KinoGroove: Composing with Muscle and Motion in Extended Reality

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Figure 1: A dancer during a recording session wearing electromyography (EMG) sensors and motion-capture markers. Below: the reconstructed skeleton used to replay her movements in virtual reality. The rightmost image shows the same avatar with EMG interaction boxes corresponding to the physical sensor placement.

Abstract

Extended reality and motion capture technologies have been explored as tools for embodied artistic performance, allowing dancers and musicians to interact with sound within immersive environments. However, motion capture systems primarily track gross motor gestures and solid body segments, which restricts their ability to represent dance styles that rely on muscular activation and subtle movement rather than large gestures. Electromyography (EMG), by contrast, captures muscular activity and can reflect finer body movements and soft tissue deformation that may not produce large-scale motion, yet are widely used in dance to convey expressive sensibility. In this work, we present KinoGroove, an extended reality interface that integrates EMG with motion capture to support expressive mapping of dance to sound. KinoGroove was developed through discussions with dancers and artists, involving close collaboration for testing, feedback, and data acquisition. Our system allows musicians to generate and control musical structures through both visible motion and internal effort, covering a wider range of dance expression. We introduce the KinoGroove design space, which formalizes how EMG signals can function as primary or complementary control parameters for musical output. Through two usage scenarios, one focusing on large-amplitude movements and the other on low-amplitude muscular activation, we illustrate how the system enables artists to shape sound through both spatial displacement and muscular intensity. We finally describe methods for synchronized acquisition, processing, and visualization of motion and EMG data.

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Keywords

Extended Reality(XR), Virtual Reality (VR), Multimodal Interaction, Creative Collaboration, Asynchronous Interaction, Spatial Sound Composition, Motion Capture, Electromyography (EMG)

1 Introduction

The rise of immersive technologies has opened new creative frontiers for artists working at the intersection of sound, movement, and digital media [11]. Extended Reality environments, in particular, provide embodied modes of interaction and spatial composition that challenge traditional models of performance and artistic collaboration.

While many XR-based systems focus on real-time gesture tracking or immersive sound interaction, few support the full expressive range of dance, particularly styles that rely on subtle movement or muscular activation rather than large, spatially visible gestures. Conventional motion capture systems capture external motion with high spatial accuracy, but they often fail to represent internal effort, tension, and micro-movements, leaving important expressive dimensions of performance inaccessible to interactive systems.

These challenges are particularly relevant in hip-hop communities, where dance and music have historically been developed through collective practices such as cyphers and battles. In these contexts, expressiveness relies not only on large expressive movement but also on subtle effort, groove, and shared embodied knowledge, highlighting the need for interaction systems that can engage with subtle muscular activation while supporting community-oriented musical practices. This limitation becomes especially apparent in dance styles such as popping [1], which emphasize controlled contractions, isolations, and internal tension with minimal spatial displacement, forms of expressivity that cannot be fully captured by traditional kinematic sensing. Electromyography (EMG), which measures muscle activity through electrical signals, offers a complementary source of data [6], enabling direct access to internal states such as contraction intensity, effort, and tension. By integrating EMG with motion capture in an XR environment, it becomes possible to transform subtle muscular activity into meaningful musical control, expanding the expressive potential of interactive performance systems [10].

This paper presents KinoGroove a system that combines prerecorded motion capture data with EMG recordings, enabling asynchronous collaboration between dance and music within an extended reality environment. Artists can map both spatial and muscular features to musical outputs, supporting interaction scenarios in which movement and sound are composed, transformed, and reinterpreted across time and space.

From a musical perspective, this work explores the relationship between movement and sound through complementary mapping strategies. Spatial motion is used to structure musical events and temporal organization, while EMG signals can provide continuous control over timbre, dynamics, and texture. This approach enables a compositional framework in which both gesture and muscle effort define musical form and shape expressive detail.

We also introduce the KinoGroove design space, which formalizes how EMG can function either as a primary control modality or as a complementary expressive layer alongside spatial motion. Through this framework, artists can configure XR-based interactions to accommodate diverse movement styles, from large-amplitude, explosive gestures to low-amplitude, high-effort micro-movements, shaping musical outputs based on both expressive motion and finer muscular effort.

To illustrate the creative potential of KinoGroove, we describe two representative usage scenarios. The first emphasizes expansive, high-intensity movements, where spatial features drive the musical structure while EMG adds expressive nuance. The second focuses on low-amplitude movements with high muscular effort, where EMG becomes the primary driver of musical output and spatial motion is secondary. Together, these scenarios highlight how the integration of EMG enables a richer, multimodal approach to embodied musical interaction, offering artists new ways to explore gesture-based and effort-driven composition in immersive virtual environments.

2 Related Work

To contextualize this approach, we now review related work on embodied musical interaction and creative systems in immersive environments.

2.1 Sound, Dance, and Creative Systems in Virtual Reality

Virtual and mixed reality environments have increasingly been explored as spaces for embodied creativity and artistic performance. Ppali *et al.* in Keep the VRhythm Going [16], investigate how virtual reality can support creative musical practice, highlighting its potential for immersive and embodied interaction. Similarly, Schlagowski *et al.* in Flow with the Beat! [19], examine how virtual environments influence creativity within individual VR-based creative experiences.

While some works focus primarily on single-user creative experiences, others explore the collaborative dimensions of artistic practice in immersive environments. Projects such as LeMo by Men and Bryan-Kinns [13], Wish You Were Here by Schlagowski *et al.* [18], and Musical Metaverse Playgrounds by Boem *et al.* [1] investigate how collaborative virtual environments impact creativity, social presence, and artistic collaboration. However, beyond their creative potential, collaborative VR systems face significant technical challenges, particularly related to latency and synchronization. To address these issues, such systems often restrict user roles or limit the complexity and frequency of interactions, which can constrain expressive possibilities.

