

Emotion-Driven Physiological Actor Dynamics For Interactive Theatre Sound

Luís Alberto Teixeira Aly



Supervisor

Gilberto Bernardes

Prof. Dr.

Faculty of Engineering of Porto-INESC-TEC

Second Supervisor

Humberto Plácido da Silva

Prof. Dr.

Instituto Superior Técnico-IT



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Resumo

Esta tese, intitulada 'Emotion-driven Physiological Actor Dynamics for Interactive Theatre Sound,' embarca numa jornada exploratória na integração de respostas emocionais expressas por sinais fisiológicos e design de som no teatro. Esta pesquisa investiga a complexa relação entre os estados emocionais dos atores e os respetivos sinais fisiológicos, explora o impacto do som gerado a partir de dados fisiológicos na expressão emocional e agência dos atores, e examina como esta integração pode redefinir narrativas teatrais tradicionais.

O estudo examina as experiências e percepções dos atores recorrendo a metodologias qualitativas e quantitativas. Utiliza grupos de foco, estudos observacionais, sensores fisiológicos e inquéritos para capturar e analisar os sinais fisiológicos e o feedback dos atores. Esta abordagem permite uma compreensão matizada da interação entre os aspectos fisiológicos e emocionais da atuação, lançando luz sobre como os atores incorporam e transmitem emoções complexas através das suas performances.

Uma contribuição empírica crucial desta pesquisa é o dataset DECEIVER, que compreende um extensivo arquivo de gravações fisiológicas. Estas gravações fornecem informações valiosas sobre a consistência e variabilidade da expressão emocional em ambientes de performance teatral. Este conjunto de dados é de interesse para investigadores e profissionais da área na compreensão da reação entre expressão emocional e respostas fisiológicas em teatro.

Além disso, a tese apresenta uma análise histórica abrangente do uso de sensores fisiológicos em música interativa, abrangendo o período de 1965 a 2023. Esta visão histórica não apenas traça a evolução tecnológica neste domínio, mas também prepara o terreno para entender as tendências atuais e os desenvolvimentos futuros. Ela contextualiza a pesquisa na trajetória mais ampla dos avanços tecnológicos, destacando as mudanças incrementais e, por vezes, revolucionárias que moldaram o estado atual dos sistemas de música interativa.

A tese introduz uma taxonomia empírica e funcional para Sistemas Musicais Interativos impulsionados por sinais fisiológicos. Esta taxonomia representa uma contribuição significativa para o design e aplicação de Sistemas Musicais Interativos, fornecendo um quadro estruturado que pode guiar desenvolvimentos futuros no campo. Ela categoriza diferentes abordagens e metodologias na integração de dados fisiológicos em design de som, oferecendo uma compreensão abrangente do potencial e das limitações destes sistemas.

A pesquisa também envolve o desenvolvimento de um protocolo experimental projetado para analisar os correlatos fisiológicos de valência emocional e excitação na atuação. Um sofisticado conjunto de ferramentas de software para processamento de dados complementa este protocolo. O design do protocolo sublinha a eficácia da elicitação em despoletar estados emocionais específicos e destaca a complexidade da expressão emocional em atores de teatro. Este aspecto da pesquisa fornece um modelo metodológico para futuros estudos que visam explorar temas e questões semelhantes.

Biosignal Processing Toolbox, uma ferramenta de software para operações em tempo real que integra sinais fisiológicos com som, é central para o desenvolvimento do estudo. A Biosignal

Processing Toolbox possibilita a criação de som de forma dinâmica e responsiva que interage com os atores, potenciando a expressão emocional através do som, e a narrativa teatral. A Biosignal Processing Toolbox está equipada para lidar com vários sinais fisiológicos, como eletromiografia, eletrocardiografia e atividade eletrodérmica, cada um oferecendo oportunidades e desafios únicos para a sonificação. A versatilidade da A Biosignal Processing Toolbox reside na sua capacidade de se adaptar e responder a diferentes entradas fisiológicas, tornando-o uma ferramenta eficaz para designers de som no teatro.

Uma parte significativa da pesquisa foi um projeto tecno-artístico colaborativo, que utilizou o teatro de Samuel Beckett como pano de fundo. Este projeto levou ao desenvolvimento de um protótipo para um Sistemas Musicais Interativos impulsionado por sensores fisiológicos. Este projeto explorou as possibilidades transformadoras da integração de sensores fisiológicos e tipologias de gestos no teatro, oferecendo novas perspectivas sobre o desenvolvimento de personagens e a construção narrativa. O projeto demonstrou o potencial desta tecnologia para trazer uma nova dimensão às performances teatrais, permitindo uma experiência mais imersiva e interativa tanto para atores quanto para diretores artísticos.

Apesar da sua natureza inovadora, a pesquisa reconhece os desafios e limitações de tais integrações tecnológicas. Estes incluem questões como a necessidade de processamento de dados em tempo real, a necessidade de calibração do sistema específico para cada ator, restrições técnicas e financeiras, requisitos de treino para atores e equipes de produção, garantindo o conforto e descrição dos sensores durante as performances, considerações éticas relacionadas ao uso de dados fisiológicos e a interpretação subjetiva de tais dados em contextos artísticos.

Em conclusão, esta tese contribui para os estudos teatrais e para a arte de mídia interativa e fornece novas perspectivas para o design de som e treinamento de atores e contribui para o discurso mais amplo sobre a interseção da tecnologia com a arte.

Abstract

This thesis, titled 'Emotion-driven Physiological Actor Dynamics For Interactive Theatre Sound,' embarks on an exploratory journey into the innovative integration of physiological responses with emotional expression and sound design within theatre. This research investigates the intricate relationship between actors' emotional states and physiological signals, delves into the impact of sound generated from physiological data on the actors' emotional expression and agency, and examines how this novel integration can redefine traditional theatrical narratives and storytelling techniques.

The study examines actors' experiences and perceptions using qualitative and quantitative methodologies. It utilizes focus groups, observational studies, and sophisticated physiological sensors and surveys to capture and analyze the physiological signals and the feedback from actors. This approach allows for a nuanced understanding of the interplay between the physiological and emotional aspects of acting, shedding light on how actors embody and convey complex emotions through their performances.

A key empirical contribution of this research is the DECEIVER dataset, which comprises extensive physiological recordings. These recordings provide valuable insights into the consistency and variability of emotional expression in performance settings. This dataset is a treasure trove for researchers and practitioners in the field, offering unprecedented detail and depth in understanding the physiological underpinnings of theatrical performance.

Furthermore, the thesis presents a comprehensive historical analysis of the use of physiological sensors in interactive music, spanning the period from 1965 to 2023. This historical overview not only charts the technological evolution in this domain but also sets the stage for understanding the current trends and potential future developments. It contextualizes the research within the broader trajectory of technological advancements, highlighting the incremental and sometimes revolutionary changes that have shaped the current state of interactive music systems.

The thesis introduces an empirical and functional taxonomy for Interactive Music Systems driven by physiological signals. This taxonomy represents a significant contribution to designing and applying physiological signals to interactive musical systems, providing a structured framework that can guide future developments in the field. It categorizes different approaches and methodologies in integrating physiological data into sound design, offering a comprehensive understanding of the potential and limitations of these systems.

The research also involves the development of an extensive experimental protocol designed to analyze the physiological correlates of emotional valence and arousal in acting. A sophisticated software toolbox for data processing complements this protocol. The protocol's design underscores the effectiveness of mental imagery in eliciting specific emotional states and highlights the complexity of emotional expression in theatre actors. This aspect of the research provides a methodological blueprint for future studies aiming to explore similar themes and questions.

The Biosignal Processing Toolbox, a software tool for real-time operations integrating physiological signals with sound, is central to the study. The Biosignal Processing Toolbox enables the

creation of dynamic, responsive soundscapes that interact with actors, enhancing the storytelling and engagement of the audience in the theatre. The toolbox is equipped to handle various physiological signals such as electromyography, electrocardiography, and electrodermal activity, each offering unique opportunities and challenges for sonification. The versatility of BarT lies in its ability to adapt and respond to different physiological inputs, making it an effective tool for sound designers in the theatre.

A significant part of the research was a collaborative techno-artistic project, which utilized Samuel Beckett's theatre as a backdrop. This project led to developing a prototype for an Interactive Music System driven by physiological sensors. This project explored the transformative possibilities of integrating physiological sensors and gesture typologies into theatre, providing fresh perspectives on character development and narrative construction. The project demonstrated the potential of this technology to bring a new dimension to theatrical performances, allowing for a more immersive and interactive experience for both actors and audiences.

Despite its groundbreaking nature, the research acknowledges the challenges and limitations of such technological integrations. These include issues such as the need for real-time data processing, the necessity of actor-specific system calibration, technical and financial constraints, training requirements for actors and production teams, ensuring the comfort and unobtrusiveness of sensors during performances, ethical considerations related to the use of physiological data, and the subjective interpretation of such data in artistic contexts.

In conclusion, this thesis contributes to theatre and interactive media art. Exploring the integration of physiological sensors in theatre sound design opens up new avenues for artistic expression and audience engagement. The development of the Biosignal Processing Toolbox and the DECEIVER dataset represent significant advancements in the field, paving the way for more immersive, interactive, and expressive forms of storytelling. This research provides novel perspectives for sound design and actor training and contributes to the broader discourse on the intersection of technology and art.

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Luís Aly

“Life is just correlated noise.”

Beau Lotto

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List of Abbreviations

ACC	Accelerometer
ADCs	Analog-to-Digital Converters
AF	Air Flow
AI	Artificial Intelligence
ALS	Ambient Light Sensor
ANN	Artificial Neural Network
AP	Action Potentials
AP	Air Pressure
ASN	Autonomic Nervous System
AUD	Audiences
AUD+SYS	Audience Interacting With A Computational System
AUs	Action Units
BarT	Biosignal Processing Toolbox
BCI	Brain-Computer Interfaces
CNN	Convolutional Neural Networks
DECEiVeR	Dataset of Acting Emotions Valence and Arousal
ECG	Electrocardiography
ECoG	Electrocorticogram
EDA	Electrodermal Activity
EEG	Electroencephalography
EGG	Electrogastrogram
EOG	Electrooculogram
FER	Facial Emotion Recognition
FLEX	Flex Sensors
FSR	Force Sensors
GEN	Generative
GYR	Gyroscope
HCI	Human-Computer Interaction
HRV	Heart Rate Variability
HUM	Humidity
Hz	Hertz
ML	Interactive Machine Learning
IMS	Interactive Musical Systems
IRCAM	Institut de Recherche et Coordination Acoustique/Musique
IoT	Internet of Things

LBT	Local Binary Patterns
LFP	Local Field Potentials
MCU	Micro Controller Unit
MIDI	Musical Instrument Digital Interface
MMG	Mechanomyography
MOCAP	Motion Capture
MBS	Model-Based Sonification
MSP	Max Sound Processing
mV	Microvolts
MULTIPERF+MULTISYS	Multiple Human Performers With Various Computational Systems
MULTIPERF+SYS	Several Human Performers With A Single Computational Systems
OSC	Open Sound Control
PER	Physiological Emotion Recognition
PERF+SYS	Single Human Performer With A Computational System
PMS	Parameter-Mapping Sonification
PSPs	Postsynaptic Potentials
PPG	Photoplethysmography
PST	Position
PZT	Piezoelectric Sensors
RESP	Respiration
SCL	Skin Conductance Level
SCR	Skin Conductance Responses
sEMG	Surface Electromyography
SEQ	Sequenced
TEMP	Temperature
TRANSF	Transformative
UDP	User Datagram Protocol
VR	Virtual Reality

Chapter 1

Introduction

This research explores the intersection of the actor's body, theatre sound, and interactive musical systems (IMS) within the theatrical context. Central to this investigation is examining IMS as extensions of human physiology and emotion, influencing sound creation during theatrical performances.

The study examines the evolving role of IMS in theatre, particularly their impact on acting techniques and narrative structures. This study aims to shed light on the changing dynamics of theatre sound and its implications for acting. This research provides a perspective on this convergence by employing a multidisciplinary methodology integrating insights from theatre studies, physiology, and technology. This thesis aims to establish connections between the physiological responses of human actors and electronic sound production. It seeks to enlighten how interactive systems enhance actors' expressivity and emotional engagement in performances. The primary goal is to study comprehension of sound's significance in contemporary theatre, acknowledging the ongoing technological advancements and their integration into performance art.

As it delves deeper into these interactions, the present thesis specifies opportunities for technological integration in theatre. It proposes innovative approaches for IMS to enrich the theatrical experience. This work aspires to contribute to the field by presenting insights and viewpoints on the collaboration between actors, sound, and technology in modern theatre.

1.1 Overview Of Theatrical Practices

The introduction chapter guides the complex terrain of theatre practices, emphasizing the nuanced domain of emotional expression in acting. It begins this exploration with a dive into the philosophy of Denis Diderot (1713-1784), whose seminal work laid the groundwork for understanding the paradox of emotional expression in theatre. Diderot's reflections propose a fascinating dichotomy between the actor's internal emotional state and the external portrayal of those emotions on stage, challenging actors to navigate the intricate balance between genuine emotion and the artifice required by performance. This foundational perspective sets the stage for a broader examination

of how emotions are conveyed and perceived in the theatrical context, underscoring the enduring relevance of Diderot's theories in contemporary theatre studies.

Considering contemporary theatre practices, this study examines Samuel Beckett's approach to corporeality, as analyzed by Charlotta P. Einarsson (2017). Einarsson categorizing Beckett's work into material, organic, and atmospheric phases facilitates a nuanced comprehension of the emotional landscapes within Beckettian theatre, laying a theoretical groundwork for the research.

Expanding upon this framework, the discourse encompasses the fusion of the body with technology, as explained in Mark B. N. Hansen's "Bodies in Code" (2012). Hansen's exploration untangles the intricacies of digital and physical interfaces, elucidating how technological advancements have blurred the boundaries between the body and its digital extensions. This intersection emerges as a pivotal area of inquiry for this study, particularly within the domain of theatre sound.

Traditionally relegated to a background role, theatre sound has become an active participant in theatrical performance. Contemporary practices have transformed sound into an auditory backdrop and an interactive layer that interfaces with the body and performance. These emerging practices embrace sensing technologies capable of detecting and responding to performers' movements, fostering a responsive and immersive environment. Such technologies empower sound to function as an extension of the body, engaging with the performative ecosystem encompassing light, set design, and sound. Consequently, they enhance the emotional expression and narrative depth of theatre productions. This chapter culminates in examining the creative potential inherent in these interactions, paving the way for experimentation with innovative theatrical explorations and further integrating sensing technologies in theatre. In doing so, the present study aims to explore new ways for emotional engagement and expression within theatre.

1.2 Diderot's *The Paradox of Acting*

Denis Diderot's *Le Paradox du Comédien* (Paradox of Acting)-(Diderot, 1883), was written in the 18th century, a period marked by the Enlightenment. This cultural and intellectual movement emphasized reason, science, and skepticism of traditional authority. The Enlightenment was a fertile ground for new ideas in philosophy, politics, and the arts, and it significantly influenced Diderot, a prominent French philosopher and writer. Diderot was a key figure in the *Encyclopédie* project, which aimed to disseminate human knowledge and critical thinking. The *Encyclopédie* was a monumental work that gathered contributions from various Enlightenment thinkers like Voltaire and Montesquieu (Lebrun, 1998, p. 257).

The theater was a significant cultural institution during this period, serving as entertainment and a platform for social and political critique (Gumbrecht, 1986). French classical drama, influenced by the works of Molière, Racine, and Corneille, was dominant. However, new forms of theater emerged that challenged the traditional norms of French classical drama, characterized by its strict adherence to the Aristotelian unities of time, place, and action, as well as its focus on tragedy and high moral themes. New forms included *Comédie Larmoyante* or 'tearful comedy', which blended elements of comedy and tragedy. This form aimed to elicit emotional responses



Figure 1.1: Denis Diderot (5 October 1713 – 31 July 1784) was a French philosopher from the Enlightenment era and he wrote *Le Paradox du Comédien* (Diderot, 1883), a thought-provoking treatise on theatrical performance.

from the audience through sentimental plots and characters. Diderot himself contributed to this genre with plays like *Le Fils naturel* (1757) and *Le Père de famille* (1758) (Hartnoll and Brater, 1985, pp. 134-135). The bourgeois drama was another form that gained prominence, focusing on the lives and moral dilemmas of the middle class rather than the nobility, breaking the classical focus on royal or mythological subjects, and aiming to make theater more relatable to a broader audience. The use of pantomime and physical theater also began to challenge the primacy of spoken text, offering a different kind of theatrical experience that emphasized visual and bodily expression (Broadhurst, 1999, pp. 20-21). These emerging forms were not just a break from tradition but also a response to the social and cultural changes of the time. They reflected the Enlightenment's focus on individual emotion and reason and engaged with the period's shifts in class structure and public taste.

Paradox of Acting presents a complex and counterintuitive theory that has had a lasting impact on performance studies. Written in the form of a dialogue, the text challenges the conventional wisdom that the most compelling actors are those who genuinely feel the emotions they are portraying. Instead, Diderot posits that the most compelling performances are delivered by actors who maintain an emotional detachment from their roles, allowing them to exercise greater control over their expressions and actions. The paradox itself lies in the notion that an actor's performance is most effective when it is, in fact, emotionally detached (Ley, 1995). Diderot argues that an actor who is genuinely swept up in the character's emotions is likely to lose control, thus becoming less effective in evoking a specific emotional response from the audience. In contrast, an actor who maintains emotional detachment can more skillfully manipulate voice, gesture, and

facial expression to produce the desired emotional impact on the audience (Roach, 1993, pp. 60-80). Diderot posited that a skilled actor has the ability to compellingly depict an emotion without necessarily experiencing it authentically. This ability demands a mastery of technique, control, and an intricate understanding of human emotion. Drawing parallels with other art forms, Diderot emphasized the significance of detachment in artistic expression. A sculptor, for instance, does not need to feel heroic to craft a statue of a hero. Similarly, an actor's brilliance is not rooted in their emotional vulnerability but in their capability to harness and project emotions on demand, utilizing their skills, training, and comprehension of the human psyche (Magnat, 2002).

Diderot's theory was groundbreaking for several reasons. First, it shifted the focus from the actor's internal emotional state to the techniques and skills employed to produce an emotional impact. This was a radical departure from the prevailing belief in the "natural genius" of actors, who were thought to excel through emotional sincerity. Secondly, Diderot's ideas aligned with Enlightenment principles, emphasizing rationality and control over emotional impulsivity. In Diderot's view, the actor's craft lies in simulating emotion convincingly without actually experiencing it. This requires mastering various techniques, such as voice modulation, timing, and physical expression. His views can be seen as part of a broader Enlightenment skepticism about the reliability of emotional expression, favoring instead the predictability and control of rational technique.

In modern performance theory, Diderot's paradox continues to be a subject of extensive scholarly debate and interpretation. While some critics argue that the advent of method acting, which emphasizes emotional authenticity, challenges Diderot's claims, others contend that even method actors employ a form of technical mastery that aligns with Diderot's emphasis on control and technique (Stanislavski, 1989, pp. 136-150).

Diderot's *Paradox of Acting* focuses on the emotional aspects of performance and does not explicitly delve into physical theater as a separate genre or style. The text is more concerned with the emotional authenticity and technique of actors in traditional dramatic roles rather than the physicality or movement-based aspects central to physical theater. However, the principles outlined in the *Paradox of Acting* can be applied to physical theater to some extent. Diderot's emphasis on control and technique over emotional impulsivity is relevant to physical theater, where bodily control and precise movement are crucial. In physical theater, the actor's body becomes the primary medium for storytelling. A similar paradox could exist: the more controlled and deliberate the physical performance, the more emotionally resonant it may appear to the audience (Pitches, 2005, pp. 45-60). For research purposes, this approach to physical theater could be framed as an extension of "post-dramatic theater," a term coined by Hans-Thies Lehmann to describe theater that goes beyond the traditional text-based drama to incorporate various media and modes of performance (Lehmann, 2006, pp. 81-100). The *Paradox of Acting* also has implications that extend beyond theater. Its principles have been applied to various other disciplines, including psychology, to explore emotional expression and perception complexities. The paradox has even found relevance in the field of neuroscience, as researchers investigate how emotional states can be simulated or induced, both in oneself and in others.

In summary, Diderot's *Paradox of Acting* offers a nuanced and challenging perspective on the

nature of performance. By emphasizing the importance of control and technique over emotional authenticity, Diderot not only revolutionized theories of acting but also contributed to broader intellectual currents of his time, leaving a legacy that continues to be explored and debated in various disciplines today.

1.3 The body in Lehmann's *Postdramatic Theatre*

Diderot's perspective on emotional expression in theatre, advocating for an actor's ability to convincingly portray emotions without truly feeling them, contrasts sharply with Hans-Thies Lehmann's concept of post-dramatic theatre. While Diderot focuses on the actor's internal process and technique, Lehmann's approach emphasizes the physicality and presence of the actor's body itself. In post-dramatic theatre, as described by Lehmann, the body transcends its traditional role as a mere conduit for narrative or character-driven drama. Instead, it becomes a central performance element, capable of expressing complex ideas and emotions independently of a scripted text. This evolution marks a significant departure from conventional theatrical practices, redefining the actor's body not just as a tool for emotional representation but as a powerful medium of expression in its own right, thereby challenging and expanding the boundaries of theatrical expression.

The landscape of contemporary theatre has undergone a radical transformation, heralding the emergence of what Hans-Thies Lehmann terms "post-dramatic theatre" in his seminal work. A vital feature of this transformation is the redefined role of the actor's body, which has shifted from primarily a medium for character representation and narrative unfolding to a focal point in its own right. Traditionally, the actor's body was viewed mainly as a vessel to support the Aristotelian notion of drama, where the text or script was paramount, and all other elements, including the actor's body, were secondary. Lehmann's work, however, challenges this perspective by highlighting the body's increased significance in post-dramatic theatre. According to the author

"The dramatic process occurred between the bodies; the post-dramatic process occurs with/on/to the body" (Lehmann, 2006, p. 174)

This shift means that the actor's body in post-dramatic theatre is not just an instrument for conveying a pre-written text but becomes a focal point in its own right. The body is no longer a carrier of meaning but an entity that offers 'the image of its agony', thereby resisting all forms of representation and interpretation (Lehmann, 2006, p. 174). Lehmann introduces the concept of the 'self-dramatization of physis', where the dynamic that traditionally maintained drama has moved into the body itself (Lehmann, 2006, p. 174). This shift is characterized by an intensified physical motor activity, shape or shapelessness, wholeness or fragmentation, and an intensified presence or 'anthropophany'. The body in post-dramatic theatre becomes a site for exploring human potentiality and limitations, often engaging with themes of suffering, ecstasy, and the sublime. This focus on the body's physicality over its role as a signifier marks a significant departure from traditional dramatic theatre.

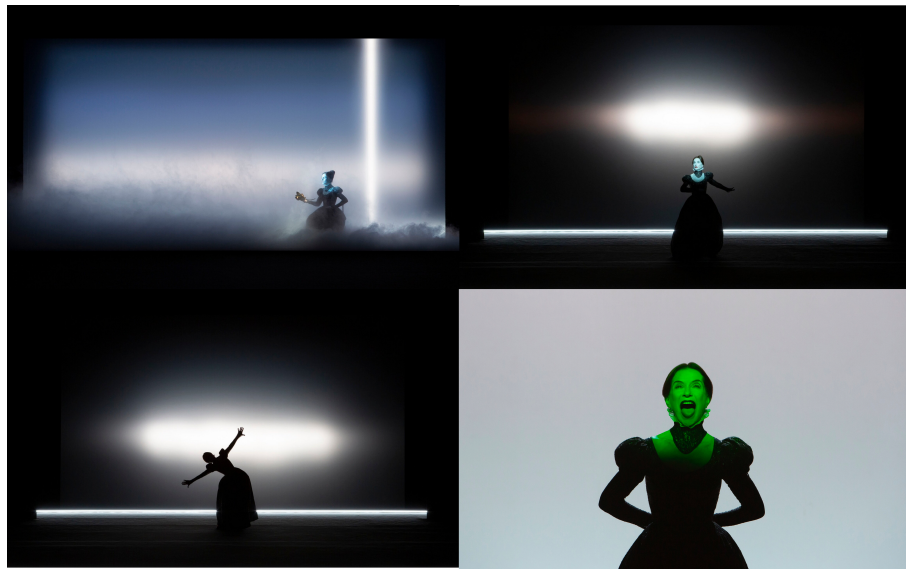


Figure 1.2: *Mary Said What She Said*, directed by Robert Wilson, featured at the Festival de Almada in 2019, Portugal. Photograph by Lucie Jansch. Licensed under CCBY. More information available at <https://robertwilson.com/mary-said-what-she-said-1>.

Hans-Thies Lehmann's post-dramatic theatre references various works and practitioners that exemplify the shift from traditional dramatic forms to post-dramatic practices. While Lehmann discusses numerous examples to illustrate the diversity and scope of post-dramatic theatre, three significant works are often associated with this movement. Robert Wilson (Figure 1.2)¹ is a central figure in avant-garde theatre and opera. He is known for his groundbreaking and innovative contributions to the performing arts. His work is characterized by a distinctive use of lighting, sound, and scenic design, creating visually stunning and emotionally powerful performances that defy traditional narrative structures. Wilson's approach to theatre is holistic and multidisciplinary, integrating elements of dance, opera, and visual art to explore and expand the boundaries of theatrical expression.

Hamletmachine (Figure 1.3) is a postmodernist play by German playwright Heiner Müller, written in 1977. It is a radical reworking of Shakespeare's *Hamlet*. It is known for its dense, poetic language and departure from narrative structure. The play critically examines the intellectual and political landscapes of the 20th century, including themes of revolution, despair, and the collapse of ideologies. Its fragmented structure, mixing of historical and fictional characters, and dense intertextuality make it a quintessential example of post-dramatic theatre.

Finally, the Wooster Group (Figure 1.4), an experimental theatre company based in New York City, has influenced post-dramatic theatre. Their productions often incorporate multimedia, including live video feeds, pre-recorded sounds, and unconventional staging. Works like *LSD (...Just the High Points...)* and *The Emperor Jones* deconstruct and reinterpret existing texts, blending high and low culture and challenging traditional notions of narrative and character. The Wooster

¹<https://robertwilson.com>



Figure 1.3: *Hamletmachine* by Heiner Müller, presented by Trapdoor Theatre under the artistic direction of Max Truax in Chicago, United States, 2011. For more details, visit <https://trapdoortheatre.com/performance-history/hamletmachine/>.



Figure 1.4: Stills from *North Atlantic* and *House/Lights*, captured by Helen Pickett, showcase the signature multimedia integration of The Wooster Group. Available at <https://helenpickett.com/wooster-group/>.

Group's innovative use of technology and its interrogation of the performance medium are hallmarks of post-dramatic theatre.

These examples illustrate the breadth of post-dramatic theatre, encompassing a range of styles, themes, and methodologies. They share a common departure from traditional drama's linear narrative and character-driven plots, exploring new forms of expression and audience engagement.

In post-dramatic theatre, the body becomes the center of attention 'not as a carrier of meaning but in its physicality and gesticulation' (Lehmann, 2006, p. 106). The actor's body refuses to serve signification and often presents itself as an "auto-sufficient physicality." Through its movements, gestures, and presence, the actor's body becomes a site for transmitting emotional tensions, both internally and externally. This emotional intensity is not merely an add-on to the physical performance but is integral to it, adding layers of complexity and depth to the theatrical experience.

Lehmann also discusses the presence of the "deviant body," which, through illness, disability, or deformation, deviates from the norm and causes an "amoral" fascination (Lehmann, 2006, pp. 106-107). This emotional impact is crucial to the body's role in post-dramatic theatre. The deviant body critiques societal constructs around normality and deviance while also engaging the audience emotionally, often eliciting strong reactions of discomfort, empathy, or intrigue. Postdramatic theatre often transgresses the pain threshold to reintroduce the painful and pleasurable physicality that Julia Kristeva has called the semiotic within the signifying process (Lehmann, 2006, p. 107). This transgression revokes the separation of the body from language and reintroduces emotional

physicality into the realm of expression. It adds an emotional texture to the performance, making the body a site for exploring human vulnerabilities, joys, and sorrows.

Another crucial aspect that Lehmann discusses is the body's relationship with time. Techniques like slow motion focus on the body's physicality and manipulate its temporality, creating a heightened sense of presence (Lehmann, 2006, pp. 174-175). This manipulation of time adds another layer of complexity to the role of the body in post-dramatic theatre, making it a subject of both spatial and temporal exploration. The redefined role of the body also impacts the audience's engagement with the performance. The body's heightened presence and resistance to traditional forms of representation demand a more active form of audience participation. The audience is no longer a passive receiver of a pre-defined narrative. However, it becomes active in the performance's unfolding, often directly engaging or even challenged by the actor's body.

In post-dramatic theatre, the relationship between the body and technology also emerges as a critical area of exploration. Lehmann touches upon the "technically infiltrated body," where the body interacts with machinery and technology (Lehmann, 2006, pp. 173-174). This interaction opens up new avenues for exploring the body's capabilities and limitations, often blurring the lines between the organic and the mechanical. One of the most significant aspects of the body's interaction with technology in post-dramatic theatre is the concept of augmentation and extension. In the context of Lehmann's analysis, technology in theatre can be understood as encompassing a wide range of tools and media that extend beyond traditional theatrical techniques and apparatuses, including, but not limited to, digital media, sound and lighting technologies, video projection, and other forms of multimedia that contribute to the creation of theatrical space and narrative. Technology, in this framework, is seen as a critical component in creating immersive environments, disrupting linear narratives, and engaging audiences in new ways. It serves not just as a backdrop or a tool for storytelling, but as an integral part of the theatrical experience, often challenging traditional distinctions between performer and audience, and between live performance and recorded media. The actor's body is augmented or extended beyond its natural capabilities through various technological devices, from simple props to complex machinery and digital interfaces. The augmentation of the body in post-dramatic theatre can include:

- **Simple Props:** Objects that actors can manipulate or interact with to extend or emphasize their physical presence symbolic meaning, or to create visual metaphors.
- **Costumes and Wearable Art:** Costumes transform the appearance, shape, or movement capabilities of the actor, often making a statement or serving as an extension of the character or theme.
- **Puppetry and Animatronics:** Using puppets or mechanically controlled figures to represent characters' ideas or create a particular aesthetic effect, blending the line between the animate and inanimate.

- **Projection and Video Art:** The use of video projections on bodies or surfaces to create dynamic backgrounds, alter the visual perception of the space, or integrate multimedia elements directly into the performance.
- **Sound and Lighting:** Advanced sound systems and lighting designs that can alter the mood, focus attention, or even interact with performers, effectively augmenting the sensory experience of the body in space.
- **Digital Interfaces and Interactive Technology:** Use of sensors, motion capture, or interactive software that responds to the movements or actions of performers, creating a direct interaction between technology and the human body.
- **Virtual and Augmented Reality:** Incorporation of VR and AR to create immersive environments or to blend digital and physical realities, directly affecting the audience's perception and experience of the performance space.

Lehmann's highlights the importance of these technologies' significance as tools for creating spectacle and as integral elements that contribute to the meaning, experience, and critique embedded within the performance. From the simplest to the most complex, these technologies and props are used in post-dramatic theatre to explore new forms of expression, question traditional narratives and representations, and engage with the audience innovatively.

The concept of the body as an interface is part of a broader discussion on the transformation of theatrical forms and the role of performers within them. While Lehmann's work encompasses a wide range of topics related to post-dramatic theatre, the idea of the body as an interface can be understood as a metaphor for how the performer's body serves as a medium of communication and interaction between the performance and the audience, as well as between the physical and conceptual elements of the theatre.

This role as an interface allows the body to engage in dialogue with technology, where each influences and shapes the other. The body is not merely a passive recipient of technological intervention but an active participant in creating and manipulating digital landscapes. This interaction leads to a more complex and nuanced understanding of the body, where its boundaries are continually negotiated and redefined.

The interaction between the body and technology, is not always harmonious or empowering. At times, technology serves to disrupt or distort the body, challenging its integrity and autonomy. This disruption can be seen in various forms, from the mechanization of movement to the digital manipulation of the body's image. Such disruptions serve as a form of critique, questioning the impact of technology on the human condition and exploring themes of alienation, dehumanization, and loss of control.

According to Lehmann the body's interaction with technology in post-dramatic theatre raises several philosophical questions. What does it mean to be human in an age of increasing technological intervention? How do we negotiate the boundaries between the organic and the mechanical, the natural and the artificial? These questions are theoretical and actively explored through the

body's performance, making post-dramatic theatre a critical platform for engaging with technology's ethical and philosophical implications. Given the increasing ubiquity of digital technology, the role of the body in post-dramatic theatre has become particularly relevant. The body's interaction with technology becomes essential to the human experience, influencing artistic expression, social interaction, personal identity, and cultural norms. In this context, post-dramatic theatre serves as a critical lens through which we can explore and understand the complexities of the body in the digital age.

The role of the body in relation to emotional expression in theatre is multifaceted and complex. It becomes evident that the body is not merely a physical entity but a vessel for emotional intensity and affective experiences. Through its physical presence, emotional intensity, and even its deviance and pain, the body is a critical site for emotional expression and engagement in theatre. It challenges traditional norms, engages the audience, and adds layers of emotional depth to the theatrical experience. As Lehmann aptly puts it, the body in post-dramatic theatre serves as an "agent provocateur of an experience without 'meaning,' an experience aimed not at the realization of a reality and meaning but at the experience of potentiality" (Lehmann, 2006, pp. 173-174). This potentiality includes the rich tapestry of human emotions, making the body an indispensable element in the emotional landscape of theatre.

1.4 The Body in Samuel Beckett's Theatre

Hans-Thies Lehmann does refer to the works of Samuel Beckett (1906-1989) in the context of post-dramatic theatre, particularly highlighting Beckett's innovative use of stage elements, the human body, and technology. Beckett's work, with its minimalist approach, focuses on existential themes, and experimentation with theatrical form significantly influences post-dramatic theatre's development. Although Lehmann's primary focus in discussing post-dramatic theatre is on the shift away from traditional narrative and dramatic structures towards more fragmented, visual, and experiential forms of theatre, Beckett's contributions are acknowledged as precursors to many of these ideas.

The concept of *body as technology* in Samuel Beckett's works signifies a profound departure from traditional performance art paradigms. Beckett's methodology disrupts established norms that typically relegate the body to a mere vessel for delivering scripted narratives or emotions. As previously described by Einarsson (Palmstierna, 2017), Beckett reconceptualizes the body as a technological apparatus, a dynamic entity capable of crafting new experiential realms and meanings. This perspective posits the body as an active, technologically mediated participant, reshaping the process of creating and interpreting experiences within the theatrical milieu.

Beckett's intricate methodological approach manifests through calculated framings that transcend representational function. Einarsson elaborates on these framings, which include *mis-movements*, idiosyncratic gestures, and motions, all deliberately employed to challenge and engage audience perception. Other techniques, such as isolating body parts, employing silence and stillness, and dissociating words from physical movements, form part of Beckett's sophisticated

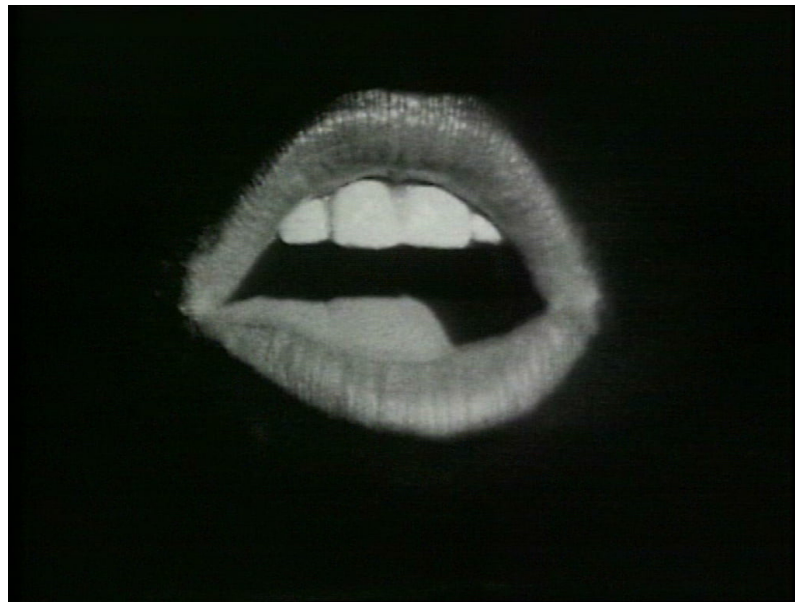


Figure 1.5: Plays like *Not I*, Samuel Beckett reduces the presence of the body to a mouth suspended in darkness, focusing on the disembodied voice and challenging traditional representations of character and narrative in theatre. This extreme minimalism and the use of the body as a site of expression rather than as a vehicle for character-driven drama align with the post-dramatic theatre's exploration of new theatrical languages and forms. <https://revistausina.com/2014/01/22/samuel-beckett-not-i/>

rhythm of sounds and actions, meticulously designed to subvert conventional narrative structures (Palmstierna, 2017, pp.59-60).

