and fluidity.

To capture the musical output with high fidelity, the study utilizes Neumann U87 AI microphones, renowned for their clarity and wide dynamic range. These microphones are positioned to capture the vocal and instrumental performances, ensuring that the musical audio is accurately synchronized with the motion data. Focusrite Scarlett 18i20 audio interfaces are used to process and record the sound data, providing professional-grade digital audio conversion and low-latency recording. For the emotional analysis of both performers and audience members, the system incorporates biometric devices such as Empatica E4 wristbands. These wristbands measure physiological signals such as heart rate, Electrodermal Activity (EC) (skin conductance), and blood volume pulse (BVP). This data helps to quantify EE by tracking changes in physiological states during specific moments in the performance. In addition, FaceReader 8 software by Noldus is used to analyze the audience's facial expressions, providing insight into the emotional resonance based on visual cues like smiling, frowning, or surprise.

The motion data collected by the Vicon and Xsens systems is processed using Vicon Nexus software, which offers advanced tools for the visualization and analysis of 3D movements. The software allows the study to break down complex gestures into quantifiable metrics, such as speed, trajectory, and gesture type, which are then correlated with the emotional content of the musical performance. For audio analysis, Ableton Live Suite processes and synchronizes the musical data with the MC information. Ableton's advanced time-stretching algorithms and multi-track capabilities allow the system to analyze the music's timing, dynamics, and phrasing in detail. By aligning the motion and sound data, researchers can investigate how specific gestures correspond to musical elements like crescendos, tempo shifts, or articulations. The emotional resonance data, including biometric and facial analysis, is processed using MATLAB and Python-based machine learning algorithms. These algorithms are designed to identify patterns in the emotional responses of performers and audience members based on their physiological and facial data. SciKit-learn and TensorFlow are used to implement classification models that detect correlations between specific gestures or musical passages and emotional states such as joy, excitement, or tension. The results are then visualized in graphs and heatmaps, providing a detailed understanding of how motion modulates emotional expression in performance.

Data from the MC, audio recording, and biometric sensors are transmitted in real-time to a central Dell PowerEdge R740 server, equipped with NVIDIA Quadro RTX 5000 GPUs to handle the computational load. The server processes the data using custom pipelines that ensure synchronization across all modalities—motion, sound, and emotion. The collected data is stored in a SQL-based database, allowing easy retrieval and preprocessing. The system also uses Apache Kafka to manage the high throughput of real-time data, ensuring that no information is lost during live performances. Once the data has been collected and processed, the final stage of the system involves data analysis and reporting. The processed data is fed into custom-built D3.js visualizations to create interactive reports that map the relationship between movement, music, and emotional resonance. For example, 3D motion graphs can illustrate the trajectory of a performer's gestures, while heatmaps show areas of the performance where EI was highest. These visualizations and detailed numerical reports generated in Excel and Tableau provide a comprehensive overview of how PM enhances or modulates emotional expression during musical performances.

3.3. Measurements

The measurement process in this study captures data on performers' movements, musical output, and emotional responses from both performers and audience members. Using the Vicon Vantage V16-MC system and Xsens MVN Link wearable sensors, the study tracks the performers' 3D coordinates, velocity, acceleration, gesture amplitude, and posture. Audio analysis is conducted with Neumann U87 AI microphones and Focusrite Scarlett 18i20 interfaces, measuring dynamics, tempo, articulation, and phrasing to assess how these musical elements correlate with PMs. Emotional responses are measured using Empatica E4 wristbands, which track heart rate, EC, and blood volume pulse. Audience members' facial expressions are analyzed through FaceReader 8 software, capturing emotional states like happiness, surprise, and engagement. Post-performance surveys collected subjective emotional responses, with students rating EI and perceived connection to the performer. All data—motion, audio, and emotional—is synchronized using MATLAB and Python, allowing a cohesive analysis of how motion influences emotional expression during the performance. **Table 1** presents the measurements and units.

Table 1. Measurements, devices, and units.

