



Journal of Arts & Humanities

Volume 15, Issue 05, 2026: 01-13

Article Received: 13-07-2026

Accepted: 04-09-2026

Available Online: 01-10-2026

ISSN: 2167-9045 (Print), 2167-9053 (Online)

DOI: <http://dx.doi.org/10.18533/journal.v15i5.2721>

Musical structure, micromotion, and adaptive gesture in saxophone performance: A critical cross-study synthesis

Nádia Moura¹

ABSTRACT

This article presents an integrative synthesis of seven studies conducted within a research program on expert saxophone performance: five performer-centered observational, kinematic, and interview studies, complemented by two perceptual experiments. The studies are compared according to musical and task conditions, movement descriptors and scales, and evidential perspective. Across the corpus, rhythm and pitch were the musical components most consistently associated with movement: faster or rhythmically denser passages were linked to increased movement frequency, whereas amplitude varied across conditions; body flexion-extension patterns accompanied pitch contour and, in some cases, preceded melodic changes. Under movement restriction, spatial and velocity measures of motion decreased, whereas frequency-based measures remained comparatively stable or increased relative to free-movement conditions. Three non-exclusive interpretations of persistent micromotion are considered: postural regulation, sensorimotor entrainment and prediction, and motor learning. On this basis, the paper proposes an adaptive, multidimensional model in which musical structure and task constraints selectively reorganize movement across dimensions and scales, while expressive, technical, postural, and communicative functions remain overlapping and context-dependent. Instead of assigning gestures to fixed categories, the model reframes their study as an empirically tractable question of which movement dimensions change under which constraints, providing a framework for causal experiments and learning interventions on the functions of performative movement.

Keywords: Performative gesture; micromovement; embodied music cognition; music performance; motor restriction.

This is an open access article under Creative Commons Attribution 4.0 License.

1. Introduction

To perform music is to think through the body. Embodied cognition holds that thinking is not confined to the brain: cognitive processes involve the whole living body and its ongoing engagement with the world (Varela et al., 2016). Recent formulations gather this position under the heading of 4E

¹ Faculty of Arts and Humanities (FLUC), Centre for Interdisciplinary Studies (CEIS20), University of Coimbra (UC), Coimbra, Portugal. Email: nmoura@fl.uc.pt

cognition, in which cognition is embodied in the living system, embedded in physical, social, and cultural surroundings, extended into the objects and devices an agent uses, and enacted through a two-way exchange between organism and environment (Schiavio & van der Schyff, 2018). The musical instrument belongs to the third principle: through practice it can come to be experienced as an extension of the performer (Nijs et al., 2013). Embodied music cognition extends this view to the musical domain, treating the body as the central mediator in the formation of musical meaning, through which expressive gestures are encoded into sounds and sounds decoded into expressive gestures (Leman, 2008; Leman & Maes, 2014). The form this mediation takes depends on the constraints in play, which dynamical accounts of performance describe as organismic, task, and environmental, each shaping which movement trajectories remain viable as a performance unfolds (Nijs et al., 2023). Bodily movement is therefore one of the means through which musical action is organized and experienced.

Empirical work has approached this embodied processing by asking how performers' gestures relate to musical structure. Phrasing and cadential organization have been associated with postural sway (Demos et al., 2017) and increased non-technical movement (Chander et al., 2022); pitch contour (Davidson, 2012) and melodic discontinuity (Huberth et al., 2020) with vertical body motion; rhythm and tempo with movement periodicity, velocity, and quantity (Coorevits et al., 2019); and accents or changes in articulation with impulsive or higher-velocity gestures (Dahl, 2004; Wanderley et al., 2005). Technical demands may also constrain ancillary movement (Massie-Laberge et al., 2019; Wanderley et al., 2005). These associations do not establish causal function, but they indicate that bodily activity is organized in relation to musical processes. They also show that musical components do not affect "movement" as a unitary variable: amplitude, range, velocity, direction, frequency, periodicity, and temporal alignment may respond differently to the same passage.

Another empirical tradition asks how deliberately varied performance manners reorganize bodily behavior and, in some studies, affect the sonic and perceptual dimensions of performance. Davidson's foundational experiments asked musicians to perform in deadpan, projected expressiveness, and exaggerated manners, showing that intended levels of expression could be discriminated from performers' bodily movements (Davidson, 1993, 1994). Later studies adapted this logic through combinations of standard, deadpan, projected, exaggerated, and movement-restricted conditions in clarinet (Wanderley, 2002; Wanderley et al., 2005), piano (Massie-Laberge et al., 2019; Thompson & Luck, 2012), and marimba performance (Broughton & Stevens, 2009). Similarly, multiple studies considered here (Moura, Fonseca, et al., 2023; Moura, Vidal, et al., 2023; Moura et al., 2024; Moura, Fonseca, Magalhães, et al., 2025) compared free expressive movement with an instruction to restrict movement to what performers judged minimally necessary for effective playing. This comparison sought to distinguish motor patterns associated with projected expressiveness from movement more closely tied to the physical demands of execution, without assuming that the separation could be complete.

The interpretive value of this contrast nevertheless depends on what movement restriction can reasonably be assumed to isolate. Research has distinguished effective or sound-producing gestures, mechanically involved in sound production, from or ancillary gestures, which support the effective ones without contributing directly to sound production, and has further differentiated sound-facilitating, sound-accompanying, expressive, and communicative movements (Delalande, 1988; Jensenius et al., 2010). Such categories provide useful analytical distinctions, but they do not imply that each bodily action serves only one role. A recent review of ancillary movement in piano performance supports this. The evidence tying movements conventionally labeled ancillary to any one specific cognitive or biomechanical function remains thin, and multifunctionality looks more like the norm than an exception (Sun & Wang, 2026). Nor does the persistence of a movement under restriction demonstrate that it is technically necessary, just as its reduction does not establish that it was exclusively expressive. Moreover, "immobility" cannot be literal in instrumental performance: breathing, embouchure, fingering, instrument support, balance, and postural regulation continue when visible movement is minimized. Standstill research likewise shows that low-amplitude bodily motion remains measurable during attempted stillness (González Sánchez et al., 2018; Jensenius et al., 2017). A movement-restricted condition is therefore better understood as a relative task constraint than as an absence of body motion.

