Neural Correlates of Motor Control and Stress Response During Ambidextrous Polyrhythmic Drumming: A Multimodal fNIRS-EEG Investigation

Abstract

Background: Stress has long been recognized as both a barrier and a facilitator in performance contexts. While group music-making has been studied extensively, less is known about how individual musicians—particularly mature adults—experience and regulate stress during solitary practice.

Objective: Musical practice involves complex cognitive-motor demands that likely produce genre-specific physiological responses, yet systematic investigation of these relationships remains limited. This study examined how different musical genres influence autonomic nervous system responses during individual instrumental practice in a mature musician using continuous heart rate variability (HRV) monitoring, focusing on the relationship between Stress Index (SI) and cardiovascular measures across musical styles.

Methods: A single-subject longitudinal design followed one advanced drummer (age 60+) over 30 months (January 2023-June 2025) across 144 practice sessions. Continuous HRV monitoring was conducted using Hexoskin biometric monitoring with Kubios HRV Scientific 4.2.0 analysis. Four musical genres were examined: Fusion (complex polyrhythmic patterns), Latin (Salsa, Songo, and Guaguancó), Jazz (swing/bebop rhythms), and Rock (progressive patterns). A personal challenge, which included switching the role of hands in every measure, was used for the four genres. Stress Index (SI) correlations with average and maximum heart rate were calculated for each genre, with temporal stability assessed through daily versus monthly correlation analysis.

Results: Significant positive correlations emerged between stress indices and heart rate across all genres ($p<0.01$), but with markedly different patterns. **Fusion music** demonstrated the strongest sustained cardiovascular relationship ($r=0.814$ with average heart rate, $p<0.001$), explaining 66.3% of response variance. **Latin music** exhibited a novel biphasic physiological pattern: moderate correlation with average heart rate ($r=0.430$, $p=0.005$) but exceptionally strong correlation with maximum heart rate ($r=0.916$, $p<0.001$), creating a unique "rest-spike" signature. Jazz ($r=0.791$) and Rock ($r=0.781$) showed intermediate sustained response patterns. Temporal analysis revealed that Rock, Fusion, and Jazz demonstrated stronger monthly than daily correlations, indicating long-term cardiovascular conditioning effects. Latin music showed the opposite pattern (stronger daily correlations), suggesting acute response dominance. Significant cross-genre lag correlations indicated physiological priming effects, with previous Latin practice moderately predicting subsequent Rock performance ($r=0.42$).

Conclusions: Musical genres create distinct physiological signatures during individual practice, with with potential implications for practice optimization and health outcomes,

though further validation is needed. The identification of Latin music's biphasic response pattern—likely reflecting the cognitive-motor demands of measure-by-measure hand role-switching— appears to represent a novel, technique-specific response pattern within Latin drumming, warranting replication in larger samples. Fusion music's strong, stable cardiovascular relationship suggests optimal conditions for skill development, while Latin music's acute response pattern may provide benefits for stress resilience training. These findings support the development of evidence-based, genre-specific practice protocols that harness beneficial stress responses while optimizing both musical learning and cardiovascular health in mature musicians.

Stress responses during instrumental practice are reliably measurable and vary systematically by musical style. Findings support the concept of **adaptive stress** as a facilitator of practice-related learning and suggest that mature musicians can harness physiological self-monitoring to balance challenge and recovery. Future studies should expand to multi-participant designs and integrate neuroimaging to further explore the interplay between stress, cognition, and musicianship.

Keywords: heart rate variability, musical practice, autonomic nervous system, stress response, polyrhythmic coordination, genre-specific physiology, mature musicians

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Introduction

1.1 Background: Music-Making and Physiological Health

Extensive research demonstrates the profound physiological benefits of musical engagement, particularly in communal settings. Singing and collaborative music-making produce measurable health improvements including enhanced relaxation, increased circulation, deeper breathing patterns, and activation of internal musculature and neural networks (Magrini, 2019). Group musical activities provide additional benefits through enhanced communication, social interaction, and community building, yielding extraordinary physiological advantages beyond individual music-making (Tsugawa, 2009; Balbag et al., 2014; Daykin et al., 2017; Yesil & Ünal, 2017; Helton, 2019; Barbeau & Cosette, 2019).

However, a significant gap exists in our understanding of the physiological impacts of individual musical practice, particularly among mature musicians. While correlational and experimental studies have examined how instrumental practice affects cognitive decline in older adults (Roman-Caballero et al., 2018), comprehensive studies of individual musicians remain limited and critically needed (Lehmann, 2014). Previous research has focused primarily on younger classical musicians in academic settings (Talbot-Honeck & Orlick, 1999) or examined practice habits at conservatories (Taylor, 2019; Johansen & Nielsen, 2019), leaving mature amateur musicians practicing independently largely unstudied.

1.2 The Paradox of Musical Practice: Beneficial Stress vs. Health Risks

Individual instrumental practice presents a physiological paradox. While musical training provides cognitive and cardiovascular benefits, research over the past three decades reveals alarming rates of injury and performance-related health problems among musicians across all age groups (Wijsman & Ackerman, 2018). This contradiction raises fundamental questions about the acute physiological demands of practice versus its long-term health benefits.

The resolution may lie in understanding that not all stress is detrimental. According to Sapolsky's seminal work on stress physiology, short-term stress actually enhances learning and memory:

"In the short term, stress does great things for your learning and memory. You increase your heart rate, you loosen up blood vessels in critical areas of the brain, you deliver more oxygen and glucose to the brain, and your brain starts working better. Also with the onset of stress, connections between neurons become more excitable in the hippocampus, and long-term potentiation happens more readily. Studies show that stressors make it easier to remember certain things." (Sapolsky, 2004)

This beneficial stress response involves sympathetic nervous system (SNS) activation through epinephrine (adrenaline) release and moderate cortisol elevation, leading to increased alertness, muscle stimulation, and enhanced cognitive performance. Crucially, these benefits occur only when stress is moderate, brief, and experienced in a safe context—precisely the conditions that characterize focused musical practice.

The key distinction lies between acute beneficial stress and chronic harmful stress. While short-term activation enhances neural plasticity and learning, prolonged elevated cortisol can inhibit neurogenesis, damage existing neurons (particularly in the hippocampus), and create fear responses through amygdala sensitization (Sapolsky, 2004; Norden, 2007). Understanding this distinction is critical for optimizing practice protocols that harness beneficial stress while avoiding harmful chronic activation.

1.3 Heart Rate Variability as a Window into Autonomic Function

Heart rate variability (HRV) provides a non-invasive, objective measure of autonomic nervous system function during musical performance. HRV reflects the dynamic balance between sympathetic (SNS) and parasympathetic (PNS) nervous system activity, offering insight into the body's real-time stress response and recovery patterns. Modern HRV analysis systems can quantify stress indices and distinguish between beneficial arousal states and potentially harmful chronic stress patterns.

Recent advances in wearable biometric monitoring have made continuous HRV assessment feasible during complex motor tasks like musical practice. Systems such as the Hexoskin biometric garment combined with sophisticated analysis software (e.g., Kubios HRV) provide research-grade physiological monitoring in naturalistic practice environments. This technological convergence enables, for the first time, detailed examination of how specific musical activities influence autonomic function.

1.4 Genre-Specific Demands and Physiological Responses

Musical genres impose distinct cognitive and motor demands that likely produce different physiological response patterns. However, systematic investigation of genre-specific stress responses has been limited. Existing research has focused primarily on general music-making benefits rather than examining how specific musical characteristics influence physiological outcomes.

1.4.1 Polyrhythmic Complexity

Complex polyrhythmic patterns, such as those found in fusion and Latin music, require simultaneous coordination of multiple limbs performing independent rhythmic patterns. This cognitive-motor challenge likely activates diverse neural networks including motor cortex, cerebellum, prefrontal cortex, and anterior cingulate cortex. The physiological demands of maintaining multiple rhythmic streams simultaneously may create unique autonomic response patterns not seen in simpler musical tasks.