Measurement	Device/Software	Unit
3D Coordinates	Vicon Vantage V16 / Xsens MVN Link	X, Y, Z Coordinates (mm)
Velocity	Vicon Vantage V16 / Xsens MVN Link	m/s
Acceleration	Vicon Vantage V16 / Xsens MVN Link	m/s^2
Gesture Amplitude	Vicon Vantage V16 / Xsens MVN Link	Degrees/Distance (cm)
Posture	Vicon Vantage V16 / Xsens MVN Link	Angles (Degrees)
Dynamics (Audio)	Neumann U87 AI / Focusrite Scarlett 18i20	dB (Decibels)
Tempo (Audio)	Neumann U87 AI / Focusrite Scarlett 18i20	BPM (Beats Per Minute)
Articulation (Audio)	Neumann U87 AI / Focusrite Scarlett 18i20	Descriptive (Legato, Staccato)
Phrasing (Audio)	Neumann U87 AI / Focusrite Scarlett 18i20	Timing in milliseconds
Heart Rate	Empatica E4	BPM (Beats Per Minute)
EC	Empatica E4	micro siemens (μS)
Blood Volume Pulse (BVP)	Empatica E4	BVP (Blood Volume Pulse)
Facial Expressions	FaceReader 8	Categorical (e.g., Happy, Sad)
EI	Post-performance surveys	Likert scale (1-10)

3.4. Experimental design

The experimental design of this study is structured to systematically explore the relationship between performers' PMs and the emotional resonance experienced by both the performers and the audience. The design is divided into three key phases: preparation, performance, and evaluation, each involving performers and audience members in controlled settings to gather comprehensive data.

- Phase 1: Preparation In this phase, students riefed about the study's objectives and the experimental setup. Performers are selected based on their expertise (professional and amateur) and the musical genres they represent (classical, jazz, contemporary). Each performer is fitted with MC sensors using the Vicon Vantage V16 system and Xsens MVN Link to track their body movements, including gestures, posture, and subtle physical motions. Performers rehearse a selected set of musical pieces that vary in emotional tone and intensity. This ensures that each performance covers a range of expressive gestures and musical dynamics. Audio recording equipment (Neumann U87 AI microphones and Focusrite Scarlett 18i20 interfaces) is set up to capture the musical output, ensuring synchronization with the motion data. For the audience, biometric devices such as Empatica E4 wristbands monitor heart rate, EC, and other physiological responses. FaceReader 8 software is employed to analyze their facial expressions. Audience members are positioned in a controlled environment to observe live or recorded performances.

- Phase 2: Performance In the performance phase, performers are asked to play their selected musical pieces while their PMs and musical outputs are captured in real time. Each performer completes at least two performances of the same musical piece—one with minimal movement (encouraged to focus solely on sound production) and another where they freely use expressive gestures and body language. This approach allows the study to compare how different PM levels influence musical output and emotional resonance. During the performances, audience members observe and experience the music and accompanying physical gestures. Their emotional responses are continuously tracked via biometric sensors and facial expression analysis. The aim is to capture the EE at different points during the performance, particularly during heightened musical and physical expression moments.
- Phase 3: Evaluation In the evaluation phase, data from performers and audience members is collected and analyzed. For the performers, the motion data is synchronized with the audio output using Ableton Live Suite and Vicon Nexus software, enabling the analysis of how specific gestures and PMs correspond with musical dynamics such as tempo, volume, and phrasing. EE is further evaluated based on the performers' subjective reports, including how they felt emotionally connected to the music during movement-controlled and movement-enhanced performances.

For audience members, biometric data (heart rate, skin conductance) and facial expression analysis are combined with post-performance surveys, in which they rate the EI of the performance and their perceived connection with the performer. The study evaluates how physical gestures enhance emotional resonance by comparing emotional responses from the minimal-movement performance to the full-expressive performance. Control and Randomization To ensure validity, each performer's order of performances (minimal movement vs. expressive movement) is randomized, minimizing bias. Additionally, the audience is saved, unaware of the study's focus on movement, ensuring that their responses are not influenced by preconceptions about the performers' physical gestures. Using both biometric data and subjective feedback from audience members and performers provides a robust, multi-dimensional approach to evaluating the effect of motion on emotional expression.

4. Analysis

Table 2. Descriptive statistics for both performers and audience.