Despite the prevalence of multidisciplinary artistic practices, relatively few systems attempt to tightly integrate multiple art forms such as dance and sound within immersive environments. One notable example, although not immersive, is CO/DA by Françoise *et al.* [7], a hybrid movement–sound system that demonstrates how dance improvisation can be coupled with sound generation and live coding practices. While such systems emphasize movement as a compositional input, they remain largely dependent on observable motion features derived from external movement tracking.

2.2 Motion Capture and Dance Interaction

To capture dancer's movements, motion capture technologies are widely used in interactive systems to enhance visual representation, sound generation, and audience engagement. Solberg and Jensenius[20], provide overviews of different motion tracking systems grounded in studies of dance group behaviors and performance contexts. Motion capture systems can generally be divided into two main categories: optical and inertial.

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[1] https://www.dailymotion.com/video/x2eg6y4

Optical systems offer high spatial precision but are limited by issues such as sensor occlusion and interference from reflective surfaces. In contrast, inertial systems are independent of lighting conditions and do not suffer from occlusion, allowing for longer recording sessions in more natural performance settings. However, inertial motion capture technologies are prone to positional drift and require frequent recalibration during extended recording sessions.

Khutorna *et al.* [11] review the role of motion capture in live dance performances, by using inertial motion tracking to project shadows that replicate the dancer's movement, enhancing the artistic performance. Libraries such as Modosc [5] try to formalize motion-based descriptors, providing real-time features derived from kinematic data to support movement–sound interaction.

2.3 From Kinematic Motion to Muscular Expression: Dance and EMG

However, these systems primarily rely on external motion and spatial displacement. Certain dance styles challenge motion-capture-based interaction by emphasizing internal muscular contractions, isolations, and tension, often with minimal spatial displacement. As a result, purely kinematic descriptors may fail to capture essential expressive elements, motivating alternative sensing approaches that access internal bodily activity. Electromyography (EMG), which measures muscle activation, provides a complementary source of data capable of revealing subtle dynamics that remain invisible to motion tracking.

Early work in interactive music explored the use of EMG and other biosignals as real-time musical input. In *MINI BIO MUSE*, Yoichi Nagashima [14] demonstrates that muscular activity can serve as an expressive parameter for sound interaction beyond gesture or spatial displacement. Building on this foundation, subsequent research has framed EMG as an expressive media that can shape perception and embodied experience [21], rather than merely acting as a simple signal controller. Donnarumma's Muscular Interactions project [6], shows that even minimal visible movement can produce rich, expressive interaction with sound. Together, these works situate EMG as a tool not only for capturing muscle activation but as a tool that can offer meaningful data to artists.

More recently, projects such as KONTRAKTION by Weber and Kuhn [22] have used muscle activation data to detect gestural events that are subsequently sonified, relying on consumer-grade EMG devices such as the Myo armband to provide auditory feedback linked to dancers' movements. Using the same sensing technology, Côté-Allard *et al.* [3] investigate the use of the Myo armband in interactive artistic robotics performances, highlighting the feasibility of real-time EMG sensing outside controlled laboratory environments. Similarly, Jaimovich's Emovere [8] explores the use of biosignals, including EMG, in dance contexts, treating physiological data as a source of affective and expressive interaction between the dancer and sound.

However, in many early implementations, EMG signals required substantial preprocessing and calibration to yield meaningful output, and were often sensitive to noise and variability. These limitations could lead to instability and reliability issues during live performance and real-time interaction.

Beyond artistic applications, EMG sonification has been extensively explored as a form of biofeedback in rehabilitation contexts. Matsubara *et al.* [12] and Corredera and Tanaka [2] show that EMG sonification can support understanding muscle activity and aid motor rehabilitation. More generally, interactive sonification research provides principles for mapping dynamic data streams to real-time auditory feedback [15]. Although these approaches primarily target training and clinical outcomes rather than artistic expression, they demonstrate that EMG-based sound feedback can be perceptually meaningful and capable of shaping embodied experience.

3 Motivations and Contributions

This work emerges from collaborations with a Hip-Hop choreographic collective exploring Extended Reality (XR) environments as spaces for co-creation between dancers and musicians. Within this context, prerecorded dance performances are used not only as visual material but as compositional resources, enabling musicians to shape sound through embodied interaction with a virtual performer. This asynchronous workflow positions dance as a temporal and spatial score, fostering new forms of dialogue between movement and music.

Through these discussions, a key limitation of existing motion-based systems became apparent, particularly when engaging with dance styles such as popping. Popping relies heavily on rapid muscular contractions, isolations, and sustained tension, often with minimal visible displacement. In such cases, expressive intent is rooted in internal muscular effort rather than large-scale motion.

Building upon our previous work on the asynchronous dance–music paradigm with the Spatial Performance Avatar Response Kit (S.P.A.R.K.) [17], we introduce KinoGroove, which responds to these limitations by integrating electromyography (EMG) as a complementary sensing modality to motion capture. Similar to S.P.A.R.K., KinoGroove is an XR-based system supporting asynchronous collaboration between dancers and musicians through the mapping of prerecorded motion capture data to sound synthesis. As shown in Figure 3, musicians, immersed using XR headsets, place interactive *Boxes* in the 3D space of the recorded performance. These boxes capture kinematic descriptors such as position, velocity, and joint trajectories, which can then be sent through OpenSoundControl (OSC) messages, in order to trigger musical events and modulate sound parameters. Interaction with the boxes happens with both precise and embodied control in XR. Users can adjust box parameters through sliders, buttons, or numerical input via a virtual keyboard. Boxes can also be directly grabbed and manipulated in space, leveraging the advantages of the XR medium to place and adjust them within the environment.