What existing accounts do not settle is whether the findings of the manner-manipulation tradition extend below the visible. Instructed changes in expressive intention are known to reorganize visible movement; their bearing on the low-amplitude activity that persists under restriction has not been established. Nor do these accounts specify which movement descriptor responds to which musical component, or at which scale, although the components are known to act on descriptors differently. The present article addresses both through a single recent research program dedicated exclusively to the saxophone, in which a shared methodology across studies allows findings to be compared directly: five observational, kinematic, and interview-based studies of expert saxophone performance, complemented by two perceptual experiments concerning audience perception of gesture. It asks which movement descriptors vary with musical structure, how bodily behavior differs between expressive and movement-restricted conditions, and how micromotion and postural activity should be interpreted when visible movement is minimized. The comparison supports an adaptive, multidimensional model of performative gesture organized around interacting factors, movement descriptors, and analytical scales.

2. Empirical basis and analytical approach of the cross-study synthesis

2.1 Corpus and evidential basis

The empirical core of this synthesis comprises five performer-centered studies of gesture description, kinematics, and performers' self-perceptions, complemented by two perceptual experiments on the visual communication and context-dependent evaluation of movement. All seven studies were conducted within the same research program and address a shared problem: how saxophonists' body motion varies in relation to musical structure, expressive intention, and technical demand, and how that motion influences audience perception. Published between 2022 and 2026, they have not previously been considered together. Observational analyses identify recurrent gestures and their alignment with musical events; kinematic studies quantify movement dimensions and scales; interviews document performers' interpretations of bodily behavior; and perceptual experiments examine how movement is interpreted by observers. Table 1 summarizes each study's design, focus, and role.

Table 1. *Empirical studies contributing to the cross-study synthesis. Rows with gray background refer to complementary studies.*

Study	Evidence and design	Analytical focus	Role in the synthesis
Moura et al. (2022)	Qualitative observational analysis using score-related annotation of synchronized video and motion data	Recurrent gestures, involved body regions, movement directions, and alignment with pitch, rhythm, phrasing, accents, and technical passages	Establishes an initial descriptive vocabulary for saxophonists' gestures and identifies candidate relationships between movement and musical structure
Moura, Fonseca, Graça, et al. (2025)	Interrater observational coding and frequency analysis of synchronized video and motion data	Distribution and prevalence of gesture categories across performers and musical contexts	Systematizes the descriptive vocabulary and validates a 15-category gesture system; shows how gesture types vary across musical materials
Moura, Vidal, et al. (2023)	Kinematic and audio-feature analysis of knee movement under expressive and movement-restricted conditions	Knee-angle amplitude and frequency in relation to pitch or tonal expectation, rhythmic density, and performance condition	Shows that different dimensions of the same localized movement may relate differently to musical structure and task constraint
Moura, Fonseca, Magalhães,	Kinematic and audio-feature analysis of projected center-of-mass	Anterior-posterior and mediolateral range, velocity, traveled distance, sway area,	Extends the analysis to full-body postural organization

et al. (2025)	motion and postural sway under expressive and movement-restricted conditions	frequency, and musical characteristics (rhythmic density, tempo, articulation, technical difficulty)	
Moura and Serra (2024)	Qualitative interview study with professional and pre-professional saxophonists	Performers' awareness of movement, perceived technical and expressive roles, bodily habits, pedagogy, and movement restriction	Documents performers' interpretations of movement and pedagogy, clarifying the distinction between perceived and objectively demonstrated function
Moura, Fonseca, et al. (2023)	Perceptual experiment using audiovisual performances presented through different visual-motion displays	Observers' ratings of expressiveness, music-movement correspondence, overall evaluation, and effects of motion representation	Examines the communicative consequences of gesture and the extent to which evaluation depends on how movement is visually represented
Moura et al. (2024)	Perceptual experiment comparing motion profiles, musical excerpts, and sensory presentation modes	Effects of movement quantity and quality, musical style, sensory mode, and musical expertise on performance evaluation	Shows that the perceptual value of movement depends on the repertoire, and musicians and non-musicians present different sensory dominances

The synthesis is interpretive and concept-driven. Its corpus was defined by programmatic coherence – shared musical instrument, performance context, and conceptual framework – rather than systematic database search. Nonetheless, the following features make it an adequate basis for a first-pass model. The studies differ in sample, design, and measures, yet characterized musical structure in consistent terms, so that agreement between them reflects agreement about the same musical variables. They constitute, to our knowledge, the whole of the published kinematic and observational literature on saxophone performance, so no larger body of work exists from which favorable studies might have been drawn. Finally, they span the four evidential perspectives described above, so no single method carries the comparison.

2.2 Data extraction and comparison procedure

Data were extracted by the first author into a spreadsheet under four categories. Musical and task conditions comprised the musical components characterized in each study and the performance conditions under which movement was recorded. Movement descriptors and scale covered the kinematic or observational measures reported, together with the analytical scale at which they were obtained. Findings recorded the direction and consistency of each reported association. Evidential perspective distinguished observational coding, kinematic measurement, performer self-report, and audience evaluation.

Findings were then compared across studies within each category and classified as convergent where two or more studies reported associations in the same direction, complementary where studies addressed different descriptors or scales of the same musical component, and unresolved where interpretations diverged. The three interpretations of persistent micromotion presented in Section 4.2 were derived from this comparison, each retained only where the supporting pattern appeared under more than one evidential perspective. The adaptive model in Section 5 was then specified by identifying which descriptors covaried across conditions, which varied independently, and which of the model's four interacting factors – musical structure, task constraints, performer-instrument dynamics, and social-perceptual context – accounted for each dissociation.

2.3 Scope and interpretive limitations

Because all studies stem from a single research program, convergence is weighed as cross-method complementarity instead of independent replication. The corpus may also reproduce assumptions shared across the program; external replication is therefore required to test the broader applicability of the synthesis. The evidence concerns expert classical alto saxophone performance in standing position and should not be transferred automatically to other instruments, seated performance, or ensemble interaction. The movement-restricted condition was self-regulated according to performers' judgments, and no device was used to physically constrain movement (as used in some research, e.g., Tsai et al., 2020). It therefore provides a constrained comparison, not an objectively verified technical baseline. Finally, movement-music associations do not identify biomechanical or cognitive function. The Granger analysis in Moura, Vidal, et al. (2023) establishes predictive temporal precedence under the time-series model, not physical, psychological, or intentional causation. The purpose of the present discussion is accordingly to formulate hypotheses that can be tested through controlled experiments and learning interventions.