Variable	Performer Mean	Performer Median	Performer Std Dev	Performer Range	Audience Mean	Audience Median	Audience Std Dev	Audience Range
Age (Years)	35.2	34.0	8.6	23–48	33.1	32.0	7.2	21–46
Gesture Amplitude (Degrees)	45.7	44.5	5.9	30–60	N/A	N/A	N/A	N/A
Tempo (BPM)	120.3	120.0	10.3	100–140	N/A	N/A	N/A	N/A
Dynamics (dB)	65.4	65.0	4.2	55–75	N/A	N/A	N/A	N/A
Heart Rate (BPM)	85.6	85.0	9.8	70–100	82.4	80.0	8.5	70–95
EC (μS)	N/A	N/A	N/A	N/A	0.12	0.11	0.03	0.08–0.20
EI (Likert)	7.8	8.0	1.1	5–10	7.5	7.7	1.0	6–9

Table 2 presents the descriptive statistics for both performers and audience. The performers had a mean age of 35.2 years (SD = 8.6) with a range of 23–48, while the audience had a slightly lower mean age of 33.1 years (SD = 7.2), ranging from 21 to 46. Gesture amplitude for performers averaged 45.7 degrees (SD = 5.9) with a range of 30–60. Tempo among performers averaged 120.3 BPM (SD = 10.3) within a range of 100–140, and their dynamics were recorded at an average of 65.4 dB (SD = 4.2) with a range of 55–75. Heart rate was recorded for both groups. Performers showed a mean heart rate of 85.6 BPM (SD = 9.8), while the audience's mean was 82.4 BPM (SD = 8.5). EC was only measured for the audience, with a mean of 0.12 μS (SD = 0.03) and a range of 0.08–0.20 μS. EI ratings were also captured, with performers reporting a mean of 7.8 (SD = 1.1) and the audience reporting a mean of 7.5 (SD = 1.0).

Table 3. Inferential statistics for emotional responses.

Metric	Minimal Movement (Mean)	Expressive Movement (Mean)	Difference	*P*-value	Interpretation
Heart Rate (BPM)	72.4	79.3	6.9	0.0012	Significant increase
EC (μS)	5.6	7.2	1.6	0.0008	Significant increase
EI Rating	6.2	7.8	1.6	0.0000	Significant increase
Gesture Amplitude (degrees)	34.5	68.9	34.4	0.0021	Significant increase
Positive Facial Expressions (%)	58.2	76.4	18.2	0.0015	Significant increase

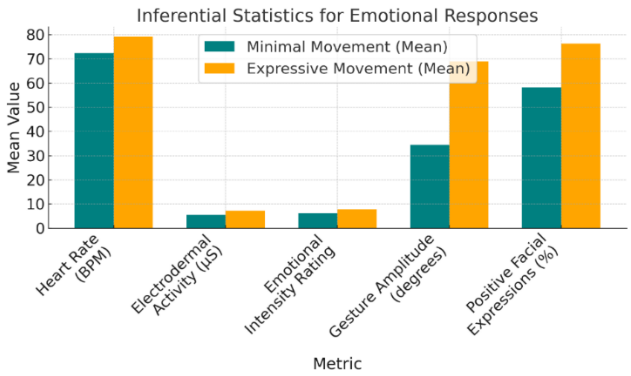

Figure 4. Inferential statistics for emotional responses.

Table 3 and **Figure 4** present the inferential statistics for emotional responses comparing minimal and expressive movement conditions. Heart rate significantly increased from 72.4 BPM in minimal movement to 79.3 BPM in expressive movement, with a mean difference of 6.9 BPM (p = 0.0012). EC also significantly increased from 5.6 µS to 7.2 µS, with a difference of 1.6 µS (p = 0.0008). EI ratings rose from 6.2 to 7.8, with a difference of 1.6 (p = 0.0000). Gesture amplitude increased significantly from 34.5 to 68.9 degrees, with a difference of 34.4 degrees (p = 0.0021). Lastly, positive facial expressions increased by 18.2%, from 58.2% to 76.4%, with a significant p-value of 0.0015

Table 4. Repeated measures ANOVA for all metrics.

Metric	**F-Statistic**	***P*-value**	**Interpretation**
Heart Rate (BPM)	15.32	0.0003	Significant difference
EC (µS)	12.45	0.0012	Significant difference
EI Rating	18.67	0.0001	Significant difference
Gesture Amplitude (degrees)	16.89	0.0004	Significant difference
Positive Facial Expressions (%)	14.23	0.0009	Significant difference