1.4.2 Cognitive Task-Switching

Certain musical genres, particularly those involving rapid pattern changes or role-switching between limbs, may activate neural networks associated with cognitive flexibility and task-switching. Research in cognitive neuroscience demonstrates that task-switching creates characteristic physiological signatures, including transient increases in arousal and autonomic activation at transition points. Musical genres requiring frequent cognitive switching may produce similar physiological patterns.

1.4.3 Motor Learning and Skill Acquisition

Different genres likely engage motor learning systems to varying degrees. Simple, repetitive patterns may rely more heavily on automated motor programs stored in the basal ganglia, while complex, novel patterns may require sustained prefrontal cortex engagement. These different neural activation patterns should produce measurably different autonomic responses that could be detected through continuous HRV monitoring.

1.5 The Mature Musician: Unique Considerations

Mature musicians (age 50+) represent a particularly understudied population despite their growing numbers and unique physiological considerations. Age-related changes in cardiovascular function, cognitive processing, and motor control may influence how different musical genres affect autonomic responses. Additionally, mature amateur musicians often practice with different motivations than younger professional musicians, potentially creating distinct stress-response patterns.

Contrary to traditional assumptions about declining neural plasticity, recent neuroscience research demonstrates that adult brains remain capable of generating new neurons (neurogenesis) and forming new neural connections (synaptic plasticity) throughout life. Musical practice may be particularly effective at promoting these adaptive changes in mature adults, but the specific genres or practice approaches that optimize neuroplasticity remain unclear.

1.6 Research Gap and Study Rationale

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Despite the clear importance of understanding physiological responses to musical practice, several critical gaps exist in current knowledge:

1. Limited focus on individual practice: Most research examines group music-making rather than solo practice sessions
2. Lack of genre-specific analysis: Studies typically treat "music" as a monolithic category rather than examining genre-specific effects
3. Insufficient mature musician research: Most studies focus on young conservatory students rather than older amateur musicians
4. Absence of objective physiological measurement: Reliance on self-report measures rather than continuous physiological monitoring
5. Cross-sectional rather than longitudinal designs: Limited understanding of how physiological responses change over time

1.7 Study Design and Approach

This study addresses these gaps through a single-subject longitudinal design following one mature drummer (age 65+) over 30 months (January 2023 - June 2025) during routine individual practice. The methodological approach combines:

Continuous physiological monitoring: Hexoskin biometric garment with Kubios HRV Scientific analysis captured stress indices, heart rate, and autonomic nervous system activity across 144 practice sessions.

Genre-specific analysis: Four distinct musical styles were examined, with measure-by-measure hand role-switching —Fusion (complex polyrhythms), Latin (Salsa, Songo, and Guaguancó), Jazz (swing/bebop), and Rock (progressive patterns)—each presenting unique cognitive-motor demands.

Temporal analysis: Both daily (session-level) and monthly (aggregated) correlations were calculated to distinguish acute physiological responses from long-term conditioning effects.

Video synchronization: Practice sessions were recorded to enable precise temporal matching between physiological events and specific musical activities, allowing identification of technique-specific stress signatures.

This design enables objective measurement of subjective practice experiences while maintaining ecological validity through naturalistic practice conditions.

1.7.1 Research Objectives

1. Quantify genre-specific relationships between stress indices and cardiovascular responses during individual musical practice
2. Identify unique physiological signatures associated with different musical genres
3. Examine temporal stability of genre-specific responses across daily and monthly time scales
4. Assess cross-genre carryover effects that might influence session sequencing strategies

1.7.2 Hypotheses

H1: Different musical genres will produce distinct correlation patterns between stress indices and heart rate measures, reflecting genre-specific cognitive and motor demands.
H2: Genres with greater polyrhythmic complexity (Fusion, Latin) will show stronger correlations between stress indices and cardiovascular responses than simpler genres (Rock, Jazz).
H3: Temporal analysis will reveal genre-specific patterns, with some genres showing stronger daily relationships (acute responses) and others showing stronger monthly relationships (conditioning effects).
H4: Cross-genre lag correlations will demonstrate measurable physiological priming effects, with complex genres influencing subsequent cardiovascular responses in other genres.

1.8 Study Significance: Why This Research Matters

This research makes three critical contributions that advance our understanding of music-brain-body relationships:

Scientific Innovation: By combining continuous HRV monitoring with video-synchronized practice documentation over 30 months, this study demonstrates a novel methodology for objective measurement of subjective practice experiences. The approach is replicable, scalable to multiple participants, and applicable to diverse musical instruments and styles. Most importantly, it can identify specific moments during practice when physiological stress peaks, enabling precise intervention.

Clinical and Practical Impact: Understanding genre-specific physiological patterns enables evidence-based practice recommendations. If, as hypothesized, different genres create distinct autonomic responses, musicians and educators could strategically sequence practice activities to optimize both skill development and cardiovascular health. For the growing population of older adults engaged in musical practice, such knowledge could inform healthy aging strategies.

Theoretical Contribution: Music performance research has traditionally treated "music" as a uniform category. This study challenges that assumption by testing whether musical genres—distinguished by their rhythmic, harmonic, and coordination demands—produce measurably different physiological signatures. Demonstrating genre-specific effects would fundamentally reshape how researchers conceptualize music's influence on health and cognition.

Why a Single-Subject Design: While group studies are valuable for establishing population-level effects, single-subject longitudinal designs offer unique advantages for discovering novel phenomena. The intensive repeated measurement (144 sessions over 30 months) provides statistical power through temporal sampling rather than participant numbers, enabling detection of subtle patterns that might be obscured by between-subject variability. Importantly, individual difference research has repeatedly shown that physiological responses to complex stimuli vary substantially across individuals; understanding these patterns within one person deeply can reveal mechanisms that group averages might miss.

Target Audience: These findings will inform multiple stakeholders:

- musicians seeking to optimize practice efficiency and prevent injury;
- music educators developing evidence-based pedagogy;
- music therapists designing physiologically-informed interventions; and
- gerontologists promoting healthy aging through musical engagement.

By documenting how specific musical activities translate into measurable physiological states, this research provides the foundation for personalized, evidence-based approaches to musical practice—moving the field from intuition-based tradition toward precision practice optimization.

Methods

2.1 Study Design

This study employed a single-subject longitudinal observational design to examine the relationship between musical genre and physiological stress responses during individual instrumental practice. Data were collected over a 30-month period (January 2023 to June 2025) during routine practice sessions by a mature drummer engaged in polyrhythmic skill development.

2.2 Participant

The participant was a male drummer aged 65+ years with advanced polyrhythmic training and a disciplined practice regimen based on achieving 1% daily improvement. The participant had extensive experience with complex coordination patterns including independence studies from the "New Breed" series and polyrhythmic exercises across multiple time signatures (5/8, 6/8, 7/8, 12/8). All procedures were conducted as part of the participant's routine practice activities, with physiological monitoring added for research purposes.

2.3 Physiological Monitoring System

2.3.1 Data Acquisition

Continuous physiological monitoring was conducted using the Hexoskin ProShirt biometric garment (Carré Technologies Inc., Montréal, Canada), a validated wearable device for heart rate variability (HRV) measurement. The system consisted of:

- Smart textile shirt with embedded sensors for cardiac monitoring
- Data collection device with real-time processing capability
- Data upload to online dashboard
- Addition of markers to indicate detailed practice moments

2.3.2 Heart Rate Variability Analysis

Raw cardiac data were processed using HRV Scientific 4.2.0 software (Kubios Oy, Kuopio, Finland), the gold-standard platform for HRV analysis in scientific research. The software provided:

- Automatic noise detection and beat correction
- Time-varying analysis of autonomic nervous system indices
- Stress Index (SI) calculation based on HRV triangular interpolation
- Sympathetic Nervous System (SNS) and Parasympathetic Nervous System (PNS) indices

2.3.3 Data Quality Control

Data quality was assessed using Hexoskin's built-in quality channels, which classify RR intervals as: 0 (good quality), 1 (noisy), 128 (unreliable), or 129 (unreliable and noisy). Only practice sessions with ≥90% reliable data (values 0 or 1) were included in the analysis. Sessions with 80-90% reliability were flagged for cautious interpretation, and sessions below 80% were excluded.