3. Musical structure across scales of performative movement

3.1 Rhythm organization and interactions with articulation and technical difficulty

Rhythm was one of the musical dimensions most consistently associated with saxophonists' motion across observational, kinematic, and interview-based evidence. This pattern accords with research relating performers' gestures to beat, meter, tempo, and rhythmic grouping across different instruments (Buck et al., 2013; Davidson, 2007; MacRitchie et al., 2013; Wanderley, 2002; Wanderley et al., 2005).

Qualitative observation indicated that slower passages were accompanied by slower, more continuous movements, whereas faster passages involved shorter, quicker, and more impulsive actions (Moura et al., 2022). Repeated rhythmic motifs were also accompanied by recurring gestures: performers swayed with the beat, changed direction around metrical events, or repeated wrist actions across successive iterations. The gesture categorization study supported this pattern quantitatively, showing a higher summed gesture frequency in faster excerpts (Moura, Fonseca, Graça, et al., 2025). At the postural level, excerpts combining higher tempo and rhythmic density were generally associated with greater sway velocity and higher anterior-posterior (AP) and mediolateral (ML) frequency (Moura, Fonseca, Magalhães, et al., 2025). Performers likewise described adapting movement to tempo and its subdivisions. They associated slower tempi with greater spatial freedom and faster tempi with shorter actions aligned to beats or subdivisions (Moura & Serra, 2024).

These findings are consistent with evidence that bodily activity coordinates with periodic auditory structure in listening and locomotor tasks (Buhmann et al., 2016, 2018; Repp & Su, 2013; Rose et al., 2021; Spiech et al., 2023). Perceptible pulses and rhythmic motifs have likewise been related to movement acceleration, quantity, and temporal structure or fractality of listeners' movement (Burger et al., 2013; Burger & Toiviainen, 2018, 2020; González Sánchez et al., 2020). In drummers, slower tempi have been associated with greater movement fluidity (Burger & Wöllner, 2023).

Rhythmic density nevertheless reflected a more complex pattern than tempo alone. Rhythmically denser passages were associated with more frequent knee flexion-extension cycles but smaller angular amplitude (Moura, Vidal, et al., 2023). Therefore, greater rhythmic activity did not simply correspond with "more movement": localized movement became more frequent while decreasing in amplitude. Across the studies, velocity and frequency tended to increase with tempo, whereas knee amplitude varied inversely with rhythmic density. Frequency, velocity, and amplitude can thus change in different directions within the same broad domain of rhythmic demand.

Rhythm-related patterns were also modified by the technical characteristics of particular passages. In one rhythmically dense excerpt, sway velocity decreased rather than increased; unlike the other excerpts, this passage required repeated staccato articulation (Moura, Fonseca, Magalhães, et al., 2025), implying coordinated tonguing with continuous air support (Hofmann & Goebel, 2014; Pàmies-Vilà et al., 2017, 2018; Slis et al., 2021). Performers' reports that movement was restricted during technical challenges support the relevance of this interpretation. Conversely, accented tongued notes were frequently accompanied by impulsive ancillary actions, including head nods and trunk flexions,

consistent with earlier work on accent-related gestures (Dahl, 2004; Dahl et al., 2010; Jensenius et al., 2010). Rhythm therefore provided a strong organizing reference for movement, but its bodily manifestation depended on articulation, technical demand, body region, and the movement descriptor.

3.2 Pitch contour, tonal expectation, and anticipatory movement

Pitch-related organization emerged consistently across observational, kinematic, and performer-reported evidence. Previous research has related movement to melodic grouping, phrase structure, and pitch contour, although these studies examine different body regions and analytical levels (Davidson, 2012; Demos et al., 2017; Huberth et al., 2020; MacRitchie et al., 2013; Nusseck et al., 2022; Thompson & Luck, 2012). Qualitative observation showed that performers frequently accompanied melodic direction through changes in vertical body configuration (Moura et al., 2022). Descending contours were often associated with knee and trunk flexion, whereas ascending contours were accompanied by extension, feet elevation, or a more open posture. Depending on the passage, contour-related flexion or extension occurred in approximately 70%–100% of the performers analyzed. Extension also appeared around large pitch intervals and developing phrasing targets. These relationships were passage-dependent: the same action could coincide with pitch direction, interval size, dynamics, and phrase culmination.

The kinematic study addressed a different relationship by comparing knee-angle trajectories with pitch-expectation profiles generated from performers' audio recordings (Moura, Vidal, et al., 2023). The Granger analysis indicated predictive temporal precedence of knee trajectories relative to the modeled profile at a short lag. This establishes time-series ordering, not physical causation, conscious anticipation, or a functional contribution to performance. Because performers knew the repertoire, prospective organization is a plausible interpretation. Performer accounts provide a complementary phenomenological perspective: only 35% described flexing or extending their bodies in relation to note height or melodic direction (Moura & Serra, 2024). This contrast between observed prevalence and self-report suggests that pitch-related movement may often occur without deliberate awareness, although the absence of report does not itself demonstrate that the behavior is unconscious — it may be unnoticed, difficult to verbalize, or simply not salient in retrospective accounts. Taken together, the evidence supports three distinct claims. Observationally, bodily movement accompanied pitch contour; statistically, knee trajectories preceded a modeled pitch-expectation profile; theoretically, these findings are compatible with prospective or anticipatory organization.