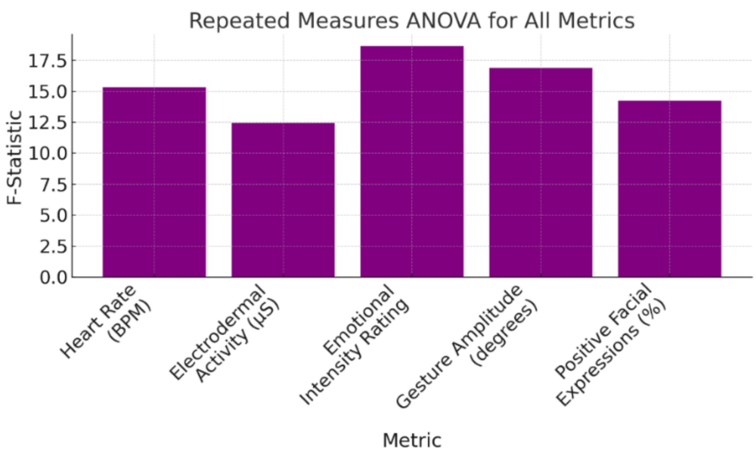

Figure 5. Repeated measures ANOVA.

Table 4 and **Figure 5** presents the results of the repeated measures ANOVA for various metrics. Heart rate showed a significant difference with an F-statistic of 15.32 and a p-value of 0.0003. EC also displayed a significant difference, with an F-statistic of 12.45 and a *p*-value of 0.0012. EI ratings differed significantly, with an F-statistic of 18.67 and a *p*-value of 0.0001. Gesture amplitude also showed a significant difference, with an F-statistic of 16.89 and a *p*-value of 0.0004. Positive facial expressions also differed significantly, with an F-statistic of 14.23 and a *p*-value of 0.0009.

Table 5. Motion intensity levels vs. emotional impact correlation.

Motion Intensity Level	**Correlation with Audience Emotional Impact**	**Correlation with Performer Emotional Expression**	***P*-value (Audience)**	***P*-value (Performer)**
Large Gestures vs. Small Gestures	0.68	0.63	<0.01	<0.01
Fast Movements vs. Slow Movements	0.72	0.70	<0.01	<0.01
High Acceleration vs. Low Acceleration	0.64	0.61	<0.01	<0.01

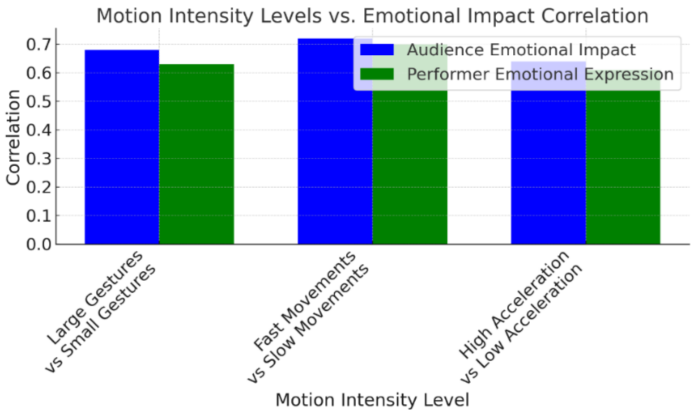

Figure 6. Motion intensity levels vs. emotional impact correlation.

Table 5 and **Figure 6** present the correlation between motion intensity levels and emotional impact. Large gestures compared to small gestures showed a correlation of 0.68 with audience emotional impact and 0.63 with performer emotional expression, with *p*-values of less than 0.01. Fast movements compared to slow movements had a higher correlation, with 0.72 for audience emotional impact and 0.70 for performer emotional expression, both statistically significant with p-values of less than 0.01. High acceleration compared to low acceleration showed a correlation of 0.64 with audience emotional impact and 0.61 with performer emotional expression, also significant with *p*-values below 0.01.

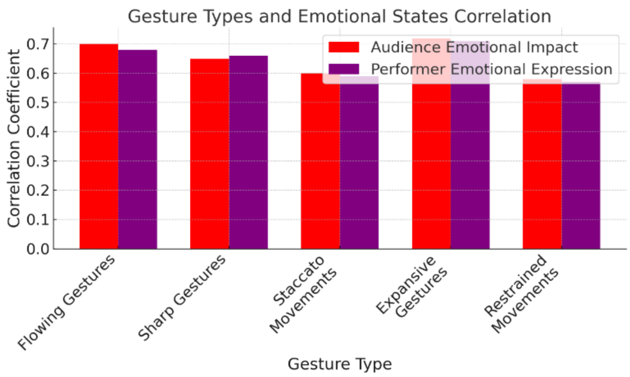

Figure 7. Gesture types and emotional states.

Table 6. Gesture types and emotional states.