The significance of the body in Beckett's oeuvre is corroborated by extensive academic work, including studies by (Tajiri, 2004; Fifield, 2010) and Ulrika Maude's *Beckett, Technology and the Body*, as well as (McMullan, 2020, p.49). These investigations underscore that Beckett's focus on the body is a deliberate artistic strategy deeply entrenched in performance and embodiment studies.

Beckett systematically explores the interplay between the body and elements such as movement, space, sound, and language. Contrary to the conventional secondary role of the body in theatre, Beckett places it at the forefront. He eschews psychological directives for actors, instead emphasizing the precision of physical movement. Thus, the body transforms into a complex web of signs, forming part of a dramaturgical structure free from predetermined philosophical or psychological biases (Palmstierna, 2017, p.65, pp.80-81).

This nuanced treatment categorizes various functional aspects of the body, questioning the importance of intelligibility in Beckett's plays. Over time, his works have evolved to represent the body as an aesthetic object in its own right, enabling audiences to immerse themselves aesthetically and reinterpret narratives and emotional responses within this new framework (Palmstierna, 2017, p.73).

Beckett's choreographic writing suggests that the performance itself is the final text. The body is inscribed within the play's textual framework and 'written' into the performance's temporal-

spatial dimensions as a pre-linguistic experience. This approach undermines the traditional dichotomy between movement and semiotics, giving rise to a novel form of dramatic text with each performance (Palmstierna, 2017, p.59).

The tremendous implications of *body as technology* for contemporary theatre and performance studies are. It upends the traditional hierarchy that privileges the written script over the corporeal, advocating for an integrated approach that positions the body at the heart of the theatrical experience. This shift could change how performances are staged and experienced, redefining the audience's role from passive observers to active participants.

Body as technology in Beckett's work serves as an intellectual concept disrupting conventional narrative structures and engages audiences in a unique, corporeal manner. It expands performance studies horizons, intersecting with philosophy, technology, and the humanities, making Beckett's work a microcosm for broader inquiries into embodiment, technology, and human experience. In our increasingly digitized world, Beckett's insights into the body's interactions with technology become more relevant, challenging us to redefine human existence in a technologically mediated world. The *Corporeal Turn* is a crucial concept encapsulating Beckett's aesthetic evolution (Palmstierna, 2017, p.99). This turn is methodologically geared towards creating an *assault against words*, highlighting the significance of aesthetic perception in Beckett's work. It unfolds through three distinct phases: the *material phase* (1953–1962), the *organic phase* (1962–1975), and the *atmospheric phase* (1975–1983), representing a progressive shift in Beckett's use of the body in performance (Palmstierna, 2017, pp.99-100).

The following subsections will delve into these three phases, examining how each phase contributes to the evolving role of the body in Beckett's theatre, highlighting its significance in dramatic expression and audience engagement.

1.4.1 The Material Phase: Presence-Effect and Mismovements

The *material phase* in Samuel Beckett's artistic journey, as part of "The Corporeal Turn," marks a pivotal shift in his approach to theatre, profoundly affecting the interplay of language and physicality in performance. This phase, stretching from 1953 to 1962, represents a decisive departure from conventional theatrical norms, emphasizing the linguistic and corporeal elements of acting. A key aspect of this phase is the use of *mis-movements*, which are far from incidental; they serve as tactical devices and thematic signifiers. For example, a character stating "I am going", while remaining stationary creates discord between spoken language and physical action, challenging the audience's conventional understanding of narrative and meaning-making (Palmstierna, 2017, pp.113-114).

This period in Beckett's work he deliberately undermines the text to foreground theatre's corporeal and formal aspects. This assault serves to unsettle and liberate, moving away from the traditional gesture of mastery in classical theatre interpretations. By eroding the semantic foundations, Beckett opens up new avenues for aesthetic exploration, laying the groundwork for more complex frameworks in later phases of the Corporeal Turn (Palmstierna, 2017, pp.113-114).



Figure 1.6: Claere Kaiser, Sigfrit Steiner and Erich Thormann in Samuel Beckett's *Endgame* in 1958.

The *material phase* is marked by Beckett's exploration of various formats and structures, from minimalist to absurd. The focus on mis-movements and the assault on words during this phase can be viewed as foundational techniques later evolving into more intricate aesthetic and thematic innovations. These early experiments challenge traditional narrative structures, paving the way for future expansions into more complex artistic practices.

Crucially, the *material phase* also redefines the audience's role in theatre. The dissonance created by the dichotomies of word and movement, form and meaning, forces the audience into an active role. Instead of passively consuming a narrative, spectators are compelled to question, reconcile, or reframe their perceptions, turning them from passive recipients into active constructors of meaning (Palmstierna, 2017, pp.113-114).

In summary, the Material Phase is an experimental phase and a foundational methodology that informs Beckett's later works. The techniques of mis-movements and linguistic deconstruction introduced here are integral to his broader aesthetic strategy. This phase serves as a conceptual springboard for the subsequent phases of the corporeal turn, each evolving in complexity and thematic depth. The innovations of this phase provide critical insights into Beckett's artistic trajectory, offering a lens to decode the more elaborate practices in his later works. It contextualizes the evolution of Beckett's artistic endeavor, making the abstract elements of his later works more comprehensible when traced back to their foundational principles.

1.4.2 The Organic Phase: Organic Structuring

The *organic phase*, articulated within the overarching paradigm of Beckett's corporeal turn, marks a significant evolution in the playwright's exploration of aesthetic forms. While the Material Phase was fundamentally preoccupied with disrupting linguistic semantics through *mis-movements*, the



Figure 1.7: *Play* (2001) directed by Anthony Minghella was part of the *Beckett on Film* project, a notable initiative to adapt all of Samuel Beckett's stage plays into films. Anthony Minghella's *Play* is known for its faithful adaptation of Beckett's original work, capturing the playwright's exploration of themes such as the cyclical nature of human experience, memory, and the complexities of interpersonal relationships. More information available at <https://www.imdb.com/title/tt0268536/>

organic phase shifts the focus to the visual and auditory patterns inherent in performance (Palmstierna, 2017, p.124). This phase embraces a diverse set of vehicles, of which mis-movements continue to be a part, to engage with the audience in ways that stretch beyond textual meanings to the formal aspects of the theatrical experience.

One of the most salient features of the *organic phase* is its intricate choreography of characters' movements. No longer are these actions arbitrary or merely disruptive; they are meticulously designed to constitute visual patterns that serve as aesthetic objects in their own right. This takes Beckett's already nuanced focus on the body to a heightened level of complexity. Instead of merely contradicting the text, the characters' bodily movements are orchestrated to interact synergistically with other elements like lighting, sound, and set design, creating an immersive, cohesive aesthetic experience.

Beckett's strategic choreography distances the audience from the semantic weight of the spoken words, urging them to refocus their attention on the formal attributes of the performance (Palmstierna, 2017, p.124). The audience is presented with a visual and auditory tableau that demands cognitive engagement far removed from the conventional understanding of theater. By fostering this engagement, the *organic phase* challenges spectators to shift their focus from the narrative to the formal, disrupting the conventional modes of meaning-making they might otherwise employ. Moreover, the body's function in this phase is multi-layered and highly contextual. It becomes an aesthetic object that does not operate in isolation but interacts with other theatrical elements to construct complex patterns. Here, Beckett explores the intricate dynamics between

form and content, employing the body as an expressive medium through which these dynamics are exposed.

The *organic phase* thus pushes the boundaries of traditional theater, offering a more complex, multi-sensory experience that requires the audience to grapple with several aesthetic elements simultaneously. The impact of this phase on the audience's experience is not merely additive; it is transformative. Whereas the *material phase* provoked the audience to question language's semantic reliability, the *organic phase* invited them into a layered, sensory interaction with the artwork. The focus shifts from what is being said or represented to how it is being formally constructed and presented.

1.4.3 The Atmospheric Phase: Aesthetic Atmospheres

The *atmospheric phase* marks the zenith of Beckett's *Corporeal Turn*, constructing what can best be described as a holistic aesthetic experience. Unlike its predecessors — the *material phase*, which aimed at undermining semantic meaning, and the *organic phase*, which shifted the focus towards form — the *atmospheric phase* integrates these elements into a fluid, dynamic whole. The performance transcends mere representation, blossoming into a multi-sensory experience that defies conventional theatrical understanding (Palmstierna, 2017, pp.137-138).

In the *atmospheric phase*, the body is not an isolated entity but becomes deeply entwined within a structural network of theatrical elements such as lighting, sound, and set design. Far from being a mere actor executing pre-defined movements or uttering lines, the body emerges as one facet of a multi-dimensional aesthetic composition. Choreographed movements, gestures, and postures are harmonized with other sensory elements to cultivate a specific *atmosphere*. Unlike previous phases, where the body served distinct and often countering roles, it becomes a dynamic contributor to a cohesive, fluid aesthetic experience. This constitutes a marked departure from traditional theatrical representations, engaging the audience on manifold sensory levels. This idea of *atmosphere* is pivotal in the *atmospheric phase*. It encapsulates a holistic engagement with the audience that is both visual and aural and intangibly emotional. The body serves as a conduit, a sensory interface, if you will, between the performance and the audience. This multifaceted engagement goes beyond passive consumption, making the audience an active participant in the aesthetic experience, a far cry from the traditional norms of audience engagement.

Nevertheless, what sets the *atmospheric phase* apart is its embrace of flux and change as structural elements of the performance. The atmosphere is not static; it is subject to constant transformation. Every component — the body, the lighting, the sound — is in a continual state of interaction and evolution, contributing to an atmosphere that itself becomes a dynamic aesthetic object. This transformation aligns closely with contemporary shifts away from fixed meanings or static presentations in the theatrical space. The performance becomes less about the scripted lines or planned movements and more about the immediate, lived experience of fluctuating atmospheres (Palmstierna, 2017, pp.137-138).

The concept of the *Corporeal Turn* in Beckett's work is a nuanced evolution that critiques and reimagines conventional theater. Beginning with the *material phase*, Beckett destabilizes semantic



Figure 1.8: *Ghost Trio* (1975) is a television play by Samuel Beckett, which delves into themes of longing, memory, and the spectral presence of the past. The play is structured around the motifs of Beethoven's *Ghost Trio*, creating an atmosphere of haunting introspection. It features a figure, F, waiting in a spartan room for an unspecified event or person, accompanied by the disembodied voices of a narrator and prompts from a ghostly presence. Available at <https://newmediaandenglish.wordpress.com/2016/03/14/quad-by-beckett-whats-it-all-about/>

norms and establishes a focus on dissonance, laying a foundational groundwork for his evolving aesthetics. This phase serves as an entry point and a lens through which the complexity of his later works can be understood. In the subsequent *organic phase*, the focus shifts to a tapestry of sensory elements, evolving the role of the body from a vessel to a multi-layered aesthetic object. The phase moves beyond simple contradiction to create a captivating experience for the audience, marking a distinct chapter in Beckett's continual rethinking of theatrical norms. The *atmospheric phase* culminates the *Corporeal Turn* by radically departing from traditional theater to focus on the collective experience of a dynamically changing atmosphere. It engages the audience more complexly, transforming them from spectators to active participants. In summary, the *Corporeal Turn* is a layered construct offering a revolutionary approach to theater. Each phase is both a building block and a standalone contribution, collectively redefining the potential of theatrical form and audience engagement. It provides an invaluable framework for understanding the trajectory and depth of Beckett's artistic evolution.

1.5 The Body As Extended Interface

In Beckett's theatre, the actor's body often transcends its traditional role of character portrayal to become an instrument for existential themes and abstract concepts. This instrumentalization is evident in plays like "Not I," where the focus is on a disembodied mouth, reducing the human

form to a mere vehicle for voice and narrative, or in "Quad," where the actors' precise, mechanical movements across a square stage pattern evoke a sense of ritual devoid of any conventional narrative. Here, the actor's body can be seen as a technological device programmed to execute specific actions that contribute to the piece's overall meaning rather than embody a character in the traditional sense.

This approach aligns with the principles of post-dramatic theatre, as theorized by Lehmann, where the emphasis shifts from a text-based narrative to the theatrical experience itself, including the use of space, light, sound, and the performer's body. Post-dramatic theatre often incorporates actual technological devices in performance. Still, it also conceptualizes the actor's body as a technology in its own right—a medium through which the performance is mediated and experienced. This perspective opens up new ways of understanding how contemporary theatre communicates, with the actor's body serving as an interface between the audience and the performance, capable of generating meaning through movement, presence, and interaction with physical or digital elements.

The connection between Beckett's theatre, post-dramatic theatre, and the notion of the actor's body as a technological device highlights a transformative shift in the landscape of contemporary performance. It reflects a move away from traditional representational theatre towards a theatre that foregrounds performance's sensory, experiential, and phenomenological aspects. This paradigm shift encourages a reevaluation of the role of technology in theatre, not just as a tool for enhancing stagecraft but as a fundamental aspect of how bodies, space, and narratives interact and create meaning on the contemporary stage.

In this approach, the actor's body is not just a passive recipient of direction and script but a dynamic participant interacting with, responding to, and influencing the surrounding technological landscape. This approach recognizes the actor's physical presence as an integral component of performance art, capable of nuanced interactions and expressions mediated by technology. It invites a performance reimagining where the actor's body, interwoven with technological elements, becomes a key driver in the theatre's narrative and emotional journey. Expanding actors' agency to include their interaction with technology implies that actors develop a broader and more intricate skill set. Actors should extend their expertise beyond traditional realms such as voice modulation, facial expressions, and physical gestures. They could engage with real-time technological elements intricately integrated into their performances.

The work of Hansen (Hansen, 2012) offers an innovative perspective on embodiment, advocating for its reconceptualization as a dynamic process deeply intertwined with digital media and technologies. Hansen challenges the traditional view of the body as a biological entity confined within its skin. Instead, he argues for understanding embodiment as distributed across a broader, interconnected system, particularly pertinent in the digital age. The author asserts that "embodiment is necessarily distributed beyond the skin" (Hansen, 2012, p.11), inviting a more expansive view that surpasses physical limitations.

Hansen introduces the concept of *collective individuation*, suggesting that embodiment should be part of a more extensive interconnected system (Hansen, 2012, p.108). This approach has

significant implications for individual experiences and human life's social, cultural, and ethical aspects, particularly in a world increasingly influenced by digital technologies.

The relationship between embodiment and *technics*, encompassing various techniques, methods, and technologies. Hansen explores the body's role as an *invariant* — a stable entity providing foundational access to the world (Hansen, 2012, pp.39-40). He discusses how digital technologies mediate our embodied experiences, adding a technohistorical layer to this interaction, suggesting that our understanding of embodiment evolves with technological advancements, leading to a more dynamic conception of our embodied experience.

Proprioception, or the perception of the body schema in space, is another crucial concept Hansen addresses (Hansen, 2012, p.51). He argues that digital technologies can expand this schema, thus extending the scope of human embodiment. This perspective reevaluates the previously perceived opposition between technics and embodiment, showing them as interlinked and mutually enhancing. The notion of 'embodiment as distributed beyond the skin' opens new avenues in fields like interactive music. This leads to more personalized and responsive systems that adapt to individual physiological responses in real-time. This advancement promises a more seamless interaction between the human body and technological interfaces, reshaping our understanding of embodied experience. Moreover, Hansen's emphasis on collective individuation sparks meaningful discussions in sociology and anthropology, raising questions about how society negotiates collective embodiment in shared digital or virtual spaces. It calls for new social contracts, norms, and ethical frameworks to govern these experiences, which become increasingly relevant as digital and physical realities converge.

In acting in theatre, understanding embodiment as a distributed phenomenon has profound implications. Actors are no longer confined to traditional interactions with technology; they are now part of a comprehensive embodied experience that might include augmented reality environments or AI-driven personalized training modules. This shift requires artists to design experiences that engage the 'whole' embodied individual, considering cognitive, emotional, and physiological aspects within the creative process.

This perspective envisions the body as an expansive interface surpassing its corporeal limits, particularly evident when engaging with advanced digital technologies. This theoretical lens marks a significant shift in how embodiment is discussed, offering a richer comprehension of the complex relationships between the physical body and digital environments (Hansen, 2012, pp.15-16).

One of the central claims of this approach is the dissolution of the traditional dichotomy between physicality and virtuality. In this framework, the *extended interface* is not an isolated entity but is deeply influenced and shaped by digital technologies, and acts not as a passive receptor but as an active participant in a dynamic interplay that redefines sensory experiences, going beyond merely enhancing visual or auditory capabilities, but encompassing a full range of motor functions. It indicates a shift from focusing solely on representational accuracy to a more nuanced understanding of how motor activities can effectively mediate the interaction between virtual and physical realms.

The *extended interface* thus assumes a new form of agency within digital ecosystems, functioning as a bidirectional conduit for information and experiences. Contrary to traditional interfaces that facilitate a unidirectional flow of information, the *extended interface* fosters a symbiotic relationship between the user and the digital environment, allowing the human body to influence digital environments as these environments impact the body, creating a reciprocal exchange that transforms both entities.

This perspective introduces a significant paradigm shift in our understanding of user agency within digital platforms. It moves from a 'control-based' approach to one that is more 'relational and responsive,' fundamentally altering how we interact with and experience digital technologies. The *extended Interface*, therefore, becomes a critical element in redefining the boundaries and possibilities of human engagement with digital realms, offering new avenues for exploration and understanding in the digital age.

1.6 Theater Sound: The Emergence Of An Artform

The preceding chapter has examined the actor's body beyond its role as a technological instrument, emphasizing its function as an extended interface in contemporary theatrical performance, particularly highlighting its real-time interaction with sound.

This research reconceptualizes the body as a sophisticated, multi-dimensional interface actively shaping and influencing the surrounding soundscape. This viewpoint positions the actor's body as a mediator in the real-time creation and modulation of sound. Through their performance, actors skillfully engage with technological components and physiological sensing systems that capture and translate bodily movements and expressions into auditory phenomena. This integration redefines conventional acting methodologies, empowering actors with increased agency and embodiment while fostering heightened interaction in theatrical experiences. The subsequent section will delve deeper into the specific emerging practices of theatre sound design, concentrating on their further integration with and enhancement of the actor's body as a real-time interface for sound within the theatrical domain.

As delineated by Brown, theatre sound involves the shaping of the auditory experience for the audience. A *soundscape* in theatre refers to the collective array of crafted auditory montages, sound effects, atmospheres, and music integral to the dramaturgical process.

The early history of theater sound underscores its integral role in live performances, as illustrated before the era of recorded sound when theater primarily relied on orchestrating live sounds seamlessly into performances (Curtin, 2014). In the late 19th century, groups like the Meininger Players exemplified this by integrating live, dynamic sound creation (Tresidder, 1935), as evident in Irving's stage effects and the off-stage noise-makers used by Anton Chekhov, Maurice Maeterlinck, and Henrik Ibsen (Ovadija, 2013). This era saw theater sound as an essential part of the narrative and atmosphere, emphasizing its role in storytelling and emotional engagement in theater.

However, this approach began evolving into what is now known as *sound effects* in theater, where sound is often perceived as separate from live performances (Hsieh, 2018). The path towards incorporating mechanical sound effects into theater, which significantly reshaped both the technical aspects of theater sound and the audience's listening experience, set the stage for visionaries like Frank Napier to recognize and embrace the evolving trends in theater sound during the mid-20th century (Napier, 1948). The nuanced, organic integration of live sounds, characteristic of earlier theater, gave way to a more segmented approach. Sounds started to be treated as additional, often mechanically produced effects, distinct from a performance's live auditory elements. This *acoustic turn* (Curtin and Roesner, 2015) not only transformed the technical facets of theater sound but also significantly altered the audience's auditory experience, marking a divergence from traditional, holistic soundscapes that were once integral to theater's storytelling and emotional expression (Curtin, 2014, p. 117). During this period, sound effects began to be seen as distinct from live performances, losing their earlier sense of integration and immediacy. This change made sound effects increasingly disembodied, often produced mechanically or electronically, rather than being an integral part of live stage action.

The introduction of widely available recorded audio in the twentieth century fundamentally transformed both the methods of sound effect compilation and playback within the theater. In the 1930s, theater practitioners like Bertolt Brecht pioneered the utilization of vinyl records for sound effects, enabling the incorporating of a more diverse array of sounds into theatrical productions than was previously achievable (Brecht, 1964). This expansion in sound variety was likely influenced by the increasingly complex sonic environment of urban areas, emerging from the industrial and electric revolutions, as explored in R. Murray Schaffer's *The Tuning of the World* (Schafer, 1993). Additionally, recorded media facilitated enhanced management of playback volume and, eventually, the spatial distribution of sound.

During the late 1980s, integrating recorded sound into theater introduced several challenges. This era, marked by the employment of recorded or electronic sound effects, coincided with skepticism towards artificial elements in theater. The conventional theater, celebrated for its live and natural components, faced a profound shift with the advent of advanced sound production technologies (Bay-Cheng, 2007). This shift urged directors and playwrights to reevaluate their sound strategies, moving away from a dependence on live and impromptu sound generation to the introduction of pre-recorded and electronically produced sounds, raising the complexities in managing orchestration and synchronization with live acts, prompting a rethinking of staging approaches. Consequently, this period underscored the establishment of theater sound as a distinct field within theater production, integral to the play's creative and narrative dimensions.

Moreover, the 1980s served as a critical juncture in the evolution of theater sound, profoundly influencing practices within theater sound. The introduction of digital samplers and Musical Instrument Digital Interface (MIDI) systems brought a revolutionary change to the toolbox of sound designers, offering enhanced versatility and precision (Davies, 1996). MIDI technology facilitated exact control and synchronization of electronic instruments and apparatuses, crucial for arranging intricate sound events and achieving seamless integration with live performances (Saltz, 2001).

Digital samplers enabled the storage, alteration, and instantaneous playback of various sounds, allowing theater sound designers to tap into an extensive audio sample library during rehearsals, fostering on-the-spot experimentation and fine-tuning sound effects and musical motifs. This new-found level of flexibility endowed sound designers with unparalleled creative liberty, empowering them to devise soundscapes that more closely align with the dynamic requirements of a production.

Theater sound started to become an important part of theater production, focusing on adding artificial sounds that matched well with the live parts of a performance. In the early 90s, American theatre director Peter Sellars observed in (Kaye and LeBrecht, 2015, p. 2) that sound design in theatre had moved away from the notion of sound effects, defining it as an ontological concept between the acoustic environment and the subject:

Very late in our day, technology has become available to allow sound to begin to occupy the place in theatre arts that it occupies in our lives. We are in a position to completely reorient the relationship between performer and audience, to transform a theatrical space, to create distance or sudden proximity, to create a densely populated zone or an endless arid expanse. We are in a position to evoke simultaneous layers of experience: flashbacks, premonitions, visitations, inner voices, the mind wandering or becoming suddenly, unbearably concentrated. We are beyond the era of sound “effects.” Sound is no longer an effect, an extra, supplied from time to time to mask a scene change or ease a transition. We are beyond the era of door buzzers and thunderclaps. Or rather, door buzzers and thunderclaps are no longer isolated effects but part of a total program of sound that speaks to theatre as ontology.

This time was the start of a more organized and careful way of using sound in the theater, recognizing its ability to improve the story and atmosphere and the importance of having special skills in sound editing and creation. Thus, the move to include artificial sound had a big impact on the evolution of theater, influencing its artistic direction and making sound design a key part of theater art and production.

In the 1990s, the landscape of theater sound had undergone a significant transformation, culminating in the increased prominence of theatre sound designers in the creative process. This period marked a turning point where directors began to demand named sound designers for their productions explicitly, reflecting a growing awareness of the critical role sound played in enhancing the overall theatrical experience (GRAINGE, 2023, p. 252-253). This change in attitude towards theater sound design was not merely a shift in technical requirements; it represented a deeper recognition of sound as an integral element of storytelling and mood creation in the theater (Deio-rio, 2018, p. 30). Sound was no longer seen as an ancillary or secondary component but as a vital aspect of the theatrical experience, capable of profoundly influencing the audience’s perception and engagement with the performance. This period also saw sound design becoming more sophisticated and innovative, with sound designers experimenting with new technologies and methods to create immersive and compelling auditory environments.

The advent of interactive media technologies at the turn of the 21st century revolutionized performance arts. These technologies entail sounds and images stored and often created on a computer, generating responses to a live performer's actions (Saltz, 2001). They are characterized by several distinctive features that set them apart from traditional, non-interactive media:

- **Random Access:** Unlike older analog devices like tape recorders and video cassette recorders, which necessitate sequential advancement, digital technologies such as audio compact discs and digital versatile discs allow almost instantaneous movement between noncontiguous media segments.
- **Arbitrary Link Between Trigger and Output:** Computers treat all forms of data (sounds, images, text) as binary information. There's no inherent mechanical connection between the media content and the trigger input, as seen in acoustic musical instruments and analog media devices, where the input and output are directly linked. Computers can use varied inputs (keyboard, mouse, motion detector) to trigger any output (sounds, images, lights, motor control), with a single input capable of triggering multiple outputs.
- **Media Manipulation:** A crucial aspect of interactive media is the ability to write programs that manipulate digital information based on input. This means that responses to triggers can be varied. Computers can be programmed to alter outputs based on different factors, like performers' proximity or actions. This capability enables the creation of entirely new media in real-time, responding adaptively to the subtleties of a live performance.

As discussed in (Saltz, 2001), the integration of interactive media technologies in theatre presents a compelling argument for the evolution and enrichment of theatrical practices. These technologies introduce new forms of artistic expression, blending the time-honored traditions of theatre with the dynamism of digital interactivity. This fusion not only expands the narrative and expressive capabilities of theater but also reinvigorates the concept of *liveness* – a cherished aspect of traditional theatre – by adding a level of spontaneity and responsiveness previously unattainable.

The role of media in theater is significantly reimagined through this integration. No longer just a backdrop or supplementary element, interactive media can actively interact with live performers, opening up complex and innovative narrative possibilities. This shift challenges long-standing assumptions about the separation between performers and media, the nature of theatrical space, and the audience's engagement, prompting a reevaluation of what constitutes a theatrical performance.

Moreover, interactive media technologies have the potential to enhance audience engagement, transforming the traditionally passive act of watching a performance into a more immersive and participatory experience. This shift not only makes theatre more accessible and engaging, but also aligns with contemporary trends toward interactive and immersive experiences in entertainment.

However, the integration of these technologies has its challenges. Balancing the technological aspects with the artistic intent of the performance is crucial. The technology should enhance, not overshadow, the theatrical experience. Maintaining the spontaneity and fluidity intrinsic to live

performance is also a key consideration, ensuring that the essence of theatre is preserved even as it evolves.

The advent of interactive media technologies marks a significant evolution in the world of performing arts, particularly impacting the role of the theatre sound designer. The advent of digital technologies and interactive media brought about a paradigm shift. Theatre sound designers can manipulate a vast array of sounds stored digitally, responding in real time to the actions of live performers. This capability has transformed the role of sound designers from mere creators of auditory backdrops to architects of dynamic, interactive soundscapes. The features of interactive media, such as random access, arbitrary links between trigger and output, and media manipulation, as highlighted above, have given sound designers unprecedented control over how sound is used in theatre. Theatre sound designers can now instantaneously access and manipulate sounds, link various inputs to many outputs, and even program the system to change outputs based on the live performance's context, enriching the auditory experience of theatre and redefining the relationship between sound, performers, and the audience.

Moreover, interactive media technologies have elevated the role of sound designers in the narrative and creative process of theatre production. No longer confined to the background, sound actively interacts with live performers, contributing to the story's unfolding and enhancing the emotional impact. This interaction challenges traditional notions of theatrical space and audience engagement, transforming the sound designer's role into a critical component of the theatrical experience. However, this evolution also presents challenges. Sound designers must strike a balance between leveraging technology and preserving the artistic essence of the performance. It is essential to ensure that technological elements complement rather than dominate the performance, maintaining the live, spontaneous nature intrinsic to theatre.

In summary, the transformation of theater sound, from its organic integration in early performances to the emergence of sound effects, marks an evolution in theatrical practices. Beginning with the natural orchestration of live sounds and evolving into the use of recorded or electronic sound effects reflects a significant shift in how sound is perceived and utilized in theater. The advent of interactive media technologies in the late 20th and early 21st centuries further revolutionized this landscape. Features like random access, the arbitrary link between trigger and output, and media manipulation allowed for innovative, dynamic soundscapes that could interact in real time with live performances. This shift redefined the audience's auditory experience and challenged traditional notions of theatrical space, performer-media interaction, and audience engagement.

1.7 Bridging Theatre Sound and *Acting Emotions*

Building upon the evolution detailed in the previous chapter, this research intersects with interactive media features. Such features have fostered the role of sound designers in theatre, granting them unparalleled control over sound manipulation and usage. More significantly, theatre sound designers can program systems to adapt outputs in response to the nuances of a live performance.

This technological leap has enhanced the auditory experience in theater, and transformed the dynamics between sound, performers, and the audience.

This shift aligns perfectly with the central inquiry of the thesis: leveraging sound in theatre to intensify emotional expression in acting. The capabilities of interactive media allow for a more profound and active engagement of sound in theatre, going beyond traditional roles. Sound can actively interact with and respond to the actors' performances, creating a more immersive and emotionally resonant experience. The flexibility to manipulate sound in real-time, reacting to the performers' emotional expressions and movements, opens up new possibilities for storytelling and audience engagement. It enables the creation of soundscapes that are not just complementary to the performance but are integral to it, dynamically evolving with the unfolding narrative.

In this study is adopted the term *acting emotions* from Konijn (2000), defining it as the realm of emotional expression intrinsic to the art of acting. This investigation explores the relatively unexplored intersection between acting emotions and theatre sound, particularly in the contexts of interactive media and theatre studies. Traditionally, theatre sound has been seen as a background element or a support to visual cues. My research challenges this notion, proposing that sound can be pivotal in mirroring and shaping acting emotions, thereby establishing a symbiotic relationship between the actor and the auditory environment. This approach opens up new possibilities for sound to become a dynamic contributor to storytelling, enriching the emotional depth and engagement of theatrical performances.

My research examines the complex interaction between an actor's emotional expressions and the art of sound creation (Curtin, 2012). Acting emotions go beyond mere superficial portrayal on stage; they embody the depth and authenticity of emotions conveyed by actors. These emotions are dynamic, evolving through performance under the influence of the script, direction, and the actor's interpretation. The focus is on how theatre sound can capture, enhance, and subtly modify these emotions, enriching the performance's emotional landscape.

Central to this research is an essential question: "How can theatre sound principles be utilized to intensify emotional expression in acting?". This question is a guiding light, merging traditional theatre sound principles with interactive digital media. It aims to investigate how sound can bolster the narrative and emotional expression in theatre. Drawing from the authors' extensive background in theatre sound, this study explores the confluence of emotional expression in acting with innovative sound applications. In the theatre world, emotional expression is a layered and complex entity, emerging from a synergy of script, direction, sound design, and lighting. Sound complements and shapes the emotional terrain, enhancing a performance's emotional resonance and narrative depth.

To summarize, this research is positioned at the intersection of theatre sound and digital media, aiming to bridge the gap between traditional theatrical practices and modern digital applications. By exploring the emotional power of sound and its potential to transform digital media experiences, this study aspires to contribute with valuable knowledge to the field and pave the way for innovative applications of sound design in digital media.

1.8 Research Questions

This chapter outlines the primary research questions to be addressed in this study:

Q1: How do physiological signals correlate with the emotional states of actors during performances, and what are the variations in these physiological-emotional correlations across different individuals?

Q2: How do actors experience and interact with sounds generated from their physiological data, and how does this impact their emotional expression in performances?

Q3: How does integrating physiological data into theatre sound design redefine traditional theatrical narratives and storytelling techniques?

1.9 Contributions

The domain of theatre sound has traditionally been shaped by the use of pre-programmed auditory cues and the accompaniment of live musicians, which together create the auditory landscape of theatrical productions. However, in dance and performance art, sensing technologies have significantly revolutionized the interactivity of sound elements, with motion capture as a prominent example. Despite these advancements, integrating intimate, close-to-body sensing mechanisms, such as physiological sensors, remains relatively uncharted in theatrical settings.

This research advances in deciphering the complex relationship between physiological responses, the craft of emotional acting, and the dynamic world of interactive theatre sound. By exploring this intersection, the study addresses a vital gap in knowledge and application, enhancing the emotional depth and audience engagement in theatrical experiences, thereby offering a novel perspective on the emotional resonance of performance. This research contributes notably to theatre studies, broadening the understanding and application of physiological sensing in emotional acting. The specific contributions are as follows:

- **Innovative Methodological Approach:** Introducing a method for analyzing acting emotions through a physiological lens, this research provides a fresh perspective in understanding the actor's emotional journey and its physiological manifestations, marking a significant departure from conventional auditory and visual analyses.
- **Comprehensive Experimental Protocol:** Developing a tailored experimental protocol for professional theatre actors signifies a methodological innovation. The proposed protocol was specifically designed for the nuanced exploration of emotional elicitation in a theatrical context; this protocol can be adapted for broader applications, such as theatre education.

- **Technological Integration for Data Capture:** Creating a robust integration of hardware and software for capturing, recording, and storing physiological data is a significant technical contribution. This system enables the collection of high-fidelity data essential for detailed analysis.
- **Extensive Physiological Dataset:** Assembling a considerable dataset of over four hours of physiological recordings from experimental sessions is an extensive empirical contribution. This dataset, alongside low and mid-level analyses, provides an unparalleled resource for understanding the physiological aspects of emotional acting.
- **Sound Interaction Software Toolbox:** Developing a specialized toolbox marks a practical advancement. This software facilitates innovative interactions between sound elements and physiological data in a theatrical context, empowering sound designers and directors to create more immersive and responsive auditory experiences.
- **Empirical Case Study:** Conducting a comprehensive case study based on Samuel Beckett's approach to body in theatre provides empirical support for the research hypotheses. Developed collaboratively with a theatre actor and an artistic director, this case study validates this research's theoretical and methodological frameworks in a real-world theatrical setting.

The implications of these outcomes contribute to the field by establishing a framework for analyzing and interacting with emotional expression in theatre. The contributions demonstrate the potential of technology to enhance emotional expression and audience engagement in theatre, highlighting the originality, practical applicability, and potential for further innovation and exploration at the intersection of technology, psychology, and the performing arts.

This research methodology integrates quantitative and qualitative tools in a mixed-method approach. The quantitative aspects provide a framework for designing experiments involving physiological sensing and emotion recognition, which can be generalized and refined for future studies. Introducing a software platform for capturing, parsing, and mapping physiological data to sound elements addresses the limitations of market-available tools, providing the artistic community with an accessible and comprehensive toolset.