Unlike S.P.A.R.K., which treats movement solely as a spatial phenomenon, KinoGroove introduces muscular activation as an expressive parameter. This makes otherwise imperceptible dynamics tangible: micro-contractions of the forearm, sustained tension in the shoulders, or rapid pulses in the chest can be captured as continuous streams of muscular activity and used for musical control. As a result, even minimal or invisible contractions can produce substantial sonic effects, amplifying what would otherwise remain imperceptible to the audience due to motion capture limitations.

More fundamentally, KinoGroove establishes EMG signals as a new class of control modality, capable of serving as both primary and complementary input. It formalizes a design space for integrating spatial and physiological data and supports both event-based and continuous mappings. This enables a shift from gesture-triggered interaction to sustained, effort-driven sound shaping, redefining the body as a hybrid source of musical structure and expression.

This reorientation challenges conventional notions of "movement" in computational systems [9], expanding them to include subtle, internal, and affective dynamics.

Beyond its technical contribution, KinoGroove is conceived as a novel musical interface for practitioners working at the intersection of choreography, electronic music, and immersive media. The system is primarily aimed at electronic musicians and sound artists interested in designing embodied mapping strategies, as well as choreographers exploring motion capture and physiological sensing as compositional tools.

4 KinoGroove Design Space

To make this conceptual shift concrete, we introduce a design space that structures how EMG data can be meaningfully integrated. Rather than treating muscular signals as raw physiological measurements, this design space frames them as expressive and compositional resources that can be shaped, mapped, and interpreted in multiple ways. The following section presents the KinoGroove design space, which formalizes the roles that EMG can play within the system and guides the design of interaction primitives, mappings, and musical outputs.

4.1 Output Features

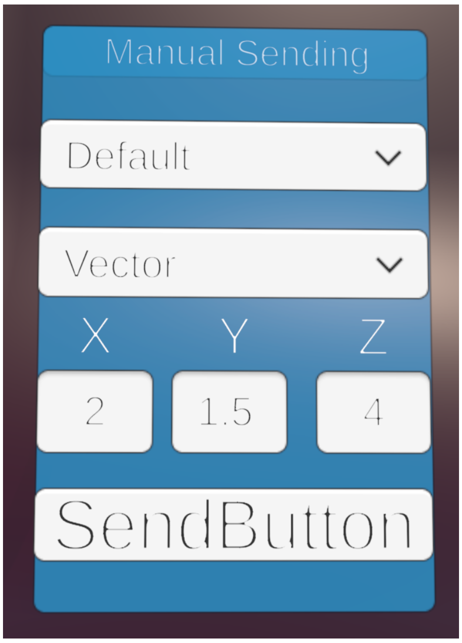
This dimension defines the type of data that a KinoGroove Box can generate or manipulate. These features correspond to the musical or control-relevant parameters that the box outputs, whether they are event-based or continuous. Supporting multiple output features allows KinoGroove boxes to address a wide range of musical interaction scenarios.

This dimension has the following possible values:

- **Spatial triggers**: Event-based outputs generated when a spatial condition is met, such as the avatar passing through a box.
- **Contraction triggers**: Event-based outputs generated when muscle contraction exceeds a given threshold defined by the user or by entering or moving within a box.
- **Spatial position**: Continuous spatial output based on the coordinates of the avatar entering or moving within a box. The user can select whether the output includes all spatial axes simultaneously or is restricted to a single axis.
- **Spatial speed**: Continuous or discrete output representing the speed of a specific avatar body part. The user can select whether the output includes all spatial axes simultaneously or is restricted to a single axis.
- **Spatial orientation**: Continuous output representing the rotation of a body part entering or moving within a box. The user can select whether the output includes all spatial axes simultaneously or is restricted to a single axis.
- **Contraction**: Continuous or discrete physiological output representing muscle contraction intensity.

4.2 Output Mode

This dimension describes how the output of a KinoGroove Box is generated and transmitted over time. It defines whether the output is produced continuously, triggered manually, or conditionally based on spatial or physiological constraints. This distinction is essential in the context of musical production, where different control strategies are required for rhythmic modulation, or threshold-based behaviours. An example output mode is shown in Figure 2.



Default

Vector

X: 2 Y: 1.5 Z: 4

Figure 2: Illustration of the user interface used for sending manual trigger events.

This dimension has the following possible values:

- **Manual trigger**: Output is generated through explicit user activation, allowing for dynamic and fine-grained control over activation and value resetting.
- **Continuous**: Output is streamed continuously.
- **Speed gate**: Output is triggered when a speed threshold is met.
- **Spatial gate**: Output is triggered when a spatial condition is met, mainly when the avatar moves or enters a box.
- **Contraction gate**: Output is triggered when a contraction threshold is met.

4.3 Anchoring Type

This dimension characterises how KinoGroove Boxes are spatially referenced within the environment. In a musical performance context, anchoring affects how stable or mobile a control element is, and how it relates to the performer's body or the surrounding space. An example of this anchoring is shown in Figure 3.

This dimension has the following possible values:

- **World-anchored**: The box is fixed in the environment.
- **Avatar-anchored**: The box is attached to the avatar and moves with it during the dance.
- **User-grabbed**: The box can be freely re-positioned by the user and follow user movement.

4.4 Temporality Control

This dimension describes how the output of a KinoGroove Box relates to time and playback. It distinguishes between live interaction, recorded playback, and looping behaviors, which are central to musical composition and performance.

This dimension has the following possible values:

Figure 3: Illustration of three box anchor types: a box linked to the user's controller, a world-anchored box located above the avatar's head, and a box anchored to the avatar's thighs that follows their leg movement.