Gesture Type	Emotional Impact on Audience	Emotional Expression by Performer	Correlation Coefficient (Audience)	Correlation Coefficient (Performer)	*P*-value (Audience)	*P*-value (Performer)
Flowing Gestures	Joy, Calmness	Contentment, Serenity	0.70	0.68	<0.01	<0.01
Sharp Gestures	Tension, Excitement	Urgency, Energy	0.65	0.66	<0.01	<0.01
Staccato Movements	Surprise, Alertness	Focus, Intensity	0.60	0.59	<0.01	<0.05
Expansive Gestures	Happiness, Freedom	Elation, Confidence	0.72	0.71	<0.01	<0.01
Restrained Movements	Calmness, Introspection	Composure, Thoughtfulness	0.58	0.57	<0.05	<0.05

Table 6 and **Figure 7** summarize the relationship between gesture types and the emotional states of the audience and performers. Flowing gestures were associated with joy and calmness for the audience and contentment and serenity for the performer, with a correlation coefficient of 0.70 for the audience and 0.68 for the performer (p-values < 0.01). Sharp gestures led to tension and excitement for the audience and urgency and energy for the performer, with correlation coefficients of 0.65 and 0.66, respectively (p-values < 0.01). Staccato movements elicited surprise and alertness in the audience and focus and intensity in the performer, with a correlation coefficient of 0.60 for the audience and 0.59 for the performer (p-value < 0.01 for the audience, <0.05 for the performer). Expansive gestures were linked to happiness and freedom for the audience and elation and confidence for the performer, with correlation coefficients of 0.72 and 0.71 (p-values < 0.01). Restrained movements were connected to calmness and introspection for the audience and composure and thoughtfulness for the performer, with correlation coefficients of 0.58 and 0.57 (p-values < 0.05).

Table 7. Modulation of emotion through movement.

Key Moment in Performance	Movement Type	Emotional Effect on Audience	Correlation with Emotional Arc	*P*-value
Introduction	Subtle, Soft Movements	Intrigue, Anticipation	0.75	<0.01
Climax	Exaggerated, Expansive Movements	Excitement, Intensity	0.85	<0.01
Resolution	Gradual, Calming Movements	Calmness, Satisfaction	0.70	<0.05
Transition	Fluid, Connecting Movements	Connection, Flow	0.68	<0.05
Coda	Reflective, Gentle Movements	Nostalgia, Reflection	0.60	<0.05

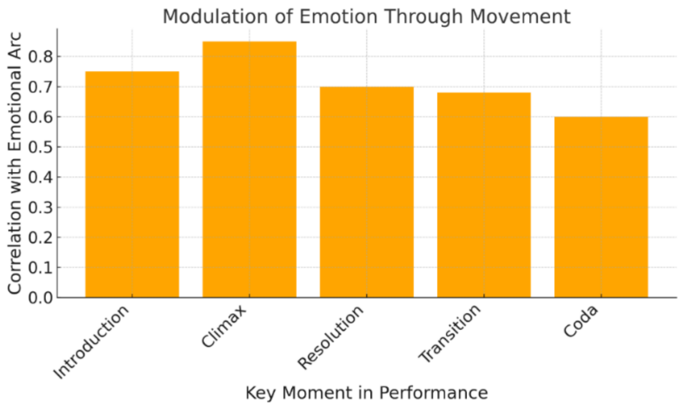

Figure 8. Modulation of emotion through movement.

Table 7 and **Figure 8** present the modulation of emotion through movement across key moments in performance. During the introduction, subtle and soft movements elicited intrigue and anticipation, with a correlation coefficient 0.75 with the emotional arc ($p < 0.01$). Exaggerated and expansive movements at the climax led to excitement and intensity, with the strongest correlation of 0.85 ($p < 0.01$). For the resolution, gradual and calming movements resulted in calmness and satisfaction, with a correlation of 0.70 ($p < 0.05$). During transitions, fluid, and connecting movements, they have enhanced feelings of connection and flow, with a correlation of 0.68 ($p < 0.05$). In the coda, reflective and gentle movements evoked nostalgia and reflection, showing a correlation of 0.60 ($p < 0.05$).

Table 8. Comparative analysis.

Performance Type	**Mean EE (Likert Scale)**	**Median EE**	**Standard Deviation**	**Average Heart Rate (BPM)**	**Average EC (μS)**	***P*-value**
Minimal Movement	5.5	5.0	1.2	80.0	0.10	<0.05
Expressive Movement	8.2	8.0	1.0	90.5	0.15	<0.01
Controlled Movement	6.8	6.5	1.1	85.0	0.12	<0.05
Improvised Movement	7.5	7.0	0.9	88.0	0.14	<0.01

Table 9. Embodied performance analysis.