However, the inherent limitations of this approach must be recognized. The qualitative dimensions of the research limit the generalizability of the results. Focusing on a specialized and narrow population sample of actors means that the findings may only partially apply to the general population. Moreover, the challenges of universalizing insights and the complexities introduced by methodologies that facilitate broader applicability must be acknowledged. The intricate technical setup required for physiological-driven interactions demands meticulous effort from all participants, and reproducing specific emotional states after technical disruptions pose a creative challenge. Ensuring the ecological validity of the setup in real-world theatrical scenarios is crucial, and while the feasibility of such an approach has been demonstrated, transitioning from controlled laboratory conditions to the vibrant and unpredictable theatre environment requires careful consideration and adaptation.

1.10 Structure of the Dissertation

Chapter 2 provides background and context for the present research by exploring the intricate relationship between acting emotions and theatre sound through a physiological lens. It aims to provide a comprehensive analysis of *Acting Emotions*, as defined by Konijin, emphasizing the dynamic interplay between emotional expression and physicality in acting. The discussion will include a detailed overview of various methods for recognizing emotions, focusing on theories that consider the physiological aspects of emotion recognition. These theories will be carefully integrated and scrutinized within the context of this research, offering a nuanced understanding of the topic. Furthermore, the chapter will elaborate on the design of an IMS designed to demonstrate the complex interaction between emotion, physicality, and sound within a theatrical environment. This system will illustrate how physiological insights can enhance and transform the auditory experience in theater, bridging the gap between theoretical concepts and real-world application.

Chapter 3 presents the related work by examining the musicality in Samuel Beckett's theater, reflecting the integration of music, language, and consciousness, as characterized by Hans-Thies Lehmann in post-dramatic theatre. It then transitions to the experimental works of The Wooster Group, known for their avant-garde, dreamlike productions and multimedia innovation, focusing on their *Three Places in Rhode Island* trilogy and subsequent works. The discussion progresses to IMS driven by physiological signals, tracing their evolution from 1965 to contemporary biophysical music, highlighting key works like Alvin Lucier's *Music for a Solo Performer*. The chapter concludes with an overview of IMS, noting the increasing use of physiological sensors and the expanding scope of these systems, now encompassing emotional, cognitive, and collaborative aspects.

Chapter 4 provides an overview of the primary technologies that underpin affective computing, encompassing emotional speech processing, facial expression recognition, and concluding with a discussion on physiological emotion recognition. Accompanying this discussion is a comprehensive description of physiological sensors.

Chapter 5 explains the methodology adopted for integrating physiological signals into IMS in theater. It focuses on how actors' emotional states, physiological responses, and the consequent sound manifestations interplay in a theatrical setting. It addresses three core questions: First, it investigates the correlation between physiological signals and actors' emotional states during performances, including variations across individuals. Second, the study examines actors' experiences and interactions with sounds generated from their physiological data, exploring its impact on their emotional expression and agency in performances. Lastly, it examines how incorporating physiological data into theatre sound design redefines traditional narratives and storytelling techniques.

Chapter 6 delves into Acting Emotions 1, a detailed experimental framework investigating the physiological dimensions of emotional valence and arousal in professional actors. The experiment examines how valence and arousal are physiologically manifested across diverse actors. This study's distinctive aspect is its protocol, which allows participants to select their emotional state

from four predefined emotional categories, followed by a self-assessment after the experiment. The methodology employed in this research includes analyzing inter-rater agreement, studying continuous annotation trajectories, and comparing box plots across different emotional categories. Results from this study indicate that actors effectively induced the targeted emotions, resulting in significant differences in the levels of valence and arousal.

Moreover, the research includes an initial analysis intended to model the recognition of acting emotions using raw and processed temporal and spectral data, evaluating the reliability of physiological data over time. Creating the DECEiVeR dataset was a pivotal part of this research, aimed at deepening the understanding of the intricate link between physiological signals and emotional expressions in acting. This dataset is particularly significant for advancements in acting emotion recognition and the broader field of affective computing, highlighting how physiological signals can mirror emotions stemming from internal stimuli.

Chapter 7 discusses the second experiment, Acting Emotions 2, delves into Samuel Beckett's theater, particularly examining the *Corporeal Turn* and its evolution through material, organic, and atmospheric phases, as discussed in Section 1.4. Central to this study is the intersection of sound generation, physiology, and theater, intending to enhance emotional expression in acting. Through a detailed case study, the research investigates how sound, created from physiological data, influences actors' emotional expression and sense of control in performances.

This experiment offers comprehensive guidelines for integrating physiological sensors into theatrical environments, enabling practitioners to utilize the full potential of these tools in enriching emotional expression on stage. Furthermore, it advises selecting the most suitable physiological sensor for distinct emotional tasks, aiding actors and directors in fine-tuning their performances for greater authenticity and emotional impact. While recognizing the potential limitations due to individual physiological variations and specific roles, the experiment establishes a framework for implementing physiological-driven sonification in theater. This approach enhances the understanding of emotional expressions in performances. It is a valuable resource for the theater community, enriching the art form with innovative technological integration.

Chapter 8 is dedicated to interpreting and elucidating the study's results, offering an in-depth analysis of the findings. It focuses on the implications of these results, examining their relevance, significance, and potential impact within the broader context of the field. The discussion will delve into how these findings contribute to existing knowledge, highlighting their importance in advancing understanding in the area of study. Additionally, the chapter acknowledges and addresses the limitations encountered during the research, involving a reflection on the constraints of the study, considering how these limitations may have influenced the outcomes and the interpretations drawn from them. This self-critical examination is crucial for contextualizing the results and understanding their scope and applicability.

Chapter 2

Background and Context

The primary aim of this chapter is to elucidate the context and background of the present research. It initiates by elucidating the theory of Acting Emotions, examining its influence on contemporary acting strategies, and contrasting it with Diderot’s perspective on the Paradox Of Acting as referenced in Section 1.2. Furthermore, the chapter introduces the concept of task emotions, proposing that actors experience emotions associated with the act of performing itself, rather than emotionally identifying with their characters. The discussion further explores how task emotions serve as a bridge between acting, physicality, and physiological phenomena. Additionally, it addresses the question of repeatability and control. Moreover, a conceptual framework is proposed, elucidating the connection between acting and sound through emotional expression. Ultimately, the chapter concludes with a section that analyzes interaction, primarily within the context of Interactive Musical Systems (IMS).

2.1 Emotion Expression in Theatre in Konijn *Acting Emotions*

The concept of “acting emotions” serves as the conceptual foundation for the present research, aiming to explore the complex relationship between actors and the emotions they convey. This multidimensional topic intersects psychology, theatre studies, and philosophy, challenging conventional paradigms and expanding the boundaries of character embodiment.

The concept of “acting emotions” traces its origins to Denis Diderot’s *The Paradox of Acting* (refer to Section 2), published in the 18th century. Diderot’s work introduced the notion that a proficient actor should not personally experience the emotions they portray—a departure from the prevailing sentiment of his era, which emphasized the significance of emotional expression in acting. In the 21st century, Diderot’s paradox has evolved into what is commonly known as the “actor’s dilemma”, grappling with the tension between an actor’s own emotions and those they depict on stage. At the core of the concept of *Acting Emotions* lies the “actor’s paradox”, which questions whether an actor’s emotions should align with those of the character they portray. This dilemma prompts reflection on whether actors should prioritize technical execution or emotional

engagement in their performance. This theoretical inquiry carries practical implications for acting, influencing aspects ranging from training methodologies to performance assessment (Hetzler, 2007).

A main contribution of *Acting Emotions* is the idea of “task-emotions”, i.e., emotions related to the act of performing itself, as opposed to the character’s emotions. This innovative perspective suggests that actors experience these task emotions rather than identifying emotionally with their characters. This offers a new lens to view the emotional complexities of acting, providing a more nuanced understanding of the actor’s experience (Konijn, 2000, pp. 7-8). The concept of *Acting Emotions* also brings into focus the ongoing debate between emotional expression and technical proficiency. Some schools of thought, like Method Acting, endorse emotional immersion to achieve a more “authentic” performance. Others, often rooted in classical training, argue for a more technical approach, prioritizing control and precision over emotional involvement. This debate is a modern manifestation of the actor’s dilemma and serves as a critical point of discussion in the study of *Acting Emotions*.

Understanding the concept of *Acting Emotions* has far-reaching implications for contemporary acting theory and practice. It challenges actors to be more self-aware and reflective about their emotional processes, encouraging a more nuanced approach to character portrayal. Moreover, it opens up new avenues for research and pedagogy, offering a more comprehensive framework for understanding the emotional dimensions of acting. This paradigm shift is not just academic but has real-world applications, influencing how acting is taught, how performances are evaluated, and even how actors prepare for roles.

“Acting emotions” also intersect with psychological theories related to emotional labor and cognitive processes. Emotional labor, a term coined by Hochschild, refers to managing emotions to fulfill the emotional requirements of a job (Hochschild, 1979). In the context of acting, this involves portraying a character’s emotions and managing one’s own emotions before, during, and after a performance. On the other hand, cognitive processes involve the mental activities that contribute to performing, such as memory, attention, and decision-making. Understanding these psychological dimensions adds depth to the concept of *Acting Emotions*, offering a more holistic view of the actor’s experience. “Acting Emotions” has also led to the development of various methodologies and techniques aimed at helping actors navigate the complexities of emotional portrayal. From Stanislavski’s “emotional memory” (Stanislavski, 1989) to Meisner’s “moment-to-moment” technique (Shirley, 2010), different approaches offer unique ways to tackle the actor’s dilemma. These methodologies are not mutually exclusive but can be integrated to create a more versatile and adaptable actor. The evolution of these techniques reflects the ongoing exploration of “acting emotions” as a concept, demonstrating its dynamic and ever-changing nature.

In the context of the present study, “acting emotions” serves as a pivotal framework for understanding the emotional complexities involved in the craft of acting. This concept challenges traditional notions, spanning from its historical roots in Diderot’s paradox to the modern-day actor’s dilemma. It offers a more nuanced understanding of what it means to portray emotions on stage or screen. The introduction of task-emotions, the debate between emotional expression and

technical proficiency, the role of the audience, and the psychological and ethical dimensions all contribute to a comprehensive understanding of “acting emotions”. As the field of acting continues to evolve, this concept will undoubtedly remain a central topic, offering valuable insights into the emotional intricacies of this compelling art form.

2.1.1 The Actor’s Dilemma: Actor’s Emotion and Character’s Emotion

Denis Diderot’s *The Paradox of Acting* introduces a counter-intuitive notion: that a proficient actor should not personally experience the emotions they portray. This idea has evolved into what is commonly known as the *Actor’s Dilemma*, which grapples with the tension between an actor’s own emotions and those they are expected to depict on stage. This section delves into the intricacies of Diderot’s *Paradox* and the “actor’s dilemma”, exploring their implications for contemporary acting theory and practice.

Diderot’s *Paradox* presents a radical viewpoint that challenges conventional wisdom about acting. He argues that a good actor should not personally experience the emotions they portray but should instead focus on technique, control, and calculation. Diderot’s argument stems from the belief that emotional involvement could cloud judgment and hinder performance—a departure from the prevailing sentiment of his time, which often emphasized the importance of emotional expression in acting.

The Actor’s Dilemma provides a nuanced understanding of the complexities inherent in acting. It questions whether actors should approach their craft with “the head”, emphasizing “cool calculation” and “technique”, or with “the heart”, prioritizing “emotions” and “involvement” (Konijn, 2000, p. 32). This dilemma is further compounded by the dual role of the actor as both the instrument and the interpreter, leading to four levels of enactment: the private emotions of the actor, the task-emotions of the actor as a craftsman, the intended emotions of the inner model, and the emotions of the character in the realized performance (Konijn, 2000, p. 36). *The Actor’s Dilemma* has polarized theorists and practitioners into two camps: emotionalists and anti-emotionalists. Emotionalists argue that actors must personally experience the emotions they portray to deliver an authentic performance. In contrast, anti-emotionalists assert that emotional involvement can be detrimental, advocating for a more calculated approach. This division mirrors the original sentiments expressed in Diderot’s *Paradox*, where he took an extreme anti-emotionalist stance.

Rooted in Diderot’s *Paradox*, the *Actor’s Dilemma* continues to be a subject of intense debate and study. While Diderot’s extreme viewpoint may not find universal acceptance in today’s diverse landscape of acting theories, his questions about emotional involvement and technical proficiency remain highly relevant. It serves as a framework for understanding the intricate balance that actors must strike between their own emotions and the emotions they are tasked with portraying. As acting theory continues to evolve, the *Actor’s Dilemma* will undoubtedly remain a central issue, challenging actors and theorists alike to rethink the emotional dimensions of this complex craft.

2.1.2 Task-Emotions: Bridging the Gap

The concept of task-emotions was introduced to address the long-standing *Actor's Dilemma*, which grapples with the tension between an actor's emotions and the emotions they are supposed to portray on stage. Traditional acting theory often focuses on the idea that actors should either fully embody the emotions of their characters or maintain a level of detachment to execute a technically proficient performance. Task-emotions offer a third perspective, suggesting that actors experience emotions related to the act of performing itself rather than identifying emotionally with their characters (Konijn, 2000, pp. 7-8). One of the most critical aspects of understanding task-emotions is distinguishing them from character-emotions. While character emotions are the feelings that the actor is supposed to portray as part of their role, task-emotions are the emotions that the actor experiences due to the act of performing. These could range from the anxiety of being on stage to the exhilaration of successfully executing a challenging scene. This distinction is crucial because it shifts the focus from the emotional expression of the character portrayal to the emotional experience of the actor, offering a more holistic view of performance. Task-emotions are deeply rooted in psychological processes involving cognitive and emotional elements. On the cognitive side, task-emotions may be influenced by the actor's focus, concentration, and decision-making during a performance. On the emotional side, they may involve feelings like excitement, nervousness, or even fear, which are directly related to the act of performing. Understanding these psychological underpinnings adds depth to task-emotions, offering a more comprehensive view of the actor's emotional landscape.

The concept of task-emotions has significant practical implications for both training and performance. In terms of training, understanding task-emotions can help acting coaches develop methodologies that focus on managing these performance-related emotions. This could involve techniques for channeling nervous energy into a performance or exercises for maintaining focus and concentration. In terms of performance, being aware of task-emotions can help actors deliver more nuanced portrayals, as they can distinguish between their own emotions and those of their characters.

The concept of task-emotions has led to the development of various methodologies and techniques aimed at helping actors navigate the complexities of emotional portrayal. These methodologies are not mutually exclusive but can be integrated to create a more versatile and adaptable actor. For instance, Stanislavski's "emotional memory" technique focuses on drawing from the actor's experiences to authentically portray the character's emotions. However, understanding task-emotions can add another layer to this, allowing actors to differentiate between their own emotions and the task-emotions related to performing. This can lead to a more nuanced performance, where the actor knows multiple emotional layers at play. Another crucial aspect of task-emotions is the audience's role in shaping a performance's emotional landscape. The actor's task-emotions are influenced by their internal processes and the audience's reactions. For instance, an actor may experience a surge of adrenaline and excitement if the audience responds positively to a particular scene. Conversely, a lackluster response may lead to disappointment or even self-doubt. This dy-

dynamic interplay adds another layer of complexity to task-emotions, as actors must navigate their emotions while also being attuned to the emotional responses they elicit from the audience.

The concept of task-emotions is not limited to theatrical performances but extends to various genres and media, including film, television, and interactive media like video games. In each of these contexts, the actor's task-emotions may vary based on the specific demands and challenges of the medium. For example, the task-emotions experienced during a live theatrical performance may differ significantly from those experienced on a film set, where multiple takes and the absence of a live audience create a different emotional landscape.

2.1.3 Task-Emotions and Physicality: Shaping Physiological Phenomena

While much has been discussed about the theoretical underpinnings and practical implications of task-emotions, one area that warrants further exploration is the relationship between task-emotions and physicality. This section analyzes this relationship, examining how task-emotions manifest physically and influence the actor's performance.

Task-emotions serve as a third perspective to the long-standing Actor's Dilemma, which grapples with the tension between an actor's own emotions and the emotions they are supposed to portray on stage. Unlike character emotions, which are the feelings the actor is supposed to portray as part of their role, task-emotions are the emotions that the actor experiences due to the act of performing. These could range from the anxiety of being on stage to the exhilaration of successfully executing a challenging scene (Konijn, 2000, pp. 7-8). According to the author, specific physiological activations often accompany task-emotions. For example, task-emotions such as tension, excitement, and challenge are coupled with physical reactions like general excitement, sweating, blushing, tingling, and butterflies in the stomach. Many professional actors surveyed reported these physical sensations occurring strongly or very strongly (Konijn, 2000, pp. 140-141). One of the most intriguing aspects of task-emotions is their influence on the actor's behavioral expression. Task-emotions and their accompanying action tendencies must be shaped to create the illusion for the audience that the observed behavior expresses the character's action tendencies and emotions. This complex task requires a deep understanding of the character's emotions and the actor's task-emotions (Konijn, 2000, p. 73).

Task-emotions are functional and contribute to the actor's presence on stage or screen. Physiological phenomena observed in studies with actors suggest that they have intense task-related emotions that serve a twofold purpose: a) They lend the portrayal of character-emotions "the illusion of spontaneity", and b) they contribute to the actor's presence. Therefore, task-emotions' physicality is not merely a by-product but an integral part of the actor's performance (Konijn, 2000, p. 79). The study also revealed that positive task-emotions in actors were coupled with action tendencies to approach, contributing to the generally positive nature of actors' emotions on stage. These approach tendencies are consistent with challenge and concentration. There was a significant correlation between these action tendencies and the "gutsy feeling" actors experienced. Positive task-emotions were especially true for excitement with physical activation (Konijn, 2000,

p. 153). Understanding the physical manifestations of task-emotions can have significant implications for actor training. Techniques can be developed to help actors manage their task-emotions effectively, channeling them into a more nuanced performance. For instance, breathing exercises could be used to manage task-emotions like anxiety or tension. At the same time, physical warm-up routines could be designed to prepare the actor for the emotional demands of a performance.

The concept of task-emotions offers a groundbreaking framework for understanding the emotional complexities involved in the craft of acting. When examined in conjunction with physicality, task-emotions provide a more comprehensive understanding of the actor's emotional landscape. From physiological manifestations to behavioral expressions, task-emotions' physicality is critical in shaping the actor's performance. As acting theory and practice continue to evolve, task-emotions and their physical manifestations will undoubtedly remain a central topic, offering valuable insights into this compelling art form's emotional and physical intricacies.

2.1.4 Repeatability and Control

In the world of acting, repeatability is not just a desirable trait but an imperative. Whether it is a theatrical performance that runs for several nights or a film scene that requires multiple takes, the actor's ability to replicate emotional expressions is crucial. Every performance must closely resemble the previous one, and the actor's expression must be "unambiguous, ordered, tenacious, and persevering" (Konijn, 2000, pp. 49-50). This requirement for repeatability poses a unique challenge: how to make a repeatable, fixed, stylized expression seem 'like new' each time it is performed. Control serves as the counterpoint to repeatability in the realm of acting emotions. While the characters portrayed may be out of control emotionally, the professional actor must nonetheless maintain control over their performance to ensure that it proceeds as planned (Konijn, 2000, p. 67). This control extends to various facets of acting, from voice modulation and facial expressions to body language and movement. The actor's capacity to undertake the demands of the situation is a testament to their level of control. Training is an integral part of an actor's journey, serving as the foundation for their craft. In acting emotions, training is directed towards forming 'the instrument,' which includes voice training, text training, posture, gesture, and movement. This extensive training aims to equip actors with the skills needed for both general and character-specific features of emotions (Konijn, 2000, p. 50) and includes components such as:

- **Voice Training:** Voice is an essential tool for an actor, and training in voice modulation allows for greater control over emotional expression. Techniques such as pitch control, tone modulation, and breath control are taught to enable actors to convey emotions convincingly and repeatably.
- **Text Training:** Understanding the script's nuances and the characters' emotional arcs is crucial. Actors are trained to dissect the text, understand its emotional undertones, and prepare for the emotional demands of the role.

- **Physical Training:** Posture, gesture, and movement are integral to an actor's performance. Physical training includes exercises that help actors control their body language better, allowing for a more nuanced and repeatable emotional expression.
- **Emotional Training:** Involves techniques that help actors tap into their emotional reservoirs. Methods like Stanislavski's "emotional memory" or Meisner's "moment-to-moment" technique are often employed to help actors achieve emotional expression.

Different acting methodologies offer unique approaches to achieving control over emotional expression. For instance, Method Acting emphasizes emotional immersion and uses techniques like sense memory to help actors achieve emotional expression. On the other hand, classical training often employs a more technical approach, focusing on voice modulation, timing, and physicality to achieve control (Konijn, 2000, p. 112). Practice is the cornerstone of repeatability. Actors often rehearse extensively to ensure their emotional expressions can be repeated consistently across performances. This rehearsal process is not just about memorizing lines but involves a deep emotional preparation that allows for the 'illusion of the first time' in each performance. Feedback from directors and peers is crucial in training for repeatability and control. Constructive criticism helps actors understand where they need to exert more control or where their performance lacks repeatability.

Training for repeatability and control in acting emotions is a multifaceted process involving voice training, text analysis, physical preparation, and emotional techniques. Different acting methodologies offer unique perspectives on achieving control, and extensive practice is crucial for ensuring repeatability. As the field of acting continues to evolve, training methodologies will undoubtedly adapt to provide actors with the tools they need to navigate the complex emotional landscape of performance.

2.2 Bridging Acting Emotions and Theatre Sound

The present study is situated in an interdisciplinary domain, exploring the intersection where theatre sound converges with the physicality and physiological processes inherent in acting. This exploration delves into methods by which theatre sound can interact with and enhance the actor's performance.

One method used is "Reinforcement", which utilizes auditory signals to accentuate the actor's physical responses. An example is the performance *HeartBeat:mb*¹, included in the White Oak Dance Project, in which the music will be accompanied by sounds produced by Baryshnikov's body, thanks to a device developed by Chris Janney, an interactive architecture artist and composer.

Another approach is "Counterpoint", where sound is strategically used in contrast to the actor's portrayal. This method can add a layer of emotional complexity to a scene by subverting audience

¹Created by Christopher Janney, choreography by Sara Rudner. Opening night at MC93 in Bobigny (Paris, France) in 1997: <https://www.youtube.com/watch?v=eAVwr-BwGck>

expectations. For instance, juxtaposed with a tense scene, a serene soundscape can create an intriguing paradox that invites deeper audience contemplation and engagement.

The “Triggering Emotion” method utilizes sound as a cue for actors, facilitating rapid emotional transitions essential in scenes requiring swift shifts in expression. This technique helps maintain the authenticity of the performance, as it aids actors in navigating complex emotional landscapes with precision and believability.

These methods represent how theatre sound design can profoundly influence theatrical performance. By investigating these techniques, this research aims to explore how sound can be effectively harnessed to enhance a performance’s emotional impact.

While the approaches mentioned above provide valuable insights into the relationship between sound design and acting, this study is set to explore a different technique: “Physiological Sensing”. This method uniquely leverages real-time monitoring of physiological indicators—such as heart rate, skin conductance, and muscle tension — and integrates these into the sound design of a theatrical performance. Using specialized sensors and software, “physiological sensing” transforms physiological data into adaptable sound parameters. Imagine, for example, an actor’s accelerated heartbeat influencing the soundtrack’s tempo, thus creating a live, reactive soundscape intimately tied to the actor’s inner emotional state. This innovative technique blurs the lines between performance and performer, merging them into a cohesive and dynamic entity. The actor’s physiological responses become a direct input for the auditory experience, making each performance uniquely responsive to their emotional and physical state.

“Physiological sensing” not only enhances the immersive quality of the performance but also grants the actors real-time influence over the soundscape through their physiological states. This method significantly enhances their control over the narrative and deepens their embodiment of the character. By allowing actors to “live” the emotions rather than merely perform them, this technique has the potential to foster emotional expressions rarely achieved through conventional methods (Rostami et al., 2017). Furthermore, the application of “Physiological sensing” in theatre opens up new possibilities for audience engagement. The theatre sound directly reflects the actors’ emotional and physiological states, creating a more authentic and resonant experience for the audience. This method can transform the actors from traditional performers into agents of their narrative, dynamically shaping the theatrical experience with each heartbeat, breath, and gesture.

This empowerment, facilitated by “physiological sensing”, extends significantly to the audience’s experience. Authentic actor engagement, supported by real-time physiological feedback, has the potential to culminate in performances that are not only more immersive but also emotionally charged (Rostami et al., 2017).

The present research endeavors to address a gap in understanding the influence of physiological reactions on theatrical performances. It suggests that integrating physiological sensing into sound design will significantly enhance the actor’s emotional expression during performance.

As outlined in the research questions in Section 1.8, the present study aims to (i) explore the correlation between physiological signals and the emotional states of actors during performances,

(ii) utilize sound as a means for conveying emotional expression, and (iii) redefine traditional theatrical narratives.

Furthermore, the exploration of physiological sensing in theatre sound design could yield insights into emotional expression in performances. Through the utilization of real-time physiological data, actors' emotional states become integral to the narrative, facilitating a more nuanced and dynamic portrayal. This approach has the potential to redefine the boundaries of storytelling in theatre, fostering a profound tapestry of emotional expressivity that resonates deeply with audiences. In essence, applying physiological sensing in theatre is not just a step forward in technological innovation; it represents a paradigm shift in the understanding and execution of performance art.

The next section will focus on the role of the body in contemporary theatre, exploring how physicality and movement further contribute to the narrative and emotional depth of performances, complementing the research's core emphasis on sound and physiological interplay.

2.3 Intersecting Physiology and Theatre Sound

As a holistic exploration, theatre acting intricately blends the broad spectrum of human emotions with physical expression, establishing a synergy that surpasses the confines of traditional performance, engaging actors and audience in a shared experience of the emotional landscape depicted on stage. Each movement and gesture by an actor acts as a brushstroke on a canvas, unveiling the character's internal world. These silent yet expressive narrative components not only accompany but also enhance the spoken words. At the same time, the deliberate rhythm and tempo of movements echo the character's emotional state, driving the narrative's progression.

In theatre, an actor's physiological responses play a pivotal role in this complex interplay of performance, grounding the character's portrayal in a tangible emotional reality. Are physiological reactions in acting genuine human responses rather than mere pretenses in contemporary theatre practices? As an example, an actor's physical signs of fear – such as an accelerated heartbeat or increased alertness – are real, not simply acted. This intersection adds a deep layer of realism, transforming the actor into the embodiment of the character's emotional journey. The actor's bodily responses are, therefore, integral, not ancillary, to the storytelling process. They bridge the gap between the audience's perception and the narrative. Moreover, these physiological responses establish a feedback loop between the actor and the audience. While beyond the scope of the present research, observing the actor's genuine emotional and physical reactions may enhance the audience's engagement with the performance. This connection enriches the theatrical experience, transforming it from a presentation into a shared emotional and experiential journey. Thus, theatre acting evolves into an art form that mirrors life and resonates profoundly with the human experience, rendering each performance a distinct and transformative occurrence.

Nevertheless, acting is not an isolated art; it exists within a broader context that includes sensory dimensions, such as visual and auditory. A key component in this multisensory experience is theatre sound.

As referenced in Section 2.2, theatre sound transcends its role as a mere background element, becoming a dynamic and essential component of theatrical performance. It reinforces the emotional subtleties of an actor's portrayal, serves as a counterpoint, subverts audience expectations, and facilitates rapid emotional transitions. Through these strategies, actors experience an enrichment of their performances by theatre sound. This auditory dimension plays a pivotal role in augmenting the emotional texture of the performance. Furthermore, theatre sound does more than complement the visual; it interacts with the nuances of the performance, adding layers of meaning and emotional depth. It can underscore a character's internal monologue, accentuate the climax of a scene, or subtly shift the audience's perception. This symbiosis between actor and theatre sound transforms the stage into a living, breathing world, where each sonic element contributes to the storytelling. The resonance of theatre sound with the actor's emotional landscape enriches the performance and invites the audience into the heart of the narrative (Leonard, 2001).

The synergy between theatre sound and physiological response can markedly intensify the emotional atmosphere of a scene. A well-timed underscore or sound cue can amplify a tense moment, creating a physiological echo in the actor that elevates the emotional experience. In this regard, theatre sound is not just an artistic enhancement but also a psychological tool that interfaces directly with the physiological aspects of emotion, tuning and intensifying the actor-audience connection.

- By pioneering innovative actor training methodologies that teach performers to align their physiological and emotional responses with sound cues, actors can achieve a more interactive connection with their characters.
- By developing theatre sound strategies that consider the physiological aspects of emotion, performances can be imbued with a more profound sense of emotional expression, elevating the auditory experience of theatre-goers.
- The insights from this research could transcend the theatre, enhancing our understanding of how sound influences physiology in other settings, such as virtual reality simulations or interactive digital installations.
- As a catalyst for future interdisciplinary research, this study may inspire collaborative investigations among technologists, psychologists, and artists, aiming to unravel further the complex interplay between sound, emotion, and physiological response.

This research unravels the intricate connections between theatre sound, physiological signals, and emotional expressions within theatrical contexts. By delving into this interplay, the research seeks to enrich the crafting and perception of emotional experiences, particularly within theatre, where sound is pivotal in user engagement. This investigation aims to perceive theatre sound as an auditory backdrop and a vital element capable of deepening actors' engagement and emotional immersion. The research explores how nuanced theatre sound, informed by an understanding of physiological responses and emotional expressivity, can transfigure the acting experience. It integrates these elements to construct a compelling and emotionally resonant narrative.

2.4 Interactive Musical Systems

The 1970s witnessed a pivotal transformation in contemporary music, driven by the emergence of compact and personal computers ². This revolution had a profound impact, particularly in improvisational music genres, and gave rise to a distinctive aesthetic in musical performance known as "interactive composing" (Chadabe, 1984). In this paradigm, electronic instruments dynamically respond to human performers, fostering collaborative control over the musical narrative and opening up a novel channel for human-machine communication.

While the concept of "interaction" permeates various musical contexts, interactive music specifically denotes a compositional style deeply rooted in the reciprocal relationship between humans and computational entities (Rowe, 1992). Figure 2.1 illustrates the fundamental structure of IMS, comprising two primary entities: a human and a computer. However, in IMS featuring versatile multi-agent configurations that mirror the collaborative nature of ensemble music, interactions can manifest between a human and a computer, involve multiple computers and an audience, or even occur exclusively among computational entities (Codognet and Pasquet, 2009).

In Winkler (Winkler, 1995b), interaction implies flexible compositional algorithms that can generate an infinite variety of music with selected parameters influenced by performers. In interactive computer music, these generative processes manifested as algorithms, use musical material sourced from previously stored data or derived from the performance itself. Modifiable parameters enable performers to shape and influence the musical output continually. Incorporating constrained random variables establishes improvisational scenarios wherein the music remains consistently different and unpredictable yet always within a predefined range that delineates a coherent musical style. Winkler's definition of interactive music systems, i.e., closely aligns with Rowe's perspective, both emphasizing the shared interaction between the performer and the computer to generate musical output (Winkler, 1995a).

In an IMS, agents engage in bidirectional communication through their sensor and actuator components, facilitating control and feedback processes. These agents possess natural and artificial cognitive abilities and memory capacities, enabling them to process sensed data and respond accordingly. While traditional acoustic instruments offer a range of interpretative possibilities, digital instruments like IMS provide heightened flexibility. Their instructions, rooted in their intangible electronic nature, afford a dynamic interplay between control and feedback (Magnusson, 2009). IMS practices, which are grounded in metacompositional approaches, encompass a spectrum from random or stochastic methods to rule-based systems (Chadabe, 1997) and cognitive frameworks (Çamcı, 2012).

Within an IMS, agents can modify the foundational compositional structure, leading to the evolution of the musical piece through this dynamic interplay of control and feedback (Drummond, 2009). Key attributes of IMS include their sensing and control mechanisms and their capacity

²Personal computers are compact and powerful hardware computing units that enhance quality in human-computer interactions (Kay, 1977)

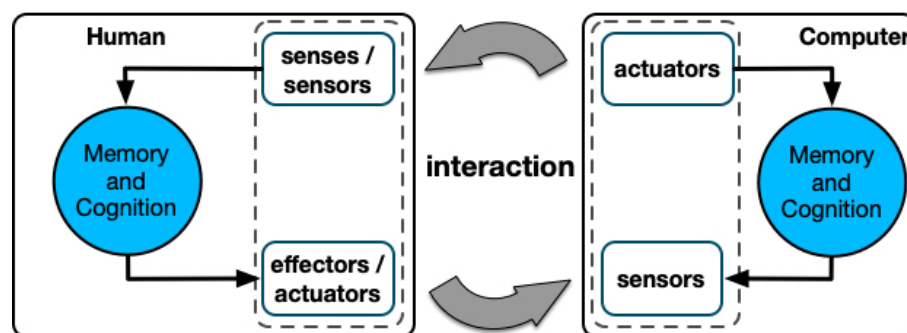


Figure 2.1: An interactive system architecture as a control and feedback loop, adapted from (Bongers, 2000). This diagram represents a model of interaction between a human and a computer, emphasizing the parallels in the mechanisms both use to perceive and act upon the world. Breakdown: **Human senses/sensors**: how humans perceive the world, such as eyes, ears, and skin; **memory and cognition** represent the human's ability to process, store, and recall information; and **effectors/actuators** represent the mechanisms humans act on the world, like hands and voice. **Computer sensors**: allow the computer to receive data from its environment, such as a camera, microphone, keyboard, or mouse; **memory and cognition**: composed by the computer's RAM, storage, and the software processes that analyze and store data; and **actuators**: allow the computer to affect its environment. Examples include a monitor (to display information), speakers (to produce sound), or motors (in the case of robots). **Interaction**: the curved arrows indicate the interaction flow between humans and computers. The human perceives outputs from the computer via their senses (like seeing something on a screen or hearing a sound) and responds using effectors (like typing on a keyboard or moving a mouse). Similarly, the computer senses inputs from the human via sensors and responds using its actuators.

for independent action. Moreover, the architectural designs of IMS increasingly promote cross-disciplinary collaboration, merging fields such as HCI and music. This convergence highlights the intricate relationship between an IMS, the human brain, and physiological sensing tools. The dynamic interplay between humans and machines, particularly within IMS, offers a captivating exploration of the capabilities and potential of human-machine interaction. In (Bongers, 2000) asserts that interaction modalities are deeply ingrained in human perception and motor functions, extending beyond the commonly recognized senses to encompass more subtle interactions.

At the forefront, we find primary sensory modalities, such as vision, which involves the act of seeing and the interpretation of visual stimuli. This extends to activities like reading a book, deciphering a musical score or immersing oneself in a film. Similarly, the auditory modality transcends mere hearing; it encompasses the processing and comprehension of sounds that reach our ears.

The sense of touch, or tactile perception, holds a unique position. Unlike passive senses like hearing, touch is inherently active. It involves gathering information about our surroundings by exploring through touch and feeling, discerning attributes like texture and temperature.

Beyond these sensory modalities, human interaction with the environment relies on output modalities, primarily governed by our motor system. This system, powered by muscles, enables a wide range of tasks, from handwriting to the intricate nuances of speech. Bio-electricity is an intriguing facet of human output, which includes signals like EMG that indicate muscle activity and EEG signals that provide insights into brain activity. These bioelectric signals can be harnessed to control external systems through electrodes.

Digging deeper into the mechanics of IMS, these systems interact with their surroundings through transducers. These devices act as intermediaries, facilitating the translation of real-world signals into a format comprehensible to machines (via sensors) and converting machine responses into real-world outputs (via actuators). In essence, sensors can be likened to the machine's sensory organs, capable of converting various forms of physical energy from the environment into electrical signals that machines can process. Intriguingly, the scope of these sensors extends beyond human perception, enabling the detection of phenomena that elude human senses, such as specific electromagnetic fields or ultrasonic sounds. This expansive array of interaction modalities, coupled with the potential for even more advanced interfaces, underscores the boundless possibilities in human-machine interactions.

Physiological sensing harnesses physiological—analytical devices that convert electrical events within the human body into measurable signals. This technology presents musicians performing with an Interactive Music System (IMS) with a range of sensorimotor control opportunities, offering novel bodily experiences during musical performances. The integration of body physiology with music gives rise to innovative modes of interaction and, in turn, redefines the role of the musician's body in the performance.