- **Playback**: Output follows a recorded dance sequence (Figure 4).
- **Loop**: Output repeats periodically over a defined part of the recorded dance sequence (Figure 5).
- **Live**: Output is generated in real-time from user input through the user's direct interactions.

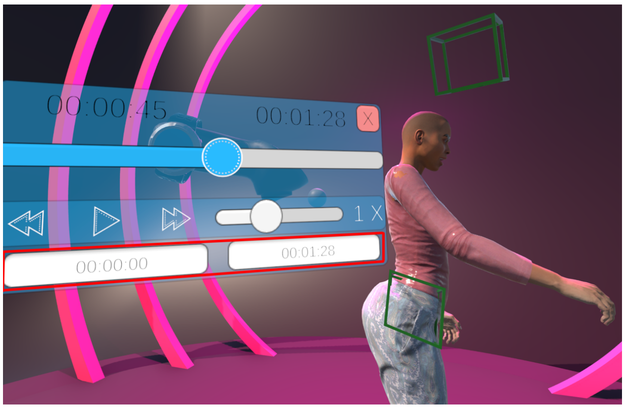


Figure 4: Timeline UI illustrating the playback mode of a recorded dance, indicated by the value displayed in the red box.

4.5 Visual Feedback

This dimension defines the feedback mechanisms through which KinoGroove Boxes communicate their current state to the user. In musical systems, feedback is essential for supporting real-time performance, as users must be able to perceive changes in system state and parameter values while interacting. Figure 6 shows a visual example of all types of feedback.

This dimension has the following possible values:

- **None**: No explicit visual feedback is provided.
- **Colors**: Color is used to communicate changes in value, for example by becoming brighter when transmitting output and darker when inactive. Alternatively, a continuous color ramp can be used to reflect the evolution of the output value over time.
- **Text**: Output values or states are displayed numerically or symbolically within the UI or directly on the box.
- **Graphs**: Output values are displayed as curves or plots inside the UI or directly on the box. One type of graph is a temporal graph, which shows both the current value being transmitted and the previously transmitted values within a defined time window.

Figure 5: Timeline UI illustrating looping mode for a recorded dance, where a 10-second loop replays the segment between 45 and 55 seconds of the original recording.

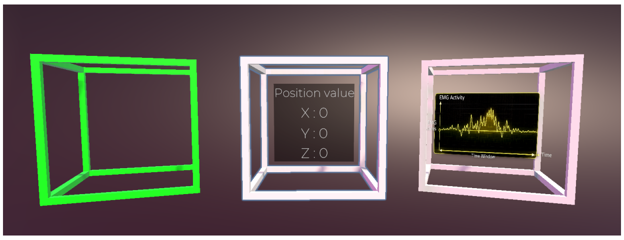


Figure 6: All available types of feedback: on the left, color feedback; in the center, text feedback; and on the right, graph feedback.

4.6 Box Transformation

This dimension defines which geometric properties of a KinoGroove Box itself can be manipulated by the user. These transformations determine how boxes can be positioned, oriented, and resized within the environment, thereby affecting their spatial organization, accessibility, and usability. The interface used to apply these transformations is illustrated in Figure 7.

This dimension has the following possible values:

- **Position**: The box can be positioned within the environment or relative to the avatar.
- **Rotation**: The box can be rotated within the environment or relative to the avatar.
- **Scale**: The box can be resized within the environment or relative to the avatar.

4.7 Data Control

This dimension describes how the raw output values of a KinoGroove Box can be modified or constrained. These mechanisms

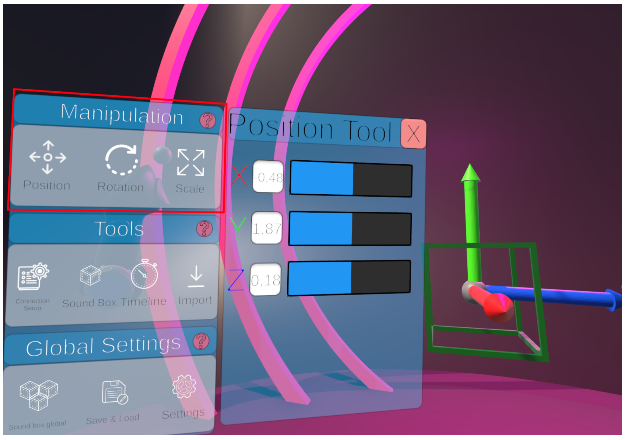


Figure 7: Illustration of the user interface used to modify the box transform. The interface is shown in position-editing mode.

allow users to shape the expressiveness, sensitivity, and interaction range of each box. An example of this Data Control is shown in Figure 8 .

This dimension has the following possible values:

- **Min–max control**: Output values are clamped within a user-defined minimum and maximum range.
- **Multiplicative factor**: Output values are scaled by a multiplicative factor, allowing finer control over the resulting output.
- **Outside data influence**: Output values are modulated by external data sources. For example, EMG data could be multiplied by the speed of the corresponding body part, creating a modulation driven by external parameters.

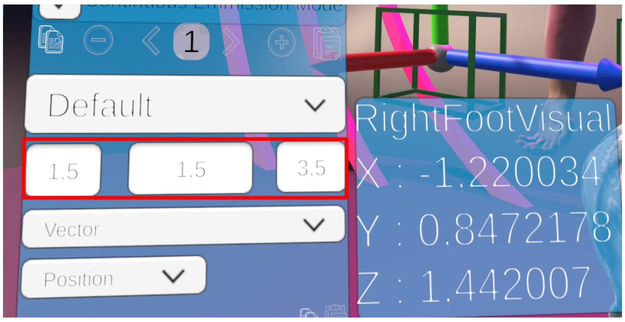


Figure 8: The upper box configured with a Min–Max control, with a minimum value of 1.5 and a maximum value of 3.5 (left and right, respectively), and a multiplier of 1.5 (center).