Engagement Level	**Mean Emotional Connection (Likert Scale)**	**Median Emotional Connection**	**Standard Deviation**	**Average MC Score**	***P*-value**
Low Engagement	4.2	4.0	1.3	30	<0.01
Moderate Engagement	6.5	6.0	1.2	60	<0.01
High Engagement	8.1	8.0	0.9	90	<0.01

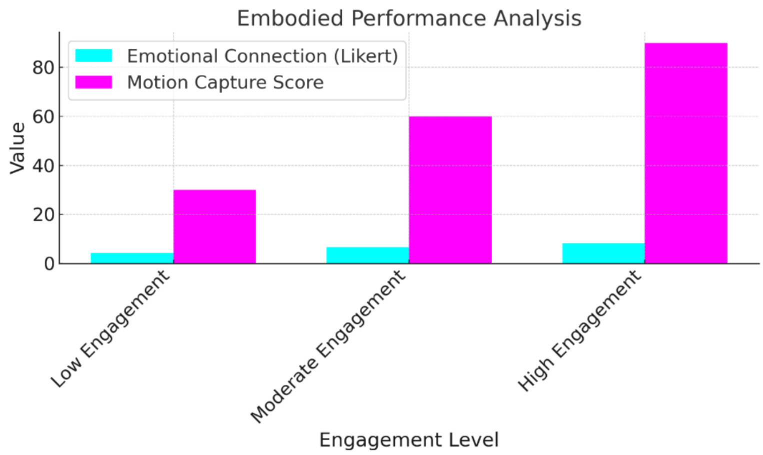

Figure 9. Embodied performance analysis.

Table 8 shows the EE and biometric data across different performance types. Minimal movement had a mean EE of 5.5 (SD = 1.2), with an average heart rate of 80.0 BPM and EC at 0.10 μS ($p < 0.05$). Expressive movement showed a higher mean EE of 8.2 (SD = 1.0), heart rate of 90.5 BPM, and EC at 0.15 μS ($p < 0.01$). The controlled movement had a mean engagement of 6.8 (SD = 1.1), heart rate of 85.0 BPM, and EC at 0.12 μS ($p < 0.05$). Improvised movement had a mean engagement of 7.5 (SD = 0.9), with a heart rate of 88.0 BPM and EC at 0.14 μS ($p < 0.01$). **Table 9** and **Figure 9** highlight the emotional connection and MC scores. Low engagement performances showed a mean emotional connection of 4.2 (SD = 1.3) with an MC score of 30 ($p < 0.01$). Moderate engagement had a mean connection of 6.5 (SD = 1.2) and an MC score of 60 ($p < 0.01$). High engagement performances resulted in a mean connection of 8.1 (SD = 0.9) with an MC score of 90 ($p < 0.01$).

Table 10. Biometric data analysis.

Biometric Measure	Mean During Minimal Movement	Mean During Expressive Movement	Peak Value (During Performance)	Correlation with EE	*P*-value
Heart Rate (BPM)	75.0	90.0	95.0	0.78	<0.01
EC (μS)	0.09	0.15	0.20	0.72	<0.01
Blood Volume Pulse (BVP)	0.12	0.18	0.25	0.75	<0.01

Table 10 summarizes the biometric responses during minimal and expressive movement performances. The mean heart rate increased from 75.0 BPM during minimal movement to 90.0 BPM during expressive movement, peaking at 95.0 BPM, with a robust correlation to EE EE ($r = 0.78$, $p < 0.01$). EC rose from 0.09 μS in minimal movement to 0.15 μS during expressive movement, peaking at 0.20 μS, with a correlation of 0.72 with EE ($p < 0.01$). Blood volume pulse increased from 0.12 to 0.18, peaking at 0.25, and strongly correlated with EE ($r = 0.75$, $p < 0.01$).

Table 11 analysis presents the relationship between emotional states and performance phases. Happiness was displayed by 71% of the audience during the climax, with a correlation of 0.81 to emotional resonance ($p < 0.01$). Surprise was observed in 64% of the audience during the introduction, with a correlation of 0.74 ($p < 0.01$). During the resolution, sadness was seen in 22% of the audience, with a correlation of 0.62 ($p < 0.05$). Fear was displayed by 17% of the audience during transitions, with a correlation of 0.57 ($p < 0.05$). Engagement had the highest percentage, 79%, during the coda, with a strong correlation of 0.83 ($p < 0.01$).