Moreover, the inclusion of physiological sensors raises intriguing questions related to creativity, impacting both researchers and IMS musicians. Expanding the use of these sensors to capture

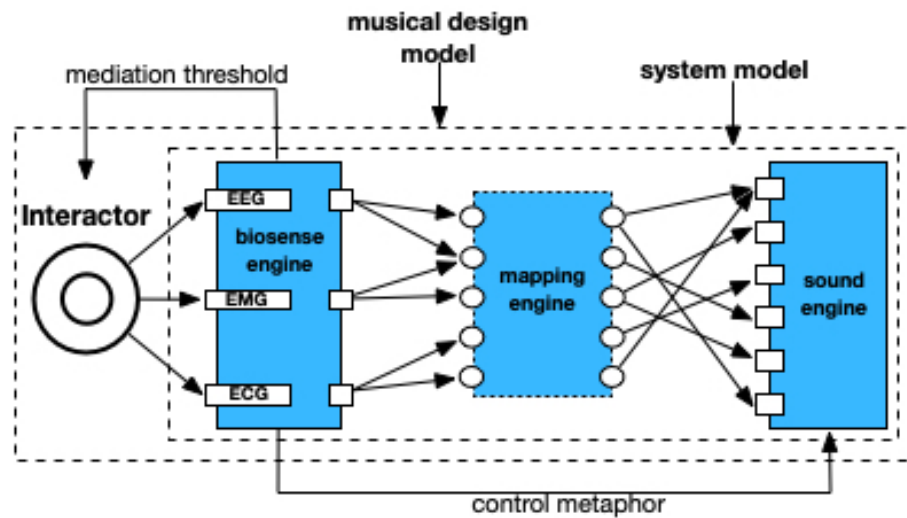


Figure 2.2: A diagram illustrating a system that transforms physiological signals from a person or user into sound for a musical or interactive audio experience. Follows a breakdown of the components: **Interactor**: represents a person or user providing input through physiological signals. **Biosense Engine**: this module gathers and preprocesses physiological signals. The labels indicate that the module can measure several physiological signals, namely brain, muscle, and heart activity, for the sake of the example. **Mapping Engine**: responsible for converting the raw physiological data into some form of standardized or useful data that can be used to generate sound. **Sound Engine**: generates or modulates sound based on the input from the mapping engine. **Musical Design Model**: represents the rules, parameters, or algorithms that guide how the physiological data should transform into musical sound. **System Model**: The overarching structure or framework within which the physiological sensing, mapping, and sound generation occurs. **Mediation Threshold**: criteria determining the conditions for the system to start or stop processing the interactor's signals or how intensely the interactor's signals influence the output. **Control Metaphor**: This could indicate a conceptual model or user-interface element that allows the interactor or user to influence or control the system.

the audience's physiology introduces a realm of possibilities. For instance, by utilizing physiological sensors to gather high-level cognitive data from audience members, interactive musicians can gain insight into the emotional states of the audience during a live performance. This opens the door to new strategies for interaction, not only between musicians and computational systems but also across multiple humans, reshaping the dynamics of musical engagement.

In recent times, artists within the realm of IMS have increasingly incorporated physiological sensors as dynamic control mechanisms for music generation. The term "appropriation" signifies the innovative utilization of a specific technology beyond its original purpose (Naccarato & MacCallum, 2017). Our research affirms that including physiological sensors significantly expands musicians' range of interaction possibilities. Unlike conventional sensor tracking tools like video tracking, physiological sensors can capture an extensive spectrum of movements when in direct contact with the body. These movements encompass everything from subtle to pronounced body expressions.

When we refer to "subtle and micro-expressions," we allude to the minutest human motions

that are controllable and observable. This category includes subtle facial gestures and the consistent movements inherent in the human body, such as the rhythmic patterns of respiration or heartbeat. Consequently, within the context of musical interaction, physiological sensing serves as the conduit through which the intricate internal processes of a performer's body are translated into controllable variables within an IMS. In the context of IMS, the concept of "mapping" assumes a central role, serving as the crucial link that connects various stages of the system. This process entails establishing connections between the outputs obtained from sensing mechanisms and the inputs designated for processing. These mapping relationships, which underpin the functionality of IMS, can be classified into three primary types:

- **One-to-One:** In this type, a single output corresponds to a single input.
- **One-to-Many:** Here, one output has the capacity to influence multiple inputs.
- **Many-to-One:** In this scenario, multiple outputs converge on a single input.
- **Many-to-Many:** This complex type involves multiple outputs corresponding to multiple inputs, resulting in an intricate web of interactions (Hunt and Kirk, 2000).

Mapping is the critical framework that defines how information flows within an IMS, enabling the system to respond dynamically to various inputs and produce rich musical expressions.

Mapping assumes an even more nuanced role in the intricate domain of IMS, as elucidated in (Zhang and Miranda, 2006). In this context, it delineates the intricate connections between the outputs originating from a gestural controller—responsible for capturing the physical or digital gestures of the performer—and the inputs of a sound generator. This sound generator subsequently produces the desired auditory response. This intricate interplay guarantees the precise translation of the musician's gestures into the intended musical output, thereby facilitating a seamless and expressive performance. Figure 2.3 illustrates four models that exemplify the process of processing input signals, in our case, physiological signals, through the mapping engine and subsequently transforming them into sound via the sound engine.

Designing IMS is a multifaceted endeavor, and one of its most prominent challenges revolves around developing effective mapping metaphors. These metaphors serve as the vital link between user input and system output, facilitating the translation of gestures or actions into sonic or visual outcomes. The challenge can be dissected into several critical areas:

- **Responsiveness vs. Variability:** An ideally designed IMS should exhibit immediate and precise responses to a user's actions. Nevertheless, the instrument's appeal can diminish if its responses become overly predictable. Designers must strike a delicate balance, ensuring that the instrument offers diverse responses while maintaining a degree of predictability.
- **Control vs. Complexity:** Musicians and users place a premium on control to ensure that their actions consistently yield the desired outcomes. However, to engender a rich and immersive experience, the system must possess a certain level of complexity. Striking a harmonious

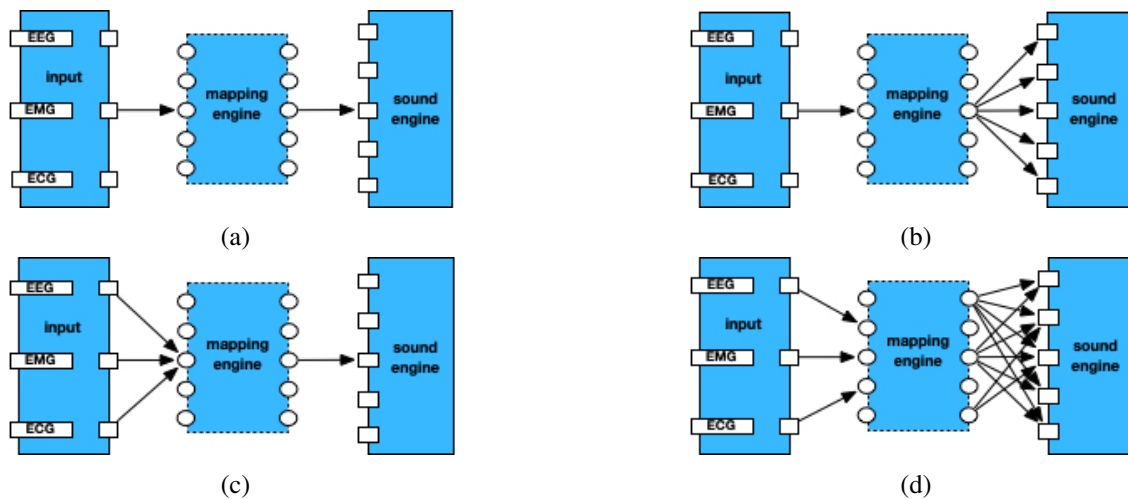


Figure 2.3: The figure showcases four models demonstrating how we process input signals, in our case physiological signals, by the mapping engine and then transform them into sound by the sound engine. Breakdown: (a) In the **one-to-one mapping**, we directly connect the input signal to a specific input of the sound engine. (b) In the **one-to-many mapping**, similar to (a), we directly connect a specific input signal to several parameters in the sound engine, which allows for more nuanced or complex sound outputs. (c) In the **many-to-one mapping**, we directly connect several input signals to one specific parameter in the sound engine. (d) In the **many-to-many mapping**, we directly connect several input signals to several parameters in the sound engine. These models can represent various experimental setups or strategies for transforming physiological signals into music or sound. Each model may be more suitable for different purposes or produce different auditory experiences, depending on how the mapping engine processes the physiological inputs.

equilibrium between control and complexity can be challenging, as excessive complexity can render the instrument unwieldy.

- **Repeatability vs. The Unexpected**: For a performer, repeatability is paramount, implying that a specific action should consistently produce a predictable result, particularly in a live performance setting. However, to sustain the experience's freshness and engagement, elements of surprise or the unexpected must be integrated.
- **Intuitiveness**: Beyond the aforementioned balancing acts, the mapping must exhibit high intuitiveness. If users or performers are compelled to invest excessive time in comprehending the relationship between their actions and the system's output, it can impede the creative process.
- **Adaptability**: As users become more acquainted with the instrument, their needs and expectations may evolve. Designers should contemplate how mappings can be adjusted or customized over time.

In essence, the challenge confronting IMS designers is the creation of instruments that function as both tools and creative collaborators. These instruments must be dependable and consistent

yet simultaneously flexible and inspirational. Achieving this delicate equilibrium necessitates a profound comprehension of both technology and the artistic process.

2.5 Summary

This section explores the intersection between theatre sound, physiological sensing, and acting, focusing on how these elements can enhance theatrical performances. The research investigates innovative techniques like “Reinforcement”, “Counterpoint”, and “Physiological Sensing”, and their impact on actors’ performances and audience engagement.

Special focus is put into “Physiological Sensing”, which integrates real-time monitoring of physiological indicators such as heart rate and muscle tension into sound design. This method transforms physiological data into adaptable sound parameters, creating a live, responsive soundscape that reflects the actor’s emotional state. This technique enhances the immersive quality of the performance and gives actors real-time influence over the soundscape.

The research aims to bridge the gap in understanding how physiological reactions can profoundly influence theatrical performances, involving disciplines like performance studies, theatre sound design, and psychology. The study hypothesizes that integrating physiological sensing in sound design will augment the actors’ agency and embodiment in their roles, deepening their immersion and connection with the character. The study also delves into the concept of ‘Acting Emotions,’ exploring the intricate relationship between actors and the emotions they portray. It examines historical perspectives like Denis Diderot’s *The Paradox of Acting* and modern approaches like the “Actor’s Dilemma” and “Task-Emotions”. The research discusses the implications of these concepts for contemporary acting theory and practice, emphasizing the need for a balanced approach that considers the emotional and human elements of acting.

Chapter 3

Related Work

Integrating physiological sensors as a methodology for enhancing theatre sound design has garnered attention within contemporary dance and electronic music. This innovative approach seeks to bridge the gap between human physiological responses and auditory experiences, enriching the level of interaction in the performance. By leveraging physiological sensors, such as heart rate monitors, galvanic skin response sensors, and electromyography devices, sound designers aim to capture and interpret the real-time physiological data of performers or audience members. This data serves as a dynamic input for generating and modulating soundscapes, music compositions, or audiovisual elements, effectively blurring the boundaries between the physical and sonic dimensions of the theatrical experience.

In (Morand, 2022), the author reviews different historical milestones that led toward how interactivity is experienced today, looking at dance artists who considered the body-machine relationship to be an essential part of their artistic discourse. According to the author, interactivity in performance art represents a collaborative process facilitated through media, wherein the gestures and movements of the performer are meticulously tracked and analyzed. Through the integration of motion tracking technologies and sensor-based systems, the performer's bodily expressions serve as input data that inform real-time alterations in the sonic and visual dimensions of the performance environment.

Contrary to dance and music, integrating physiological sensors to generate real-time sound in theatre still needs to be explored. Different from the extensive applications observed in music composition and dance, the utilization of physiological sensors for live sound creation within theatrical contexts is notably limited. This scarcity of examples underscores a notable gap in the current discourse surrounding the intersection of physiological sensing and theatrical sound design. As such, there exists a compelling opportunity for exploration and experimentation in this domain, with the potential to unlock novel avenues for creative expression and audience engagement within the realm of theatre.

In this study, a meticulous analysis will focus on three distinct examples — two from theatre and one from dance — that have been selected as foundational references guiding the present research. These exemplars showcase varying degrees of engagement with sound within the per-

formance context, offering valuable insights into the interplay between physiological sensing and artistic expression. Through a comprehensive examination of these chosen instances and analyzing the nuances of each case study, including the techniques employed and the aesthetic objectives pursued, this research seeks to inform and contextualize the development of novel methodologies for incorporating physiological sensors into sound design practices across diverse performance genres.

The first work selected for analysis is Samuel Beckett's *Play*, a piece that explores the interplay between music, language, and consciousness — a thematic motif recurrent throughout Beckett's body of work. *Play* is an example of Beckett's avant-garde theatrical style, wherein the boundaries between spoken word, musical rhythm, and psychological introspection blur to create a multitude of sensory experiences. Furthermore, a notable aspect of *Play* is the immobilization of the actors. This directorial choice heightens the significance of sound and language in conveying emotional depth and narrative progression. Within the constrained physical space of their respective urns, the characters are deprived of conventional bodily movement, compelling them to rely solely on vocal delivery and auditory cues to express emotions and advance the plot. This deliberate immobility not only underscores the centrality of sound as a primary communication medium but also accentuates the psychological tension and existential turmoil experienced by the characters.

The second example under analysis is not a singular piece but rather a methodological approach to designing live interaction within a theatrical context, exemplified by the innovative practices of the Wooster Group. Renowned for their contributions to avant-garde theatre, the Wooster Group's oeuvre is characterized by its non-linear narratives and pioneering integration of multimedia elements. This section elucidates the group's seminal role in reshaping the landscape of contemporary theatre, tracing their trajectory from early productions to more contentious works. Through a comprehensive analysis, the study examines the distinctive narrative styles the Wooster Group employs, especially their inventive use of multimedia technology. This analysis aims to extract valuable insights into the methodologies employed by the Wooster Group for orchestrating immersive and interactive experiences within the theatrical context, thereby informing the development of innovative approaches to live performance design.

The third example under review is *HeartBeat* by artist and composer Christopher Janney. Premiering in 1998 in collaboration with dancer Sara Rudner, *HeartBeat* represents a pioneering exploration of the symbiotic relationship between physiological data and artistic expression within performance art. Central to the piece is the utilization of a wireless heart monitor worn by the dancer, which captures and transmits the rhythmic pulsations of the performer's heartbeat to a musical synthesizer. This real-time transmission transforms the dancer's heartbeat into an auditory stimulus, serving as the foundational rhythm for an improvisational performance. The dancer's movements, guided by the amplified and musically interpreted heartbeat, establish a dynamic feedback loop between the performer and the generated sound. This interactive exchange between the physiological signals of the dancer and the synthesized music binds corporeal expression and sonic modulation, blurring the boundaries between the performer's internal sensations and external auditory experiences. Through the innovative integration of technology and embodiment, *Heart-*

Beat exemplifies a paradigmatic shift in the conceptualization of performance, foregrounding the intrinsic connection between human physiology, artistic interpretation, and sonic exploration.

The chapter concludes with an in-depth review conducted within the framework of the present research and published in the *Journal of Human Technology* as part of an issue themed 'Mind, Music, and Technology.' This systematic review investigates the utilization of physiological sensors as control structures in interactive musical systems, shedding light on the evolving landscape of interdisciplinary research at the intersection of physiology, music, and technology. By synthesizing findings from diverse artistic and academic works, the review critically evaluates the efficacy, feasibility, and implications of employing physiological sensors to control interactive musical environments. The review offers insights into the potentialities and challenges of harnessing physiological data to inform and shape musical interactions through an analysis of empirical studies, theoretical frameworks, and technological innovations. Moreover, it identifies emerging trends, methodological considerations, and future directions for research in this burgeoning field, thereby contributing to the advancement of knowledge and practice at the nexus of physiology, music cognition, and technological innovation.

3.1 The Musicality of Beckett: Play

Lehmann (2006, p. 31) characterizes post-dramatic theatre as a convergence of various art forms, signifying a new phase in theatre that gravitates towards the sensory richness offered by multimedia, moving away from traditional linear storytelling and illusion-based drama. In contemporary theatre, elements such as music, dance, visual arts, film, and electronic media have become as fundamental as music, dance, ritual, and the spoken word were in ancient Greek theatre. The essence of theatre inherently involves various expressive methods rooted deeply in its fundamental purpose. Interestingly, throughout the dynamic history of post-dramatic theatre, while many components have been seen as expendable or interchangeable, music remains indispensable. Modern theatre has shown resilience and adaptability, flourishing even without traditional elements like costumes, props, scenography, drama, narrative, and spoken language, as exemplified in works like Heiner Goebbels's *Stifters Dinge* (2007). Furthermore, the notion of conceiving theatre itself as a form of music has gained prominence in recent years ((Lehmann, 2006; Roesner, 2008), aligning theatre with a wide spectrum of human creative pursuits deeply influenced by music, spanning across all art forms and even influencing the foundational concepts of modern science.

The earliest scientific interpretations of the cosmos, as theorized by Pythagoras, mirror its structure and rules in the mathematical principles underlying musical harmony. This concept, known as the "harmony of the spheres," continues to resonate in contemporary thought. Music's role as a source of inspiration and a paradigm for other artistic forms is deeply entrenched and widespread, making it challenging to trace its precise beginnings in theater. However, Samuel Beckett's work has undoubtedly influenced post-dramatic theater's embrace of this concept. In his initial published essay, *Proust* (Pilling, 1976), Beckett aligned himself with Schopenhauer's perspective, which holds music as the sole art form capable of revealing the true essence of all

things. Schopenhauer posited that music's direct perceptual impact surpasses that of other art forms and is crucial for acquiring knowledge through perception, a process otherwise accessible only indirectly through conceptual understanding (Pilling, 1976, p. 265).

This philosophical stance is evident across Beckett's body of work, including the integration of music in his novels, stage, and radio works, the application of traditional prosodic and musical techniques in his use of language, and the use of music as both a metaphor for cognitive processes and a tool for transforming language from its literal, denotative form to what Eric Prieto describes as 'exemplification' in Beckett's later novels (Prieto, 2002). This approach in Beckett's work demonstrates a profound engagement with the intersection of music, language, and consciousness, reflecting a deep exploration of how musical concepts can inform and enhance literary expression.

In discussing Beckett's approach to language, Prieto utilizes Nelson Goodman's framework, which delineates three modes of symbolization in art: denotative, expressive, and exemplificational. He highlights that while literature predominantly employs denotative symbolization, music primarily relies on exemplificational symbolization, where the essence of a musical piece is found in the qualities it exemplifies rather than in representational or non-musical elements (Prieto, 2002, p. 33). This concept sheds light on Beckett's bold departure from traditional linguistic functions in his works. Beckett's quest was not limited to transforming literary discourse. He sought a sensory experience comparable to listening to music, which drew him to the realm of theater. This medium proved ideal for exploring language's tactile and musical qualities, where spoken words transcend mere communication to embody a musical form. *Play* (1963/64) stands out in Beckett's oeuvre as a testament to this exploration. Through his innovative use of language and structure, Beckett effectively musicalizes the narrative, challenging the conventional semiotic role of language in theater and opening doors to diverse perceptual interpretations.

Play is a short theatrical work portraying a complex love triangle involving a man, his wife, and his mistress. Designed like a musical composition, it includes solo parts for three characters and choruses, complete with rhythm, tempo, volume, and expression directions. The unique staging buries the actors up to their necks in identical grey urns, with their orations triggered by a spotlight, mimicking the cues of an unseen conductor. The performance, lasting about eight minutes, is then repeated from start to finish.

Kenneth Gaburo, recognized for his support of "compositional linguistics" (Laws, 2003) in his critique of *Play*, posits that the piece crafts its distinct linguistic sensibility through its compositional nature. Contrasting with other works of Beckett like "Watt," where language's musicality is conveyed through a character's sensory-based world perception rather than intellectual understanding, *Play* more directly mirrors the immediate perception characteristic of music, achieved through a rigorously structured rhythm, marked by repetition and enhanced with a blend of spoken, sung, and visual elements.

Play accentuates its rhythm through meticulous micro-repetitions. The *Man* character often begins his dialogues by echoing the final phrases of his prior speech. Additionally, certain words and phrases recur throughout the script as motifs or signature lines of the characters, such as "poor thing" for *Woman 2* and "get off me" for *Woman 1*. These refrains, including shared lines like "give

her up" and "poor creature," are woven into the narrative alongside non-verbal elements such as the *Man's* hiccups or *Woman 2's* sighs and mad laughter. As the drama progresses, momentum is achieved by reducing the duration of each character's speaking part and condensing their dialogue. Their speech patterns evolve to resemble poetic lines, becoming more rhythmic and punctuated, as demonstrated in *Woman 2's* dialogue, "She came again. Just strolled in. All honey. Licking her lips. Poor thing." and *Woman 1's* abrupt speech, "Pudding face, puffy, spots, blubber mouth, jowls, no neck, dugs, you could—."

An expression of linguistic musicality occurs in the choruses, which feature at the play's beginning, middle, and end. The characters are directed to deliver distinct lines simultaneously in a contrapuntal fashion. Their rapid, murmured speech, blending into a nearly indecipherable chorus, discards semantic and prosodic clarity in favor of a Cageian¹ approach where noise becomes an element of music, recurring as a thematic refrain. This use of repetition, a common element in Beckett's plays symbolizing despair, defeat, and desperation, imbues *Play* with a sense of cyclical entrapment. The play concludes with an unresolved coda, as it cuts off with the *Man's* first line repeating for the third time, only to be abruptly submerged in darkness. These repeated elements, both on small and large scales, are deliberately used as musical techniques, creating a rhythmically vibrant structure. This pulsating rhythm is augmented by linguistic, visual, and vocal elements, such as spotlights, sighs, hiccups, laughter, and murmuring, weaving together to form the unique tapestry of *Play*.

In Beckett's theatre, it is frequently observed that actors serve less as interpreters of his scripts and more as instruments through which his artistic vision is realized. This concept is particularly evident in *Play*, where Beckett's focus on vocal expression is so intense that it effectively eclipses the physical presence of the actors, who are depicted as heads protruding from urns. The nuances of voice — including pitch, tone, duration, rhythm, and clarity — are not mere enhancements in Beckett's works but form the core of the theatrical experience. These elements embody both the substance and form of the performance.

Anecdotes abound of Beckett meticulously shaping the auditory aspects of his plays, such as using a metronome to set the pace of his actors' delivery and a piano to determine their pitch. Beckett's photographer, James Knowlson, highlights Beckett's emphasis on pacing, tone, and rhythm over traditional aspects like character definition and emotional depth.

This musicality inherent in Beckett's language has not gone unnoticed by composers. For instance, Heinz Holliger was inspired to compose *What Where* (1988) after attending a Beckett play directed by Alan Schneider. Similarly, Ian Wilson's *Play* (2007), a composition for saxophone, piano, string quartet, and double bass, was influenced by the film adaptation of *Play* by Anthony Minghella². These examples underscore the profound impact of Beckett's approach to language and performance, where the auditory experience is central to the theatrical expression.

¹John Cage was a contemporary American composer who was known for introducing noise and worldly sounds into music, in other words, for stepping outside the confines of Western art music, as well as proposing a mode of being within the world based on listening, through hearing the sounds of the world as music."(Kahn, 1997)

²<https://www.imdb.com/title/tt0268536/>

In *Play*, silences may be less conspicuous than in some of Beckett's other stage works like *Come and Go* (1965-66). However, this phenomenon is primarily attributed to its musical nature. Silences in Beckett's plays serve both a musical and dramatic purpose. They often carry an air of anticipation and desperation or serve to convey the passage of time. Simultaneously, these silences are intricately woven into the fabric of the dialogue, just as in music, where silences provide structure to rhythmic patterns, melodies, and compositions.

Beckett was acutely aware of the musicality inherent in silences. During a meeting with Igor Stravinsky in 1962, he expressed interest in notating the tempo of performances in his plays. This musical consideration extended to *Play*, where the tempo and duration of pauses and blackouts on stage are meticulously marked. However, silences may seem less prominent in *Play* because its musicality leans towards a motoric quality characterized by rhythmically conceived sentences and continuous motion.

Play features one of the swiftest tempos in Beckett's stage works, marked as consistently rapid. The silences, lasting between three to five seconds, align roughly with the duration of a few musical bars in a very fast tempo. Consequently, these silences emphasize the cyclic nature of the play through textual repetitions and the repetition of the entire work.

Regarding the adaptation of Beckett's plays into film, some scholars argue that this act is considered heretical due to the inherent interpretative nature of the film medium, characterized by close-ups and montage. This approach conflicts with Beckett's preference for his plays to be performed rather than interpreted. It is worth noting that while Beckett declined offers to adapt *Waiting for Godot* (1952) for the screen, his reluctance was not driven by a dislike of television and film but by his belief that an essential aspect of the play was the image of "small men locked in a big space," which he felt would be lost in a screen adaptation.

Beckett deeply mistrusts language and famously likened it to "a veil that must be torn apart in order to get at the things behind it." (Van Hulle, 2005) Consequently, Prieto suggests that Beckett's shift in language from denotative and descriptive to exemplificational stemmed from his realization that "all the words in the world will not suffice to adequately name the simplest of subjective experiences." (Prieto, 2002) Instead, how one employed words in relation to each other and their delivery could "exemplify the laws that govern those experiences." In Beckett's case, this led to a meticulous process of refining and purifying language to the extent that entire librettos were condensed to a mere sixteen lines, and grunts, utterances, gestures, and silences assumed equal or even greater significance than the words themselves. While some might argue that in his later works, Beckett's language transitioned from being the sole intelligence to becoming a compositional technique, it is plausible that in this context, Beckett would view this shift as an upgrade rather than a downgrade.

In contrast to some of his later works, the written word in *Play* predominantly adheres to the realm of discourse and denotation, notwithstanding the presence of unintelligible choruses. Various structural and prosodic devices vividly convey the mundane, exhausting, humiliating, yet profoundly familiar and painful experiences of being ensnared in an emotional triangle. However, their perceptual impact is wholly contingent on the precision and virtuosity of the performers.

In this sense, Beckett's inherently musical text resembles a musical score, requiring a performer to bring it to life and be recognized and experienced as music, underscoring the musical underpinnings of Beckett's concepts more than the repetitions, staccato lines, rhythmic accents, or polyphonic choruses in *Play*. This is why theater played a pivotal role in articulating Beckett's revolutionary ideas, compelling him to continue directing his plays even at an advanced age. His imagination was haunted by the sounds, rhythms, and music that needed to be awakened from the written word and the silence of the page.

Furthermore, Minghella's screen adaptation of *Play* reaffirms that in Beckett's theater works, where the physicality of actors and their gestures are diminished, the visual dimension (excluding lighting) remains static, and the focus shifts toward auditory content. This transition from performance to screen retains the perceptual immediacy of Beckett's original intentions and ideas, perhaps even enhancing the work's musicality.

Lastly, it is important to acknowledge that the overt musicality in *Play*, achieved through structural, linguistic, and performative elements, is just one facet of Beckett's theatrical reinvention inspired by music. His manipulation and reevaluation of linguistic, gestural, visual, musical, and structural elements in his other plays suggest a complex interplay between the exactitude of structure and the dissolution of verbal meaning, especially in his later works. Whether one interprets these elements as manifestations of a "serial paradigm" applied to the theater or as a collection of meticulously developed techniques honed over a lifetime of exploration, there is no denying that music was the primary wellspring of inspiration and motivation behind Beckett's transformative contributions to modern theater.

3.2 Angle of Perception: The Wooster Group

The Wooster Group³, a company specializing in experimental theater, has carved a unique niche in the performing arts world. Originating from the ashes of the Performance Group, a collective established by Richard Schechner in 1967, the Wooster Group emerged as a distinct entity in the late 1970s. Its formation marked a significant shift in the landscape of avant-garde theater, particularly in New York City. The group's inception can be traced back to the creative vision of Elizabeth LeCompte, a founding member who played a pivotal role in steering the group's artistic direction. Under her leadership, the Wooster Group established its headquarters at the Performing Garage in the SoHo district of New York. More than just a physical location, this space became synonymous with the group's identity, serving as a crucible for their innovative and boundary-pushing performances. In its early years, the Wooster Group's productions were characterized by a dreamlike, nonlinear narrative style, quickly becoming a hallmark of their work. This approach was vividly showcased in their trilogy *Three Places in Rhode Island*, which included notable pieces like *Sakonnet Point* and *Rumstick Road*. These productions were not just plays but intricate collages of sound, video, and performance that defied conventional storytelling and theatrical norms.

³<https://thewoostergroup.org/blog/>

The group's experimental nature was not limited to narrative structure alone. They were pioneers in integrating multimedia elements into their performances, blending live action with manipulated sound and video. This multimedia approach was not merely an aesthetic choice but a fundamental aspect of their storytelling. It allowed them to explore themes and emotions in a manner that traditional theater could not. One of the most significant productions during this period was *Rumstick Road* which combined documentary elements, expressive props, and a profoundly emotional narrative. This piece, in particular, exemplified the group's ability to weave personal stories with broader themes, creating a rich tapestry of human experience. As the 1980s dawned, the Wooster Group continued to push the boundaries of theater with their series *The Road to Immortality*. This period saw them experimenting with radical reinterpretations of classic texts, a move that often put them at odds with the established theater community. Their production *Route 1 & 9 (The Last Act)* was particularly controversial, challenging audiences' expectations and conventional interpretations of well-known works.

Central to the Wooster Group's productions is the adept integration of various media. They skillfully meld live performances with video and audio elements, crafting a multi-layered theatrical experience that defies conventional norms. Video projections in their productions are not mere backdrops but active narrative components. They interact with and sometimes contradict the live action on stage, creating a dynamic interplay between reality and virtuality, the present and the recorded. This approach results in a rich, immersive experience that challenges audience perceptions. Sound in the Wooster Group's performances transcends the role of mere accompaniment to become a pivotal narrative tool. The group often manipulates audio to create specific atmospheres or to alter audience perceptions of the onstage action. The use of distorted voices, ambient sounds, and musical elements contributes to their performances' surreal, dreamlike quality. This auditory manipulation is integral to the storytelling, complementing the visual elements to create a unique sensory experience. The group frequently adopts a nonlinear approach to storytelling. Eschewing traditional plot structures, they opt for a collage-like assembly of scenes and images. This technique fosters a fluid, interpretive form of storytelling, focusing on mood creation and thematic exploration rather than adhering to a conventional storyline. This approach allows for greater creative freedom and encourages audiences to engage with the performance more interpretively. The Wooster Group is also known for its radical reinterpretations of classic plays and texts. They deconstruct and reconstruct these works, often incorporating contemporary references and multimedia elements. This approach revitalizes classic texts and invites audiences to engage with them in new, often challenging ways. The Wooster Group's props and set design approach is as unconventional as their narrative structures. They creatively repurpose everyday objects to serve symbolic or thematic purposes, often using them unexpectedly. The set design is typically minimalistic yet highly functional, facilitating quick transformations and interactions with the multimedia elements. This minimalism underscores the group's emphasis on performance and technology over elaborate scenic designs.

A significant aspect of their technique involves actors interacting with technology on stage. The performers often engage directly with video and sound equipment, blurring the lines between

actor, technician, and media. This interaction highlights the group's exploration of the human-technology relationship, a recurring theme in their work. In (Sterritt, 2018), this interaction is multifaceted and deeply integrated into the fabric of their performances, significantly enhancing the theatrical experience. **Video Technology Integration:** A key feature of the Wooster Group's productions is the extensive use of video projections. These are not mere backdrops but are dynamic components of the narrative. The actors interact directly with these projections, creating a seamless blend of live-action and pre-recorded video. This technique blurs the boundaries between reality and virtuality, adding a complex layer to the storytelling and challenging the audience's perception of what is real and fictional. **Live Video Feeds:** The group often employs live video feeds, where cameras on stage capture the actors and project their images onto screens in real-time. This approach allows for a unique interplay between the live performance and digital representation. The live feed can be manipulated in various ways, such as altering angles or incorporating effects to create a specific visual narrative or emphasize certain performance aspects. **Sound Manipulation and Audio Equipment:** Sound manipulation is another area where the Wooster Group excels. They frequently manipulate audio live, using mixers, synthesizers, and other sound equipment. This includes altering the pitch, tone, and volume of live dialogue or blending live sound with pre-recorded audio, creating a rich, layered auditory experience that complements the visual elements of the performance. **Interaction with Stage Technology:** In Wooster Group productions, actors often interact with the technology on stage. This interaction goes beyond performing in front of or around these elements; actors often control or manipulate them. The actors' direct engagement with technology dissolves traditional roles as they become part technicians and part performers, highlighting the group's experimental and collaborative spirit. **Use of Digital and Computer Technology:** The group also incorporates digital and computer technologies to manipulate video and audio elements, including editing live video feeds, applying filters or effects, or integrating digital media into the performance. Computer technology is also prevalent in the design phase, where digital tools are used to create set designs, plan stage layouts, and conceptualize multimedia elements. **Thematic Exploration of Technology:** Beyond its practical use, the Wooster Group often explores technology-related themes, such as the impact of digital media on human perception, the relationship between humans and machines, and the nature of reality in the digital age. This thematic exploration is intricately woven into their performances, using technology as a tool and as a subject of inquiry and commentary.

3.3 Rhythmic Resonance: Chris Janney's HeartBeat

An American artist and architect, Chris Janney has long been fascinated with the intersection of sound, light, and architecture. His work aims to transform mundane spaces into interactive experiences, encouraging viewers to engage with their surroundings in novel ways. Among his most notable works is *HeartBeat*⁴, a unique installation that merges dance, music, and audience participation, creating an immersive and dynamic artistic experience.

⁴<https://news.mit.edu/1998/artheart-0513>

Janney's journey as an artist began with his studies in architecture and music at Princeton University and the Massachusetts Institute of Technology. His interest in combining these fields led to the creation of "sound sculptures" and interactive installations that play with the sensory perceptions of space and sound. (Janney, 1997)

HeartBeat epitomizes Janney's innovative approach. First performed in 1998 with the dancer Sara Rudner, the piece involves a dancer wearing a wireless heart monitor. This monitor transmits the sound of the dancer's heartbeat to a musical synthesizer, which becomes the foundation for an improvised performance. The heartbeat amplified and musically interpreted, guides the dancer's movements, creating a feedback loop between the performer and the sound.

This installation is not just about the dancer's performance; it explores human connection and emotion. The heartbeat, a fundamental sign of life, becomes a real-time shared rhythm the audience experiences. It is a reminder of the commonality of the human experience, transcending the usual boundaries between performer and spectator (Blauert, 2007).

Janney's work often challenges the traditional notions of architectural space and its role in art. In *HeartBeat* the performance space becomes integral to the experience. The installation can be adapted to various environments, offering a new interpretation and interaction with the audience each time. This adaptability highlights the fluid nature of Janney's art, where the lines between architecture, sound, and performance are blurred (Kahn, 1999).

The technical aspects of *HeartBeat* are also noteworthy. Using a wireless heart monitor and synthesizer was innovative, especially in the late 1990s. This technology allowed for real-time translation of biological rhythms into sound, a concept relatively unexplored in art. Janney's pioneering use of technology in art has influenced the field, inspiring other artists to explore the possibilities of interactive and multimedia installations.

Moreover, *HeartBeat* delves into the concept of improvisation in dance and music. The unpredictability of the heartbeat, influenced by the dancer's movements and emotions, ensures that each performance is unique. This spontaneity is a critical element of Janney's work, reflecting his belief in the importance of the present moment and the ever-changing nature of human experience (Goldberg, 2013).

The piece also raises questions about the relationship between the body and technology. Janney transforms a private, internal rhythm into a public, shared experience by amplifying and musicalizing the heartbeat. This transformation prompts viewers to consider their bodily rhythms and how technology can alter our perception of the human body (Hayles, 2000).