4.8 Box Configuration

This dimension defines how KinoGroove Boxes are initialized, stored, and reused. It supports different workflows, ranging from live improvisation to preconfigured performance setups.

This dimension has the following possible values:

- **Manual**: Each box is configured individually and manually by the user.
- **Per-box preset**: Individual boxes can load predefined configurations, enabling faster setup and easier composition when working with multiple boxes that share similar functionality.
- **Scene preset**: Entire sets of boxes can be loaded as a group. For example, different configurations of boxes can be associated with different scenes, allowing the user to switch between complete setups on the fly.

5 Usage scenarios

To illustrate the use of the proposed design space, we present two complementary usage scenarios that emphasize different roles of EMG within KinoGroove. These scenarios are not intended to be exhaustive, but rather to represent distinct regions of the design space, demonstrating how EMG can function either as a secondary expressive layer or as a primary control modality.

Both scenarios assume an asynchronous creative process: movement and EMG data are first captured from a dancer and applied to a virtual human avatar. A musician then uses the KinoGroove system to compose by interacting with the dancer's virtual movements through spatial boxes and musical patches. Together, these scenarios illustrate how the system adapts to a wide range of movement qualities, spatial configurations, and interaction strategies.

5.1 Scenario 1: Large-Amplitude and Explosive Movement

The first scenario relies on a hip-hop beat at 115 bpm, aligned with the tempo of the recorded dance movements. The goal is to make use of expansive gestures, strong spatial displacements, and high dynamic intensity. Interactive boxes are placed at the spatial extremities of the performance area, corresponding to the furthest reachable positions of the limbs. Each of these *spatial triggers* is associated with discrete and salient events in the sound, which therefore are synchronized with the beat and with very visible movements, such as sample triggers or strong changes in effects (*e.g.*, delay duration). In parallel, EMG signals, with more frequent and continuous variations, are mapped to audio effects applied to the drum loop, enabling variations in muscular activation to bring more subtle variety in the beat, through gating and bandpass filters.

Overall, the scenario privileges spatial output features and event-based mappings: musical structure emerges from physical reach, spatial extremes, and energetic punctuation. EMG is positioned as a secondary expressive layer, modulating sound qualities without redefining the musical form. This configuration illustrates how EMG can augment gesture-driven interaction by revealing internal effort behind large-scale movement, while keeping spatial exploration as the primary compositional mechanism.

5.2 Scenario 2: Low-Amplitude Movement with High Muscular Activity

In this scenario, the performer engages in dance with low spatial displacement but high-intensity muscular activation. The musical goal is to make contraction the primary driver of musical changes, such that muscular effort is directly reflected in the sound.

To realize this intent, KinoGroove Boxes are configured to prioritize contraction-related outputs; an example of this placement is shown in Figure 10. Boxes are mostly avatar-anchored

Figure 9: Box placement for large-amplitude, explosive movements: OSC boxes are positioned at the extremities of the movement to capture explosiveness, while EMG boxes placed on the trapezius record neck and arm muscle activity.

or placed close to the body, ensuring that minimal motion is sufficient to engage the system.

On the sonic side, this scenario relies on three granular synthesizers, each continuously playing a note from a set of recorded piano notes. A soft low-frequency amplitude modulation is applied to the highest one in sync with the dance tempo. More importantly, the amplitude of each granular synthesizer is modulated by the EMG output of a different box, generating a modulated chord that reflects bursts of activity across various muscles. In order to amplify that effect, two other EMG boxes are mapped to the center frequency of two bandpass filters applied to the two lowest piano notes. The EMG signal is adapted for more pleasant musical output through exponentiation and scaling operations.

The result is a continuously evolving soundscape composed of multiple modulated layers.

This configuration demonstrates how EMG can function as a central compositional resource rather than a mere augmentation of motion capture.

Together, these scenarios explore two contrasting regions of the same design space, highlighting how control can shift between spatial movement and muscular effort.

Figure 10: Box placement for low-amplitude movements: two OSC boxes are positioned to capture the up-and-down motion of the hands and arms, while the majority of the boxes are EMG sensors placed on the trapezius, triceps brachii, and erector spinae to capture upper-torso muscle activity, allowing for gradual sound control using the entire upper body.

6 Data Acquisition and Processing

Another key contribution of this work is in the data acquisition and processing pipeline developed to integrate motion capture and EMG signals within a unified workflow. This section details the methods used to record, synchronize, and process these heterogeneous data streams.

6.1 Motion Data Acquisition

To record the dancer's motion, we used a Qualisys [2] motion capture system. Qualisys is an optical motion tracking system that provides a comprehensive software suite, enabling efficient data acquisition under our experimental conditions. All motion capture recordings were conducted within a laboratory-equipped gymnasium. The facility was outfitted with 27 Qualisys Oqus 700+ [3] motion tracking system cameras. The cameras were distributed across two vertical levels to ensure full-body coverage and to reduce marker occlusion during large-amplitude dance movements.

A calibrated skeletal model was fitted to the performer using Qualisys Track Manager (QTM)[4], enabling the reconstruction

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[2] https://www.qualisys.com/

[3] https://www.qualisys.com/cameras/5-6-7/

[4] https://www.qualisys.com/software/qualisys-track-manager/

of joint trajectories in the presence of temporary marker occlusion. To minimize tracking artifacts, recordings were conducted in a controlled environment with non-reflective surfaces and clothing.