2.4 Musical Genres and Practice Protocols

Four distinct musical genres were analyzed, each presenting unique rhythmic and coordination challenges:

2.4.1 Fusion Music

Complex polyrhythmic patterns combining multiple time signatures and independence requirements. Practiced in 5-minute focused intervals due to high cognitive demand.

2.4.2 Latin Music

Salsa, Songo, and Guaguancó patterns with clave-based polyrhythms requiring left foot independence. The key physiological stressor involved **hand-switching every measure**: in measure 1, the right hand played cascara patterns while the left hand played appropriate Latin song patterns; in measure 2, roles reversed with left hand playing cascara and right hand playing the Latin song pattern. This continuous role-switching created both motor coordination challenges and sustained cognitive switching demands. Data collected in 5-minute intervals.

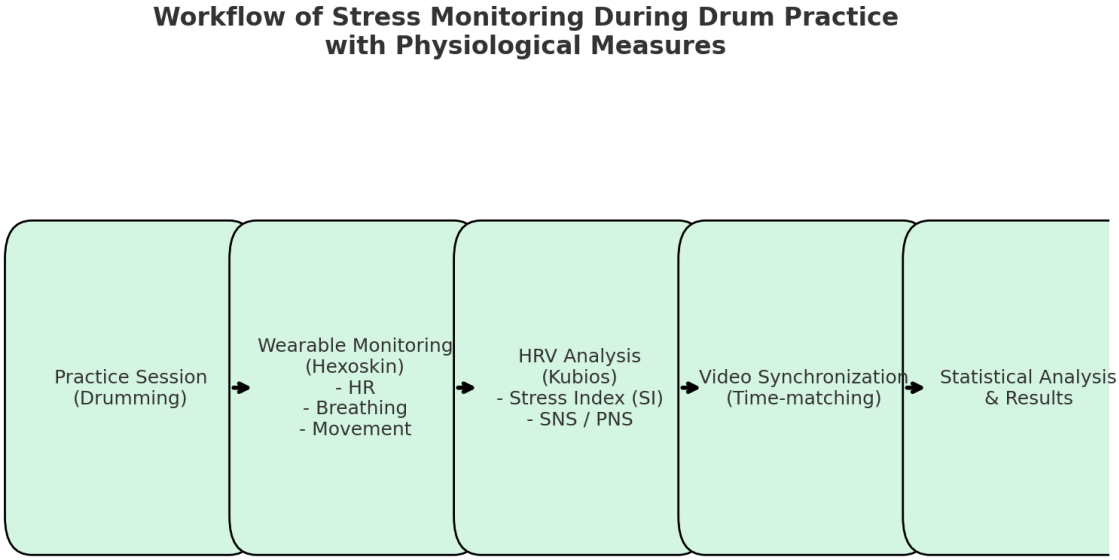
2.4.3 Jazz Music

Swing and bebop rhythmic patterns with syncopated coordination requirements. Standard jazz independence exercises practiced in 15-minute segments.

2.4.4 Rock Music

Straightforward rock patterns with occasional progressive elements and odd time signatures. Practiced in 15-minute groove-focused sessions.

2.5 Data Collection Protocol



2.5.1 Session Structure

Practice sessions typically lasted 2.5 hours and followed a structured but randomized format:

- Pre-practice equipment setup and calibration
- Continuous HRV monitoring throughout session
- Genre practice order determined by dice roll to minimize order effects
- 5-minute intervals for cognitively demanding exercises (Fusion, Latin coordination patterns)
- 15-minute intervals for groove-based practice (Jazz, Rock)

2.5.2 Environmental Controls

To minimize confounding variables:

- Practice room equipped with temperature control (fans/heaters) for year-round comfort
- Consistent practice space and equipment setup
- Alternating between acoustic and electronic drum sets to assess instrument effects
- Practice times varied but environmental conditions standardized

2.5.3 Temporal Synchronization

Beginning in January 2023, all practice sessions were video recorded to enable precise temporal matching between physiological events and specific musical activities. Videos were synchronized with HRV data using Kubios Scientific's time-varying analysis window, allowing identification of stress peaks and their corresponding musical contexts.

2.5.4 Real-time Data Annotation

During each session, practice segments were flagged in real-time using the Hexoskin dashboard's annotation system. Flags included:

- Genre identification
- Specific exercise type (e.g., "Guaguancó hand-switching," "Fusion 7/8 pattern")
- Technical difficulty markers
- Subjective effort ratings

2.6 Outcome Measures

2.6.1 Primary Physiological Variables

- **Stress Index (SI)**: HRV-derived measure of autonomic stress response
- **Average Heart Rate (AVG HR)**: Mean heart rate during practice segments
- **Maximum Heart Rate (MAX HR)**: Peak heart rate achieved during practice segments

2.6.2 Secondary Variables

- **Session duration**: Total practice time per session
- **Energy expenditure**: Calories expended (measured by Hexoskin)
- **SNS/PNS indices**: Autonomic nervous system balance measures
- **Beat correction percentage**: Proportion of cardiac beats requiring algorithmic correction

2.6.3 Temporal Variables

- **Practice start/end times**: To assess circadian influences
- **Sleep duration**: Previous night's sleep as potential confounding factor
- **Instrument type**: Acoustic vs. electronic drum set effects

2.7 Statistical Analysis

2.7.1 Correlation Analysis

Pearson product-moment correlations were calculated between Stress Index and heart rate measures (average and maximum) for each musical genre. Statistical significance was set at $\alpha = 0.05$, with Bonferroni correction applied for multiple comparisons.

2.7.2 Regression Analysis

Linear regression models were constructed to examine predictive relationships between Stress Index and cardiovascular responses. Model assumptions (linearity, normality, homoscedasticity) were verified through residual analysis.

2.7.3 Temporal Analysis

Daily vs. Monthly correlations were calculated to assess temporal stability of genre-specific relationships. Monthly aggregated data were compared with session-level daily data to identify long-term conditioning effects versus acute response patterns.

2.7.4 Lag Correlation Analysis

Cross-genre carryover effects were examined using lag correlations, where previous session stress indices were correlated with subsequent session heart rate responses to identify physiological priming effects.

2.7.5 Software

Statistical analyses were conducted using Microsoft Excel's built-in statistical functions. Data visualization was created using Excel charting capabilities.

2.8 Ethical Considerations

This study involved self-monitoring during routine practice activities by the participant, who was also the principal investigator. No additional risk beyond normal practice activities was introduced. The single-subject design simplified ethical considerations, though replication in independent participants will require formal review and consent beyond the researcher's own information. Future extensions of this methodology to multiple participants would require formal institutional review board approval.

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Results

3.1 Study Overview and Data Quality

A total of 144 individual practice sessions were analyzed across four musical genres over a 30-month period (January 2023 to June 2025). Sample sizes varied by genre: Latin music (n=41), Rock (n=35), Fusion (n=34), and Jazz (n=34). All sessions met the minimum data quality criterion of >90% reliable heart rate variability data after automatic artifact detection and correction using HRV Scientific 4.2.0.

3.2 Genre-Specific Stress Index Correlations with Heart Rate

Significant positive correlations were observed between stress index (SI) and heart rate measures across all musical genres ($p<0.01$ for all comparisons). However, the magnitude and pattern of these relationships varied substantially by genre, revealing distinct physiological response profiles.