4. Gesture under constraint: What changes, what persists, and what micromotion may mean

4.1 What changes and what persists under movement restriction

Restriction did not scale all movement down uniformly, consistent with earlier studies (Broughton & Stevens, 2009; Massie-Laberge et al., 2019). Magnitude-based measures fell – AP and ML range, mean velocities, traveled distance, and sway area (Moura, Fonseca, Magalhães, et al., 2025), together with gross knee-flexion amplitude (Moura, Vidal, et al., 2023) – while lower-amplitude and frequency-based activity proved comparatively resistant, as Section 4.2 develops. Performers therefore occupied less space, followed shorter trajectories, and moved more slowly when instructed to minimize movement. The condition difference was also legible to observers. Projected-expressiveness performances were generally rated as more expressive and more congruent in music-movement terms than movement-restricted performances, although ratings varied depending on the avatar used to present the motion (Moura, Fonseca, et al., 2023). The constraint also coincided with changes in realized performance duration. In three of four excerpts, movement-restricted performances were significantly longer than expressive performances (Moura, Fonseca, Magalhães, et al., 2025). Several explanations are compatible with this difference, including altered tempo regulation under motor constraint, changes in breathing organization, or an interaction between movement condition and performers' temporal experience; the available data do not allow this distinction to be made.

However, reduced magnitude under the movement-restricted conditions did not entail equivalent suppression of frequency. After knee trajectories were high-pass filtered (cutoff at 1 Hz), performers showed higher weighted phase counts and more phase changes per second in the

movement-restricted condition (Moura, Vidal, et al., 2023). These low-amplitude microflexions persisted despite the instruction to minimize movement. A comparable dissociation appeared at the postural scale: only AP and ML sway-frequency measures did not differ significantly between expressive and restricted performances, even though all the other sway measures decreased (Moura, Fonseca, Magalhães, et al., 2025). Restriction affected how far and how fast performers moved more consistently than it affected frequency-based or low-amplitude activity. The conditions reveal a shift in the distribution of activity across large-scale movement, postural sway, and micromotion. The role of that activity, however, remains underexplored.

4.2 Interpreting latent micromotion

4.2.1 Postural control hypothesis

Micromotion may participate in balance, stabilization, breathing-related adjustment, or coordination between proximal posture and distal actions. In quiet stance, knee, ankle, and hip joints contribute jointly to center-of-mass regulation, and leg musculature can prepare for destabilizing arm movements (Cordo & Nashner, 1982; Günther et al., 2011; Hsu et al., 2007). Saxophone playing adds instrument weight, mouthpiece contact, respiration, and rapid upper-limb movement. Observational data also showed knee and trunk flexion around breathing and technical passages, while the staccato excerpt produced condition-specific ML adaptations (Moura, Vidal, et al., 2023; Moura, Fonseca, Magalhães, et al., 2025). These findings are compatible with postural control but do not validate it. Center of mass was estimated kinematically rather than measured with force platforms, and muscular or respiratory activity was not recorded. Direct tests would require force-platform measures, electromyography, respiratory recording, and selective perturbation, evaluated against balance, distal kinematics, sound stability, and effort.

4.2.2 Sensorimotor-entrainment and prediction hypothesis

Micromotion may reflect continued bodily organization around pulse, rhythmic grouping, or prospective musical events when larger movement is suppressed. The observational studies documented recurrent beat- and motif-related gestures; knee phase changes and sway frequency varied with rhythmic density; and knee trajectories temporally predicted modeled pitch-expectation profiles (Moura et al., 2022; Moura, Vidal, et al., 2023; Moura, Fonseca, Graça, et al., 2025; Moura, Fonseca, Magalhães, et al., 2025). Related research shows micromotion during musical standstill, groove-related changes in postural sway, and sensorimotor synchronization even when movement is small or not deliberately displayed (González Sánchez et al., 2018; Repp & Su, 2013; Ross et al., 2016). Yet the studies analyzed did not measure entrainment strength, neural prediction, conscious expectation, or causal benefit to timing. Direct tests could manipulate pulse clarity, rhythmic or tonal predictability, and movement permission while measuring phase alignment, expressive microtiming, temporal prediction, and subjective temporal experience.

4.2.3 Motor learning hypothesis

Long-term practice consolidates coordinative patterns in which sound-producing and ancillary actions are learned together. The observational studies found a recurrent hierarchy of knee, trunk, foot, sway, arm, and instrument gestures across performers, while interviewees described movement as frequently spontaneous or automatic in performance, even when deliberately addressed during practice (Moura & Serra, 2024; Moura, Fonseca, Graça, et al., 2025). Clarinet studies likewise report intra-performer stability of ancillary schemes across repeated performances (Wanderley et al., 2005). The corpus contains one expertise contrast bearing on this account: professional players showed higher ML sway frequency than university students, and reduced AP sway velocity in passages of high rhythmic density (Moura, Fonseca, Magalhães, et al., 2025). Recent work on music skill acquisition also points to movement efficiency and refined postural regulation as embodiment markers of consolidated expertise (Marin et al., 2026). Under this account, a stillness instruction may preferentially reduce larger or more consciously adjustable components without eliminating all elements of a learned whole-body pattern. Habit, however, is not equivalent to function. A movement can be stable because it is learned, culturally modeled, or idiosyncratic, yet remain unnecessary or even counterproductive. The hypothesis

requires comparisons across expertise, longitudinal observation during learning, and transfer to novel repertoire. Training studies could examine whether motor patterns emerge with practice, whether they survive changes in posture or instrument, and whether their suppression alters muscular effort, timing, sound, or subjective control.

5. An adaptive and multidimensional model of performative gesture

This model, presented in Figure 1, treats performative gesture as bodily activity whose movement descriptors are reorganized across analytical scales in association with four interacting factors: musical structure, task constraints, performer-instrument dynamics, and social-perceptual context. “Adaptive” denotes responsiveness to changing conditions; it does not imply that a movement is optimal, beneficial, efficient, necessary, or consciously selected. The four factors bear a specific relation to the constraints described in dynamical accounts of performance. Those accounts distinguish organismic constraints, arising from the performer’s own body and capacities; task constraints, arising from what the music asks of the player; and environmental constraints, arising from the setting in which performance occurs (Nijs et al., 2023). The present model retains task constraints in a narrower sense, covering the technical demand of the task and any instruction under which it is played, and separates out musical structure as a factor in its own right. Among the constraints acting on a performer, musical structure is the one that varies at the timescale of the movement it shapes: the body and the setting hold broadly constant across a performance, while rhythm, pitch organization, articulation, and phrasing change from bar to bar. It is also the constraint that carries its own analytical apparatus, describable from the score, from audio features, or from both, and its components act on movement descriptors in different directions. Folding it into a single task constraint forfeits that resolution.