Qualisys provides two standardized marker sets: the Animation Marker Set, designed for efficient full-body tracking in film and game production, and the Sports Marker Set, which follows biomechanical conventions and supports more anatomically accurate joint reconstruction. Although precise joint-angle analysis was not required in this work, we selected the Sports Marker Set (41 markers) to maximize recording accuracy and improve correspondence with concurrently acquired EMG data. Passive spherical retroreflective markers were attached to the dancer's clothing or skin according to the Sports Marker Set specifications. In addition, Qualisys's native support for external data streams enabled synchronized acquisition of motion capture and EMG signals within a single recording framework.

6.2 EMG Data Acquisition

Surface electromyography (EMG) sensors were placed on selected muscles of the upper body, trunk, and lower limbs to capture muscular activity underlying popping dance practice. The Trigno Avanti Sensor [5] were the EMG sensors used during the recording. These EMG sensors are cable-free and non-intrusive, making them well suited for recording the dancer's movement. Sensor placement followed the recommendations of the SENIAM project (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles)[6].

In the upper body, bilateral EMG recordings were obtained from the trapezius and triceps brachii muscles, as well as from forearm muscles involved in wrist and hand articulation. These placements capture muscle activity associated with upper-body accents, arm hits, and fine isolations commonly used in popping.

Trunk muscle activity was recorded bilaterally from the erector spinae muscles and centrally from the transversus abdominis. These muscles are involved in postural control, torso isolation, and sustained tension, which play an important role in controlled popping sequences. While surface EMG of abdominal muscles is known to be sensitive to noise and cross-talk, this placement provides access to core-related activation relevant to the dance practice.

For the lower body, bilateral EMG sensors were placed on the quadriceps femoris, gastrocnemius, and tibialis anterior muscles to capture muscular activity related to stance control, foot articulation, and rhythmic weight shifts.

This selection of muscles displayed in Figure 11 enables the capture of coordinated muscular activity across the whole body, supporting the analysis of both visible movement and internal effort characteristic of popping dance.

6.3 Motion Data processing

For the motion capture data, the main processing step was the construction of the skeleton using Qualisys Track Manager (QTM). The skeleton was built based on a calibration recording in which the dancer performed a wide range of movements involving all limbs, providing a robust basis for the skeletal model. The skeleton was then refined using the other movement recordings. The resulting skeleton is shown in Figure 12. In addition to the automatic handling of marker occlusion by the skeleton, a manual cleaning step was performed to remove ghost markers (*i.e.,* markers recorded multiple times or appearing due to reflections).

6.4 EMG Data processing

Regarding the EMG data, initial processing was applied during recording using the default preset of the Delsys acquisition system. The main task consisted of extracting the data from Qualisys. Although Qualisys allows data export in several formats, such as JSON, the exported files are not directly usable, as all signals are stored within a single file. To address this issue, a custom Python script was developed to extract the EMG data from the exported JSON file into individual files. The script extracts the EMG channel names, signal values, timestamps, and sampling frequency. This data is then saved in CSV format using a custom structure, allowing for easy import and use in Unity. Within Unity, the EMG data underwent light post-processing. Artifacts and anomalous spikes were removed, and extreme values were attenuated to preserve the overall signal envelope while maintaining usability for artistic applications, particularly when working with normalized data.

6.5 Data support and Processing on Unity

Due to the proprietary nature of the FBX format and Unity's restriction on animation recording to editor mode, a custom Unity editor application was developed to bridge Qualisys Tracking Manager (QTM) and Unity. While Unity provides built-in animation recording tools, these are only accessible in the editor; this limitation is acceptable, as the application's purpose is solely to support data transfer between the motion capture process and the final KinoGroove application. After establishing a connection between Unity and Qualisys Tracking Manager (QTM), Unity is granted control access to initiate and stop recordings on the motion capture system. An initialization step aligns the skeletal pose by playing the initial frames of the motion data, ensuring correct synchronization between QTM and the Unity avatar. During recording, streamed motion data from QTM are applied to the avatar and captured using Unity's animation system. Once recording is complete, the captured motion is exported as an FBX animation formatted to meet KinoGroove 's import requirements.

The resulting workflow (see Figure 13) enables synchronized transfer of skeletal motion from QTM to KinoGroove, supporting reliable playback and interaction with recorded movement inside the system.

6.6 Applying EMG Data

To interact with EMG data, artists use EMG Boxes, virtual boxes which are body-anchored so that their virtual position mirrors the placement of the corresponding physical EMG sensor. This anchoring ensures a one-to-one correspondence between recorded muscle activity and the virtual control element.

The immersive nature of XR gives us the possibility to go beyond a simple continuous stream. We therefore introduced linked KinoGroove trigger boxes. A trigger box can be placed anywhere in the virtual world and connected to an EMG Box (its "parent"). When the performer's avatar collides with the trigger, the parent EMG Box emits its current value once, creating a discrete, event-driven control channel for rhythmic or expressive gestures. A dotted line visually links the trigger to its parent, making the relationship immediately apparent.