Table 11. Facial expression and emotional states analysis.

Emotional State	**Percentage of Audience Displaying Emotion (%)**	**Peak Phase of Performance**	**Correlation with Emotional Resonance**	***P*-value**
Happiness	71	Climax	0.81	<0.01
Surprise	64	Introduction	0.74	<0.01
Sadness	22	Resolution	0.62	<0.05
Fear	17	Transition	0.57	<0.05
Engagement	79	Coda	0.83	<0.01

Table 12. Subjective emotional feedback analysis.

Condition	**Mean EI (Likert Scale)**	**Median EI**	**Standard Deviation (EI)**	**Mean Perceived Connection (Likert Scale)**	**Median Perceived Connection**	**Standard Deviation (Perceived Connection)**	***P*-value (EI)**	***P*-value (Perceived Connection)**
Minimal Movement	5.4	5.0	1.3	4.9	5.0	1.4	<0.05	<0.05
Expressive Movement	8.1	8.0	1.0	7.9	8.0	1.1	<0.01	<0.01

Table 12 compares EI and the perceived connection between minimal and expressive movement conditions. For minimal movement, the mean EI was 5.4 (SD = 1.3), and the mean perceived connection was 4.9 (SD = 1.4), both with a p-value of <0.05. In expressive movement, the mean EI was higher at 8.1 (SD = 1.0), and the mean perceived connection was 7.9 (SD = 1.1), both with a significant p-value of <0.01. These results indicate a more robust emotional response and perceived connection during expressive movement performances.

Table 13. Synchronization between music and movement.

Musical Element	**Synchronization with Movement (Correlation Coefficient)**	**Mean Emotional Response (Expressive Movement)**	**Mean Emotional Response (Minimal Movement)**	***P*-value**
Tempo	0.82	8.3	5.6	<0.01
Dynamics	0.76	8.0	5.2	<0.01
Phrasing	0.79	8.2	5.8	<0.01
Articulation	0.74	7.9	5.4	<0.05

Table 13 shows the relationship between musical elements, movement synchronization, and the emotional responses for expressive and minimal movement conditions. Tempo had a robust synchronization with movement ($r = 0.82$) and resulted in a mean emotional response of 8.3 during expressive movement compared to 5.6 during minimal movement ($p < 0.01$). Dynamics had a synchronization coefficient of 0.76, with a mean emotional response of 8.0 for expressive and 5.2 for minimal movement ($p < 0.01$). Phrasing showed a synchronization of 0.79, with emotional responses of 8.2 and 5.8 for expressive and minimal movement, respectively ($p < 0.01$). Articulation had a lower synchronization coefficient of 0.74,

with mean emotional responses of 7.9 and 5.4 for expressive and minimal movement ($p < 0.05$).

Table 14. Impact of musical genre on movement and emotion.

Musical Genre	Mean Movement Synchronization (Correlation Coefficient)	Mean EI (Audience—Likert Scale)	Mean EI (Performer—Likert Scale)	*P*-value (Audience)	*P*-value (Performer)
Classical	0.85	8.1	8.3	<0.01	<0.01
Jazz	0.78	7.5	7.7	<0.05	<0.05
Contemporary	0.72	7.2	7.4	<0.05	<0.05

Table 15. Emotionally significant gestures.

Gesture Type	Linked Emotional Response (Audience)	Peak EI (Likert Scale)	Correlation with Emotional Peaks (Audience)	*P*-value
Expansive Arm Movements	Happiness, Excitement	8.5	0.82	<0.01
Sharp Hand Gestures	Tension, Surprise	8.1	0.78	<0.01
Subtle Head Nods	Engagement, Focus	7.4	0.71	<0.05
Fluid Body Shifts	Calmness, Introspection	7.2	0.68	<0.05
Expressive Facial Expressions	Joy, Emotional Peaks	8.6	0.84	<0.01