In conclusion, Chris Janney's *HeartBeat* is more than just a performance; it explores the connections between sound, movement, and human emotion. Through this piece, Janney invites us to reconsider our relationship with our surroundings, each other, and the rhythms that drive us. His innovative approach to integrating architecture, sound, and interactive elements has expanded the boundaries of art and offered new ways for us to engage with and understand the world around us.

3.4 Appropriating Physiological Sensors in Interactive Musical Systems

As outlined earlier in the chapter, this section provides a systematic review that delves into integrating physiological sensors as control mechanisms within IMS. Through a comprehensive examination of existing literature, this review aims to elucidate physiological sensing technologies' multifaceted roles and implications in shaping interactive musical experiences. As a result of this investigation, three tables were compiled, designated as **A.1**, **A.2**, and **A.3**, respectively. These tables organize and present the findings derived from the systematic review conducted within this study. Each table encapsulates essential information from the reviewed literature, including key research studies, methodologies employed, and outcomes observed. By structuring the data in a tabular format, these tables facilitate the synthesis and comparison of research findings, enabling readers to discern patterns, trends, and areas of divergence across the examined studies. Moreover, these tables serve as valuable reference tools for researchers, educators, and practitioners seeking to explore the landscape of physiological sensing in the context of IMS.

The entries within these tables span a chronological range from 1965 to 2019, underscoring the historical evolution and enduring relevance of physiological signals as fundamental control structures within music performances. This temporal range highlights the longstanding interest and ongoing exploration of the intersection between physiological sensing and musical interaction, tracing the trajectory of research and innovation in this interdisciplinary domain over the past several decades. This longitudinal perspective illustrates the historical roots of physiological sensing in music performance. It emphasizes its continued relevance and potential for innovation in contemporary IMS design and practice.

A comprehensive statistical analysis of the cataloged data has been conducted to enhance understanding beyond the tabulated data to discern and illustrate significant historical trends. Subsequent figures visually represent these trends. Specific dimensions indicating the progression of physiological-driven IMSs were selected and plotted from the various categories in the tables. These dimensions encompass empirical categorization, including the specific physiological signal employed, the anticipated response from a given IMS, and the performative affordances musicians prioritize when designing an IMS.

Global statistics were derived from the cataloged data to provide insight beyond a mere textual listing, enabling the discernment of overarching historical trends visually represented in subsequent figures. Three distinct historical trends emerge from the analysis:

- **1965-1985:** This period signifies the inception and early development of physiological-driven IMS.
- **1985-2005:** Witnessing the maturation and diversification of the technology and its artistic applications, this phase reflects a pivotal evolution.
- **2005-2019:** Characterized by a surge in accessibility, this phase promotes widespread adoption of physiological-driven IMSs.

Identifying these three distinct phases guides the structuring of the subsequent subsections, delineating the evolution of physiological-driven IMS into three distinct periods.

In the accompanying visual representations, the left column displays data as stacked columns, where each column's cumulative total always sums up to 100%. This format effectively illustrates the part-to-whole relationship over time. For instance, Figure 3.1 chart delineates physiological device evolution from 1965 to 2019. While this column chart offers a historical perspective, directly comparing the relative sizes of each component within the columns can be challenging. A stacked area chart is presented on the right to address this problem, providing a clearer view of progression and composition over time. This dual representation ensures both a comprehensive overview and precise comparative insights.

As described above, the first historical phase involved a small group of early adopters of physiological-driven IMS. The novelty of physiological sensing explains this as a means of control and interaction within IMS. From 1985 to 2005, we identify a second historical phase marked by a decrease in the use of physiological sensors during the late 1980s but a resurgence in IMS practices in the 1990s. Finally, from 2005 to 2019, a third historical phase encompassed a significant physiological sensor appropriation. A growth in the availability of open-source devices can explain this, supplemented by the introduction of wearable technology that facilitated the logistics for installing, running, and repeating a specific physiological-driven IMS in various performative contexts. We now provide a critical overview of the results computed to extrapolate representative historical trends. Thus, we interpreted the statistics of each identified historical phase and their representative IMSs.

By computing global statistics from data in the table, we extrapolated representatives to identify historical trends. As illustrated in Figure 3.1, EEG sensors emerged as the predominant choice in physiologically-driven IMSs, accounting for 55.9% of the IMSs documented in Table XXX. This widespread utilization of EEG sensor technology in IMSs can be attributed to its early adoption by pioneers, aiming to establish intangible communication pathways between the brain and the musical content. This trend also mirrors old human aspirations, as depicted in myths and legendary figures, to exert influence over the physical world with the brain's power.

Following EEG sensors, the subsequent most adopted sensors were EMG (12.5%), ECG (11.8%), MMG (10.2%), and EDA (6.6%). These sensors primarily measure muscle movements (including cardiac activity and skeleton muscles) and skin conductance, the latter being an outcome of sympathetic nervous system activity. EMG and MMG sensors promote intentional control over auditory feedback, consistent with the nuanced control typically associated with traditional musical practice. Contrarily, EDA and ECG sensors highlight the influence of external factors that humans can only control indirectly. Other physiological sensors, such as PPG, RESP, TEMP, and ACC, had minimal representation in IMS, appearing in merely 3% in that period. Notably, AF, AP, EGG, EOG, FSR, BSR, GYR, HUM, MOCAP, and PST physiological sensors were lacking in any IMS works between 1965 and 1985. We can attribute this absence to technical challenges. For instance, EOG requires stationary cameras, limiting eye movement detection to fixed eye positions, which involves less available technology. Sensors like HUM possess extended signal durations,

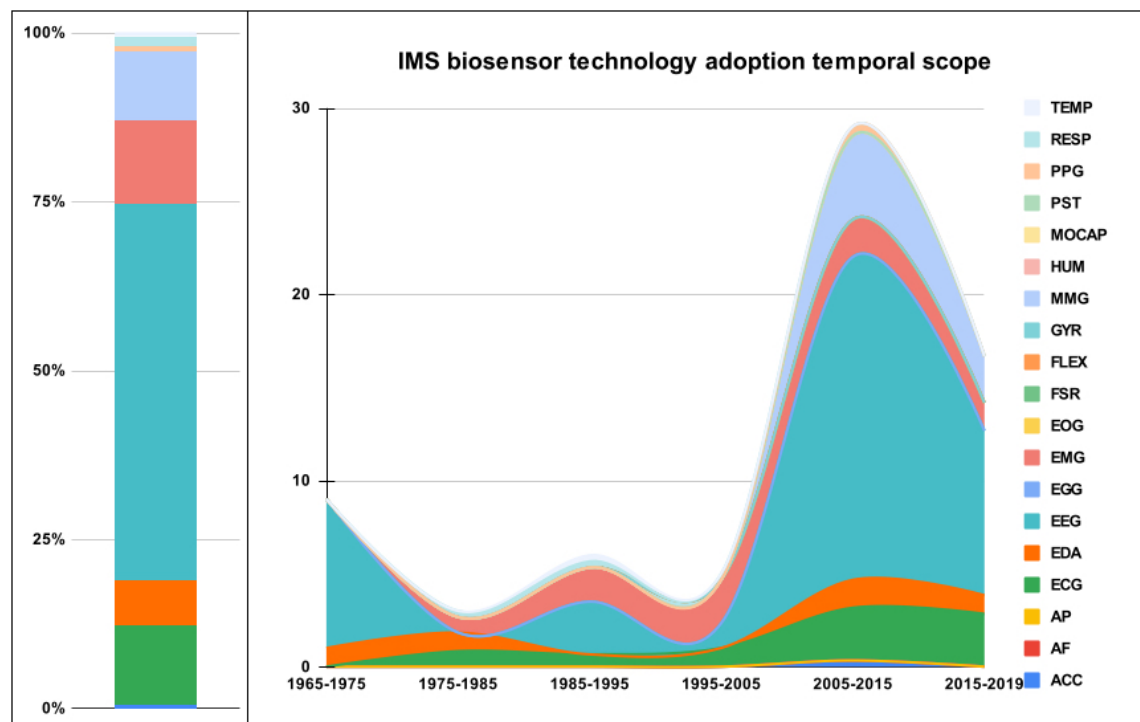


Figure 3.1: Visualization of global statistics showcasing the use of physiological sensors in IMSs from 1965 to 2019. Key: ACC (accelerometer), AF (airflow), AP (air pressure), ECG (electrocardiogram), EDA (electrodermal activity), EEG (electroencephalogram), EGG (electrogastrogram), EMG (electromyogram), EOG (electrooculogram), FSR (force sensors), FLEX (flex sensors), GYR (gyroscope), MMG (mechanomyography), HUM (humidity), MOCAP (motion capture), PST (position), PPG (photoplethysmography), RESP (respiration), and TEMP (temperature).

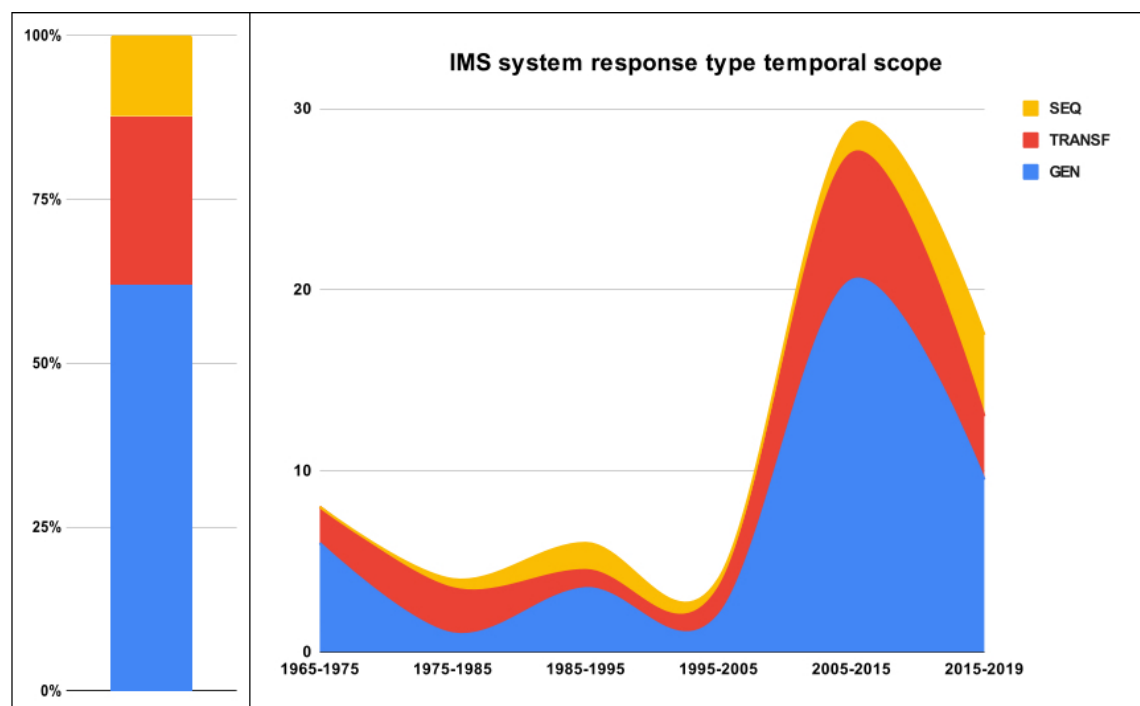


Figure 3.2: Statistical overview of system responses in physiologically-driven IMS. Key: GEN (generative) denotes the system’s autonomous creation, either uninfluenced or shaped by external input; TRANSF (transformative) indicates an algorithmic processing approach using methods like filtering, transposing, delay, distortion, or granulation; SEQ (sequenced) pertains to the execution of preset musical directives.

making them unsuitable for the temporal confines of a musical performance. Interestingly, despite the ubiquity of GYR and ACC sensors, they have yet to be prominently featured in IMSs on their own. Instead, they have been integrated alongside other sensors, such as EMG, to provide a comprehensive view of limb movement.

The chronological analysis in Figure 3.1’s right graph reveals that EEG sensors have been the dominant control structure in IMS since 1965. However, post-1995, there has been a noticeable surge in the adoption of EMG as a control mechanism in IMS. This shift can be largely attributed to the influential works of Tanaka and Donnarumma, who predominantly used muscle-based IMSs. Additionally, the rise in EMG utilization likely corresponds with the advent of faster computing capabilities, enabling operations at higher sample rates. Despite these technological and artistic advancements, the appropriation of EDA and ECG sensors has remained relatively consistent.

Figure 3.2 categorizes IMSs based on their generative, transformative, or sequenced response types. The data reveals that a significant majority (62.1%) of IMSs employ a generative response, 25.5% utilize a transformative response, and 12.4% adopt a sequenced response. The dominance of generative responses underscores the increasing tendency towards IMSs that incorporate higher levels of unpredictability, reflecting a growing interest in co-creative systems involving computer programs collaborating with human musicians on creative tasks. The primary graph in Figure XXX further emphasizes the prevalence of generative responses in the cataloged IMS, clarify-

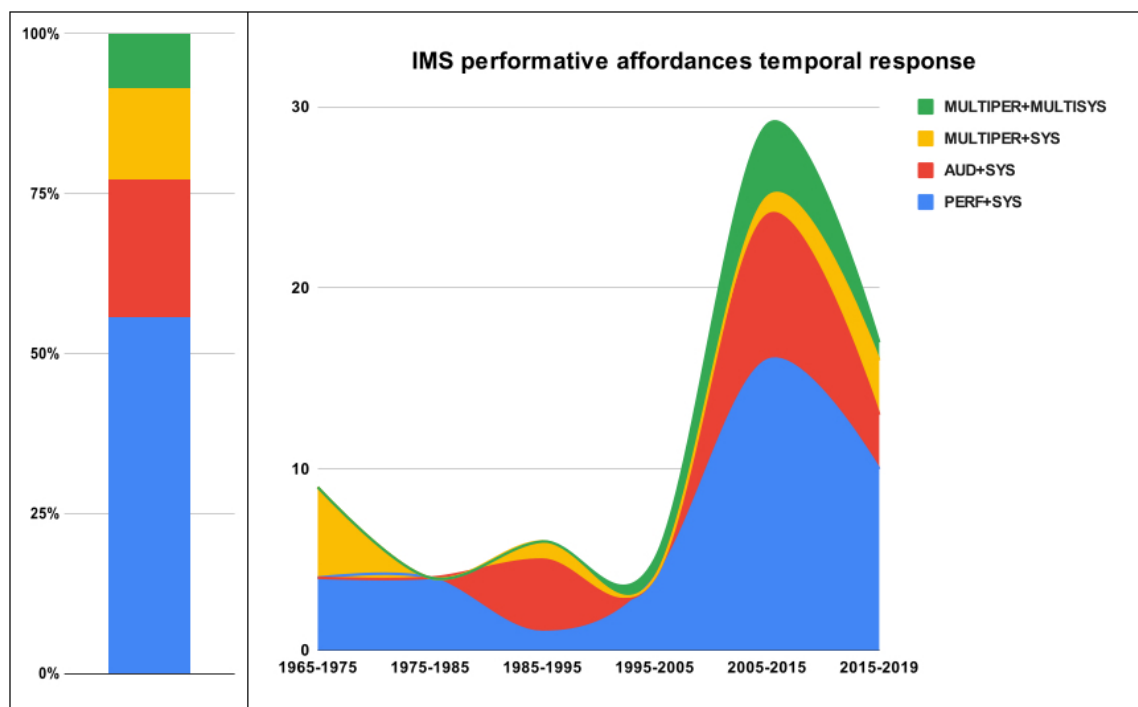


Figure 3.3: Stacked chart representation of interaction modes in physiologically-driven IMSs. Key: PERF+SYS (single human performer with a computational system), AUD+SYS (audience interacting with a computational system), MULTIPERF+SYS (several human performers with a single computational system), and MULTIPERF+MULTISYS (multiple human performers with various computational systems).

ing the concept of interactive composing introduced earlier. Concurrently, there is a noticeable uptick in IMS leveraging transformative responses. This can be attributed to the advanced algorithms in contemporary live sound processing, offering vast possibilities for real-time immersive experiences.

Figure 3.3 delineates the affordances of physiologically-driven IMSs. A significant majority, 55.7%, of the IMSs were tailored for a solo performer interacting with a single IMS. This trend underscores the intricate expertise needed to craft these systems, suggesting their use is predominantly within the realm of techno-fluent artists. The data reveals a preference among artists to design physiologically-driven IMSs for personal artistic expression. Intriguingly, 21.4% of the works incorporated audience interaction with a single system, reflecting artists' intent to immerse the audience more deeply into the artwork's experience. Multi-performer setups interacting with a single system accounted for 14.3%, often in scenarios involving musical ensembles; a smaller fraction, 8.6%, showcased multi-performer and multi-system interactions. As indicated in Figure 3.3, this trend suggests an interest in remote collaborative performances. With technological advancements in connectivity and bandwidth, the future of musical practices likely leans towards collaborative IMSs, emphasizing their potential social impact.

3.4.1 Innovators in Biophysical Music

The period from 1960 to 1985 was crucial in integrating physiological sensors into IMS, a development that had profound implications in music, namely musical interaction. During this formative era, composers and technologists collaborated to explore the potential of appropriating physiological signals, particularly brain waves, as a novel means for musical expression. This interdisciplinary approach led to the creation of groundbreaking compositions and technological innovations that impacted the landscape of experimental music and interactive systems.

One of the pioneering works in this domain was Alvin Lucier's *Music for a Solo Performer*. (Lucier, 1976) The premiere occurred at Brandeis University on May 5th, 1965, at the Rose Art Museum, Boston, Massachusetts. *Music for a Solo Performer* was groundbreaking in employing alpha brain waves to control a series of servomotors that acted mechanically on percussion instruments. Alpha waves, operating in a frequency range of 8 to 13 Hz that falls below the human hearing threshold, can be audible through adequate amplification and routing via a suitable transducer. These waves can be activated by either closing or opening one's eyes. The modulation of alpha waves can be achieved without engaging any components of the body's motor system. The primary challenge lies in calibrating the system to acquire a clear and sufficiently robust signal to be distinguishable from ambient noise. This issue is particularly pronounced when dealing with noisy analog devices akin to those employed by Lucier in the 1960s. The final sound is influenced by the composer's selection of transducers, such as integrating a loudspeaker with percussion instruments, altering resonant surfaces, or incorporating unconventional materials like scrap metal, marbles, or rubber balls into the loudspeaker cone. An assistant assigns the input signal to various output loudspeakers and transducer systems, shaping the piece's overall structure and tonal quality. The composition catalyzed further explorations of biofeedback in musical compositions. Lucier's composition was not merely a technological feat but also a conceptual breakthrough, as it challenged traditional notions of musical agency and control, positing the human brain as a musical mediator in its own right.

In 1966, Richard Teitelbaum embraced a distinct methodology from Lucier to sonify brain-wave signals (Teitelbaum, 1964). Dr. Robert Moog (b. 1934) introduced a novel way to control analog synthesizer parameters through signal voltage in that period. Inspired by Moog, Teitelbaum envisioned extending this concept by incorporating a performer's brain activity into the synthesizer's architecture. Following Lucier's work, Teitelbaum composed two improvisational pieces: *Spacecraft* and *In Tune*, further expanding biofeedback in musical compositions. *Spacecraft* was composed in collaboration with the collective Musica Elettronica Viva, of which Teitelbaum was a member. Instead of depending on a written score, each musician embarked on an introspective journey, delving deep into their consciousness. Teitelbaum utilized his body's neurological and physiological signals as live musical elements. He harnessed heartbeat, chest cavity, and throat contact microphones as transducers and used electrodes for electrocardiograms. These signals actively controlled the parameters of the Moog synthesizer. *In Tune*, an oscilloscope showcased the brainwave signal to the audience alongside the performer. The piece started with familiar sounds,

such as respiration and heart rhythms. As the composition evolved, it delved deeper into the internal physiological processes of the performer. When the performer shut her eyes, the Moog system's envelope followers identified the alpha waves, resulting in pronounced sound bursts. The performer manipulated the sound by opening and closing her eyes, collaborating in a duet with the composer. The composer acted as a supportive accompanist, adjusting sound parameters to enhance the immersive experience. Teitelbaum compositions were crucial in demonstrating the viability of using biofeedback mechanisms for real-time musical control, thereby opening new avenues for artistic expression.

Erkki Kurenniemi (b. 1941) is the foremost pioneer in Finnish electroacoustic music. As a musical instrument creator, composer, and multimedia artist, Kurenniemi was a key figure in the Finnish avant-garde music community during the 1960s and early 1970s. In that era, he crafted various distinctive electronic musical instruments, each of which remains unconventional even by contemporary standards. In 1970, he invented a series of synthesizers named DIMI, which stands for Digital Music Instrument. Dimi-T, where "T" represents "thinking," was an electronic instrument that uses alpha waves generated by the human brain during sleep to control the electronic instrument. The user places electrodes on their scalp to measure the electroencephalogram signal, which then dictates the oscillator's pitch. Kurenniemi's progression in instrument design can be characterized as a systematic and sequential shift from analog mechanisms through "quasi-digital" intermediaries to fully digital electronics.

In the context of experimental music, the 1970s witnessed groundbreaking innovations that blurred the lines between science and art. One unique collaboration was between electroacoustic French composer Pierre Henry and researcher and musician Roger Lafosse. The collaborative efforts resulted in two experimental albums, *Mise en musique du Corticalart I* and *Corticalart II* in 1971 (Henry, 1971). The live performance for this album, recorded at the Musée d' Art moderne in Paris, was directed and composed by Henry, who utilized Lafosse's Corticalart Device. Both compositions involved the transcription of electric cortex waves into control signals able to manipulate prerecorded samples, creating a unique auditory experience. Henry and Lafosse's work exemplified this field's interdisciplinary nature, merging insights from neuroscience, engineering, and music to create novel forms of musical expression.

Between 1974 and 1977, Richard Teitelbaum and David Rosenboom produced physiological-driven compositions such as *BrainWave Music* and *On Being Invisible Pt.1*. These compositions were unique because they allowed for a more dynamic interaction between the performer and the musical system, creating a more immersive and responsive musical experience. In some instances, such as in their earlier composition *Ecology of The Skin*, the control of the musical system was even shared between the performer and the audience, adding a layer of communal interaction to the musical experience.

Additional contributions to this field include Alvin Lucier's *Clocker* (1978), which employed a contact microphone placed in a clock to capture the sound of its ticks (Lucier, 1991). The audio was then routed through a digital delay unit controlled by the output voltage of an Electrodermal Activity (EDA) sensor. Changes in skin resistance produced corresponding changes in voltage,

thereby modulating the clock's ticks in real time. This work expanded the scope of physiological sensors in music to include other physiological parameters beyond brain waves.

Dick Raaymakers' *Graphic Method Bicycle* (1979) was another innovative performance that employed physiological sensors to monitor various physiological parameters such as heart rate, breathing, and muscular and emotional activity during a specific action—in this case, a man dismounting from a bicycle. The acoustic signals generated from these physiological sensors were amplified and transmitted to the audience, thereby creating an auditory representation of the physiological processes involved in the action.

In 1983, Chris Janney and Sara Rudner's *HeartBeat:mb* took a different approach by capturing electrical impulses from the performer's heart and surrounding muscles via wireless telemetry (Bone, 1998). The biotechnological equipment, crafted by Transkinetics, Inc., records the electrical signals directed to the heart and adjacent muscles using wireless telemetry. Positioned on the performer's chest and magnified through specific filters and a sound system devised by the author, this apparatus produces a rhythmic track that overlays music influenced by jazz scat, Indian tabla rhythms, and the author's vocalization of medical literature.

In summary, 1960 to 1985 was a transformative era in integrating physiological sensors into Interactive Music Systems. This interdisciplinary endeavor led to groundbreaking compositions and technological innovations that challenged traditional musical agency and control notions. By leveraging advancements in biomedical engineering and neuroscience, composers and technologists were able to create novel forms of artistic expression that have had a lasting impact on music, technology, and interactive systems. These pioneering works laid the foundation for subsequent developments in the field, setting the stage for the myriad possibilities that continue to unfold in the realm of interactive and bio-responsive music.

3.4.2 Contemporary Biophysical Music

Despite advancements in computational capabilities, storage potential, and digital signal processing techniques, from 1985 to 1995, physiological sensors were scarcely adopted as control metaphors in IMS. This limited uptake might be attributed to musicians recognizing brain signals' complexity and analytical tools' constraints for discerning relevant features from the then-noisy physiological sensor technology. However, with the emergence of cutting-edge brain-controlled interfaces starting in 1995, the field of IMS witnessed a resurgence in physiologically-driven IMS. Enhanced interoperability between various computational agents and humans within IMS and greater transparency in hardware components paved the way for innovative methodologies within established IMS practices. Notably, miniaturization led to the development of numerous IMS that more fluidly integrated physiological sensors with advanced mapping techniques.

This technological milieu facilitated the creation of the BioMuse system, a musical instrument rooted in physiological sensing (Knapp and Lusted, 1988). The BioMuse is a musical interface that utilizes physiological sensors technology. The device employs gold-plated dry electrodes that

make electrical contact with the skin, detecting electrical activity from neuron impulses in the body and allowing the interface to sense cerebral activity, cardioid activity, and muscular activity. These signals are then digitized and mapped to control computer processes and media such as digital audio, video, and computer graphics (Lusted and Knapp, 1996).

Tanaka's work with BioMuse focused solely on muscle channels. Elastic bands were employed to position the electrodes in areas to capture arm movements. The BioMuse operated a program that implemented envelope following based on the muscle tension signal. This information was transmitted to the host computer as MIDI. Once in the MAX software environment, the data underwent further processing before directing the MSP real-time audio engine. This approach effectively transforms the performer's body into a musical instrument, establishing a unique performance practice across various musical contexts. The BioMuse's proximity to the performer's body emphasizes its visceral nature and potential for intimacy, setting the BioMuse apart from other interactive systems where sensors are external to the subject. In (Tanaka, 2012), the author argues that while external sensors, such as accelerometers, effectively detect the result of an action, physiological sensors captures the intention behind the gesture by detecting the physiological signal at the origin of an action. This intention may or may not manifest in a legible media output, creating a space for ambiguity and interpretation. Within this space lies the potential for intimacy. The gap between the performer's intention and the audience's interpretation creates a mutual engagement that goes beyond the typical user-oriented focus of enactive interaction, offering a distinct approach to musical expression.

In the 1990s, physiological interfaces expanded their reach beyond musical composition and performance, finding applications in other creative fields such as virtual reality. A prime example of this integration is Addison's work. The author pioneered an interactive art initiative titled *Synesthesia* (1992), wherein electrocardiogram, respiration, and muscular activity measurements from individuals crafted and steered a virtual reality landscape (Zeltzer and Addison, 1997). Initially, the system captured a participant's heartbeat sonified it, producing an identifiable sound. Subsequently, the modalities were switched, converting auditory signals to visual ones. The inspiration behind the project director's creative pursuit stemmed from her personal experience with brain trauma, a consequence of a car accident she endured. Participants could bridge multisensory voids within these real-time virtual reality settings through an "invisible" interactive framework. As a result, proprioceptive and kinesthetic movements activated certain aspects of this networking.

In alignment with the trend of incorporating physiological technologies into interactive installations, Dunning and Woodrow conceptualized and executed a series of installations, notably *The Mnemonic Body* (2002), *The Madhouse* (2001), *Derive* (2001), and *Body Degree Zero* (2004) (Dunning and Woodrow, 2005). Within these installations, participants were encouraged to interact with specific regions of a life-sized cast of a male human form, eliciting corresponding visual and auditory responses in the primary virtual domain. Concurrently, electrodes captured the participants' brainwave activity, which was integrated into a three-dimensional virtual reality framework. This integration yielded visual and auditory representations projected onto an auxiliary display and sonically expanded within the exhibition space.

In 1998, Marrin and Piccard introduced The Conductor Jacket (Marrin and Piccard, 1998). The authors custom-designed an apparatus to gather and analyze data from orchestral conductors. The Conductor's Jacket system is a comprehensive wearable sensing system designed to capture physiological and motion data from conductors during their performances. The system's design ensures minimal interference with the conductor's natural movements while providing valuable data for analysis. The system focuses on signals detectable at the skin's surface. The final system includes one EMG sensor on each bicep and forearm extensor, sensors for respiration, temperature, skin conductance, and heart rate, and sensors measuring 3D position and orientation on each wrist, elbow, shoulder, nape of the neck, and trim of the back.

In partnership with designer Greg Turner, Dave Everitt developed an artwork named *cubeLife* (1999), influenced by a heartbeat monitor (Everitt, 2002). The piece is set in a virtual environment featuring "magic cubes" (three-dimensional matrices) created using participants' heartbeat data collected online or at the exhibition site. Each with a distinct sound, these cubes existed in a simulated ecosystem where they could interact with other cubes or follow set patterns. The cube colors and designs were chosen based on a color system or artist-defined configurations for desired visual outcomes.

The BIOS—Bidirectional Input/Output System (2002) collective engaged participants in an interdisciplinary endeavor, intertwining interactive audio-visual and technological domains. This collaboration culminated in multiple projects encompassing interactive 3D, audio-visual productions, and virtual reality. *Sensor Sonic Sights* (2003), a composition by Tanaka, Babiole, and Dailleau, delved into the expressiveness of gestures by employing muscular activity sensors as a control mechanism to produce both visual and auditory synthesis. Meanwhile, Overton's *Sitting Breathing [NOT Thinking]* (2004) spanned seven afternoons of meditative sessions, utilizing electroencephalogram, electrocardiogram, and respiration sensors in conjunction with interactive sound software (Overton, 2006). The performer's respiratory patterns, cardiac rhythms, and neural activities dynamically influence digital sound in real time, revealing the intricate interplay among these perpetually shifting internal systems.

In summary, from 1985 to 2005, despite technological advancements, the adoption of physiological sensors in IMS remained limited. Musicians were cautious due to the complexities of brain signals and the limitations of the then-available analytical tools. However, post-1995 saw a resurgence in physiologically-driven IMS, with the BioMuse system emerging as a notable example. The beginning of the twentieth century was marked by the expansion of physiological interfaces beyond music, notably in virtual reality, interactive installations, and real-time data collection.

3.4.3 Present-Day Approaches To Physiologically-Driven Music

A third phase, starting in 2005, witnessed a proliferation in the accessibility of cost-effective EEG headsets, fostering artistic exploration with brain signals. Companies introduced devices such as ThoughtTec, Neurotech's Emotiv Epoc, and Neurosky, along with proprietary software designed

to gauge levels of meditation and arousal. Notably, while these commercial devices exhibit a diminished signal-to-noise ratio compared to their medical-grade counterparts, certain IMS artists have strategically harnessed this noise as a control source within an IMS (Vavarella, 2015). For instance, phenomena such as eye blinking, typically deemed as noise during EEG measurements, can be innovatively repurposed as a control mechanism in artistic settings, thereby transforming a traditionally undesired by-product into a pivotal control structure for a physiological-driven IMS. In contemporary times, there has been a discernible augmentation in the depth of information extracted from physiological sensors. Modern IMSs are adept at deriving sophisticated insights from physiological signals, encompassing emotional, cognitive, and collaborative dimensions among the involved participants.

The BioTools project represents an innovative way to develop a modular hardware and software toolbox for composers and performers (Pérez and Knapp, 2008). The authors conceived the toolbox to quickly establish physiological monitoring and measurement systems specifically for musical applications. The impetus behind this initiative stems from the increasing interest in integrating physiological data into musical compositions and performances. To illustrate the versatility and applicability of BioTools, the authors developed three distinct works: *Díamair*, a composition involving a choir and integrating physiological sensors. The piece showcases how physiological signals can harmonize with traditional choral elements, offering a unique auditory experience (Pérez et al., 2007). *Out of Time*: In this project, BioTools plays a pivotal role in recording and analyzing physiological signals. The gathered data subsequently serves as a source of inspiration, guiding the compositional process. This approach underscores the potential of physiological signals in influencing and shaping musical narratives. *Carne*: This improvisational piece leverages BioTools modules as its primary control interface. The authors show how one can harness real-time physiological data to steer and modulate an improvisational musical performance (Benovoy et al., 2007). In essence, BioTools provides a technical framework and paves the way for novel compositional strategies, fostering a deeper integration of biology and music.

Another groundbreaking project, *The Multimodal Brain Orchestra*, raised an intriguing question: *What artistic content can a collective of brains produce when interfaced directly with external stimuli, circumventing their physical embodiments?* Orchestra participants employed virtual musical instruments via EEG interface technology (Le Groux et al., 2010). Concurrently, emotion analysis determined the affective components of a multimodal composition, resulting in a dynamic interplay where the brain functioned both as an initiator and a spectator of its actions. Lastly, *The subConch* (2009), an interactive installation by Sivertsen, seamlessly integrated phenomenological and textual facets with advanced technology. Using EEG sensors, participants were granted cognitive control over auditory and visual elements, culminating in a rich, multidimensional aesthetic experience.

Examples of physiological-driven artworks that merged kinetics and sound are De Boeck's *Staalhemel* presented in 2009 an immersive representation of the brain's topography, manifested through 80 steel ceiling tiles (De Boeck, 2009). Equipped with a wireless EEG interface, participants traversed beneath this acoustic portrayal of their brainwaves. The resulting resonances from

the impacted steel sheets produced profound overtones, creating a tangible soundscape for an otherwise intangible cognitive stream. *Brain Machine* (2010) was a kinetic sculpture controlled by mental energy, producing a continuous chaotic noise stream. When the machine detected heightened mental focus, it entered a silent state, persisting as long as the user maintained concentration.

Grace Leslie's *MoodMixer* was an interactive installation that allowed participants to collaboratively navigate a two-dimensional musical space by modulating their cognitive states, conveyed through wearable EEG technology (Leslie and Mullen, 2011). Mann, Fungen, and Garten's *DECONcert* (2011) was a unique study where participants, submerged in water and connected to EEG equipment, could influence live music by modulating their alpha wave output. This study explored the five states of matter within immersive media contexts; some spanned multiple countries via networked connectivity.

Knapp, Lyon, and DuBois devised *Music for Sleeping and Waking Minds* (Ouzounian et al., 2011), an overnight concert where performers wearing EEG sensors drifted into sleep. The data from these sensors were applied in real-time to audio and image signal processing, creating a continuously evolving multichannel sound environment and visual projection.

Knapp, Jaimovich, and Coghlan conducted a study, *Music Sensors and Emotion* (Jaimovich et al., 2012). The authors conceived this study to investigate the emotional responses of individuals to diverse musical excerpts, employing a dual-method approach. Firstly, they asked participants to articulate their feelings using self-report questionnaires, providing subjective data on their emotional states. The authors took objective physiological measures using electrodermal response and heart rate signals. These methods aimed to capture the conscious emotional reactions and the underlying physiological changes induced by the musical stimuli. The experiment was conducted over three months and showcased in a public exhibition. Approximately 4,000 individuals participated in this study, offering a rich dataset. The extensive participation underscores the public's interest in understanding the intricate relationship between music and emotions. It provided a comprehensive perspective on the universality and variability of emotional responses to music.

In 2013, Long and Vines introduced *Mind Pool* (Long and Vines, 2013), an interactive brain-computer interface artwork that offered real-time feedback on brain activity sonically and physically manifested through a reactive liquid in a pool before the participant. The authors designed this setup to foster interaction and introspection, prompting participants to correlate ambiguous feedback with brain activity.

Between 2011 and 2013, audiovisual installations and performances gained prominence. Examples include Masaki Batoh's *Brain Pulse Music* (Batoh, 2011), where brainwaves controlled musical parameters of pieces featuring traditional Japanese instruments, and Vsevolod Taran's *The Escalation of Mind* (2012), where the human brain acted as a voltage generator to facilitate audiovisual transitions.

Eaton's *The Warren* (Eaton and Miranda, 2014) used an EEG machine and a steady-state visually evoked potentials technique. This method allowed users to select commands by focusing on specific icons on a computer screen, each flashing at distinct speeds. The system mapped the

brain signal reading, determined by the concentration level on an icon, to musical parameters and commands within the composition.