What dynamical accounts assign to the organismic constraint is here gathered into performer-instrument dynamics, considering that the instrument becomes incorporated into the performer’s body over years of learning (Bremmer & Nijs, 2020, 2024; Marin et al., 2026). The environmental constraint is narrowed to the social-perceptual context, since the evidence assembled here concerns observers and their judgments. The model extends previous embodied music cognition frameworks (Jensenius et al., 2010; Leman, 2008) by taking the mediating role of the body as its starting point and supplying empirically grounded terms in which mediation becomes measurable: which descriptors, at which scales, change under which factor.

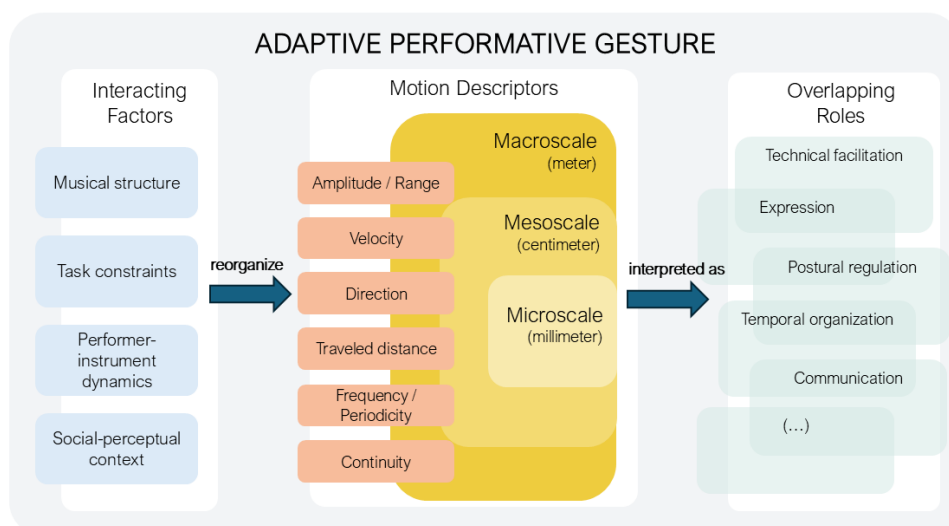


Figure 1. Adaptive performative gesture as the outcome of interacting factors, motion descriptors and analytical scales, and overlapping roles.

The model also contributes a way of describing movement as multidimensional, by descriptor and by scale. The descriptors – amplitude, range, velocity, traveled distance, direction, frequency,

periodicity, continuity, and temporal alignment – may change partly independently or in different directions. The scales follow Jensenius’s distinction among meter-, centimeter-, and millimeter-level or smaller activity (Jensenius, 2017). Macroscale activity includes spatially extended, visually salient whole-body motion; the mesoscale includes postural sway and visible local gestures; the microscale includes low-amplitude micromotion. Described this way, the movement reorganizations reported in Sections 3 and 4 become traceable, since dissociations among descriptors at a single scale, and dissociations between scales, are visible where a single measure of movement quantity would register an increase, a decrease, or no effect. Findings that appear contradictory when reduced to “more” or “less” movement become coherent when the dimensions and scales are separately analyzed, and they support conditional reorganization.

The model allows for potential functional overlap without presuming it. One action may participate in musical or temporal organization, postural regulation, technical facilitation, expression, and communication. Its roles may differ across moments or observers: a movement may have a communicative effect without improving execution, or a postural consequence without conscious expressive intent. It may equally be habitual, stylistic, redundant, or unrelated to measurable benefit. Multifunctionality is thus a testable proposition. Overlap of this kind has been observed directly in clarinetists, who extend the knees in preparation for inhalation at points that also mark melodic structure (Nusseck et al., 2024). Functional overlap is likewise acknowledged within existing gesture taxonomies (Jensenius et al., 2010), which the present model extends by supplying a means of examining it. The question the model puts to a movement concerns which dimensions and scales change under which constraint, with multifunctionality treated as the hypothesis under test. A recent review by Sun and Wang (2026), which draws partly on evidence from the present program, reaches a compatible position, finding that ancillary movements track musical structure and shape audience judgment, while claims that they reduce cognitive load or serve a specific technical function await controlled manipulation.

Why such overlap should be common is partly explained by coarticulation (Godøy, 2014), whereby sound-producing and ancillary actions are fused into larger action units through practice. The motor learning hypothesis in Section 4.2.3 can be read as a coarticulation account of why restriction fails to decompose learned whole-body patterns. Which role a movement is read as serving then depends on context: the passage, technical demand, expertise, habit, instruction, and stylistic convention. In the second perceptual study, the degree of motion judged most appropriate varied with musical style and predominant gesture rather than following a simple “more is better” relation (Moura et al., 2024). Performer and observer accounts may therefore diverge without either being reducible to the other.

The model’s claims are open to disconfirmation, although the hypotheses of Section 4.2 are unlikely to be separable by any single manipulation. A postural account predicts sensitivity to balance perturbation, instrument load, or support configuration; an entrainment account predicts sensitivity to pulse clarity and rhythmic or tonal predictability; and a learning account predicts effects of expertise, retraining, and transfer. These predictions are not mutually exclusive. Evidence that micromotion changes selectively under one class of manipulation would strengthen the corresponding account, whereas insensitivity across these manipulations would weaken the claim that the activity is systematically organized by the factors proposed here. Until such tests are conducted, the model does not classify persistent movement as necessary, low-amplitude activity as functional, recurrent movement as efficient, or audience-preferred movement as beneficial to the performer. Its principal contribution is consequently methodological as well as conceptual. It converts functional interpretations into propositions that controlled experiments and retraining interventions can examine, by altering a movement dimension or scale and observing the consequences for sound production, timing, postural stability, effort, audience perception, or retention.