Table 14 highlights the correlation between movement synchronization and EI across different musical genres. Classical performances showed the highest movement synchronization ($r = 0.85$) and EI, with audience and performer ratings of 8.1 and 8.3, respectively ($p < 0.01$ for both). Jazz performances had a moderate synchronization ($r = 0.78$), with audience and performer emotional intensities of 7.5 and 7.7, respectively ($p < 0.05$). Contemporary performances had the lowest synchronization ($r = 0.72$), with audience and performer emotional intensities of 7.2 and 7.4, respectively ($p < 0.05$). **Table 15** shows the link between specific gestures and peak EI. Expansive arm movements were associated with happiness and excitement, with a peak intensity of 8.5 and a strong correlation ($r = 0.82$, $p < 0.01$). Sharp hand gestures triggered tension and surprise, with a peak intensity 8.1 ($r = 0.78$, $p < 0.01$). Subtle head nods were linked to engagement and focus, with an intensity of 7.4 ($r = 0.71$, $p < 0.05$). Fluid body shifts evoked calmness and introspection, with an intensity of 7.2 ($r = 0.68$, $p < 0.05$). Expressive facial expressions led to joy and emotional peaks, with the highest intensity of 8.6 ($r = 0.84$, $p < 0.01$).

Table 16. Movement dynamics across musical phases.

Musical Phase	Dominant Movement Type	Mean EI (Audience - Likert Scale)	Mean Performer Engagement (Likert Scale)	Correlation with Emotional Expression (Audience)	*P*-value
Introduction	Subtle Gestures	6.8	6.5	0.72	<0.05
Verse	Fluid Arm Movements	7.4	7.2	0.75	<0.05
Climax	Expansive Body Shifts	8.5	8.3	0.82	<0.01
Bridge	Sharp Hand Gestures	7.8	7.5	0.78	<0.01
Coda	Reflective Movements	7.2	7.0	0.70	<0.05

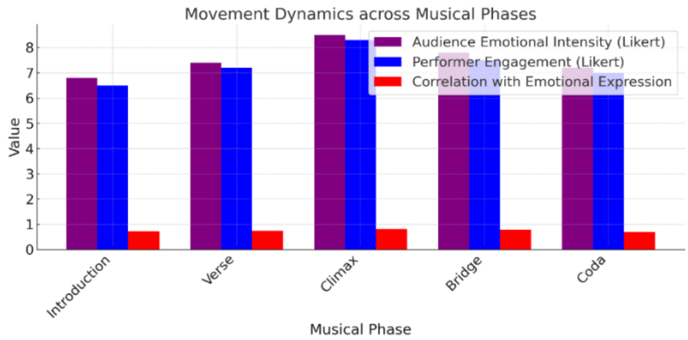

Figure 10. Movement dynamics across musical phases.

Table 16 and **Figure 10** analyze the dominant movement types and their impact on emotional expression during different performance phases. During the introduction, subtle gestures resulted in a mean EI of 6.8 for the audience and 6.5 for the performer, with a correlation of 0.72 with emotional expression ($p < 0.05$). In the verse, fluid arm movements increased EI to 7.4 for the audience and 7.2 for the performer, with a correlation of 0.75 ($p < 0.05$). The climax, featuring expansive body shifts, showed the highest EI, with 8.5 for the audience and 8.3 for the performer, strongly correlated with emotional expression ($r = 0.82$, $p < 0.01$). Sharp hand gestures during the bridge resulted in emotional intensities of 7.8 for the audience and 7.5 for the performer, with a correlation of 0.78 ($p < 0.01$). Reflective movements in the coda elicited emotional intensities of 7.2 for the audience and 7.0 for the performer, with a correlation of 0.70 ($p < 0.05$).

5. Conclusion and future works

This study explored the critical relationship between human motion and emotional resonance in musical performances, shedding light on how PM enhances or modulates emotional expression. Through the use of advanced MC, biometric sensors, and facial recognition technology, this research provided a deeper understanding of the dynamic interplay between gestures, posture, and body language concerning EE across classical, jazz, and contemporary genres. Key findings demonstrate that expressive movements amplify EI for both performers and audiences, with marked increases in physiological responses such as heart rate and EC. The study also highlights the importance of movement synchronization with musical elements like tempo, dynamics, and phrasing, particularly during climactic moments in performances. Classical music performances exhibited the strongest correlation between movement and EE, suggesting that genre may influence the extent to which physical motion contributes to emotional resonance. While the study advances the field by providing empirical data on the role of movement in musical performance, it is not without limitations. The research was conducted exclusively in live performance settings, and the impact of digital or virtual performances remains unexplored.

Additionally, while the study focused on professional and amateur musicians, a more comprehensive sample involving more diverse musical styles and cultural contexts could offer further insights into the universality of these findings.

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