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[5] https://delsys.com/product/trigno-avanti/

[6] http://seniam.org/

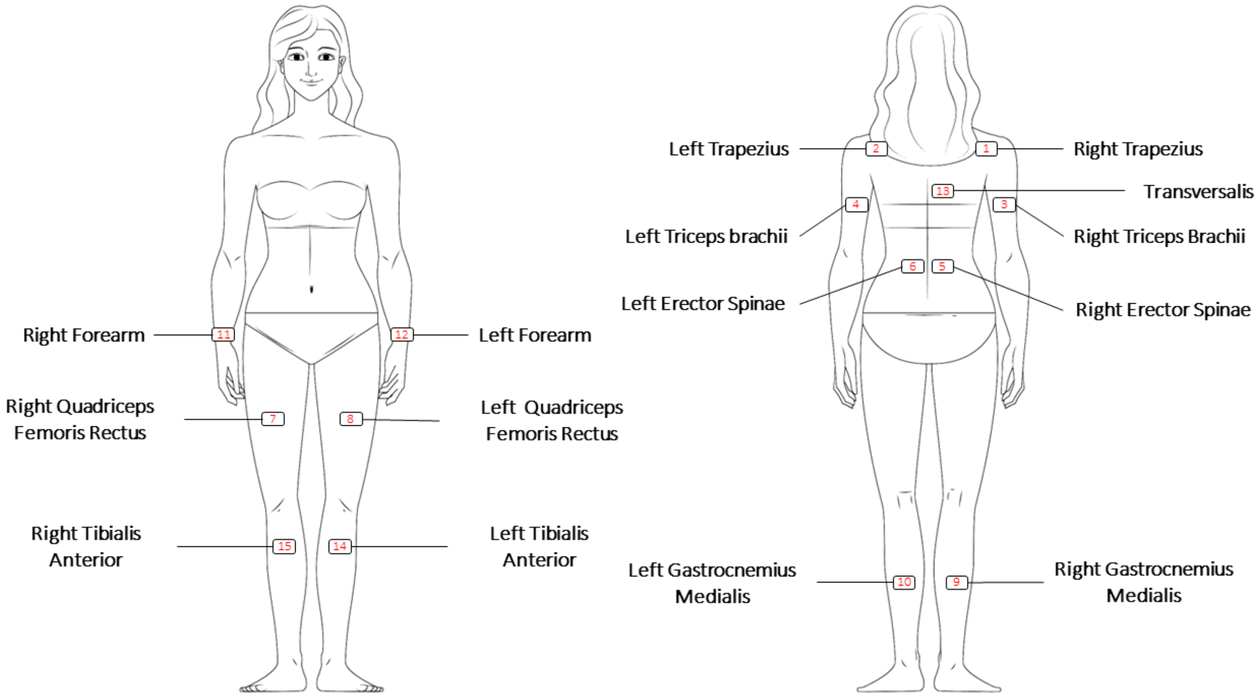

Figure 11: A visual representation of EMG electrode placement on the dancer's body.

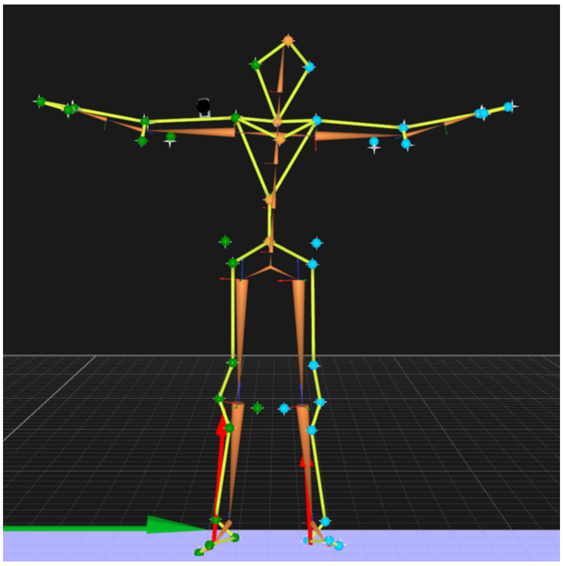

Figure 12: Skeleton obtained from the different calibrations

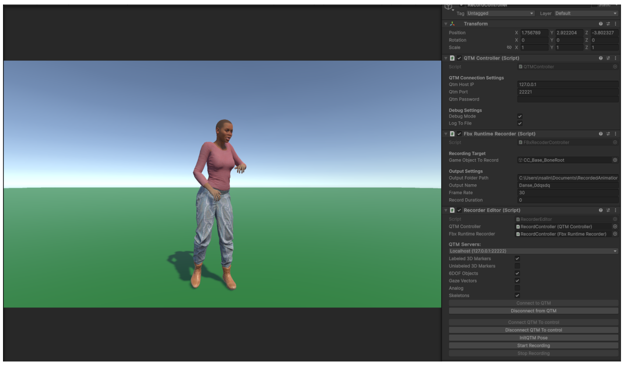
Tag Untagged
Layer Default
Transform
Position X 1.756789 Y 2.922204 Z -3.802327
Rotation X 0 Y 0 Z 0
Scale X 1 Y 1 Z 1
QTM Controller (Script)
Script QTMController
QTM Connection Settings
Qtm Host IP 127.0.0.1
Qtm Port 22221
Qtm Password
Debug Settings
Debug Mode ✓
Log To File ✓
Fbx Runtime Recorder (Script)
Script FBxRecoderController
Recording Target
Game Object To Record CC_Base_BoneRoot
Output Settings
Output Folder Path C:\Users\nsalin\Documents\RecordedAnimatio
Output Name Danse_0dqsdq
Frame Rate 30
Record Duration 0
Recorder Editor (Script)
Script RecorderEditor
QTM Controller RecordController (QTM Controller)
Fbx Runtime Recorder RecordController (Fbx Runtime Recorder)
QTM Servers:
Localhost (127.0.0.1:22222)
Labeled 3D Markers ✓
Unlabeled 3D Markers ☐
6DOF Objects ✓
Gaze Vectors ✓
Analog ☐
Skeletons ✓

Figure 13: The Unity Editor application used to convert animations for KinoGroove.

Understanding what values are being sent is equally important. EMG amplitude is encoded with a color ramp on the box surface, so the hue changes smoothly as the signal varies over time. This provides an at-a-glance indication of muscle activation without requiring the performer to look away.