6. Methodological and pedagogical implications

The model has several methodological consequences. “Immobile” should be replaced or supplemented by an operational description such as movement-restricted, with the instruction reported verbatim. Self-regulated restriction cannot be assumed to isolate an objectively necessary

technical baseline. Movement should also be measured across dimensions and scales rather than reduced to total quantity, because amplitude, range, velocity, direction, frequency, and timing can change in different directions. Research should distinguish large-scale gesture, postural organization, localized movement, and micromotion while treating these as analytical levels.

Musical structure must likewise be modeled directly. Global comparisons among excerpts can confound the co-occurrence of tempo, rhythmic density, articulation, pitch contour, phrasing, dynamics, and technical difficulty. Future studies should combine motion data with audio and expressive-timing analysis, score-based or computational descriptions, physiological or biomechanical measures, performer reports, and audience responses. These sources address different levels of the phenomenon and should not be treated as interchangeable evidence of function. Causal claims further require perturbation or intervention, together with outcomes such as timing, intonation, sound quality, stability, fatigue, and learning.

Pedagogically, the evidence argues against treating all ancillary movement as either superfluous or beneficial. Instrumental teaching has tended to address the body chiefly in service of technical skill, with interpretation and expression receiving considerably less attention (Bremmer & Nijs, 2020, 2024). The present findings bear on that imbalance through three recommendations. First, teachers should avoid prescribing movement quantity. Neither the perceptual optimum nor the persistence of a movement under restriction supports such a prescription: the first varies with repertoire, and the second does not establish necessity. Second, a proposed change in a student's movement should be evaluated against a specified outcome – intonation, sound quality, timing, postural stability, or the student's own comfort – since visual fluency and technical benefit are separable. Interviewees reported both facilitative and intrusive movements (e.g., interfering with embouchure, fingering, breathing, or stability) (Moura & Serra, 2024). Third, an instruction to stand still cannot be met literally: low-amplitude activity persists when visible movement is minimized, so work on stillness is better framed as redistributing movement across scales than as removing it. Instrument-specific ergonomics, individual anatomy, repertoire, and artistic intention remain central throughout.

7. Conclusion

This synthesis brought together findings at different evidentiary levels. First, across the performer-centered studies, musical components were associated with distinct motion descriptors and scales. Second, as expected, movement restriction reduced the magnitude and spatial extent of visible motion. However, frequency-based and low-amplitude activity persisted under these conditions. Persistent micromotion may be explained by postural regulation, sensorimotor organization, and learned motor patterns, although the studies did not test these functions. The audience-centered studies add a separate result: the communicative value attributed to motion depends on how, where, and by whom it is observed. Based on the integrated findings, the proposed adaptive model of performative gesture moves beyond rigid expressive-functional assignment by asking how bodily activity is reorganized under specific musical, technical, and communicative constraints. It provides a basis for causal experiments and learning interventions testing when motion optimizes performance, when it primarily communicates, and when it remains habitual or functionally indeterminate.

References

- Bremmer, M., & Nijs, L. (2020). The role of the body in instrumental and vocal music pedagogy: A dynamical systems theory perspective on the music teacher's bodily engagement in teaching and learning. *Frontiers in Education*, 5, Article 79. <https://doi.org/10.3389/educ.2020.00079>
- Bremmer, M., & Nijs, L. (2024). Embodiment in music education. *Journal of Research in Arts Education*, 2, 15–26. <https://doi.org/10.26034/vd.jrea.2024.4717>
- Broughton, M. C., & Stevens, C. J. (2009). Music, movement and marimba: An investigation of the role of movement and gesture in communicating musical expression to an audience. *Psychology of Music*, 37(2), 137–153. <https://doi.org/10.1177/0305735608094511>
- Buck, B., MacRitchie, J., & Bailey, N. J. (2013). The interpretive shaping of embodied musical structure in piano performance. *Empirical Musicology Review*, 8(2), 92–119. <https://doi.org/10.18061/emr.v8i2.3929>

- Buhmann, J., Desmet, F., Moens, B., Van Dyck, E., & Leman, M. (2016). Spontaneous velocity effect of musical expression on self-paced walking. *PLOS ONE*, 11(5), Article e0154414. <https://doi.org/10.1371/journal.pone.0154414>
- Buhmann, J., Moens, B., Van Dyck, E., Dotov, D., & Leman, M. (2018). Optimizing beat synchronized running to music. *PLOS ONE*, 13(12), Article e0208702. <https://doi.org/10.1371/journal.pone.0208702>
- Burger, B., Thompson, M., Luck, G., Saarikallio, S., & Toiviainen, P. (2013). Influences of rhythm- and timbre-related musical features on characteristics of music-induced movement. *Frontiers in Psychology*, 4, Article 183. <https://doi.org/10.3389/fpsyg.2013.00183>
- Burger, B., & Toiviainen, P. (2018). Embodiment in electronic dance music: Effects of musical content and structure on body movement. *Musicae Scientiae*, 24(2), 186–205. <https://doi.org/10.1177/1029864918792594>
- Burger, B., & Toiviainen, P. (2020). See how it feels to move: Relationships between movement characteristics and perception of emotions in dance. *Human Technology*, 16(3), 233–256. <https://doi.org/10.17011/HT/URN.202011256764>
- Burger, B., & Wöllner, C. (2023). Drumming action and perception: How the movements of a professional drummer influence experiences of tempo, time, and expressivity. *Music & Science*, 6, 1–17. <https://doi.org/10.1177/20592043231186870>
- Chander, A., Huberth, M., Davis, S., Silverstein, S., & Fujioka, T. (2022). Violinists employ more expressive gesture and timing around global music resolutions: A motion capture study. *Music Perception*, 39(3), 268–288. <https://doi.org/10.1525/MP.2022.39.3.268>
- Coorevits, E., Moelants, D., Maes, P. J., & Leman, M. (2019). Exploring the effect of tempo changes on violinists' body movements. *Musicae Scientiae*, 23(1), 87–110. <https://doi.org/10.1177/1029864917714609>
- Cordo, P. J., & Nashner, L. M. (1982). Properties of postural adjustments associated with rapid arm movements. *Journal of Neurophysiology*, 47(2), 287–302. <https://doi.org/10.1152/jn.1982.47.2.287>
- Dahl, S. (2004). Playing the accent: Comparing striking velocity and timing in an ostinato rhythm performed by four drummers. *Acta Acustica united with Acustica*, 90(4), 762–776.
- Dahl, S., Bevilacqua, F., Bresin, R., Clayton, M. R. L., Leante, L., Poggi, I., & Rasamimanana, N. (2010). Gestures in performance. In R. I. Godøy & M. Leman (Eds.), *Musical gestures: Sound, movement, and meaning* (pp. 36–68). Routledge.
- Davidson, J. W. (1993). Visual perception of performance manner in the movements of solo musicians. *Psychology of Music*, 21(2), 103–113. <https://doi.org/10.1177/030573569302100201>
- Davidson, J. W. (1994). What type of information is conveyed in the body movements of solo musician performers? *Journal of Human Movement Studies*, 6, 279–301.
- Davidson, J. W. (2007). Qualitative insights into the use of expressive body movement in solo piano performance: A case study approach. *Psychology of Music*, 35(3), 381–401. <https://doi.org/10.1177/0305735607072652>
- Davidson, J. W. (2012). Bodily movement and facial actions in expressive musical performance by solo and duo instrumentalists: Two distinctive case studies. *Psychology of Music*, 40(5), 595–633. <https://doi.org/10.1177/0305735612449896>
- Delalande, F. (1988). La gestic de Gould: Éléments pour une sémiologie du geste musical. In G. Guertin (Ed.), *Glenn Gould pluriel* (pp. 85–111). Louise Courteau.
- Demos, A. P., Chaffin, R., & Logan, T. (2017). Musicians' body sway embodies musical structure and expression: A recurrence-based approach. *Musicae Scientiae*, 22(2), 244–263. <https://doi.org/10.1177/1029864916685928>
- Godøy, R. I. (2014). Understanding coarticulation in musical experience. In M. Aramaki, O. Derrien, R. Kronland-Martin, & S. Ystad (Eds.), *Sound, music, and motion: CMMR 2013* (Lecture Notes in Computer Science, pp. 535–547). Springer. https://doi.org/10.1007/978-3-319-12976-1_32
- González Sánchez, V., Zelechowska, A., & Jensenius, A. R. (2018). Correspondences between music and involuntary human micromotion during standstill. *Frontiers in Psychology*, 9, Article 1382. <https://doi.org/10.3389/fpsyg.2018.01382>