Whalley, Mavros, and Furniss's *Clasp Together: Composing for Mind and Machine* (2012) (Whalley et al., 2014) explored agency, control, interaction, and the embodied nature of musical performance within HCI. The composition integrated non-instrumental physical gestures and cognitive or emotive instructions into the score. Knut's *AlphaLab* (2013) combined neurofeedback training with participatory art and electronic music, guiding participants to intense yet wakeful stillness using biofeedback sound.

The Space Between Us was a composition integrating vocals, piano, and live electronics, underpinned by an innovative brain-computer music interface system that captured the brainwave activity of a performer and an audience member during the performance. Subsequently, it translates these neural signals into a real-time musical score, drawing correlations with emotional attributes linked to the brainwave patterns. The system's dual objective was to represent emotional states musically and to actively guide and elicit specific emotional experiences through the dynamically generated score. This approach underscores the profound implications of direct neural-emotional modulation within live musical performance, suggesting a transformative avenue for audience engagement and emotional immersion (Eaton et al., 2014).

Emovere (Jaimovich, 2016) was an interdisciplinary, real-time interactive musical performance that employed physiological signals from dancers as its driving force. This innovative approach delved into the biology of emotion, serving as a foundational exploration for developing artistic works that synergize dance with physiological data. By capturing and translating the dancers' physiological responses into creative expressions, the performance analyzed the intricate relationship between bodily emotions and artistic creation, emphasizing the potential of integrating science and art in contemporary performance practices.

Marco Donnarumma presented a series of pieces, including *Hypo Chrysos* (Donnarumma et al., 2013), *Omnious* (Donnarumma, 2015a), *The Moving Forest* (2012), and *Radical Signs of Life* (Donnarumma, 2015b). These works delved into interactive sound art performances, integrating human bioacoustics and algorithms using the Xth Sense, a biophysical musical instrument developed by author himself. In 2016, Donnarumma presented *Corpus Nil* (Donnarumma, 2017), a performance that integrated the human body with hardware, software, and artificial intelligence (AI) through physiological sensors. By 2018, Donnarumma had further explored the realm of biophysical music diffusion with AI robotics in pieces like "Alia: Zu tai" [Item 68] and *Eingeweide* (Pevere and Donnarumma, 2018).

Naccarato and MacCallum's *Choreography and Composition of Internal Time* [Item 60; 2016] used real-time heart rate data from contemporary dancers to drive a poly-temporal composition.

Erdem's *Vrengt* [Item 70; 2019] focused on EMG-shared instruments for music-dance performance, emphasizing sonic microinteraction.

From 2005, there was a surge in the availability of affordable devices, accompanied by software to measure meditation and arousal levels. Despite their lower signal-to-noise ratio compared to medical-grade devices, some IMS artists utilized this "noise" innovatively in their works. The

post-2005 period saw a significant rise in IMS, with artists like Ortiz pioneering in this domain. Various artists and researchers, such as Donnarumma, Knapp, and Eaton, further expanded the boundaries of brain-signal-driven art, blending technology, emotion, and music. These endeavors have enriched the artistic landscape and showcased physiological signals' potential to create immersive experiences.

3.5 Summary

The section begins with an analysis of Samuel Beckett's theatrical works, highlighting his unique integration of music, language, and emotion. It delves into how Beckett's *Play* exemplifies the blend of various art forms characteristic of post-dramatic theater, as theorized by Hans-Thies Lehmann. Beckett's approach reflects a significant shift from traditional elements of theater, embracing a more sensory-rich and multimedia-driven form. This exploration of Beckett's work reveals his profound engagement with musical concepts and their influence on literary and theatrical expression.

Transitioning from Beckett's contributions, the focus shifts to The Wooster Group's innovative approaches in experimental theater. Known for their avant-garde style, The Wooster Group's productions stand out for their dreamlike narratives, multimedia integration, and unique interpretation of classic texts. The analysis of The Wooster Group's work underscores their groundbreaking role in reshaping the landscape of modern theater.

The section then charts the historical development of IMS driven by physiological signals from 1965 to 2023. Pioneering works in biophysical music, such as Alvin Lucier's *Music for a Solo Performer*, are discussed, highlighting the convergence of technology and artistic expression in contemporary music. This comprehensive overview underscores the evolving nature of these systems, their growing accessibility, and their broadening scope to encompass emotional, cognitive, and collaborative dimensions.

A critical overview presents global statistics and identifies three distinct historical trends in the use of physiological sensors in IMSs. The first trend (1965-1985) marks the inception of physiological-driven IMS, characterized by pioneering explorations of using brain waves for musical expression. The second trend (1985-2005) witnesses the maturation of these technologies and their artistic applications. The final trend (2005-2019) sees a surge in the accessibility and adoption of physiologically-driven IMSs, reflecting advancements in technology and an increase in open-source devices.

The expansion of physiological sensing interfaces into other creative fields, such as virtual reality and interactive installations, is also discussed, illustrating the interdisciplinary nature of this field. Contemporary practices in biophysical music are explored, showcasing modern artists' use of brain signals and physiological sensors to create engaging experiences.

Chapter 4

Emotion Recognition Methods

4.1 Affective Computing: Emotion Recognition Methods

Affective computing aims to endow machines with capabilities akin to human faculties in recognizing, interpreting, and generating affective states. This domain is crucial for augmenting human-computer interaction, fostering enhanced communication, and elevating the machine's cognitive intelligence. The underpinnings of affective computing are deeply rooted in an intersection of disciplines, encompassing psychology, cognitive science, physiology, and computer sciences. This section offers a survey of main technologies underpinning affective computing, spanning emotional speech processing facial expression recognition and culminating in a discussion on physiological emotion recognition.

4.1.1 Emotion Recognition from Speech Analysis

Emotional nuances in speech are discernible through variations in its acoustic features. These encompass prosodic attributes such as pitch variations, encompassing aspects like formant level, range, contour, and jitter, as well as the rate of speech. Several studies have delved into the intricacies of these features. The process of speech emotion recognition is typically done in two phases: extracting features and subsequent classification. Numerous acoustic features have been studied for emotion recognition, employing sophisticated pattern recognition techniques.

In a typical speech emotion recognition system, the user speaks into the microphone, the audio is processed to extract relevant features, these features are fed into a trained machine learning model, and the model predicts the emotion, which is then matched with an emotion label from the database and displayed to the user as shown in Fig. 4.1.

For instance, in (Dellaert et al., 1996) employed prosodic features and juxtaposed three classifiers for emotion recognition: maximum likelihood Bayes classification, kernel regression, and k-nearest neighbor. Their research was to discern emotions such as sadness, anger, happiness, and fear. In another study, (Petrushin, 2000) harnessed vocal parameters with a computational agent to recognize emotions. In (Lee et al., 2001), the authors employed linear discriminant classification with Gaussian class-conditional probability distribution and k-nearest neighborhood methods to

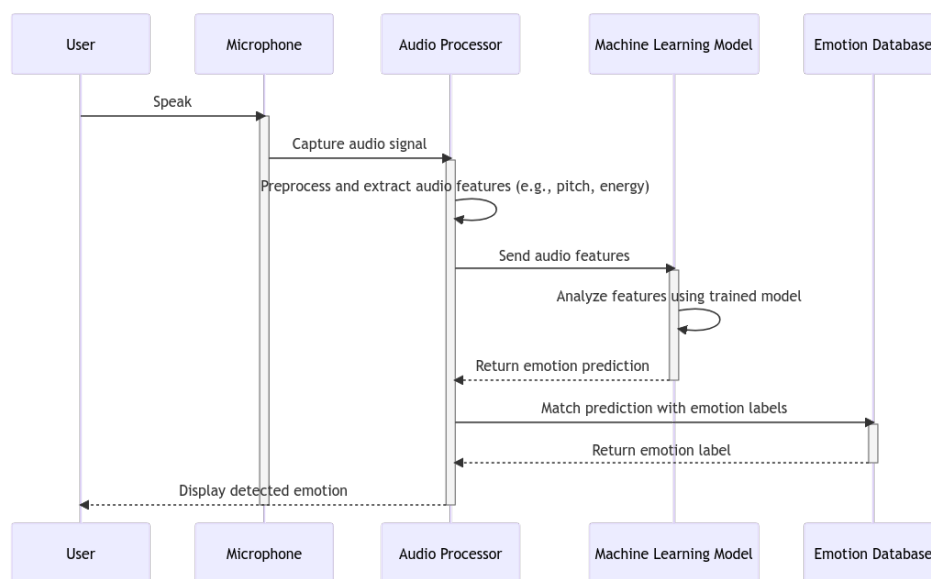


Figure 4.1: A sequence diagram showing a Speech Emotion Recognition Model: the **user** introduces speech, either in real-time or from a previously recorded source. The **microphone** translates these sound waves into electrical signals. The **audio processor** then refines this signal by eliminating noise and other extraneous elements, subsequently extracting pertinent features that signify emotional nuances. The **machine learning model**, having been trained on a dataset enriched with labeled emotional speech samples, discerns patterns within these audio features to deduce the underlying emotion. The **emotion database** is the foundation for training the machine learning model, aligning the model's predictions with established emotion labels.

segregate utterances into dichotomous emotional states: negative and non-negative. In (Yu et al., 2001), the application of Support Vector Machines for emotion detection yielded a commendable average accuracy of 73%.

Further advancements in the domain saw Mozziconacci introducing emotion control parameters predicated on tune methods, enhancing the efficacy of emotion generation in speech synthesis (Mozziconacci and Hermes, 2000). In (Cahn, 1990), an innovative approach harnessed manual inferences, leveraging a visualized acoustic parameters editor to produce emotional speech. In (Campbell, 2004), the authors created an expressive speech synthesis system, drawing from an expansive corpus amassed over half a decade. Schroeder and Eide's pioneering work resulted in an expressive Text-to-Speech engine, which could be modulated using an extended Speech Synthesis Markup Language to adopt diverse expressive styles (Schröder and Breuer, 2004). Chuang (Chuang and Wu, 2002) and Tao's (Tao, 2003) innovative approach hinged on emotional keywords and emotion trigger words, culminating in developing an emotional Text-to-Speech system, with the final emotional state being ascertained based on outputs from the textual content module.

While a significant corpus of research on emotional speech has centered on dissecting typical acoustic features across languages, there has been a discernible shift towards emotion classification and the development of rule-based emotional speech synthesis systems. Nonetheless, the quest to capture and analyze intricate and reliable physiological features remains an ongoing challenge. It is crucial to note that emotions manifest not solely through acoustic attributes but also through the semantic content of speech. Variations in words, syntactic structures, and phrases can engender a spectrum of expressive outcomes and styles.

With the recent advancements in machine learning and artificial intelligence, there has been a surge in innovative methodologies to analyze speech's emotional content. These methods leverage sophisticated algorithms and models to extract, process, and interpret the affective nuances embedded within vocal utterances. The study presented in (Mao et al., 2014) introduces a two-stage method utilizing a convolutional neural network. Initially, local invariant features are derived from unlabeled samples via a sparse auto-encoder equipped with reconstruction segregation. Subsequently, these LIFs serve as inputs to a feature extractor. Another approach delineated in (Huang et al., 2014) employs a semi-convolutional neural network in its preliminary phase, succeeded by a contractive convolutional network dedicated to feature extraction. The research in (Kim et al., 2007) proposes a method that integrates Fourier Parameters and Mel Frequency Cepstral Coefficients to achieve enhanced results compared to using Mel Frequency Cepstral Coefficients alone. This system is divided into front and back-end subsystems, utilizing Gaussian Mixture Models to train both the Multilayer Perceptron and the Support Vector Machines. In a distinct approach, (Attabi and Dumouchel, 2013) introduces Anchor Models, fundamentally rooted in either Euclidean or Cosine distance metrics, aiming to address issues related to skewed data.

Further, (Liu et al., 2007) employs Gaussian Mixture Models to determine the category-conditional distribution of speech features, followed by parameter estimation using the Expectation Maximization algorithm. A composite method presented in (Alva et al., 2015) binds Gaussian Mixture Models with the Continuous Hidden Markov Model, undergoing testing on datasets

in both English and German languages. Another technique detailed in (Alva et al., 2015) leverages a fuzzy interface system, examining all prosodic features of speech, such as pitch, duration, and energy. When tested on a dataset comprising user interactions with a call center machine, this method yielded promising results.

Additionally, (Alva et al., 2015) discusses a method that employs Linear Predictive Cepstral Coefficient features to detect dysfluencies, i.e., when the normal flow and smooth delivery of speech are disrupted in audio signals, with classification tasks being executed using k-nearest neighbors and Linear Discriminant Analysis. Another approach in (Mehmood and Lee, 2016) underscores the efficacy of the Teager Energy Operator features for speech recognition, with tests conducted on the SUSAS database and classification achieved through the Bayesian Hypothesis. Lastly, the research described in (Yogesh et al., 2017) introduces a novel technique for feature selection aimed at reducing feature dimensionality. This method employs a Particle Swarm Optimization-assisted biogeography-based algorithm, achieving remarkable accuracy rates of up to 99.47% across various datasets.

4.1.2 Emotion Recognition from Facial Expressions

Facial expressions and movements, such as smiles or nods, are integral to human communication. They serve multiple purposes, from fulfilling semantic functions to conveying emotions and acting as conversational cues. The study of facial emotion recognition (FER) has been extensive and dates back many years. Research in FER can be categorized into coding, recognition, and generation of facial expressions.

In a typical FER system, the camera captures the user's facial expression, processing the image to extract relevant features. These features are fed into a trained machine learning model, and the model predicts the emotion, which is then matched with an emotion label from the database and displayed to the user as depicted in Figure 4.2

Regarding coding, notable contributions include Etcoff's method of parameterizing the human face's main parts using 37 lines, allowing for a fundamental determination of the face's emotional state (Young et al., 1997). Another significant contribution is by Ekman, who developed the facial action coding system. He categorized human facial expressions into several action units, representing them with six fundamental emotions: joy, anger, surprise, disgust, fear, and sadness (Bartlett et al., 1999; Keltner et al., 2000). FER involves identifying and classifying emotions using various methodologies. Many researchers particularly favor the Gabor wavelets method due to its robust performance and ability to remain unaffected by changes in face posture or lighting conditions. Other methods include neural networks, Hidden Markov Models, Point Distribute Model, optical flow and geometrical tracking. The generation of facial expressions focuses on creating lifelike animated representations. Despite advancements in technology, creating realistic animated faces remains a challenge. This purpose has employed various methods, such as image-based techniques, Facial Animation Parameters, Principal Components, 3D coordinates, 3D distance measurements, and optical flows.

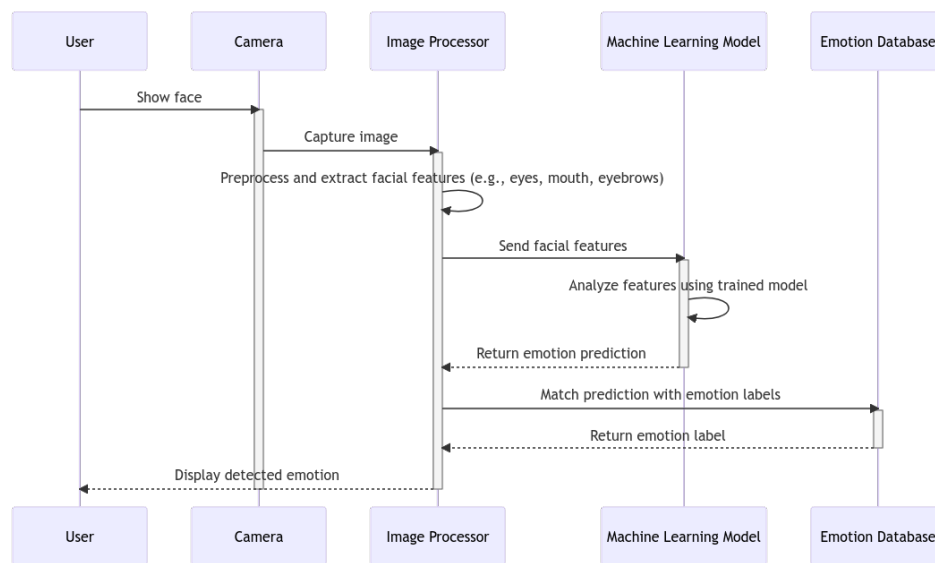


Figure 4.2: A sequence diagram showing a Facial Emotion Recognition Model: the **user** displays facial expressions, either in real-time or from a previously captured source. The **camera** captures this visual information and translates it into a digital format optimized for further processing. The **image processor** refines the captured image by improving its quality, standardizing lighting conditions, and eliminating noise. It then extracts pertinent facial features that signify emotional nuances. The **machine learning model**, having been trained on a dataset enriched with labeled facial expression images, discerns patterns within these facial features to deduce the underlying emotion. The **emotion database** serves as the foundation for training the machine learning model, aligning the model's predictions with established emotion labels.

Furthermore, research on FER emphasizes synchronizing facial expressions with speech when individuals express their thoughts or emotions. This synchronization highlights the significance of audio-visual mapping in developing a realistic talking head system. Two primary approaches exist for this synthesis: one that relies on speech recognition and another driven directly by speech.

The interest in automatic FER has been growing, especially with the advancement of artificial intelligence techniques. FER applications span human-computer interaction, virtual reality, augmented reality, advanced driver assistant systems, and entertainment. While various sensors can be used for FER, cameras are the most promising due to the informative clues they provide and the fact that they do not need to be worn.

Research related to FER typically employs the following terminology:

- **Facial Action Coding System** is based on facial muscle changes that can characterize facial actions to express individual human emotions. It encodes movements of specific facial muscles called action units (AUs).
- **Facial Landmarks** consist of visually salient points in facial regions, such as the end of the nose, eyes, and mouth. These landmarks are used as feature vectors in FER. **Basic Emotions** comprise seven fundamental human emotions - happiness, surprise, anger, sadness, fear, disgust, and neutral.
- **Compound Emotions** consist of a combination of two basic emotions. Examples include "happily surprised" and "happily disgusted."
- Moreover, **Micro Expressions** comprise spontaneous and subtle facial movements that occur involuntarily and reveal genuine emotions.

Modern approaches to facial emotion recognition have significantly evolved by integrating deep learning algorithms. These algorithms have shown promise in improving the performance of facial emotion recognition systems. Some of the notable modern approaches include (Ghayoumi, 2017), which provided a quick review of the application of deep learning in facial expression recognition. Deep learning techniques, especially convolutional neural networks (CNNs), have significantly improved accuracy and efficiency in recognizing facial emotions from images. In (Suk and Prabhakaran, 2014), the authors developed a real-time mobile facial expression recognition system. Their study confirms the potential of implementing facial emotion recognition in real-world, real-time scenarios, especially on mobile platforms. In (Ghimire and Lee, 2013) proposed a method that uses geometric features for facial expression recognition. They utilized multi-class AdaBoost and support vector machines for the recognition process, emphasizing the importance of geometric features in facial expressions. In (Happy et al., 2012) the authors introduced a real-time facial expression classification system that uses local binary patterns (LBP). LBP is a texture descriptor that has been effectively used in various image processing tasks, including facial emotion recognition.

4.1.3 Physiological Emotion Recognition Theories

Emotions play a significant role in cognitive processes like learning, memory, perception, and problem-solving. Recognizing emotions can benefit various applications, such as healthcare—the potential applications of emotion recognition in rehabilitation applications, guiding patients through their training while adapting to their emotional state could be highly motivating and might lead to faster recovery. Different systems for emotion recognition are suitable for different purposes. For example, a contactless method involves analyzing facial features using a video camera, which is useful when devices with integrated cameras, such as computers, smartphones, or tablets, are involved in the task. On the other hand, smart wearables that have contact with the skin can unobtrusively record physiological parameters like electrodermal activity and heart-related signals.

Emotions expressed through visible parameters like facial expressions, gestures, or speech can be influenced by culture, age, and gender. For instance, in some cultures, expressing emotions like anger or grief might be discouraged, leading individuals to mask their true feelings with a fake smile, resulting in inaccurate emotion classification. The autonomic nervous system (ANS) reacts according to a person's emotional state and is not easily deceived. However, interpreting a single parameter might be influenced by environmental factors like temperature or humidity and individual differences in how people react to stimuli.

In 1873, Wilhelm Wundt (Wundt, 1948) introduced an innovative three-dimensional emotion classification framework: the circumplex model. This model characterizes emotions along three distinct axes: valence, arousal, and intensity. Numerous subsequent studies have adopted a simplified two-dimensional version of this model, focusing primarily on valence and arousal. In this model, valence spans negative to positive emotions, while arousal ranges from low to high. An emotion characterized by both high valence and high arousal represents a state of pleasant, heightened activity, exemplified by feelings like happiness and excitement (Posner et al., 2005). Emotions can subsequently be mapped onto the two-dimensional emotion framework as depicted in Figure 4.3. This representation allows clear visualization of the emotional spectrum, with emotions positioned based on valence and arousal levels. Such a system facilitates a comprehensive understanding of the interrelationships between different emotions and provides a structured approach to emotion classification.

David G. Myers, in his exploration of emotions, identifies three fundamental components that constitute our emotional experiences: physiological arousal, expressive behaviors, and conscious experience (Myers and Twenge, 2019). These components provide a framework for understanding the intricate nature of human emotions and how they manifest in various situations. Several theories have been postulated over the years to explain the sequence and interplay of the conscious processing of emotions.

One of the earliest theories, the James-Lange Theory from 1884, posits that our physiological reactions to stimuli precede and give rise to our emotional experiences (James, 2013). For instance, this theory suggests that we feel fear. After all, we notice our heart racing when we feel fear. Contrastingly, the Cannon-Bard Theory introduces a different perspective, arguing that

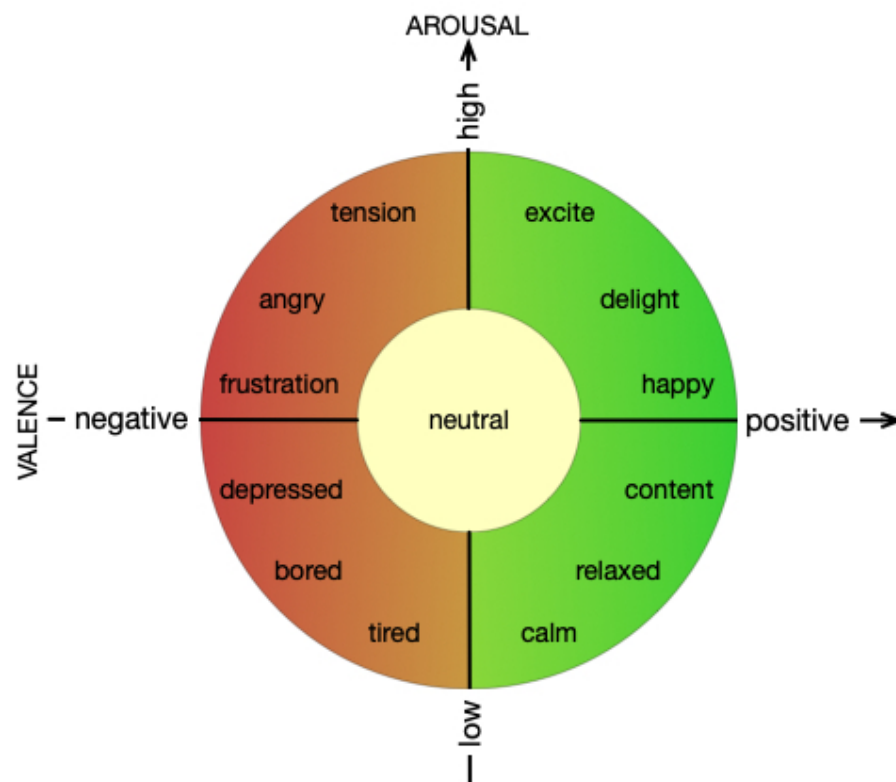


Figure 4.3: Illustration of a two-dimensional valence and arousal space. The five emotional states - calm, tired, tense, and excited - are highlighted in bold, plus the neutral. Each quadrant of the space, labeled with Roman numerals from I to IV, corresponds to the specific emotional set selected for investigation.

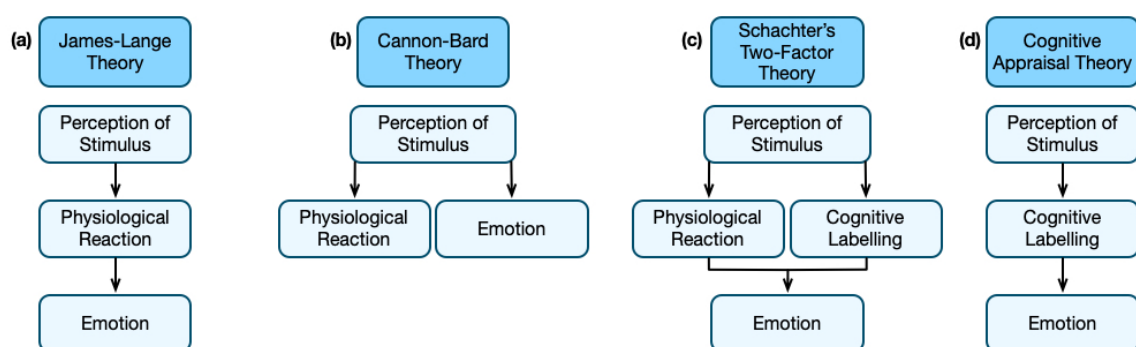


Figure 4.4: Emotion theories: **(a)** James-Lange theory: physiological reactions to stimuli precede and give rise to our emotional experiences. **(b)** Cannon-Bard theory: physiological and emotional responses to stimuli occur concurrently. **(c)** Schachter-Singer theory: emotions arise from a combination of physiological responses and subsequent cognitive interpretations influenced by the context. Finally, **(d)** Cognitive Appraisal theory: the interpretation of a stimulus, influenced by our personal experiences and personality traits

our physiological and emotional responses to stimuli occur concurrently, without one necessarily causing the other (Cannon, 1987). This perspective implies that one can experience physiological reactions, such as an increased heart rate or sweating, without necessarily feeling any associated emotion. Further building on this foundation, the Schachter-Singer Theory, often called the Two-Factor Theory, suggests a more nuanced approach. It proposes that emotions arise from a combination of physiological responses and subsequent cognitive interpretations influenced by the context and an individual's past experiences (Schachter and Singer, 1962). In other words, how we interpret or label a situation, based on our past experiences and current circumstances, can shape our emotional response to it. Lastly, the Cognitive Appraisal Theory, also known as the Lazarus Theory of emotion, emphasizes the role of cognitive labeling in our emotional experiences (Lazarus, 1982). According to this theory, our interpretation of a stimulus, influenced by our personal experiences and personality traits, occurs before we experience any associated emotion. This interpretation then plays a pivotal role in determining the intensity and the specific nature of the emotion we eventually experience.

In summary, while all these theories offer unique perspectives on the origin and processing of emotions, they collectively highlight the intricate interplay between physiological responses, cognitive interpretations, and the resulting emotional experiences.

4.1.3.1 Physiological Emotion Recognition Techniques

There is a sequence of tasks and methodologies essential for recognizing emotions. For effective recognition, three consecutive procedures are pivotal. Firstly, the emotions need to be detected, followed by the generation of emotional behavior, which encompasses synthesis, adaptation, and expression. Lastly, emotion elicitation plays a role. Emotion recognition is considered an ability machines should build in human-computer interaction. In a typical physiological emotion recognition (PER) system, the user's physiological signals are captured by the sensors, the data is processed to extract relevant features, these features are fed into a trained machine learning model, and the model predicts the emotion, which is then matched with an emotion label from the database and displayed to the user as depicted in Fig. 4.5

The chain of work for recognizing emotions is sequential. Due to the nature of physiological signals, which can be partly stochastic and partly semi-periodic, extracting specific features to facilitate the subsequent classification of emotions is critical. After capturing the raw bio-signals, distinct features are extracted and computed, encompassing frequencies, amplitudes, maxima, and minima. Various classifiers are employed for emotion recognition through physiological signals, with some of the most prevalent ones being the Support Vector Machine (Naji et al., 2014; Mehmood and Lee, 2016), Canonical Correlation Analysis (Li and Chen, 2006), Artificial Neural Network (Den Uyl and Van Kuilenburg, 2005), Fisher Linear Discriminant Projection (Healey and Picard, 1998), K-Nearest Neighbor (Rani et al., 2006), Adaptive Neuro-Fuzzy Interference System (Jang, 1993), and the Bayesian Network Method (Dai et al., 2008). Notably, emotion recognition accuracy can vary depending on the classifier used. For instance, while many studies

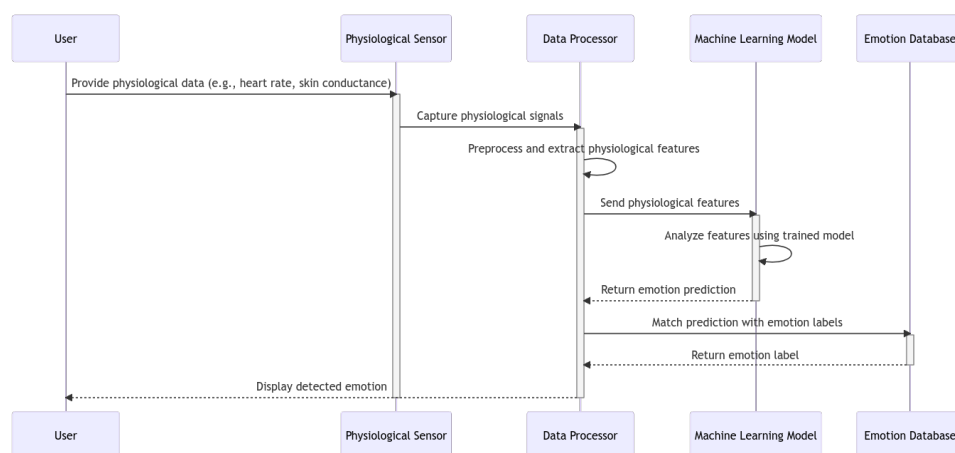


Figure 4.5: A sequence diagram showing a Physiological Emotion Recognition: the **user** represents the subject from whom emotional insights are sought, and they supply physiological data via specialized sensors. The **Physiological Sensor** captures specific physiological metrics, including heart rate, skin conductance, and respiratory rate. The **Data Processor** refines this data by eliminating noise and inconsistencies, subsequently extracting pertinent features from the physiological signals that hint at emotional states. The **Machine Learning** system, having been trained on a comprehensive dataset of labeled physiological samples, discerns patterns within these features to deduce the underlying emotion. The **Emotion Database** serves as the foundational resource for training the machine learning model, ensuring the model's predictions align with predefined emotion labels.

have employed Support Vector Machines or the Fisher Linear Discriminant Classifier, the optimal classifier often depends on the training set, and it is crucial to test which classifier yields the highest accuracy for a given dataset.

Evaluating emotions presents a complex challenge. One common approach is correlating the results with a recognized benchmark, such as facial recognition or electroencephalogram readings. However, these methods are not infallible; inauthentic emotions might trigger signals, leading to potential inaccuracies. An alternative strategy involves comparing the emotion measurements to responses from a self-assessment questionnaire. The Self Assessment Manikin (SAM), developed by M. Bradley and P. Lang ([Bradley and Lang, 1994](#)), is a well-known tool for self-assessment. SAM offers a visual, non-verbal method for individuals to articulate their emotions, as depicted in Figure 4.6.

Another evaluation technique involves expert assessments. Here, psychological experts gauge an individual's emotional state by analyzing their facial expressions and overall demeanor. While valuable, this method relies heavily on the expert's subjective judgment. Furthermore, emotions can also be assessed with the stimuli used to induce them. For instance, the international affective picture system categorizes each stimulus based on its inherent valence and arousal levels, providing a reference point for emotion evaluation. However, it is essential to acknowledge the inherent variability in emotional perception. Personal experiences, cultural backgrounds, age, and more can significantly influence how emotions are perceived and expressed. This variability under-

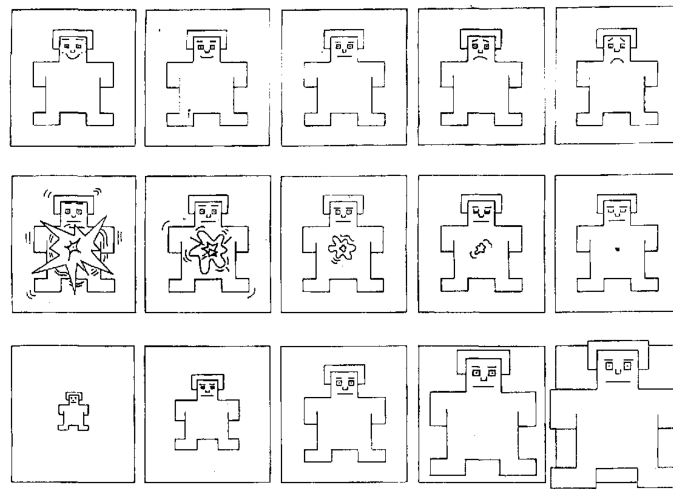


Figure 4.6: The SAM provides a visual scale that allows individuals to rate their emotional responses to stimuli without the need for language, making it particularly useful in cross-cultural research and in situations where verbal scales might be problematic. Respondents are asked to choose the figure that best represents their feelings in response to a stimulus, allowing for a direct measure of emotional state across the three dimensions.

scores the complexity of emotion evaluation and highlights the need for a multifaceted approach that considers both objective measurements and subjective interpretations.

4.1.4 Physiological Sensors: Definition and typology

The present section provides a comprehensive overview of physiological sensors as analytical devices that merge biological elements with physicochemical detectors for various applications, including medical diagnostics and environmental monitoring. Tracing the historical evolution of biosensor technology, this section highlights critical milestones, from its beginning in the early 20th century to significant advancements in the 1970s and the 2000s. It outlines the fundamental components of a typical biosensor, delving into a specialized category of biosensors known as physiological sensors (bioelectric sensors), which utilize bioelectric phenomena for sensing applications. These physiological sensors have unique applications and historical roots, offering a nuanced understanding of how bioelectricity has been harnessed for analytical purposes. This section provides a detailed guide to the complexities and capabilities of both general physiological sensors and their bioelectric counterparts.

Biosensors are analytical devices that combine a biological element with a physicochemical detector to detect the presence or concentration of a substance (Northrop, 2017) and (Saltzman, 2009). These devices have many applications, from medical diagnostics to environmental monitoring and food safety. The concept of bio-sensors dates back to the early 20th century, but it was in the 1960s that the first bio-sensor was developed. Leland C. Clark Jr., an American biochemist, is credited with the invention of the first bio-sensor, an enzyme-based electrode for measuring glucose levels in blood. Clark's work laid the foundation for the development of glucose sensors,

which are now widely used in the management of diabetes (Clark Jr and Lyons, 1962). In the 1970s and 1980s, bio-sensor technology saw significant advancements with the introduction of immuno-sensors and DNA sensors. These developments were driven by the advent of biotechnology and the increasing ability to manipulate biological molecules. The 1990s witnessed bio-sensor integration with microelectronics, leading to the miniaturization of these devices and expanding their potential applications (Turner, 2013).

A typical bio-sensor consists of three main components: a biological recognition element, a transducer, and a signal processing system. The biological recognition element, often an enzyme, antibody, or nucleic acid, interacts specifically with the target substance. The transducer converts this reaction into a measurable signal, usually an electrochemical, optical, or piezoelectric device. The signal is then processed and displayed, providing quantitative or qualitative data about the substance being analyzed (Karunakaran et al., 2015).