7 Perspective

This project highlights both the potential and the current constraints of combining high-resolution motion capture and EMG sensing for the study of expressive movement. While the recording conditions were optimal, the experimental setup relies on equipment that is difficult to reproduce outside a controlled research environment. The Qualisys motion capture system requires a large number of cameras arranged in a precise configuration, making it costly, spatially demanding, and challenging to deploy in artistic or non-laboratory contexts.

Similar limitations apply to the EMG setup. High-quality multichannel EMG systems involve expensive hardware, careful sensor placement, calibration procedures, and substantial preparation time. These requirements limit their practicality for casual or frequent use, particularly in creative settings where rapid iteration and flexibility are essential. As a result, the overall system remains difficult to reproduce and is currently accessible primarily within well-equipped research facilities.

Addressing these constraints represents a key direction for future work. One promising avenue is the adoption of more consumer-friendly technologies. For motion capture, inertial (IMU-based) systems based on wearable sensors offer an alternative that does not require complex camera setups or dedicated studio conditions. Such systems are faster to deploy, more portable, and better suited for ecological recording scenarios in real-world environments. However, they typically suffer from positional drift, lower spatial accuracy, and limited interaction with external objects, which may affect the precision of spatial mappings used in our system.

Alternatives to marker-based motion capture exist through computer vision approaches such as Rokoko Vision[7] or Move AI[8], which provide low-cost and portable solutions without requiring dedicated hardware setups. Such AI-based methods show promising results for applications like PANAMA by Cubillas et al[4]. However, unlike optical or inertial motion capture systems, these methods rely on learned models to infer body motion rather than directly measuring it. This may affect fidelity and authenticity, particularly for expressive movements, and should be further investigated before broader adoption.

The challenge is even more pronounced for EMG sensing. Consumer-grade devices, such as armband-based systems, are more affordable and easier to use but provide fewer channels, lower signal quality, and limited control over electrode placement. This restricts the range of muscles that can be captured and may reduce the expressive richness of the data. Future research should therefore explore compromises between signal quality, usability, and artistic relevance, with the goal of making muscular sensing more accessible without undermining its expressive potential.

Another perspective concerns real-time interaction. While KinoGroove currently relies on prerecorded data to support a compositional workflow, real-time use is possible but would shift the system toward improvisation and reduce control over spatial mappings and temporal structure, as well as limit features such as looping and timeline editing.

Beyond hardware considerations, several extensions of the present work are currently underway. As a first step, we are currently working on publishing the dataset of synchronized motion capture and EMG recordings acquired during this project. Making this dataset publicly available will enable reproducibility, facilitate comparative studies, and support further research on the relationship between movement and muscular activity in dance and expressive motion.

In addition, recordings integrating pressure plate data have already been collected, providing information about ground contact and force distribution. However, these data require further processing and methodological reflection to fully exploit their potential. Future work will focus on developing appropriate analysis pipelines and exploring how these measurements can be meaningfully combined with kinematic and EMG data. This multimodal integration represents a promising extension of the present project, offering a more comprehensive understanding of movement dynamics and balance strategies.

To increase the accessibility and long-term value of the dataset, we plan to annotate and label the recorded dance movements. This labeling process will allow for the creation of a structured and searchable movement database, enabling comparative studies, machine learning applications, and cross-disciplinary research.

Finally, a user study is planned as part of future work. Evaluating collaborative creation in heterogeneous XR environments remains challenging and requires further methodological development, as well as the involvement of professional practitioners, whose recruitment can be time-consuming.

8 Conclusion

This paper introduced KinoGroove, a system that integrates electromyography (EMG) with motion capture to support expressive music–dance interaction in XR. By combining external kinematic data with internal muscular activation, KinoGroove expands the representational and expressive scope of embodied musical systems, particularly for dance practices that rely on subtle contractions, tension, and internal effort rather than large-amplitude spatial gestures.

We presented a design space that formalizes how EMG can function within KinoGroove, not merely as physiological data, but as an expressive and compositional resource. This design space structures interaction possibilities across output features, modes, anchoring types, temporality, feedback, and data control, offering artists flexible ways to integrate muscular sensing into their creative workflows. Through two contrasting usage scenarios: one centered on large-amplitude, explosive movements and the other on low-amplitude, high-effort muscular activity; we demonstrated how EMG can operate either as a complementary expressive layer or as a primary driver of musical structure.

In addition, we detailed the data acquisition and processing pipeline used to record and synchronize motion capture and EMG data, as well as the extensions made to KinoGroove to support EMG-based interaction through dedicated EMG boxes and trigger mechanisms. Together, these contributions describe a technical foundation for integrating muscular sensing into XR-based musical interaction systems.

9 Ethical Standards

This research was conducted using public funding for equipment and infrastructure. The artists who participated in the recordings were compensated for their time and creative contribution. The dancer gave informed consent for the recording of motion capture and EMG data, as well as for the use of these recordings in research publications, demonstrations, and the release of a research dataset.

Given the sensitive and biometric nature of EMG and motion capture data, particular care was taken regarding data management and participant agency. Participants were informed of the potential reuse of the data and retained the right to withdraw their contributions at any stage. Identifying visual material was only shared with explicit permission, and anonymized representations (e.g., skeletal avatars) are preferred in public releases when possible.

The recording protocol was designed to minimize physical strain and discomfort, and participants were free to stop or request sensor removal at any time. The system design process involved ongoing dialogue with the artists, positioning them as collaborators rather than merely data sources.

Software and datasets will be released under open-source and open-data licenses intended to support transparency and reproducibility.

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[7] https://www.rokoko.com/products/vision

[8] https://www.move.ai/

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