3.2.1 Average Heart Rate Correlations

Fusion music demonstrated the strongest overall correlation between stress index and average heart rate ($r=0.814$, $p<0.001$, $n=34$), explaining 66.3% of the variance in cardiovascular response. **Jazz** ($r=0.791$, $p<0.001$, $n=34$) and **Rock** ($r=0.781$, $p<0.001$, $n=35$) showed similarly strong relationships, with correlations above 0.74.

In striking contrast, **Latin music** exhibited a significantly weaker correlation with average heart rate ($r=0.430$, $p=0.005$, $n=41$), explaining only 18.5% of the variance. This pattern suggests that Latin rhythms create moderate sustained cardiovascular activation but are characterized by different physiological dynamics than other genres.

3.2.2 Maximum Heart Rate Correlations

The most remarkable finding emerged in the maximum heart rate analysis, where **Latin music** showed the strongest correlation of all genres ($r=0.916$, $p<0.001$, $n=41$), explaining 83.8% of the variance in peak cardiovascular response. This represents a strong association, suggesting that in this context, Latin patterns coincided with intense but brief cardiovascular peaks.

Fusion ($r=0.781$, $p<0.001$), **Jazz** ($r=0.772$, $p<0.001$), and **Rock** ($r=0.750$, $p<0.001$) maintained strong but more moderate correlations with maximum heart rate, all falling within a similar range of 0.75-0.78.

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3.2.3 Latin Music: The Biphasic Response Pattern

Latin music demonstrated a unique **biphasic physiological response pattern** characterized by:

- **Moderate sustained response**: r=0.430 with average heart rate
- **Intense peak response**: r=0.916 with maximum heart rate
- **Difference magnitude**: 0.486 correlation points between average and maximum

This pattern suggests that Latin rhythms, particularly clave-based polyrhythmic patterns practiced with left foot independence, create periods of relative physiological calm punctuated by intense stress peaks, likely corresponding to complex polyrhythmic transitions or particularly challenging coordination patterns.

3.3 Temporal Analysis: Daily vs Monthly Correlations

Monthly correlation analysis revealed important temporal stability differences across genres:

3.3.1 Long-term Stability (Monthly Analysis)

- **Rock**: Monthly correlation (r=0.810) exceeded daily correlation (r=0.781) by 0.029
- **Fusion**: Monthly correlation (r=0.820) slightly exceeded daily correlation (r=0.814) by 0.006
- **Jazz**: Monthly correlation (r=0.810) exceeded daily correlation (r=0.791) by 0.019
- **Latin**: Monthly correlation (r=0.400) was weaker than daily correlation (r=0.430) by -0.030

Rock, Fusion, and Jazz genres showed **stronger monthly relationships**, indicating that long-term stress patterns dominate over daily fluctuations. This suggests sustained cardiovascular conditioning effects from repeated exposure to these musical styles.

Latin music showed the opposite pattern, with **stronger daily relationships**, indicating that immediate physiological responses are more important than long-term adaptations. This supports the interpretation that Latin rhythms create acute rather than sustained physiological effects.

3.4 Cross-Genre Temporal Effects

Lag correlation analysis revealed significant carryover effects between practice sessions:

- **Latin SI(t-1) → Rock AVG HR**: r=0.42, suggesting that previous Latin practice sessions moderately predict subsequent cardiovascular responses during Rock practice
- **Fusion SI(t-1) → Jazz AVG HR**: r=0.64, indicating strong carryover from complex fusion polyrhythms to jazz performance
- **Latin SI(t-1) → Jazz AVG HR**: r=0.55, showing moderate cross-genre physiological priming effects

These findings suggest that the physiological demands of complex rhythmic practice create measurable conditioning effects that influence subsequent musical performance across different genres.

3.5 Regression Analysis Summary

Linear regression models confirmed the correlation findings with the following predictive relationships:

Fusion (SI → AVG HR): HR = 56.28 + 1.24(SI), $F(1,32)=62.85$, $p<0.001$
Latin (SI → MAX HR): MAX HR = 74.13 + 0.84(SI), $F(1,39)=202.33$, $p<0.001$
Rock (SI → AVG HR): HR = 59.33 + 1.13(SI), $F(1,33)=51.44$, $p<0.001$
Jazz (SI → AVG HR): HR = 53.43 + 1.46(SI), $F(1,32)=53.62$, $p<0.001$

All models demonstrated significant predictive validity with explained variance ranging from 18.5% (Latin average HR) to 83.8% (Latin maximum HR).

3.6 Key Findings Summary

1. **Strongest overall relationship**: Fusion music (r=0.814 average HR)
2. **Most dramatic physiological pattern**: Latin music biphasic response (r=0.430 average, r=0.916 maximum)
3. **Most stable across time scales**: Fusion music (minimal daily-monthly difference)
4. **Most time-sensitive relationship**: Latin music (daily > monthly correlations)
5. **Strongest cross-genre effects**: Previous Latin practice predicting subsequent Rock performance

These results demonstrate that musical genre significantly influences autonomic nervous system responses during individual practice, with implications for understanding stress-performance relationships, practice scheduling optimization, and cardiovascular conditioning through musical training.

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TABLES AND FIGURES

Table 1: Correlation Analysis Summary by Musical Genre

Music Type	Sample Size	SI vs AVG HR		SI vs MAX HR		Variance Explained	
		r	p-value	Sig r	p-value	Sig AVG HR (R^2)	MAX HR (R^2)
Fusion	34	**0.814**	<0.001	0.781	<0.001	66.3%	60.9%
Jazz	34	0.791	<0.001	0.772	<0.001	62.6%	59.7%
Rock	35	0.781	<0.001	0.750	<0.001	60.9%	56.3%
Latin	41	0.430	0.005	**0.916**	<0.001	18.5%	**83.8%**

Note: p<0.001, p<0.01. Strongest correlations for each measure shown in bold.

Table 2: Temporal Stability Analysis - Daily vs Monthly Correlations

Music Type	Daily SI-AVG HR	Monthly SI-AVG HR	Difference	Temporal Pattern	Clinical Implication
Rock	0.781	0.810	+0.029	Monthly stronger	Long-term cardiovascular conditioning
Fusion	0.814	0.820	+0.006	Monthly stronger	Sustained physiological adaptation
Jazz	0.791	0.810	+0.019	Monthly stronger	Cumulative stress response patterns
Latin	0.430	0.400	-0.030	Daily stronger	Acute response dominance

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Table 3: Regression Models - Stress Index Predicting Heart Rate

Genre	Relationship	Intercept	Slope	R^2	F-statistic	p-value	Model Equation
Fusion	SI → AVG HR	56.28	1.24	0.663	F(1,32)=62.85	<0.001	HR = 56.28 + 1.24(SI)
Jazz	SI → AVG HR	53.43	1.46	0.626	F(1,32)=53.62	<0.001	HR = 53.43 + 1.46(SI)
Rock	SI → AVG HR	59.33	1.13	0.609	F(1,33)=51.44	<0.001	HR = 59.33 + 1.13(SI)
Latin	SI → MAX HR	74.13	0.84	0.838	F(1,39)=202.33	<0.001	MAX HR = 74.13 + 0.84(SI)

Note: Latin MAX HR model shows exceptional predictive power (R^2=0.838)