- González Sánchez, V., Zelechowska, A., & Jensenius, A. R. (2020). Analysis of the movement-inducing effects of music through the fractality of head sway during standstill. *Journal of Motor Behavior*, 52(6), 734–749. <https://doi.org/10.1080/00222895.2019.1689909>
- Günther, M., Putsche, P., Leistritz, L., & Grimmer, S. (2011). Phase synchronisation of the three leg joints in quiet human stance. *Gait & Posture*, 33(3), 412–417. <https://doi.org/10.1016/j.gaitpost.2010.12.014>
- Hofmann, A., & Goebel, W. (2014). Production and perception of legato, portato, and staccato articulation in saxophone playing. *Frontiers in Psychology*, 5, Article 690. <https://doi.org/10.3389/fpsyg.2014.00690>
- Hsu, W. L., Scholz, J. P., Schöner, G., Jeka, J. J., & Kiemel, T. (2007). Control and estimation of posture during quiet stance depends on multijoint coordination. *Journal of Neurophysiology*, 97(4), 3024–3035. <https://doi.org/10.1152/jn.01142.2006>
- Huberth, M., Davis, S., & Fujioka, T. (2020). Expressing melodic grouping discontinuities: Evidence from violinists' rubato and motion. *Musicae Scientiae*, 24(4), 494–514. <https://doi.org/10.1177/1029864919833127>
- Jensenius, A. R. (2017). Exploring music-related micromotion. In C. Wöllner (Ed.), *Body, sound and space in music and beyond: Multimodal explorations* (pp. 29–48). Routledge. <https://doi.org/10.4324/9781315569628>
- Jensenius, A. R., Wanderley, M. M., Godøy, R. I., & Leman, M. (2010). Musical gestures: Concepts and methods in research. In R. I. Godøy & M. Leman (Eds.), *Musical gestures: Sound, movement, and meaning* (pp. 12–35). Routledge. <https://doi.org/10.4324/9780203863411>
- Jensenius, A. R., Zelechowska, A., & González Sánchez, V. (2017). The musical influence on people's micromotion when standing still in groups. In *Proceedings of the 14th Sound and Music Computing Conference* (pp. 195–199).
- Leman, M. (2008). *Embodied music cognition and mediation technology*. MIT Press.
- Leman, M., & Maes, P.-J. (2014). The role of embodiment in the perception of music. *Empirical Musicology Review*, 9(3–4), 236. <https://doi.org/10.18061/emr.v9i3-4.4498>
- MacRitchie, J., Buck, B., & Bailey, N. J. (2013). Inferring musical structure through bodily gestures. *Musicae Scientiae*, 17(1), 86–108. <https://doi.org/10.1177/1029864912467632>
- Marin, L. S., Gammoudi, H., Behzadaval, B., Leiva, L. A., Chihi, I., & Nijs, L. (2026). Embodiment indicators of music skill acquisition: A scoping review of psychophysiological and biomechanical studies. *Music & Science*, 9, 1–32. <https://doi.org/10.1177/20592043261439571>
- Massie-Laberge, C., Cossette, I., & Wanderley, M. M. (2019). Kinematic analysis of pianists' expressive performances of Romantic excerpts: Applications for enhanced pedagogical approaches. *Frontiers in Psychology*, 9, Article 2725. <https://doi.org/10.3389/fpsyg.2018.02725>
- Moura, N., Fonseca, P., Goethel, M., Oliveira-Silva, P., Vilas-Boas, J. P., & Serra, S. (2023). The impact of visual display of human motion on observers' perception of music performance. *PLOS ONE*, 18(3), Article e0281755. <https://doi.org/10.1371/journal.pone.0281755>
- Moura, N., Fonseca, P., Graça, J., Trovão, P., Goethel, M., Vilas-Boas, J. P., & Serra, S. (2025). Video-based categorization system and frequency analysis of gestures in saxophone playing. *Psychology of Music*, 53(4). <https://doi.org/10.1177/03057356241257425>
- Moura, N., Fonseca, P., Magalhães, B., Vidal, M., Serra, S., & Vilas-Boas, J. P. (2025). Postural adaptations of saxophone players during music performance. *Journal of New Music Research*, 54(2–3), 200–215. <https://doi.org/10.1080/09298215.2026.2648821>
- Moura, N., Fonseca, P., Vilas-Boas, J. P., & Serra, S. (2024). Increased body movement equals better performance? Not always! Musical style determines motion degree perceived as optimal in music performance. *Psychological Research*, 88, 1314–1330. <https://doi.org/10.1007/s00426-024-01928-x>
- Moura, N., & Serra, S. (2024). Saxophone players' self-perceptions about body movement in music performing and learning: An interview study. *Music Perception*, 41(3), 199–216. <https://doi.org/10.1525/MP.2024.41.3.199>
- Moura, N., Vidal, M., Aguilera, A. M., Vilas-Boas, J. P., Serra, S., & Leman, M. (2023). Knee flexion of saxophone players anticipates tonal context of music. *npj Science of Learning*, 8, Article 22. <https://doi.org/10.1038/s41539-023-00172-z>