Bioelectric sensors are a subset of biosensors that utilize bioelectric phenomena to detect the presence or concentration of a specific substance. These biosensors often employ ion channels, membrane potentials, or electrically active cells as the biological recognition element. The transduction mechanism in bioelectric sensors is usually electrochemical, converting the bioelectric signal into an electrical output that can be measured and analyzed. The concept of bioelectricity dates back to the 18th century when Luigi Galvani discovered that frog muscles twitched when exposed to an electric spark. However, bioelectric phenomena were applied in the late 20th century for biosensing applications. The development of ion-selective electrodes in the 1970s significantly boosted the field, allowing for the measurement of specific ions in biological systems (Bakker and Telting-Diaz, 2002). When the target analyte interacts with the biological element, it induces a change in the bioelectric properties, such as ion flow or membrane potential. An electrochemical transducer then detects this change, converting it into an electrical signal. For example, ion-selective biosensors use ionophores embedded in a membrane to selectively bind to specific ions, causing a change in electrical potential that can be measured (Bobacka et al., 2008). Bioelectric sensors have found applications primarily in medical diagnostics and environmental monitoring. They are used to measure ion concentrations in bodily fluids, detect neurotransmitters, and even monitor electrical activity in neural networks. In environmental applications, they can be used to detect heavy metals and other ionic pollutants in water (Pohanka and Skládal, 2008).

In HCI, particularly in music interaction, sensors are pivotal in capturing nuanced human inputs and translating them into digital signals. These sensors can be broadly categorized into bioelectric, biomechanical, optical, and environmental types, each with specific functions and applications. Table 4.1 is a comprehensive list that elucidates these categories, considering medical and HCI applications.

Table 4.1: Biosensing Technologies: A Comprehensive List of Bioelectric, Biomechanical, Optical and Environmental Sensors Grouped According to Their Specific Function.

Bioelectrical

ECG	electrocardiogram	Electrodes placed in contact with the body surface are used to measure the heart's electrical activity.
EDA	electrodermal activity	The sympathetic nervous system activity result in skin conductance changes, which are measured through electrodes applied to the palms of the hands or soles of the feet.
EEG	electroencephalogram	Measures the electrical activity of the brain using electrodes in contact with the scalp .
EGG	electrogastrogram	The electrical signals associated with the gastric muscles are measured via electrodes in contact with the skin in the stomach region.
EMG	electromyogram	The electrical activity of surface (sEMG) or internal (iEMG) muscles is gauged using electrodes noninvasively attached to the body surface for sEMG or invasively placed in contact with muscle fibers for iEMG.
EOG	electrooculogram	The variation in the corneal-retinal potential associated with eye movement is captured.
TEMP	temperature	Body internal temperature is assessed using thermistors, thermopiles, infrared, thermal imaging, or similar elements.
Biomechanical		
ACC	accelerometer	Assesses static (relative to gravity) or dynamic acceleration (due to motion, shock, or vibration), typically using a damped mass mounted on a spring.
AF	airflow	Capture air inflows and outflows, often through a thermal element or a spirometer turbine (which can estimate air volume) positioned in the nostril or mouth.
FSR	force sensing resistor	Assesses the force exerted in tension, compression, or torsion, typically using a force-sense resistor (FSR) or strain gauge.
FLEX	bending sensor	Evaluate the degree of flexion in an element on the body surface using a bend-sensitive resistor, strain gauge, or optical fibers.
GYR	gyroscope	Determines angular velocity using a vibrating structure or rotating disc.
MAG	magnetometer	Gauges the intensity of a magnetic field (such as the earth's) or magnetic irregularities in a specific area.

MMG	magnetomyography	Evaluates skin displacement due to muscle activation using ACC, FSR, piezoelectric, or strain gauge sensors.
PST	position	Assesses the body's angular and tilt position, typically through linear or rotary adjustable resistors that alter their electrical characteristics based on the position of a wiper element (a movable contact connecting with the terminals of an electrical device).
RESP	respiration	Gauges the chest's movement caused by inhalation and exhalation using a piezoelectric element, a pressurized tube, or changes in inductance in a coil integrated into the fabric.
Optical		
MOCAP	motion-capture	Evaluates an individual's movement with varying precision using multiple video cameras (either visible or infrared, with potential depth-sensing capabilities), passive infrared sensors, ultrasound, or similar sensors.
PPG	photoplethysmography	Through sensors employing an illumination element in the visible or infrared spectrum and a photodetector, it gauges blood volume fluctuations as indicated by the amount of reflected or transmitted light, which varies with the perfusion changes linked to the heart's blood pumping activity.
Environmental		
AP	air pressure	Assesses, using a force collector (e.g., a diaphragm), the pressure produced by a gas (like blowing through a mouthpiece) or liquid exerted over a defined area.
HUM	humidity	Determines the volumetric water content in a medium, typically using a sensor that detects resistance or capacitance changes.
ALS	ambient light sensor	Evaluates the strength of light (either visible or invisible) received by a photosensitive component.

4.2 Physiological Signals

The terms "biosignals" and "physiological signals" are often used interchangeably in scientific literature, but subtle distinctions deserve attention. Biosignals refer to signals generated by biological systems, capturing a wide range of phenomena from cellular to organismal levels. These

signals can include anything from the electrical activity of a single neuron to the complex patterns of heartbeats captured in an electrocardiogram (ECG). The term is often used in stress detection, where various signals such as electroencephalogram (EEG), ECG, electromyogram (EMG), and others are analyzed to understand the body's response to stressors (Giannakakis et al., 2019).

Physiological signals, conversely, are a subset of biosignals that specifically pertain to the functions and conditions of the body's systems. These signals are often used to monitor or diagnose health conditions and are commonly employed in emotion analysis, healthcare applications, and even in the development of recommender systems based on emotional states (Koelstra et al., 2011; Faust et al., 2018; Santamaria-Granados et al., 2018). For instance, physiological signals like ECG, EEG, and galvanic skin response are frequently used to assess emotional states, as seen in the Database for Emotion Analysis Using Physiological Signals (Koelstra et al., 2011). The distinction between biosignals and physiological signals is semantic and contextual. While biosignals can be broader and encompass a variety of biological phenomena, physiological signals are more focused on the functional aspects of biological systems. This focus makes physiological signals particularly useful in applied fields like healthcare, where understanding the body's functional status is crucial for diagnosis and treatment.

Given the nuances between the two terms and the broader applications associated with physiological signals, this research will adopt the term "physiological signals" henceforth. This choice is supported by the higher frequency of citations associated with physiological signals in academic literature, particularly in emotion analysis and healthcare applications. Adopting this term aligns the research with a more established and widely recognized nomenclature, facilitating more precise communication and understanding of the research.

4.2.1 Electromyography

Electromyography (EMG) is a diagnostic technique that captures and records the electrical activity of skeletal muscles. This electrical activity, often named the EMG signal, is a complex waveform representing the sum of multiple motor unit action potentials. A motor unit is a functional unit comprising a motor neuron and the muscle fibers it innervates. When a muscle contracts, the motor neurons transmit electrical impulses, triggering the muscle fibers to generate electrical signals. These signals propagate along the muscle fibers and collectively form the EMG signal, as shown in Fig. 4.7.

The EMG signal is typically analog and varies in frequency and amplitude. It is often described as a stochastic signal, which is random and unpredictable, yet it contains essential information about muscles' physiological and pathological conditions. The frequency range of EMG signals usually lies between 20 hertz (Hz) and 500 Hz, and their amplitude can range from a few microvolts up to 25 millivolts, depending on various factors such as muscle force, fatigue, and electrode placement. Capturing the EMG signal involves using either surface electrodes placed on the skin or intramuscular electrodes inserted directly into the muscle tissue. Surface electromyography (sEMG) is non-invasive and is commonly used for clinical assessments and biomechanical studies. Intramuscular EMG, on the other hand, provides a more localized measurement and is

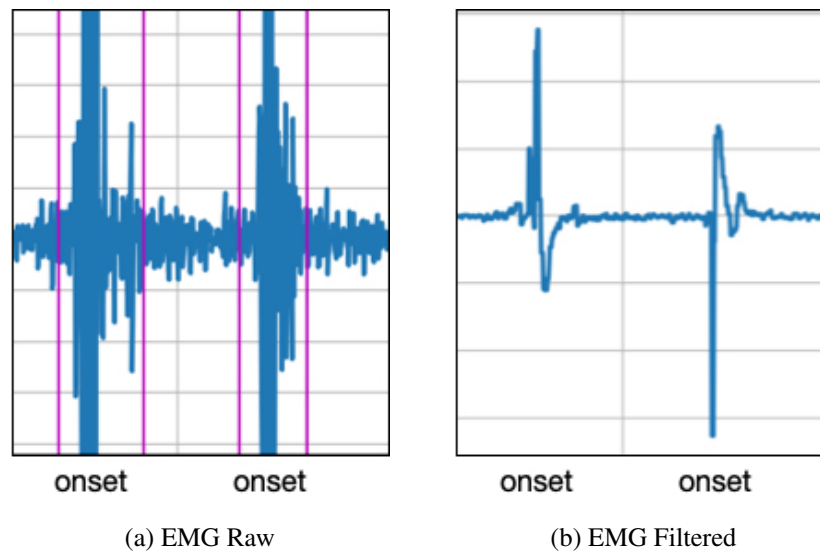


Figure 4.7: The image displays two representations of an Electromyography (EMG) signal, which is a method used to evaluate and record the electrical activity produced by muscles. (a) This plot shows the raw, unprocessed EMG signal. It exhibits a lot of noise, which is common for raw EMG data. Such noise can be caused by various sources, including movement artifacts, ambient electrical noise, and interference from nearby muscles and nerves. The areas marked as "onset" indicate when the muscle activity began. This could be due to a voluntary muscle contraction or a response to a stimulus. (b) This plot depicts the EMG signal after filtering it to remove noise and other unwanted frequencies. Filtering the signal enhances the clarity of the muscle's response. The signal becomes smoother, and the onset of muscle activity is more clearly distinguishable. The filtered plot allows for easier interpretation and analysis of the muscle's behavior.

often used in research settings to study individual motor units. Regardless of the type of electrode used, the quality of the EMG signal is highly dependent on proper skin preparation and electrode placement, as these factors can significantly influence the signal's amplitude and frequency characteristics (Peter, 2005, pp. 15-22).

EMG is particularly fascinating because it provides real-time insights into neuromuscular function. By analyzing the EMG signal, clinicians and researchers can assess muscle activation patterns, identify muscle imbalances, and even detect neuromuscular disorders. For instance, the amplitude of the EMG signal is often correlated with the level of muscle force, while the frequency content can provide information about muscle fatigue. Moreover, EMG is frequently used with other biomechanical measurements, such as force and motion analysis, to understand human movement comprehensively. However, interpreting EMG data requires a nuanced understanding of the factors that can influence the signal. For example, the angle and muscle length can directly affect the EMG amplitude as the active muscle migrates below the electrodes, and muscle mechanics change with different sarcomere distances (basic contractile units of muscle fiber). Similarly, varying the range of motion or movement velocity can significantly increase the variability of findings, necessitating appropriate standardization (Peter, 2005, pp. 53-54).

The applications of EMG are diverse and extend beyond the realm of healthcare. There has been growing interest in utilizing EMG for human-machine interaction in recent years. For instance, EMG-based systems have been developed to control prosthetic limbs, allowing for more natural and intuitive movement. These systems decode the EMG signals to understand the user's intent, translating it into specific movements of the prosthetic limb. Beyond prosthetics, EMG is also being explored for its potential in gesture recognition, offering a new modality for interacting with electronic devices and even virtual or augmented reality environments. Such applications are part of a broader field known as EMG decoding and pattern recognition, which aims to interpret complex EMG signals to control various machinery and devices (Simao et al., 2019).

In summary, electromyography is a powerful tool for capturing the electrical activity of skeletal muscles. With its complex waveform, the EMG signal provides a window into the functioning of motor units and, by extension, the neuromuscular system. Whether used for clinical diagnosis, biomechanical research, or human-machine interaction, EMG offers invaluable insights into muscle physiology. However, to accurately capturing and interpreting EMG signals requires meticulous attention to various factors, including electrode placement, muscle mechanics, and test standardization.

4.2.2 Electrocardiography

Electrocardiography (ECG) is a medical diagnostic technique that records the heart's electrical activity over time. This non-invasive procedure is commonly used to detect and analyze heart conditions, providing valuable data for healthcare providers. The electrical signals captured by electrocardiography are often referred to as electrocardiograms (ECGs), which are graphical representations of the heart's electrical activity plotted against time. The heart is a biological pump

driven by a complex system of electrical signals. These signals originate from a group of cells in the heart known as the sinoatrial node, which acts as the heart's natural pacemaker. The electrical impulses generated by the sinoatrial node propagate through the heart muscle, causing it to contract and pump blood. This electrical activity can be captured through electrodes placed on the skin, usually on the chest, arms, and legs. The ECG provides a snapshot of how the heart's electrical system functions, which can be crucial for diagnosing several cardiac conditions such as arrhythmias, heart attacks, and other heart diseases. The ECG signal represents a dynamic waveform that captures various phases of the heart's electrical cycle. This signal prominently features several key components, including the P wave, which represents the initial positive deflection on the ECG. Additionally, the ECG includes the QRS complex, signifying ventricular contraction (systole). The QRS complex comprises the Q wave, the initial negative deviation, followed by the R wave, a positive (upward) deflection, and finally, the T wave, which signifies ventricular repolarization. The P wave represents the electrical activity associated with the atrial contraction, which fills the ventricles with blood. The QRS complex results from ventricular depolarization, leading to the contraction of the ventricles and the heart's main pumping action. Finally, the T wave corresponds to ventricular repolarization, resetting the ventricles' electrical state before the next cycle. Each component provides specific information about the heart's electrical and mechanical functions (Sörnmo and Laguna, 2006).

The ECG signal is often subject to various types of noise and artifacts, which can interfere with accurate diagnosis. These include baseline wander due to body movements, powerline interference from electrical devices, and muscle noise. Advanced signal processing techniques are employed to filter out these noises and improve the signal-to-noise ratio. For instance, highpass and lowpass filters are used to remove baseline wander and powerline interference, respectively. Furthermore, specialized algorithms are developed to accurately detect the QRS complex, which is critical for determining the heart rate and rhythm (Sörnmo and Laguna, 2006). Fig. 4.8 displays two representations of an ECG signal, which captures the heart's electrical activity over 4-second window.

In recent years, electrocardiography has seen significant advancements, including the development of portable and wearable ECG devices. These innovations allow for long-term monitoring and data collection, particularly useful for capturing intermittently occurring cardiac events. Signal processing techniques have also evolved to include data compression algorithms, enabling efficient storage and transmission of ECG data for telemedicine applications.

In HCI, ECG signals are increasingly used as a biometric measure for authentication. The uniqueness of an individual's ECG waveform makes it a reliable identifier, akin to a fingerprint. This application is particularly relevant in security-sensitive environments, where traditional methods like passwords or fingerprint scans may be susceptible to breaches. Moreover, ECG signals are being explored in the context of affective computing, a subfield of HCI that aims to create systems that recognize and respond to human emotions. The ECG can provide data on an individual's emotional state, such as stress or relaxation, which can then be used to adapt the computer interface or application accordingly. For instance, if an ECG-detected elevated heart rate indicates

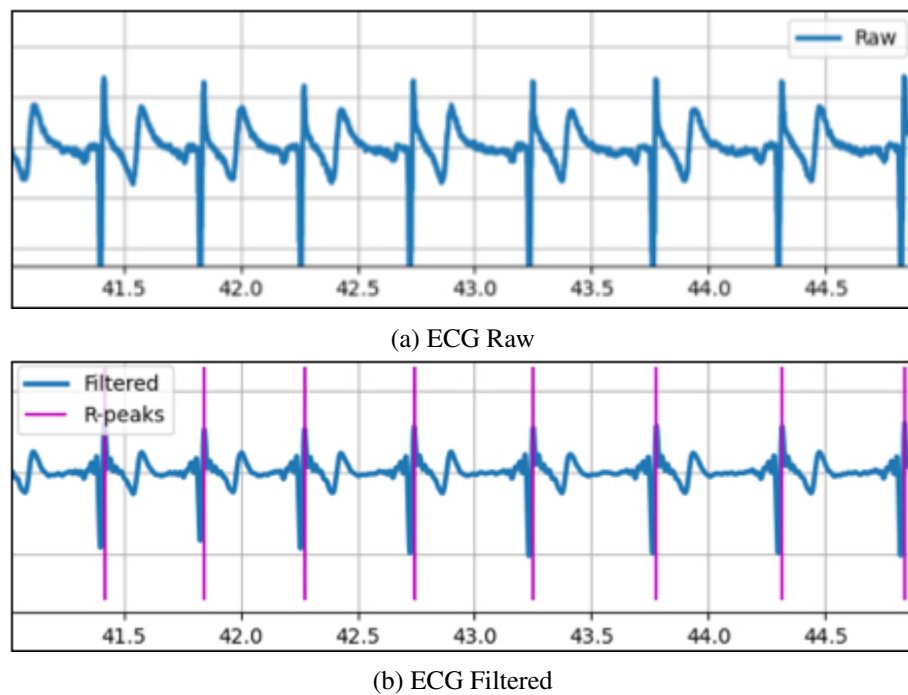


Figure 4.8: The image displays two representations of an ECG signal, which captures the electrical activity of the heart over a 4-second window. (a) Shows the raw, unprocessed ECG signal. The raw signal has more noise and minor fluctuations, which can make it slightly harder to interpret. (b) This signal has been filtered to remove noise and enhance the clarity of the ECG waveform. The filtered signal is smoother, and the various components of the ECG waveform (such as the P, Q, R, S, and T waves) can be more easily distinguished. Vertical pink lines indicate "R-peaks." The R-peak is the highest amplitude portion of the ECG signal and corresponds to the ventricular contraction. Detecting R-peaks is crucial in many ECG analysis tasks, such as determining heart rate and rhythm.

stress, a computer application could adapt to simplify its user interface, thereby reducing the user's cognitive load.

In summary, electrocardiography is an indispensable tool for monitoring the heart's electrical activity in modern medicine. The ECG signal captures various phases of the cardiac cycle, providing insights into the heart's normal and pathological conditions. Advanced signal processing techniques are crucial in enhancing the quality of ECG signals, making it a reliable and widely used diagnostic method.

4.2.3 Electroencephalography

Electroencephalography, commonly known as EEG, is a non-invasive method for measuring the electrical activities generated by the brain. The term is derived from the Greek words 'enkephalo,' meaning brain, and 'graphein,' meaning to write. EEG provides a written record of the brain's electrical impulses, offering a window into the complex neural activities that underlie everything from basic motor functions to higher-order cognitive processes (Blinowska and Durka, 2006). The landmark moment in the history of EEG came in 1929 when German psychiatrist Hans Berger recorded the first human electroencephalogram. Berger's work was initially met with skepticism, but it gained credibility after being confirmed by British scientists Edgar Douglas Adrian and Bryan Matthews in 1934. Berger is also credited with discovering the alpha wave rhythm, termed "Berger's wave." His work laid the foundation for using EEG in clinical settings, particularly in diagnosing and managing epilepsy and other neurological disorders.

In human-computer interactions, EEG has emerged as a groundbreaking technology that offers a new dimension of user engagement and system adaptability. The technology has been instrumental in creating brain-computer interfaces (BCIs), allowing direct communication between the human brain and external devices with significant impact in assistive technologies, gaming, and even in the field of digital media where real-time adjustments to audiovisual content can be made based on the user's cognitive state. For instance, in interactive music and sound design, EEG can adapt the auditory experience based on the user's emotional or cognitive state, creating a more immersive and personalized experience. The use of EEG in such interactive systems is a testament to its versatility and capability to capture a wide range of neural activities.

The EEG signal is a complex waveform representing the brain's electrical activities. It is captured through electrodes placed on the scalp, which measure the voltage fluctuations resulting from ionic current flows within the brain's neurons. These electrodes can also be placed directly on the cortex, in which the recorded signal is called an electrocorticogram (ECoG). Intracortically measured electric fields are termed Local Field Potentials (LFPs). The amplitude of a typical EEG signal in a normal, awake individual ranges from 10 to 100 microvolts (mV). However, in pathological conditions such as epilepsy, these amplitudes can increase substantially (Kida et al., 2016). The EEG signal is a summation of synchronously generated postsynaptic potentials. Neurons in the brain generate electrical activities, which manifest as action potentials (AP) and postsynaptic potentials (PSPs). While action potentials are all-or-nothing events, PSPs are graded potentials



Figure 4.9: The image depicts an Electroencephalogram (EEG) signal. EEG is a method used to record the electrical activity of the brain. The plot has multiple channels, each labeled with specific acronyms. These labels typically denote the specific electrode placement on the scalp, corresponding to different brain regions. For instance, "FP" usually stands for frontal-polar, "F" for frontal, "C" for central, "P" for parietal, "O" for occipital, and so on. The waveform for each channel represents the brain's electrical activity at that specific location. EEG signals typically consist of rhythmic waveforms that can vary in frequency and amplitude. The waves might indicate different stages of wakefulness or sleep or different cognitive processes. Some sections of the EEG display appear to be more erratic or of larger amplitude than the typical brain waves. These could be artifacts, which are unwanted or non-brain signal interferences. Artifacts can be caused by various sources like eye blinks, muscle movements, or external electrical interferences.

whose amplitudes are proportional to the amount of secreted neurotransmitter. The EEG rhythms are believed to arise from the cooperative properties of networks consisting of excitatory and inhibitory neurons connected by feedback loops. The frequency of these oscillations depends on various factors, including the intrinsic membrane properties of individual neurons and the strength of synaptic interactions (Blinowska & Durka, 2006).

One of the most fascinating aspects of EEG is the variety of rhythms it captures, each corresponding to different states of brain activity. These rhythms are categorized into the delta, theta, alpha, beta, and gamma waves, each with its own frequency range and characteristics as depicted in Fig. 4.10.

Beyond its clinical applications for diagnosing and monitoring neurological disorders, EEG has found a place in research settings for studying cognitive processes, sleep cycles, and emotional states. Its role in human-computer interactions, particularly in the development of brain-computer interfaces, marks a significant stride in the field of interactive technology.

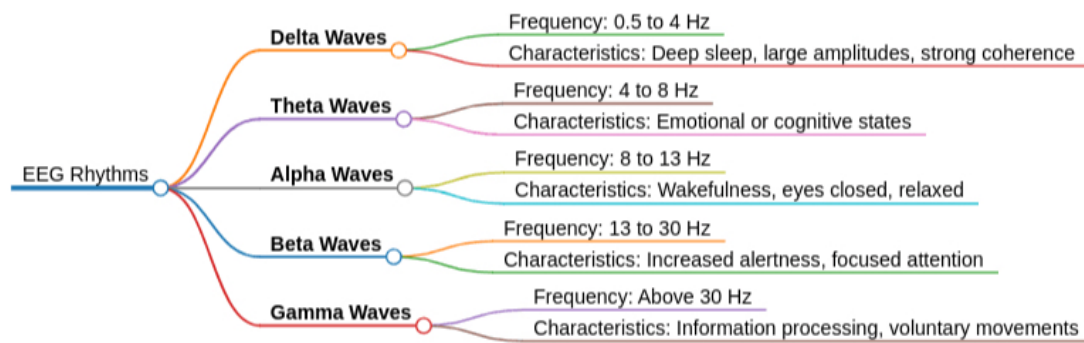


Figure 4.10: Mindmap Diagram of EEG Rhythms: This diagram categorizes the different types of EEG rhythms—Delta, Theta, Alpha, Beta, and Gamma waves—based on their frequency ranges and characteristics. It serves as a visual guide to understanding the various states of brain activity captured by EEG.

In summary, EEG is not just a medical tool but a versatile technology that provides invaluable insights into the workings of the human brain. Its ability to capture a wide range of neural activities makes it an indispensable asset in clinical and research settings, including the field of human-computer interactions.

4.2.4 Electrodermal Activity

Electrodermal Activity (EDA) is a physiological metric that has been the subject of scientific inquiry for over a century. EDA has a historical context that dates back to the late 19th and early 20th centuries. The phenomenon was initially observed by French physicians Féré and Vigouroux, who were among the first to note that emotional and cognitive states could influence skin conductance. Their work laid the foundation for the scientific study of EDA (Boucsein, 2012, pp. 1-20). In the 1950s and 1960s, EDA gained prominence as a tool in psychophysiological research, mainly due to the work of researchers like Carl Jung and William James, who were interested in the physiological correlates of emotional and psychological states. During this period, EDA was often used in lie detection tests, commonly known as polygraphs, where it was combined with other physiological measures like heart rate and respiration rate (Lykken, 1959). The latter half of the 20th century saw the refinement of EDA measurement techniques and the expansion of its applications into various fields, including psychology, medicine, and human-computer interaction. Technology advancements have made capturing and analyzing EDA data easier, leading to its widespread use in modern research.

EDA provides a window into the autonomic nervous system, offering insights into emotional, cognitive, and physical states. The method involves the measurement of the skin's electrical conductance, which is influenced by the activity of sweat glands. These glands are controlled by the sympathetic branch of the autonomic nervous system, which is often activated during states of arousal (Boucsein, 2012, pp. 1-20). The EDA signal is a continuous variable, typically measured in microsiemens (μ). The signal is characterized by two primary components: the tonic level,

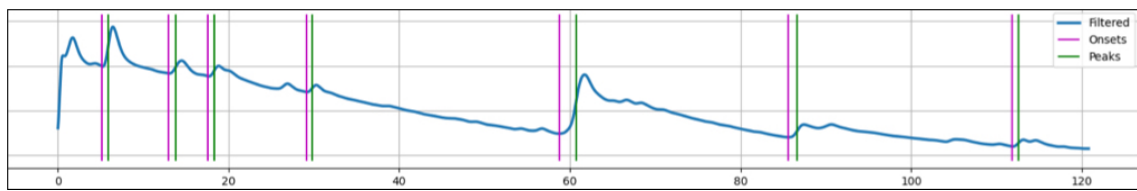


Figure 4.11: The image displays an EDA signal representing changes in the sweat gland activity, which is influenced by the sympathetic nervous system and can be indicative of emotional or physiological arousal for a 4-minute window. **Filtered Signal** (Blue Line): The smooth, continuous line in the graph represents the filtered EDA signal. It displays the skin conductance over time, indicating the individual's general level of arousal or stress. **Onsets** (Green Vertical Lines): These lines indicate the starting points or the onset of a significant change in skin conductance. This can correspond to an event or stimulus that has elicited an emotional or physiological response. **Peaks** (Purple Vertical Lines): These represent the points of maximum skin conductance after a certain onset. The time between an onset and its corresponding peak can provide insight into the speed of the respondent's reaction to a stimulus.

known as Skin Conductance Level (SCL), and the phasic changes, known as Skin Conductance Responses (SCR). SCL is the baseline measure of skin conductance, which can vary between individuals and under different environmental conditions. SCR represents the rapid, transient increases in skin conductance that occur in response to specific stimuli or events (Dawson et al., 2007, pp. 157-220).

The physiological basis of EDA is deeply rooted in the activity of the eccrine sweat glands. These glands are primarily responsible for thermoregulation but are also responsive to emotional and cognitive states. When an individual experiences emotions such as fear, excitement, or stress, the sympathetic nervous system activates the eccrine sweat glands, increasing skin conductance. This response makes EDA a valuable tool for assessing emotional and cognitive states in a non-intrusive manner (Figner et al., 2011, pp. 35-60). Capturing the EDA signal involves using electrodes on the palmar or plantar surfaces where the eccrine sweat glands are most densely present. The electrodes can be either active, where a small current is passed, or passive, where no current is applied. The conductance between the electrodes is then measured and recorded over time, providing a continuous signal that reflects autonomic arousal.

EDA has found applications in many fields, from psychology and medicine to marketing and human-computer interaction. Clinical psychology often uses it to assess emotional disorders such as anxiety and depression. In medicine, it can monitor the depth of anesthesia during surgical procedures. In marketing, it is a tool for gauging consumer reactions to advertisements or products. It is essential to highlight the increasing relevance of EDA in the field of human-computer interactions. EDA assesses user engagement, emotional states, and cognitive load during interactions with digital media. This ability is instrumental in designing and evaluating user interfaces, interactive narratives, and multimedia experiences. The EDA data can be combined with other metrics, such as eye-tracking and user surveys, to comprehensively understand user experience (Bakker et al., 2011).

Electrodermal Activity is a robust measure of autonomic nervous system activity, capturing the skin's electrical conductance influenced by the eccrine sweat glands. The signal comprises tonic and phasic components, offering unique insights into an individual's emotional and cognitive states. Its applications are vast and increasingly relevant in human-computer interactions, complementing other physiological metrics like EEG for a more holistic understanding of user experience.

4.2.5 Respiration

The practice of measuring respiration rate has roots in ancient civilizations. Egyptian medical texts, such as the Ebers Papyrus, mention counting breaths as a diagnostic tool. Ancient Greek physicians like Hippocrates also emphasized the importance of observing the breath to diagnose diseases. The 19th century marked a significant milestone with the invention of the stethoscope by René Laennec, which allowed physicians to listen to respiratory sounds, thereby standardizing the measurement process. The 20th century introduced spirometry, a method that measured the rate and captured additional metrics like lung volumes and capacities. This method was a game-changer in diagnosing and managing respiratory diseases like asthma and chronic obstructive pulmonary disease. The late 20th and early 21st centuries have seen the advent of wearable technology, which has revolutionized the measurement process. Wearables with advanced sensors can now provide continuous, real-time respiration rate monitoring, even outside clinical settings, with significant implications for remote healthcare and long-term monitoring of chronic conditions (Kundu et al., 2013).

Respiration rate, often considered crucial in human health assessment, is a physiological parameter that quantifies the number of breaths an individual takes within a minute. This seemingly simple metric has profound implications for understanding a person's well-being in routine check-ups and critical care situations. The modern era has seen a proliferation of bio-sensors designed to capture respiration rates. These range from piezoelectric sensors (PZT), measuring the mechanical movements of the chest or abdomen (Rasheed et al., 2019) to thermistors that sense the temperature change between inhaled and exhaled air (Qudsi and Gupta, 2013). Optical sensors, using photoplethysmography, are also employed to capture the rate indirectly through changes in blood volume in microvascular beds (Nilsson, 2013). Each sensor type has advantages and limitations, but they all aim to capture a signal that can be analyzed to determine the respiration rate. The signal generated by these sensors is typically time-series data, where the x-axis represents time, and the y-axis represents the amplitude of inhalation and exhalation cycles. The frequency of this signal is directly related to the respiration rate, while the amplitude can offer additional insights into the depth of each breath. This multi-dimensional data can be crucial for diagnosing various respiratory conditions. For example, a high-frequency, low-amplitude signal might indicate shallow, rapid breathing associated with hyperventilation or panic attacks. On the other hand, a low-frequency, high-amplitude signal could signify deep, slow breathing, often seen in states of relaxation or certain sleep stages.

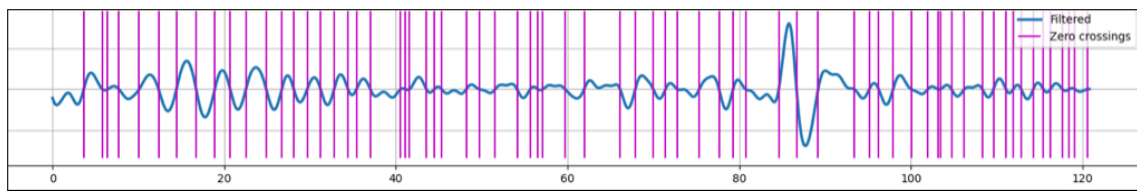


Figure 4.12: The image displays a Respiration Rate signal for a 4-minute window. **Filtered Signal:** The blue waveform represents the filtered respiration signal. This continuous waveform shows the cyclic nature of breathing, where the upward (positive) deflection typically represents inhalation, and the downward (negative) deflection represents exhalation. Proper signal filtering helps remove noise and other unwanted interferences, making the true breathing pattern more evident. **Zero Crossings:** Mark the points where the waveform crosses the zero amplitude line. In respiration signals, zero crossings can be used to determine the breathing rate or frequency. Each pair of consecutive zero crossings (from positive to negative and then back to positive) typically represents one full breath cycle (inhale and exhale). By counting the number of these cycles in a minute, you can estimate the respiration rate in breaths per minute (BPM).

While the primary focus is often on the breathing rate, the signal's characteristics can provide additional information. Variability in the respiration rate, for instance, can be an early indicator of respiratory distress or impending systemic issues. The signal can also be analyzed for patterns indicating irregular breathing rhythms often seen in heart failure patients. Thus, the breathing rate is a rich data source for a nuanced understanding of an individual's respiratory health.

One of the most intriguing applications of respiration rate in recent years is in HCI (Arroyo-Palacios and Romano, 2009; Moraveji et al., 2011; Tsaknaki et al., 2021; Burr et al., 2023). Biofeedback systems, for instance, use real-time physiological data like respiration rate to modify or control computer applications. This has applications in stress management, where software can guide individuals through relaxation techniques based on their current respiration rate. In virtual reality (VR) environments, the respiration rate can adapt to the user experience in real-time (Czub and Kowal, 2019; Pittara et al., 2023; Zhang et al., 2023). For example, in a VR meditation app, the environment could become more serene as the user's respiration rate slows, providing immediate feedback and enhancing the immersive experience (Rockstroh et al., 2021). Similarly, in high-stress training simulations for professionals like pilots or first responders, the system could adapt the scenario's difficulty based on the user's respiration rate, making the training more effective.

The respiration rate is a multifaceted physiological parameter with a rich historical background and evolving measurement techniques. Its signal captures a plethora of information extending beyond the mere count of breaths per minute, offering valuable insights into an individual's overall respiratory health. Furthermore, the advent of technology has expanded its applications into human-computer interactions, opening new avenues for more intuitive and adaptive systems. As we progress, the respiration rate will continue to be a critical focal point in healthcare and technological innovations.

4.3 Summary

In physiological monitoring, various tools—ranging from electromyography and electrocardiography to electroencephalography and electrodermal activity offer invaluable insights into human health and behavior. Each tool captures specific aspects of physiological activity, including the electrical impulses in skeletal muscles, the cardiac cycle, neural activities, or autonomic nervous system responses. These signals serve critical roles in clinical diagnosis and research and are increasingly finding applications in human-computer interactions, enhancing the user experience through biofeedback and adaptive systems. As we continue advancing in medical and technological fields, these physiological monitoring tools, including respiration rates, will remain pivotal. They deepen our understanding of human physiology and pave the way for more intuitive and adaptive systems that can respond to our physiological states in real-time. Thus, as we look to the future, it is clear that these tools will continue to be at the forefront of healthcare innovations and technological developments.

Chapter 5

Methodology

This Chapter details the methodology adopted in the present study. It provides a comprehensive overview of the research design to address the research objectives, namely the rationale for employing a mixed-methods approach and how each method complements each other in capturing the complexity of the research phenomenon. The objective of combining quantitative data analysis techniques with qualitative insights was to gain a comprehensive understanding of the research phenomenon.

Section 5.1 explains the rationale behind adopting a mixed-methodology approach by comprising two experiments conducted within the context of this research: *Acting Emotions 1: Physiological Correlates of Emotional Valence and Arousal in Theatre* and *Acting Emotions 2: Designing Emotionally Expressive Interactive Music System for Theatre*. Further details about both experiments are discussed in the following Chapters 6 and 7.

Sections 5.2 and 5.3 provide detailed descriptions of the materials utilized in the research, encompassing both hardware development and the creation of a custom software toolbox for processing physiological signals and seamless integration into IMS. These sections outline the technical specifications, software requirements, and application scenarios associated with the materials employed in the study.

In Section 5.2, the hardware development aspect of the research is explained, including detailed descriptions of the hardware components utilized. This section provides in-depth insights into the technical specifications of the hardware, such as sensors and interfaces employed for physiological data acquisition and processing. Additionally, it discusses the rationale behind selecting specific hardware components, their compatibility with existing systems, and their suitability for the research objectives.

Section 5.3 delves into the development of a custom software toolbox tailored for processing physiological signals and facilitating their rapid integration into IMS. This section meticulously outlines the software requirements, technical specifications, and functionalities of the custom software toolbox. Moreover, it elucidates the development process, including software design considerations, programming languages utilized, and any additional features or modules incorporated to enhance the software's capabilities.

The methodology chapter ends by presenting a taxonomy developed for the purposes of this research, which is to utilize physiological sensors within the context of IMS. This taxonomy is derived from the study presented in Section 3.4, providing a structured framework for understanding the diverse applications of physiological sensors in IMS settings. The taxonomy is a foundational framework that informs the subsequent methodological approach employed in the present study.