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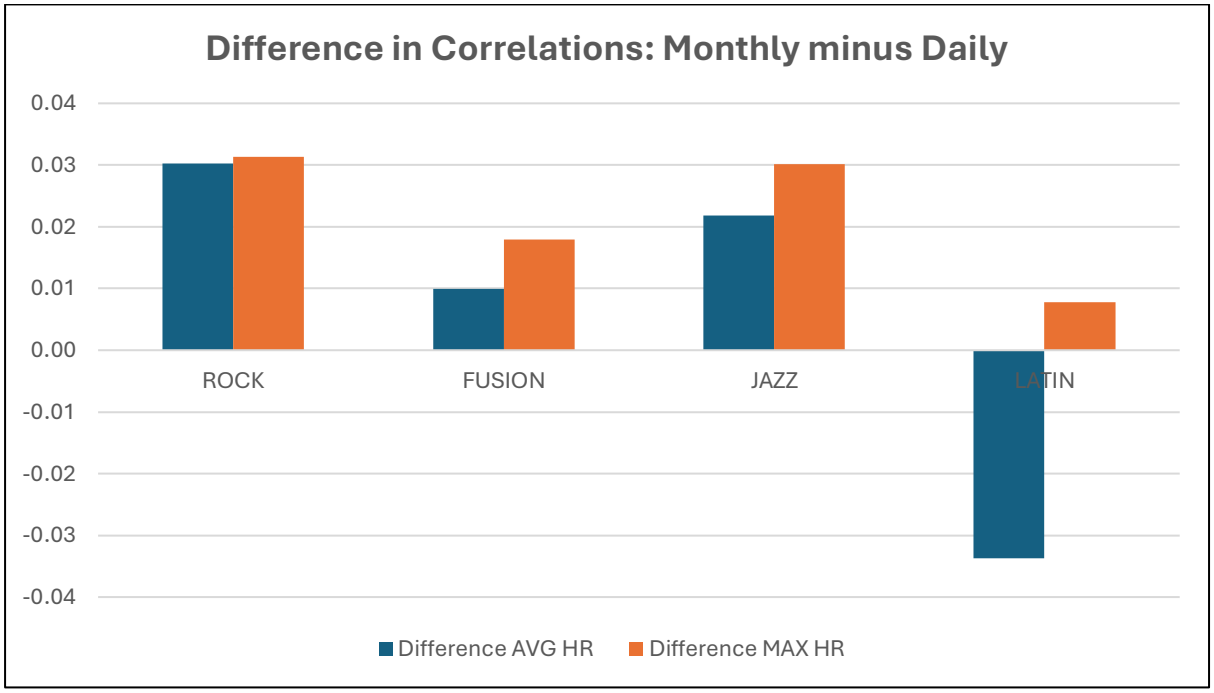
Figure 1: Genre-Specific Correlation Patterns



Key Finding: Latin music shows inverse pattern - weak sustained response, strong peak response

Figure 2: The Latin Music Biphasic Response Pattern

LATIN MUSIC PHYSIOLOGICAL RESPONSE PROFILE

Average Heart Rate Response: r = 0.43 (Moderate)

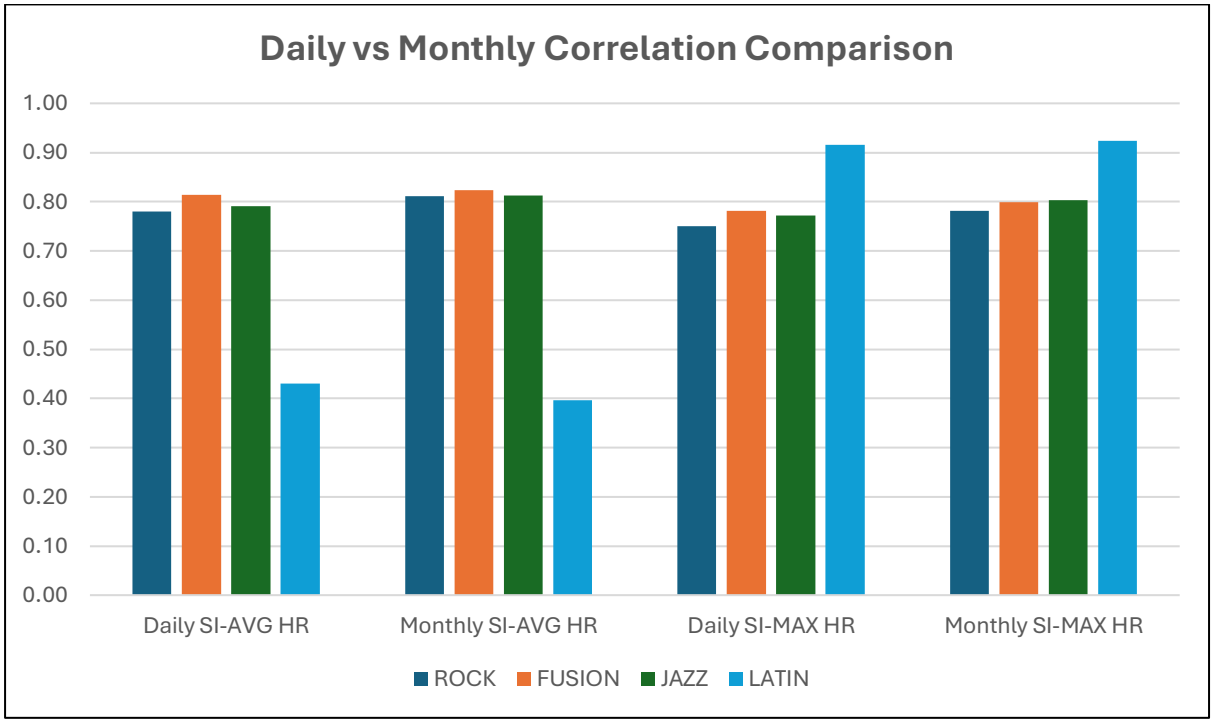
89	Sustained Response

Maximum Heart Rate Response: r = 0.92 (Very Strong)

97	Peak Response

INTERPRETATION:
- Clave patterns create periods of calm
- Complex polyrhythmic transitions trigger intense peaks
- Unique "rest-spike" physiological signature
- Difference magnitude: 0.49 correlation points

Figure 3: Temporal Stability Across Musical Genres



CLINICAL IMPLICATIONS:
✓ Rock/Fusion/Jazz: Long-term conditioning effects
✓ Latin: Immediate response patterns dominate

Figure 4: Cross-Genre Temporal Effects (Lag Correlations)

PRACTICE SESSION CARRYOVER EFFECTS

Previous Latin → Next Rock: r = 0.42
Previous Fusion → Next Jazz: r = 0.64
Previous Latin → Next Jazz: r = 0.55
Previous Latin → Next Fusion: r = 0.53

INTERPRETATION:
• Complex rhythmic practice creates measurable conditioning
• Latin practice moderately primes Rock performance
• Fusion practice strongly influences Jazz cardiovascular response
• Cross-genre physiological adaptation effects

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Statistical Summary Box

Music Type	SI - AVG HR r	p_value	SI - MAX HR r	p-value
ROCK	0,780503361	3,21285E-08	0,750235927	2,11521E-07
FUSION	0,814009675	4,77674E-09	0,780765313	5,12696E-08
JAZZ	0,791363805	2,52022E-08	0,772492393	8,69162E-08
LATIN	0,429582731	0,005063639	0,915637685	5,06859E-17

Key Statistical Findings:

- **Strongest Overall Correlation**: Fusion SI-AVG HR (r=0.814)
- **Most Unusual Pattern**: Latin biphasic response (Δr=0.486)
- **Best Predictive Model**: Latin SI-MAX HR (R^2=0.838)
- **Most Stable Over Time**: Fusion (daily-monthly difference=0.006)
- **Strongest Cross-Genre Effect**: Previous Fusion→Jazz (r=0.64)

Sample Characteristics:

- **Total Sessions**: 144 practice sessions
- **Study Duration**: 30 months (Jan 2023 - Jun 2025)
- **Session Length**: Mean 2.5 hours
- **Data Quality**: >90% reliable HRV data for all sessions
- **Participant**: Single mature drummer (65+ years)