- Moura, N., Vilas-Boas, J. P., & Serra, S. (2022). How do saxophonists communicate through bodily behavior? A contribution to embodied performance pedagogies. In *Advances in design, music and arts II* (pp. 655–673). Springer. https://doi.org/10.1007/978-3-031-09659-4_47
- Nijs, L., Bremmer, M., van der Schyff, D., & Schiavio, A. (2023). Embodying dynamical systems in music performance. *Music Performance Research*, 11, 58–84. <https://doi.org/10.14439/mpr.11.3>
- Nijs, L., Lesaffre, M., & Leman, M. (2013). The musical instrument as a natural extension of the musician. In M. Castellengo, H. Genevois, & J.-M. Bardez (Eds.), *Music and its instruments* (pp. 467–484). Éditions Delatour France.
- Nusseck, M., Czedik-Eysenberg, I., Spahn, C., & Reuter, C. (2022). Associations between ancillary body movements and acoustic parameters of pitch, dynamics and timbre in clarinet playing. *Frontiers in Psychology*, 13, Article 885970. <https://doi.org/10.3389/fpsyg.2022.885970>
- Nusseck, M., Immerz, A., Hohagen, J., & Spahn, C. (2024). Ancillary and instrumental body movements during inhalation in clarinetists. *Frontiers in Psychology*, 15, Article 1394035. <https://doi.org/10.3389/fpsyg.2024.1394035>
- Pàmies-Vilà, M., Hofmann, A., & Chatziioannou, V. (2018). Analysis of tonguing and blowing actions during clarinet performance. *Frontiers in Psychology*, 9, Article 617. <https://doi.org/10.3389/fpsyg.2018.00617>
- Pàmies-Vilà, M., Scavone, G., Hofmann, A., & Chatziioannou, V. (2017). Investigating vocal tract modifications during saxophone performance. *Proceedings of Meetings on Acoustics*, 31(1). <https://doi.org/10.1121/2.0000758>
- Repp, B. H., & Su, Y. H. (2013). Sensorimotor synchronization: A review of recent research (2006–2012). *Psychonomic Bulletin & Review*, 20(3), 403–452. <https://doi.org/10.3758/s13423-012-0371-2>
- Rose, D., Ott, L., Guérin, S. M. R., Annett, L. E., Lovatt, P., & Delevoye-Turrell, Y. N. (2021). A general procedure to measure the pacing of body movements timed to music and metronome in younger and older adults. *Scientific Reports*, 11, Article 3264. <https://doi.org/10.1038/s41598-021-82283-4>
- Ross, J. M., Warlaumont, A. S., Abney, D. H., Rigoli, L. M., & Balasubramaniam, R. (2016). Influence of musical groove on postural sway. *Journal of Experimental Psychology: Human Perception and Performance*, 42(3), 308–319. <https://doi.org/10.1037/xhp0000198>
- Schiavio, A., & van der Schyff, D. (2018). 4E music pedagogy and the principles of self-organization. *Behavioral Sciences*, 8(8), Article 72. <https://doi.org/10.3390/bs8080072>
- Slis, A., Wolak, K., Namasivayam, A., & van Lieshout, P. (2021). Lingual behavior in clarinet articulation: A multiple-case study into single and double tonguing. *Music & Science*, 4, 1–12. <https://doi.org/10.1177/20592043211034117>
- Spiech, C., Endestad, T., Laeng, B., Danielsen, A., & Haghish, E. F. (2023). Beat alignment ability is associated with formal musical training not current music playing. *Frontiers in Psychology*, 14, Article 1034561. <https://doi.org/10.3389/fpsyg.2023.1034561>
- Sun, Y., & Wang, Y. (2026). Ancillary body movements in piano performance: A critical narrative review of structural coupling, audience cues, and cognitive-scaffolding claims. *Frontiers in Psychology*, 17, Article 1838025. <https://doi.org/10.3389/fpsyg.2026.1838025>
- Thompson, M., & Luck, G. (2012). Exploring relationships between pianists' body movements, their expressive intentions, and structural elements of the music. *Musicae Scientiae*, 16(1), 19–40. <https://doi.org/10.1177/1029864911423457>
- Tsai, Y. Y., Chang, G. C., & Hwang, I. S. (2020). Changes in postural strategy of the lower limb under mechanical knee constraint on an unsteady stance surface. *PLOS ONE*, 15(11), Article e0242790. <https://doi.org/10.1371/journal.pone.0242790>
- Varela, F. J., Thompson, E., & Rosch, E. (2016). *The embodied mind: Cognitive science and human experience* (Rev. ed.). MIT Press.
- Wanderley, M. M. (2002). Quantitative analysis of non-obvious performer gestures. In I. Wachsmuth & T. Sowa (Eds.), *Gesture and sign language in human-computer interaction* (pp. 241–253). Springer.
- Wanderley, M. M., Vines, B. W., Middleton, N., McKay, C., & Hatch, W. (2005). The musical significance of clarinetists' ancillary gestures: An exploration of the field. *Journal of New Music Research*, 34(1), 97–113. <https://doi.org/10.1080/09298210500124208>