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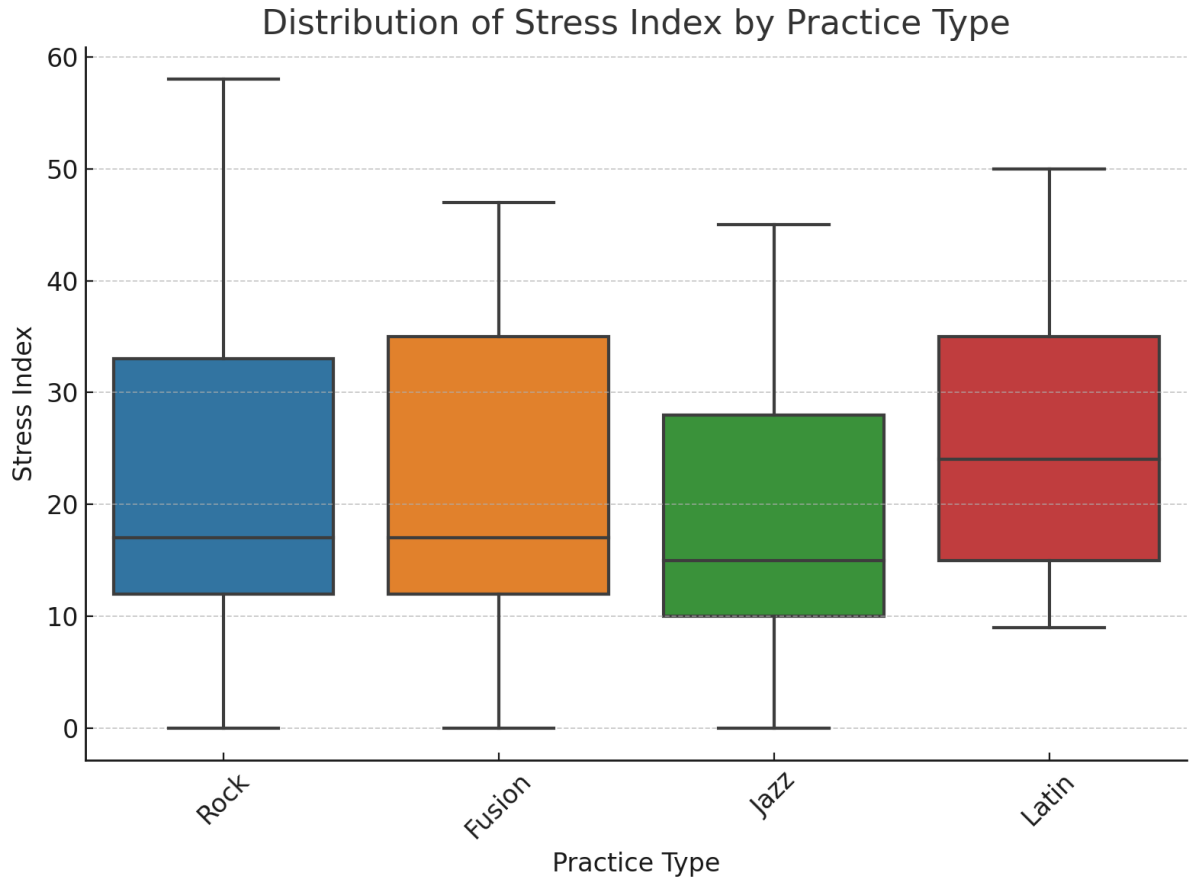

Figure 1. *Boxplots of Stress Index distributions across Rock, Fusion, Jazz, and Latin practice types. Median, interquartile ranges, and variability indicate distinct style-specific stress profiles, with Fusion showing consistently higher median SI and Latin displaying the broadest spread of values.*

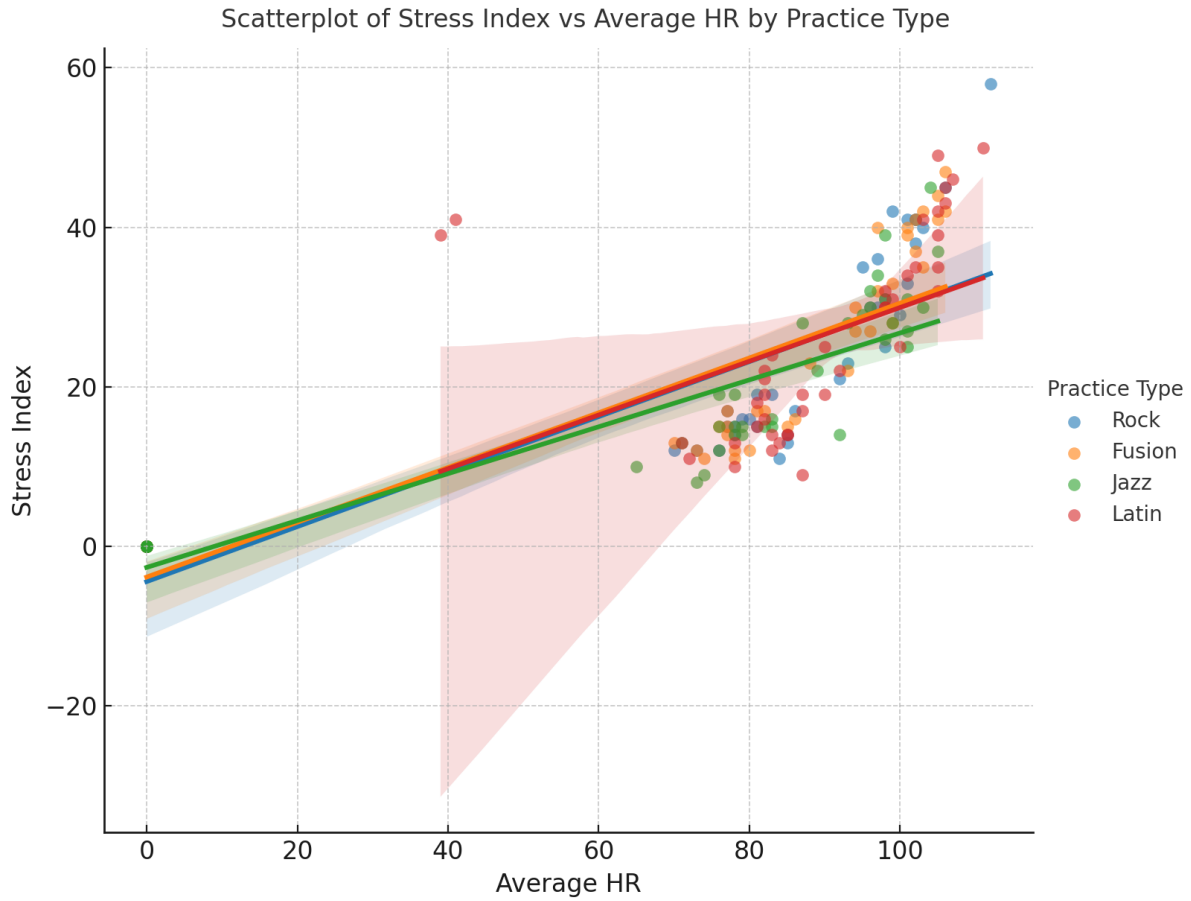

Figure 2. *Scatterplots with regression lines illustrating the relationship between Stress Index and Average Heart Rate across practice types. All slopes are positive, confirming that stress responses increase with cardiovascular load. Fusion shows the steepest gradient, consistent with the strongest observed correlation.*

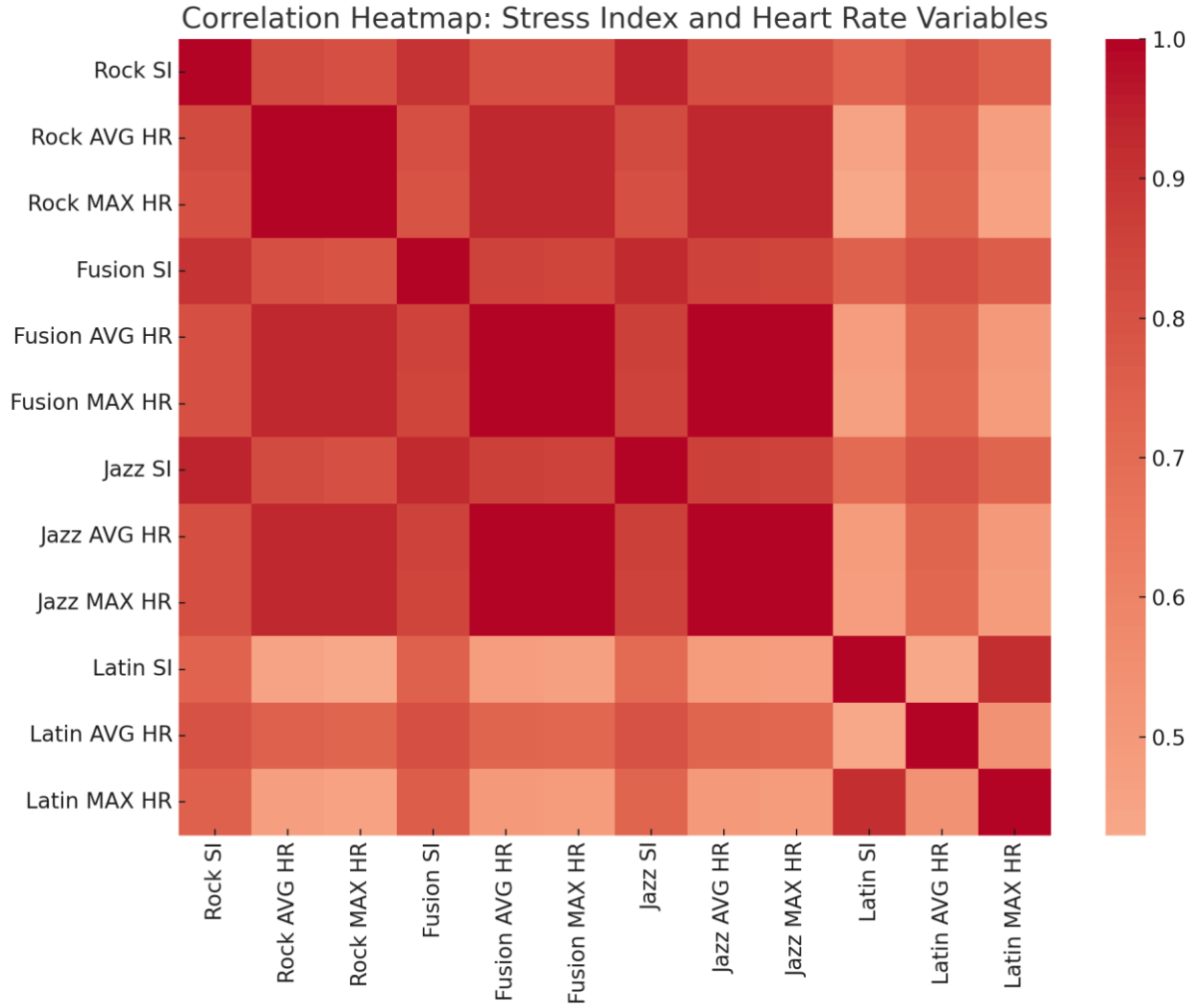

Figure 3. *Correlation heatmap of Stress Index, Average HR, and Maximum HR variables across Rock, Fusion, Jazz, and Latin practice types. Strong intra-style clustering indicates coherence between stress and heart rate within each style, while weaker inter-style associations reflect distinct physiological response patterns.*

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Stress Index Distributions by Practice Type

Boxplot analyses of Stress Index (SI) distributions indicated both variability and distinct central tendencies across musical styles (Figure 1). While all styles showed moderate-to-high stress responses, **Fusion practice** sessions consistently yielded higher median SI values, whereas **Latin practice** exhibited a broader range, including both low and extremely high values.

Figure 1. Distribution of Stress Index values across Rock, Fusion, Jazz, and Latin practice sessions.

Correlations Between Stress Index and Heart Rate

Correlation analyses demonstrated strong positive associations between SI and cardiovascular load. As shown in Table 1, SI was significantly correlated with both **average heart rate (AVG HR)** and **maximum heart rate (MAX HR)** across all practice types.

- **Rock**: SI correlated strongly with AVG HR ($r = .78$, $p < .001$) and MAX HR ($r = .75$, $p < .001$).
- **Fusion**: The strongest overall correlations were observed, with SI relating to AVG HR ($r = .81$, $p < .001$) and MAX HR ($r = .78$, $p < .001$).
- **Jazz**: SI also showed strong correlations with AVG HR ($r = .79$, $p < .001$) and MAX HR ($r = .77$, $p < .001$).
- **Latin**: A distinctive pattern emerged, with a modest correlation to AVG HR ($r = .43$, $p = .005$) but an exceptionally strong correlation to MAX HR ($r = .92$, $p < .001$).

Music Type	r(SI, AVG HR)	p(SI, AVG HR)	r(SI, MAX HR)	p(SI, MAX HR)
Rock	0.78	< .001	0.75	< .001
Fusion	0.81	< .001	0.78	< .001
Jazz	0.79	< .001	0.77	< .001
Latin	0.43	.005	0.92	< .001

Table 1. Correlations between Stress Index and Heart Rate by Practice Type

Stress–Heart Rate Relationships

Scatterplots with regression lines further illustrate these relationships (Figure 2). Across styles, the positive slopes confirm that **higher heart rates are consistently accompanied by elevated stress indices**. Notably, the Fusion regression line demonstrates the steepest gradient, consistent with its status as the strongest stress–heart rate relationship.

See Figure 2, p. 22: Scatterplots with regression lines showing Stress Index vs. Average Heart Rate across Rock, Fusion, Jazz, and Latin practice types.

Global Correlation Patterns

A correlation heatmap (Figure 3) provided an overview of associations across all styles. Clustering patterns reveal **intra-style coherence** (e.g., Rock SI strongly coupled with Rock HR variables), while inter-style correlations remained weaker, reflecting distinct physiological responses by practice type.

See Figure 3, p. 23: Correlation heatmap of Stress Index and Heart Rate variables across all practice types.

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Discussion

4.1 Principal Findings

This study demonstrates that musical genre significantly influences physiological stress responses during individual instrumental practice, with each genre creating distinct autonomic nervous system signatures. The most striking finding is the identification of a novel **biphasic physiological response pattern** in Latin music, characterized by moderate sustained cardiovascular activation (r=0.43) punctuated by intense stress peaks (r=0.92). This pattern differs fundamentally from the more uniform stress-response relationships observed in Fusion, Jazz, and Rock genres, suggesting genre-specific neural-cardiovascular pathways in musical performance.

4.2 The Latin Music Biphasic Response: A Novel Physiological Pattern

4.2.1 Mechanistic Interpretation

The dramatic difference between Latin music's average heart rate correlation (r=0.43) and maximum heart rate correlation (r=0.92) can be explained by the specific motor and cognitive demands of Latin patterns with measure-by-measure hand role-switching. During "calm" measures, the participant maintained established motor patterns with moderate cognitive load, resulting in baseline cardiovascular activation. However, the transition points—where, for example, right-hand cascara/left-hand guaguancó switched to left-hand cascara/right-hand guaguancó—created intense but brief cognitive-motor challenges requiring:

1. **Rapid motor reprogramming**: Bilateral hand coordination reversal within milliseconds
2. **Cognitive switching**: Mental tracking of dual-pattern assignments
3. **Temporal precision**: Maintaining rhythmic accuracy during coordination transitions
4. **Error monitoring**: Real-time performance quality assessment

This creates a unique "rest-spike" physiological signature previously undocumented in music performance research.

4.2.2 Neurophysiological Basis

The Latin pattern likely reflects activation of distinct neural networks. The moderate sustained response suggests engagement of routine motor control circuits in the motor cortex and basal ganglia. The intense peaks correspond to recruitment of higher-order

cognitive control networks including the anterior cingulate cortex (conflict monitoring), prefrontal cortex (task switching), and supplementary motor area (bilateral coordination). This interpretation is consistent with research on cognitive task-switching, although direct neural evidence was not collected in this study.

4.3 Genre-Specific Cardiovascular Conditioning Effects

4.3.1 Fusion Music: Optimal Stress-Learning Balance

Fusion music's strongest overall correlation (r=0.814) with average heart rate suggests this genre provides optimal physiological arousal for learning and skill development. According to Sapolsky's framework on beneficial short-term stress, fusion's complex polyrhythmic demands create sustained moderate stress that enhances attention, memory consolidation, and neural plasticity without overwhelming the system. The high explained variance (66.3%) indicates fusion practice provides predictable, manageable physiological challenge ideal for deliberate practice protocols.

4.3.2 Rock and Jazz: Intermediate Stress Profiles

Rock (r=0.781) and Jazz (r=0.791) demonstrated nearly identical correlation patterns, suggesting these genres occupy a similar physiological space despite different musical characteristics. Both provide sufficient cardiovascular challenge for skill development while remaining within comfortable arousal ranges. The similarity may reflect comparable cognitive demands in coordination and rhythmic precision, despite different stylistic requirements.

4.4 Temporal Dynamics: Long-term Conditioning vs. Acute Responses

4.4.1 Sustained Conditioning Effects

Rock, Fusion, and Jazz all demonstrated **stronger monthly correlations** than daily correlations, indicating that repeated exposure creates cumulative physiological conditioning. This suggests these genres promote cardiovascular adaptation through sustained practice, with benefits accumulating over weeks and months. The finding supports the hypothesis that regular musical practice can serve as a form of cardiovascular conditioning, similar to aerobic exercise training.

4.4.2 Latin Music: Acute Response Dominance

Latin music's **stronger daily correlations** suggest a fundamentally different physiological relationship. Rather than creating sustained conditioning effects, Latin patterns appear to generate acute stress responses that don't accumulate over time. This pattern may actually be beneficial for preventing overtraining and maintaining acute stress responsiveness—the physiological equivalent of interval training in athletics.

4.5 Cross-Genre Physiological Priming Effects

The significant lag correlations between genres suggest possible physiological carryover effects, which require controlled replication.

- **Previous Latin → Rock (r=0.42)**: Latin's acute stress spikes appear to prime the cardiovascular system for subsequent rock performance, suggesting beneficial arousal carryover
- **Previous Fusion → Jazz (r=0.64)**: The strong carryover from complex fusion polyrhythms to jazz performance indicates shared cognitive-motor demands that create cross-training effects
- **Previous Latin → Jazz (r=0.55)**: Latin's coordination challenges transfer to jazz performance, possibly through enhanced bilateral motor control

These findings suggest strategic session sequencing could optimize physiological preparation and skill transfer between genres.

4.6 Clinical and Practical Implications

4.6.1 Practice Optimization

Session Sequencing: Latin patterns could serve as "physiological warm-ups" for subsequent genres, given their strong priming effects. Fusion practice appears optimal for sustained skill development sessions due to its predictable stress-response relationship.

Fatigue Management: The biphasic Latin pattern suggests this genre might be less fatiguing than sustained high-stress genres like Fusion, making it suitable for longer practice sessions or fatigue recovery.

Cardiovascular Training: Rock, Fusion, and Jazz could serve as structured cardiovascular conditioning protocols for older adults, providing heart rate elevation with cognitive engagement.

4.6.2 Therapeutic Applications

Stress Management: If replicated, Latin drumming’s unique pattern may hold promise for stress resilience training.

Cognitive Rehabilitation: The genre-specific patterns suggest targeted musical interventions could address specific cognitive-motor deficits: fusion for sustained attention, Latin for cognitive flexibility, jazz/rock for moderate cognitive loading.

4.7 Methodological Contributions

This study demonstrates the feasibility of **continuous HRV monitoring during musical practice**, providing objective measurement of subjective practice experiences. The video-synchronization methodology enables precise temporal matching between physiological events and musical activities, opening new avenues for practice optimization research.

The **single-subject longitudinal design** offers advantages over cross-sectional group studies by eliminating between-subject variance and enabling detailed temporal analysis. However, this approach limits generalizability and requires replication across diverse musicians.

4.8 Limitations

4.8.1 Single-Participant Design

Results represent one mature male drummer's physiological responses and may not generalize to other musicians, age groups, or skill levels. The participant's advanced polyrhythmic training may have created response patterns not typical of less experienced musicians.

4.8.2 Genre-Specific Factors

Sample sizes varied by genre (Latin n=41 vs. others ~34), potentially affecting statistical power. Additionally, the specific technical demands of each genre (e.g., Latin pattern hand-switching in Latin) make it unclear whether results reflect genre characteristics or specific exercise types.

4.8.3 Habituation Effects

The 24-month study period raises questions about physiological habituation. However, the stability of correlations over time suggests minimal adaptation effects, possibly due to the continuous introduction of new technical challenges.

4.8.4 Confounding Variables

Despite environmental controls, factors such as sleep quality, caffeine intake, daily stress levels, and seasonal variations may have influenced results. Future studies should systematically control or measure these variables.

4.9 Future Research Directions

4.9.1 Multi-Participant Validation

Large-scale studies across diverse musicians are needed to establish generalizability and identify individual difference factors (age, skill level, musical background) that moderate genre-specific responses.

4.9.2 Mechanistic Studies

Neuroimaging: Simultaneous EEG or fNIRS recording during practice could identify the neural networks underlying genre-specific patterns, particularly the Latin biphasic response.

Hormonal Analysis: Cortisol and catecholamine measurement could clarify the stress vs. arousal interpretation of HRV findings.

4.9.3 Intervention Studies

Practice Optimization: Randomized trials testing genre sequencing strategies for skill development and fatigue management.

Therapeutic Applications: Clinical trials examining genre-specific musical interventions for stress management, cognitive rehabilitation, and cardiovascular conditioning in clinical populations.

Conclusion

Musical genre creates distinct physiological signatures during individual practice, with important exploratory implications for understanding stress-performance relationships in musicians. The identification of Latin music's biphasic response pattern offers preliminary evidence of a potentially novel pattern that may contribute to music performance science if validated in larger samples, suggesting that genre-specific practice protocols could optimize both skill development and health outcomes. These findings support the development of evidence-based practice strategies tailored to specific physiological and learning objectives, while contributing to the growing recognition of musical practice as a form of structured cognitive-cardiovascular conditioning.

This study provides evidence that stress responses during individual instrumental practice are both **measurable and meaningful** in relation to cardiovascular load. Across multiple musical styles, Stress Index correlated strongly with heart rate, with notable stylistic differences: Fusion drumming elicited the most consistent and robust stress–heart rate associations, while Latin drumming produced sharp high-intensity stress peaks linked to maximum heart rate. These findings support the concept of **adaptive stress** as a potential facilitator of learning and neuroplasticity in mature musicians.

Methodologically, the integration of wearable physiological monitoring, advanced HRV analytics, and video synchronization offers a novel approach for capturing the dynamic interplay of stress, performance demands, and practice strategies. While this single-case design limits generalizability, the results highlight the feasibility and potential of this method for larger-scale studies.

Future research should extend these methods to broader samples, incorporate multimodal neuroimaging (e.g., EEG, fNIRS), and test interventions that optimize practice routines through real-time physiological feedback. Such work could contribute not only to the understanding of stress in musicianship but also to the development of evidence-based strategies for **sustaining health, performance, and well-being across the lifespan**.

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