5.1 Mixed-Method Approach: Experiment Design

The rationale behind the two pursued experiments was to assess the suitability of physiological sensors as indicators of emotional states within a focus group consisting of 11 professional theatre actors. Additionally, the aim was to investigate the application of physiological sensors as input for driving both an IMS and a context closely resembling real-world scenarios.

The first experiment, *Acting Emotions 1: Physiological Correlates of Emotional Valence and Arousal in Theatre*, was designed to address the first research question: (Q1) “How do physiological signals correlate with the emotional states of actors during performances, and what are the variations in these physiological-emotional correlations across different individuals?” This experiment aimed to assess the relevance of physiological signals as a medium for emotional expression. The experiment Acting 1 pursued two primary objectives. Firstly, it sought to discern the physiological correlates associated with valence and arousal, aiming to elucidate the capacity of theatre actors to evoke distinct emotions through mental imagery alone and to ascertain whether these emotional variations were mirrored in their physiological signals. Secondly, the experiment evaluated the efficacy of physiological sensors in faithfully capturing and responding to the dynamic shifts in the actors’ emotional states, with a specific focus on their sensitivity, reliability, and responsiveness. By addressing these dual objectives, the experiment aimed to deepen our understanding of the intricate relationship between physiological responses and emotional expression in the context of theatrical performance while assessing the utility of physiological sensing technology in facilitating real-time interaction and emotional modulation within the performance space.

The second experiment, *Acting Emotions 2: Designing Emotionally Expressive Interactive Music System for Theatre*, was conceived to tackle the second and third research questions: (Q2) “How do actors experience and interact with sounds generated from their physiological data, and how does this impact their emotional expression in performances?” and (Q3) “How does integrating physiological data into theatre sound design redefine traditional theatrical narratives and storytelling techniques?” This experiment explored the experiential and expressive dimensions of actors’ interactions with sound generated from their physiological data. The experiment Acting 2, was designed to investigate the integration of physiological signals with IMS within a theatrical context. This experiment’s core was transforming the actor’s physiological responses — comprising parameters such as heart rate, skin conductance, and muscle activity — into sound events. This translation process was facilitated by applying diverse mapping techniques designed to interpret physiological data and translate it into auditory cues within the theatrical performance space.

Through these mappings, the experiment sought to explore avenues for leveraging physiological signals to enrich the sonic landscape of theatrical productions. A critical aspect of this process was its real-time functionality. The physiological data obtained from the actor were processed instantaneously, enabling the sound output to dynamically correspond with the actor's emotional and physical state throughout the performance. This real-time processing ensured that the auditory feedback remained synchronized with the actor's live performance, augmenting the theatrical experience's interactive nature.

5.2 Hardware Development: BITalino Board And Sensors

In the rapidly evolving domain of digital media, especially at the convergence of physiological computing and interactive content creation, the demand for robust and user-friendly platforms has reached unprecedented levels. With the pursuit of increasingly personalized user experiences gaining momentum, there is a growing need for versatile hardware and software solutions seamlessly integrating into research endeavors and practical applications. This section thoroughly explains the BITalino platform, exploring its capabilities, functionalities, and potential applications in physiological computing and interactive content creation.

BITalino, depicted in Fig. 5.1, is as a versatile platform for physiological data acquisition, boasting an array of modular sensors and robust streaming functionalities. Engineered with a keen focus on user accessibility and modularity, BITalino has found widespread applications across diverse domains, spanning from healthcare to human-computer interaction, and notably, within the domain of digital media (Da Silva et al., 2014). Noteworthy is the platform's R-IoT module, developed in collaboration with IRCAM, which extends its capabilities by providing a specialized solution for low-latency, high-data-rate acquisition and streaming of physiological and motion data.

The BITalino platform's core is its microcontroller unit (MCU), often based on a 32-bit architecture. This MCU is responsible for acquiring, processing, and transmitting physiological data. The MCU operates at a clock speed that allows for a sampling rate ranging from 10 Hz to 1000 Hz, providing the flexibility to capture various physiological signals. The MCU is also equipped with analog-to-digital converters (ADCs) that typically offer a 10-bit resolution, ensuring high granularity in the data collected.

The analog front end of BITalino integrates individual sensor blocks for various physiological measurements, as depicted in Fig. 5.2. These include ECG for measuring the heart's electrical activity; EMG sensors that capture the electrical activity generated by skeletal muscles; ACC for measuring acceleration forces, either static, such as the constant force of gravity, or dynamic, as in motion or vibrations; an ALS for measuring light levels in the environment; and a TEMP sensor for measuring ambient or body temperature. Each sensor is designed to be plug-and-play, allowing for easy platform customization according to specific research needs. The sensors are also calibrated to ensure accurate and reliable data acquisition. Each block can be physically detached from the main board, offering flexibility in its usage.



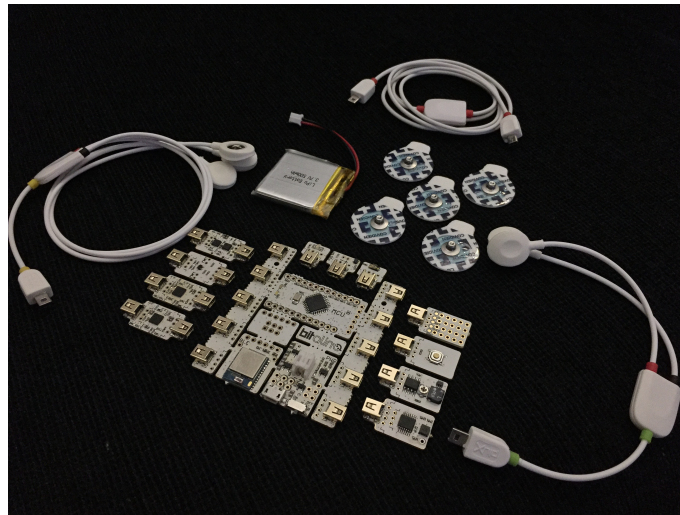
Figure 5.1: The BITalino platform offers various bundles to cater to different needs, ranging from basic to more advanced setups. These bundles typically include a variety of modular sensors, the main BITalino board, and sometimes additional accessories like cables, electrodes, and power supplies. The idea is to provide a comprehensive package that allows users to get started with physiological data acquisition right out of the box.

This architecture enables three configurations (i) Board: BITalino is used with no modifications, enabling individuals to experiment with the onboard sensors for prototyping activities or real-time observation of multiple physiological phenomena; (ii) Plugged: Plugs are added to the BITalino, and the individual sensor blocks are separated from the BITalino main board leaving the control, power, communication, and auxiliary connectivity blocks, enabling individuals to use different sensor combinations interchangeably; and (iii) Freestyle: All the individual blocks are detached from the BITalino main board, allowing users to combine them in any way that best suits their project ideas and applications. These configurations offer flexibility and adaptability to various user needs and project requirements, allowing for prototyping and more customized applications.

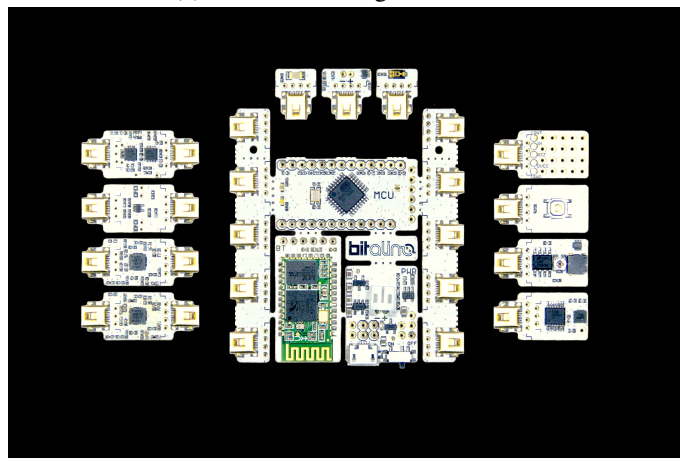
The BITalino platform offers a range of connectivity options to facilitate data transmission (i) Bluetooth: The platform often includes a Bluetooth module that supports a range of up to 10 meters. This wireless option is handy for applications requiring mobility; (ii) USB: The platform also provides a USB interface for a stable and high-throughput data connection, ideal for lab-based experiments where the device can be directly connected to a computer; and (iii) GPIO Pins: General-Purpose Input/Output (GPIO) pins are available for additional customization, allowing for the integration of other sensors or actuators.

For a more robust solution, the company developed the BITalino R-IoT, a wireless sensor digitizing unit co-developed by IRCAM (Institut de Recherche et Coordination Acoustique/Musique).

The core of the BITalino R-IoT is based on the CC3200 chip from Texas Instruments. It integrates a high-performance ARM Cortex-M4 MCU designed for Internet of Things (IoT) applications. The device features a 9-axis digital IMU sensor, which includes a 3-axis accelerometer,



(a) BITalino Analogue Front-end



(b) BITalino Detached Sensors

Figure 5.2: (a) Analog front end of BITalino integrates individual sensor blocks for various physiological measurements. (b) All the individual blocks are detached from the BITalino main board, allowing users to combine them in any way that best suits their project ideas and applications.

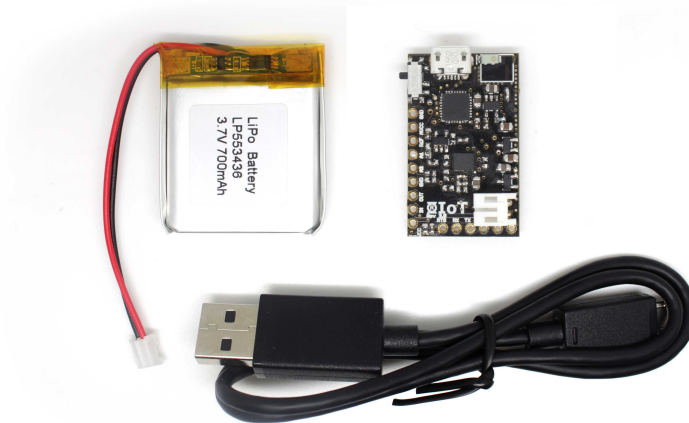


Figure 5.3: The R-IoT module is the 7th generation of IRCAM's wireless sensor digitizing units and is designed for applications in motion sensing, gestural recognition, and live performance arts. It aims to provide low latency, high data rate and resolution, and stage compatibility.

a 3-axis gyroscope, and a 3-axis magnetometer, allowing onboard computation of the module's absolute orientation in space. The sensor is attached to the SPI port for high-speed 16-bit motion data sampling. The module employs the Open Sound Control (OSC) protocol for communication, which is suited for modern networking technology. The OSC protocol offers several features that enhance the streaming capabilities of the R-IoT module:

- **Dynamic Naming Scheme:** The OSC protocol uses an open-ended, dynamic, URL-style symbolic naming scheme, allowing for flexible data routing.
- **High-Resolution Numeric Argument Data:** The protocol supports symbolic and high-resolution numeric argument data, ensuring the accuracy of the transmitted information. **Pattern Matching:** It includes a pattern-matching language to specify multiple recipients of a single message, allowing for complex data routing scenarios.
- **Time Tags:** The protocol supports high-resolution time tags, enabling precise synchronization of data streams. **Bundled Messages:** OSC allows for "bundles" of messages whose effects must co-occur, enhancing the system's real-time capabilities.

Regarding network configuration, the R-IoT module can operate in access point and Station modes. The module's default firmware implements a Wi-Fi Access Point and a Web server to configure its wireless parameters, such as the Wi-Fi network name and the OSC UDP port for data transmission. The default recipient IP address is 192.168.1.100 on port 8888. Security features like MAC address filtering can also be set up in the Access Point to prevent unauthorized access. The R-IoT module is designed to be versatile and capable of streaming gestural information to the computer from multiple performers. It captures pre-digitized BITalino sensor data and packs it into OSC messages, and the IMU data is sent in separate OSC messages. This makes the R-IoT

module highly adaptable for various use cases, from motion analysis to sensor data streaming. The platform is designed for power efficiency, operating on a single 3.7V lithium battery. The battery life can vary depending on the configuration but is generally sufficient for several hours of continuous data acquisition.

The BITalino platform is designed to be highly compatible with different software tools, making it a flexible choice for researchers and developers. One of the strengths of BITalino is its open-source nature, which allows for a high degree of customization and integration with various software environments. BITalino offers Python libraries that facilitate data acquisition and analysis. Python's extensive ecosystem for scientific computing, including libraries like NumPy, SciPy, and Matplotlib, can be leveraged alongside BITalino's libraries. MATLAB compatibility is a significant advantage for those in the academic and engineering sectors. BITalino provides a MATLAB toolbox for seamless data acquisition and signal processing. Java libraries are also available, enabling the integration of BITalino into Android applications or other Java-based software solutions. C and C++ libraries are available for performance-critical applications, allowing for integration into embedded systems or real-time applications. Furthermore, BITalino also developed a library for the visual programming language MaxMSP.

The main specifications are summarized in Table 5.1. We also provide the transformed sensor output values for each of the five physiological sensors used in our research. Detailed information about the sensors, applied transformations, and output units can be found in Table 5.2.

Table 5.1: BITalino specifications

Sampling Rate	1,10,100 or 100 Hz
Analog Ports	4 input (10-bit) + 2 input (6-bit)
Digital Ports	4 input (1-bit) + 4 output (1-bit)
Data Link	Bluetooth (range up to 10m)
Actuators	LED
Sensors	EMG;ECG;EDA;ACC;LUX
Battery	3.7 V Lithium Ion
Weight	30g/1.0 oz
Size	105x60 mm / 4.13x2.36 in

To support the specific needs of the research, a customized version of the BITalino was developed in a collaborative effort and partnership with the very creators of the BITalino. The core of the research demanded a device that could seamlessly integrate into stage environments – a context where conventional devices often falter due to their size and sensitivity to motion. Thus, the primary objectives for this customized BITalino were clear: compactness, robustness suitable for stage use, incorporation of movement sensors, and the facilitation of Wi-Fi connectivity. For compactness in a stage setting, performers and technicians require unobtrusive tools. Any device that hinders movement or becomes a focal point for the audience can disrupt the essence of the performance.

Fig. 5.4 shows the customized BITalino. The board was designed to be small, ensuring it could

Table 5.2: Overview of the sensors used in our research, including (i) the type of sensor, (ii) the number of sensors, (iii) the manufacturer, (iv) the reference model, (v) any applicable conversion equations used to transform input values, and (vi) the physical units based on the International Standard units.

Sensor	No.	Reference	Model	Transformation equation	Units
EMG	02	BITalino	EMG 100716	$EMG_{1000mv}(v) = \frac{(\frac{ADC}{2^n} - \frac{1}{2}) \cdot 3,3v}{1009_{EMG}}$	μC
ECG	01	BITalino	ECG 100716	$ECG_{1000mv}(v) = \frac{(\frac{ADC}{2^n} - \frac{1}{2}) \cdot 3,3v}{1100_{ECG}}$	mV
EDA	01	BITalino	EDA 081217	$EDA_{1000mv}(v) = \frac{\frac{ADC}{2^n} \cdot 3,3}{0,132}$	μS
RESP	01	BITalino	PZT 280519	$PZT_{\%} = (\frac{ADC}{2^n} - \frac{1}{2}) \cdot 100\%$	%
ACC	01	RIoT	BR 20200207	_____	{ -8 ; +8 } g
GYR	01	RIoT	BR 20200207	_____	{ -2 ; +2 } ° / s
ADC	06	BITalino	BR 20200207	_____	_____

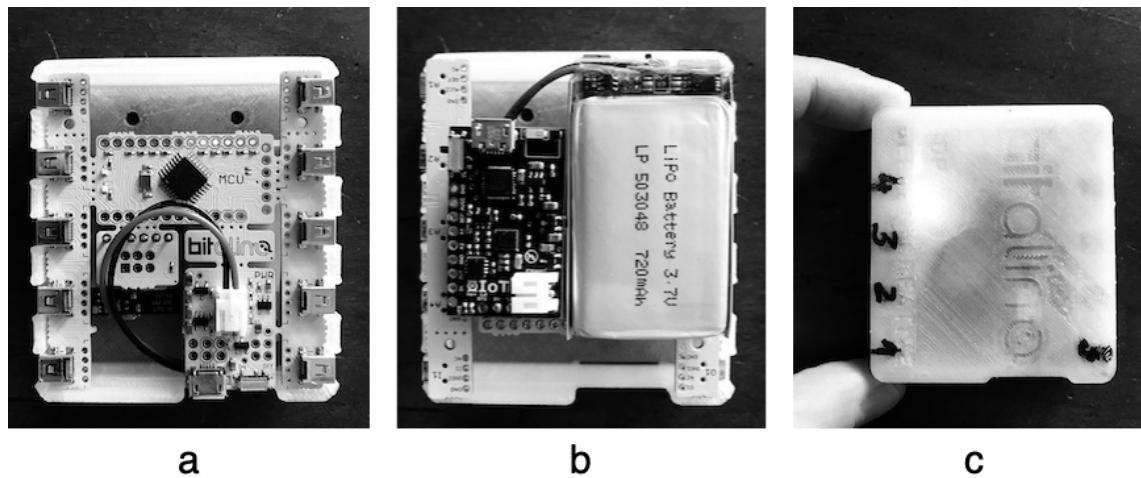


Figure 5.4: (a) the board BITalino is visible. It has connectors for various biomedical sensors. The MCU label indicates the location of the Microcontroller Unit, which is the board's processing brain. The PWR label indicates the board's power management or power source connectors. The absence of the usual Bluetooth module can be noticed, which has been replaced, as described in (b), by a RIoT board consisting of processors designed for IoT applications, often with integrated sensors and communication modules. A movement sensor designed for applications such as detecting orientation, tilt, or movement changes. The WiFi connection capability gives the board's ability to transmit data wirelessly over internet networks, allowing for remote data monitoring; (c) showcases the device's 3D printed enclosure. The holes and design cuts are for connectors, sensors, or LEDs, allowing easy access to the board's functionalities while keeping the components protected.

be comfortably worn or integrated into costumes without drawing attention. One of the most significant enhancements was the introduction of Wi-Fi capabilities. This feature not only eradicated the limitations of wires but also facilitated real-time data transmission. Instantaneous access to bio-signal data, especially in a dynamic environment like a stage, provides invaluable insights to researchers. Given the kinetic nature of stage performances, it was imperative to have movement sensors. These sensors capture the motion data and allow for a more holistic understanding of how movement can influence physiological signals. Finally, a stage is a challenging environment, with its rapid movements, lights, and potential for physical impacts. Thus, the customized BITalino was designed to endure such conditions, ensuring consistent performance despite intense stage actions.

Working in close collaboration with the BITalino company presented a unique advantage. It allowed leveraging their technical expertise and deep understanding of the product, ensuring that the modifications did not compromise the integrity and efficiency of the original design. Before the final version was green-lighted for stage use, it underwent tests. Speed was paramount; any data acquisition or transmission lag could skew results. The device consistently showcased swift data capture and transmission rates, meeting the research requirements. Accuracy, another critical metric, was also diligently assessed. Precise data is the cornerstone of any research, even more so when the environment is as dynamic as a stage. The customized BITalino accurately captured detailed physiological and movement data without noticeable deviations. Lastly, ease of use was evaluated, considering the diverse users in a stage setting. The final design ensured that even those without a technical background could operate the device efficiently.

5.3 Software Development: Biosignal Processing Toolbox

Within the scope of their research, a software suite named **Biosignal Processing Toolbox** (BarT) was developed. This toolbox was engineered to execute various functions, including data collection, data recording, feature extraction, mapping, and the real-time auditory representation of physiological signals. A key specification for BarT was its proficiency in a real-time environment, encompassing the entire process from feature extraction to the utilization of machine learning techniques, ultimately leading to sonification. In (Walker and Nees, 2011), sonification is the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation. The toolbox was pivotal in implementing the experimental framework within a theatrical setting. Its real-time features were crucial in facilitating the dynamic interaction between the physiological responses of the actors and the resulting auditory feedback, forming an integral part of the investigation.

BarT operates as a real-time computational platform for the acquisition, processing, and auditory representation of physiological signals and is specifically tailored for compatibility with a BITalino board. The primary goals of BarT are twofold: Initially, it concentrates on capturing, assessing, and interpreting physiological data. Subsequently, it introduces a structured approach

for integrating algorithms, thus assisting in the fluid integration of physiological signals into the structural design of IMS.

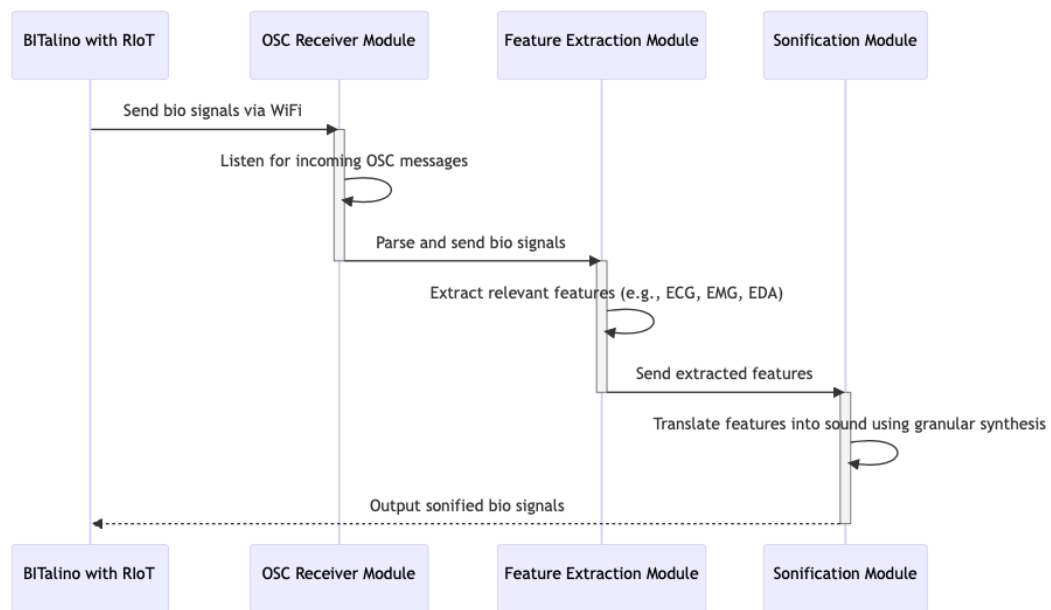


Figure 5.5: **OSC Receiver Module** (BITalino with a RiOT): This module receives data from BITalino with a RiOT (Revolutionizing IoT) providing WiFi communication and an IMU sensor. This module listens for incoming OSC messages and parses them for the next module. **Feature Extraction Module** (Specific Bio Signals): This module extracts features from bio signals received from the BITalino. Depending on the type of physiological signal (e.g., ECG, EMG, EDA), the module will extract relevant features that can be sonified. **Sonification Module** (grain synth sync, async and sample and generative algorithms): This module translates the extracted features into sound. It uses mainly granular synthesis and offers the possibility to experiment with a number of compositional techniques, such as serial procedures and controlled randomness.

The structure of BarT, illustrated in Fig. 5.5, is centered around a series of Max/MSP¹ abstractions, augmented by intuitive graphical user interfaces for rapid data analysis and visualization. In addition, the toolbox features specialized sonification modules explicitly created to interact with physiological data. These modules cover a spectrum of complexities, ranging from basic granular synthesizers to advanced granular synthesis methods that employ neural networks. Collectively, these modules manage a variety of physiological signals, including, but not limited to, EMG, ECG, and EDA. The following sections provide an in-depth examination of the specific characteristics

¹<https://cycling74.com>

relevant to each physiological signal being studied. The subsequent subsections expound on the configuration of BarT.

5.3.1 BarT: Listening, Parsing and Recording

The data acquisition process commences with establishing a Wi-Fi connection between the acquisition hardware and the software interface. This connection is facilitated by a BITalino board equipped with a RIoT module, which guarantees a stable link. The RIoT module is favored for its low latency and high data throughput, making it optimal for real-time streaming of physiological data (refer to Section XXX for a comprehensive analysis of the RIoT module). Once the Wi-Fi connection is active, the software monitors incoming data packets via the User Datagram Protocol (UDP). UDP is chosen for its simplicity and rapidity, essential for real-time operations. In contrast to Transmission Control Protocol (TCP), UDP eschews a handshake process, thereby reducing latency and computational demands.

Data packets are processed using the OSC protocol, separating them into distinct channels. OSC, known for its human-readable and machine-parsable content format, is a preferred protocol for transmitting complex data structures across networks. The software interface then displays these signals in a waveform visualization. This immediate visual representation serves dual purposes: it offers prompt feedback to the researcher and confirms the accuracy of data recording. Waveform representation, a standard in this field, is an effective way to evaluate the quality and characteristics of physiological signals.

The software archives each signal in text files in raw and resampled formats. Raw data is recorded at the board's native sample rate of 100 Hz, preserving the original data's integrity, which is crucial for later analyses. The resampled data, however, is recorded at a fixed rate of two milliseconds, or 500 Hz. This resampling, an arbitrary decision, is predicated on the hypothesis that high-resolution, interpolated data may prove beneficial for future studies. The resampling algorithm maintains the fidelity of the original signal while offering more data points for detailed examination. Both raw and resampled data are automatically saved in uniquely identified files for each session, enhancing data management efficiency. This system effectively reduces data loss or overwrite risks and simplifies data retrieval for subsequent analyses.

The software also supports the synchronized recording of video and audio streams alongside physiological data. This functionality is especially pertinent for research correlating physiological reactions with audiovisual stimuli or events. By synchronizing these diverse data streams, it becomes possible to analyze them collectively, offering a more comprehensive insight into the subject's responses. The subsequent section will elaborate on the specific characteristics extracted from the physiological signals, which were subsequently utilized for sonification objectives.

5.3.2 Real-time BarT Analysis

This section delves into the specific physiological features analyzed by BarT in real-time.

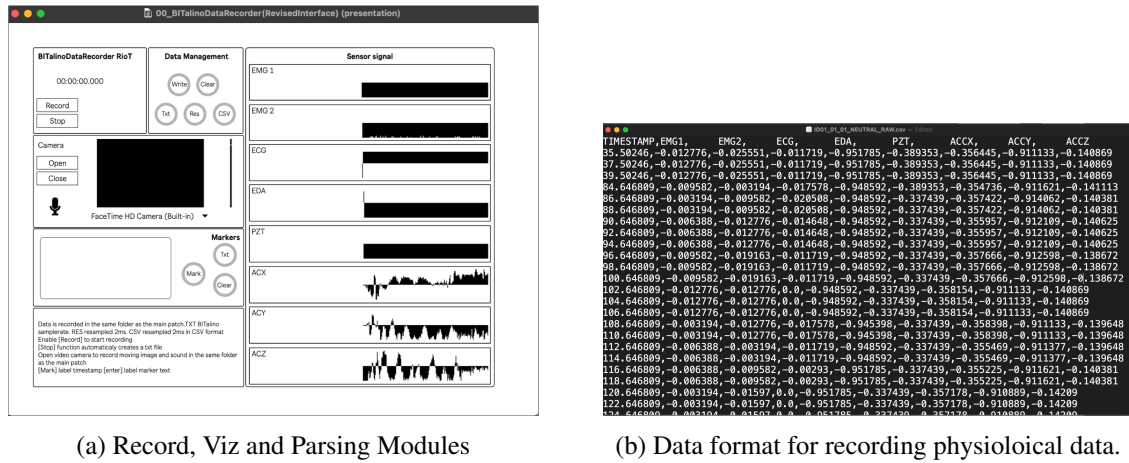


Figure 5.6: Panel (a) highlights the custom software developed for data recording and analysis. The software facilitated listening to the UDP port, parsing physiological signals, visualization of data, and saving data in raw and resampled formats. The image showcases the software interface utilized for data processing. Panel (b) displays storing sensor data in a CSV file, where each participant and emotion is assigned a unique identifier. The CSV file was structured in column format, with the following data arrangement: timestamp, EMG1, EMG2, ECG, EDA, PZT, and acceleration data (X, Y, & Z axes).

EMG readings in BarT are typically obtained from two locations: the biceps brachii muscle (Daud et al., 2013) and various facial sites (Murata et al., 2016). Key EMG metrics include:

- **Maximum amplitude (MAX):** This represents the highest value within an EMG signal, indicating peak muscle activity.
- **Root mean square (RMS):** This metric offers insights into the consistency of muscle force.
- **Onset Detection:** Identifies the commencement of muscle activity or a substantial increase in EMG signal amplitude, signaling the start of a muscle contraction.

The ECG component of BarT focuses on pinpointing peaks indicative of specific cardiac cycle events, crucial in observing the heart's electrical activity, particularly during the ventricular depolarization and repolarization phases.

- **R peak (or R wave peak):** The apex of the R wave within the QRS complex, indicating ventricular depolarization leading to contraction (Goldberger and Gold-berger, 1981).
- **RR interval variability:** This measures the time variation between consecutive heartbeats, offering insights into heart rate variability.
- **S peak (or S wave peak) and S amplitude variation:** The nadir of the S wave within the QRS complex, representing a specific phase in the cardiac cycle (Camm et al., 1996).
- **T peak (or T wave peak) and T amplitude variation:** These parameters emphasize the repolarization phase of the ventricles. The T wave signifies the period between the latter part of ventricular depolarization across two cardiac cycles (Antzelevitch and Sicouri, 1994).

- **TS value:** Represents the interval between the end of one repolarization phase and the onset of the next depolarization.

EDA analysis in BarT measures the skin's conductance, often related to physiological or psychological arousal (Boucsein, 2012). EDA metrics include:

- **Mean:** The central value of EDA measurements within a specific timeframe, indicating the average skin conductance level.
- **Standard Deviation:** Illustrates the variance of EDA readings from the mean, indicating the dispersion of data points.
- **Kurtosis:** Describes the shape of EDA measurement distribution. High kurtosis suggests heavier tails than a normal distribution, while low kurtosis indicates lighter tails.
- **Low, Mid, and High Percentile:** These values represent specific fractions of the dataset, marking the 25

Finally, PZT readings in BarT yield features pertinent to respiratory cycles (West, 2012), including:

- **Difference:** Reflects variations between consecutive respiratory measurements, such as differences in breath durations or amplitudes.
- **Variance and Standard Deviation:** These metrics assess the spread and consistency of respiratory measurements, offering insights into the variability and regularity of breathing patterns.
- **Maximum value:** The highest measurement in a series of respiratory readings, applicable to various breathing aspects like the deepest breath or the longest breath duration.

5.3.3 BarT: Sonification

Parameter-mapping sonification (PMS) is a technique that translates multi-dimensional data into sound by assigning data to various sound parameters. These parameters encompass physical attributes such as frequency and amplitude, psychophysical elements like pitch and loudness, or perceptually coherent complexes such as timbre and rhythm (Worrall, 2010). In contrast, model-based sonification (MBS) involves transforming data into a dynamic model resembling an acoustic instrument. Users can then interact with this data-driven instrument, creating a closed interaction loop to explore features of the data (Hermann and Ritter, 2005).

The principal technique employed in BarT is granular synthesis, where complex sounds are generated by overlaying small sound fragments or grains (Roads, 2003). These grains, typically lasting between 1 to 100 milliseconds, can be manipulated to produce a broad range of timbral effects and a very dynamic sonification. The sonification modules used are detailed below:

- **[simple sync grain] Paradigm: PMS**

Description: Implements granular synchronous synthesis to mimic an artificial heartbeat sound, aligning grain playback with the extracted data. **Interactive Parameters:** Focuses on the fundamental frequency (set by the user) and grain duration (adjusted according to RR interval variability), using a one-to-one mapping strategy.

- **[simple async grain] Paradigm: PMS**

Description: Employs a stochastic algorithm to determine the start of each grain, creating a denser sonification. **Interactive Parameters:** Adheres to a direct mapping strategy, modulating parameters based on a user-defined baseline.

- **[simple async grain preset] Paradigm: MBS**

Description: Similar to [simple sync grain], but with enhanced one-to-many mapping capabilities. **Interactive Parameters:** Mainly focuses on onset detection to trigger cues altering synthesizer settings dynamically. RMS may also be used to set the likelihood of sound occurrence.

- **[vari grain]**

Description: Similar to [simple async grain] but offers more precise control over the rate of parameter variation. **Interactive Parameters:** Allows for a variation range from 0

- **[grain sample] Paradigm: PMS**

Description: Uses pre-existing samples instead of oscillators to derive grains, transforming these into sounds with elements from the original samples. **Interactive Parameters:** Offers ten parameters, each with a 0

- **[grain sample ANN] Paradigm: MBS**

Description: Integrates a [grain sample] with an [ann learn] module for a complex many-to-many mapping approach. **Functionality:** Utilizes a multi-layer perceptron network (MLP) to identify relationships between biosignal inputs and auditory outputs, commonly used in classification and non-linear mapping.

[grain sample ANN][piano gen] Paradigm: PMS

Description: Generates MIDI musical note sequences using serial composition-based generative algorithms and a Brownian motion algorithm, processed by a virtual piano plugin ² (CITE as Spitfire) to create audio. **Interactive Parameters:** MIDI Note in

BarT integrates various algorithms encompassing interactive machine learning models (IML) (Fails and Olsen Jr, 2003). IML enables users to conduct training, classification/viewing, and correction of classifications. Overall, BarT stands out as a comprehensive real-time physiological signal processing tool, merging various signals with advanced audio processing techniques, making it invaluable in the intersection of physiology, technology, and art.

²<https://labs.spitfireaudio.com/soft-piano>

5.4 Taxonomy Of Physiological Signals In Interactive Musical Systems

The upcoming section will center on the taxonomy of physiological signals within the framework of the IMS developed for this study. Crafting this taxonomy served as the initial stride in comprehending the potential applications of physiological signals in an IMS context, particularly within theatre. The groundwork for this taxonomy drew inspiration from studies in digital game interaction and human-computer interaction.

Drawing from the perspective of musical interaction and acknowledging the limited availability of use cases in theatre, examples were sourced from the comprehensive review presented in Chapter 3, which delved into the integration of physiological signals in IMS.

The initial attempt to establish a taxonomy of physiological signals within the domain of IMS drew inspiration from the field of digital game interaction. This domain is recognized for extensively exploring user engagement, behavior, and experience within digital environments (Nacke et al., 2011). Digital game interaction provides a multifaceted perspective on how users interact with and respond to stimuli within virtual worlds (Nogueira et al., 2013a,b), offering valuable insights into the dynamics of user engagement and interaction patterns (Nogueira et al., 2016).

The insights garnered from studies in digital game interaction served as a foundational framework for the present study in categorizing and classifying physiological signals within IMS. By leveraging the knowledge and methodologies established in the field of digital game interaction, the study aimed to adapt and extend existing frameworks to suit the unique context of interactive music technology. This approach facilitated the development of a comprehensive taxonomy that delineates the physiological signals relevant to IMS and their respective applications in shaping user experiences and interactions within musical environments (Aly et al., 2019).

The taxonomy designed for selecting sensor technology in specific interactive tasks structures around two dimensions: Firstly, the “Degree of Control Over Physiological Signals” is a foundational aspect of this taxonomy. This dimension thoroughly assesses individuals’ capacity to influence their physiological signals, whether consciously or unconsciously. Such an evaluation is instrumental in determining the most suitable sensor technology for specific interactive scenarios. For instance, certain sensors excel at capturing involuntary physiological changes, such as ECG, of which individuals have limited conscious control. Conversely, other sensors, such as EMG or EOG, may be better suited for tracking physiological aspects that users can directly control.

Secondly, the “Temporal Variability” of physiological signals captured by sensors constitutes another crucial dimension within this taxonomy. This dimension focuses on the pace of change in physiological data. It plays a key role in distinguishing between various types of physiological information. By considering temporal variability, the taxonomy aids in identifying sensors that are particularly apt at recording fluctuating signals, such as EMG. Conversely, temporal variability distinguishes sensors as more suitable for monitoring slower, more gradual changes in physiological states, often associated with emotional responses.

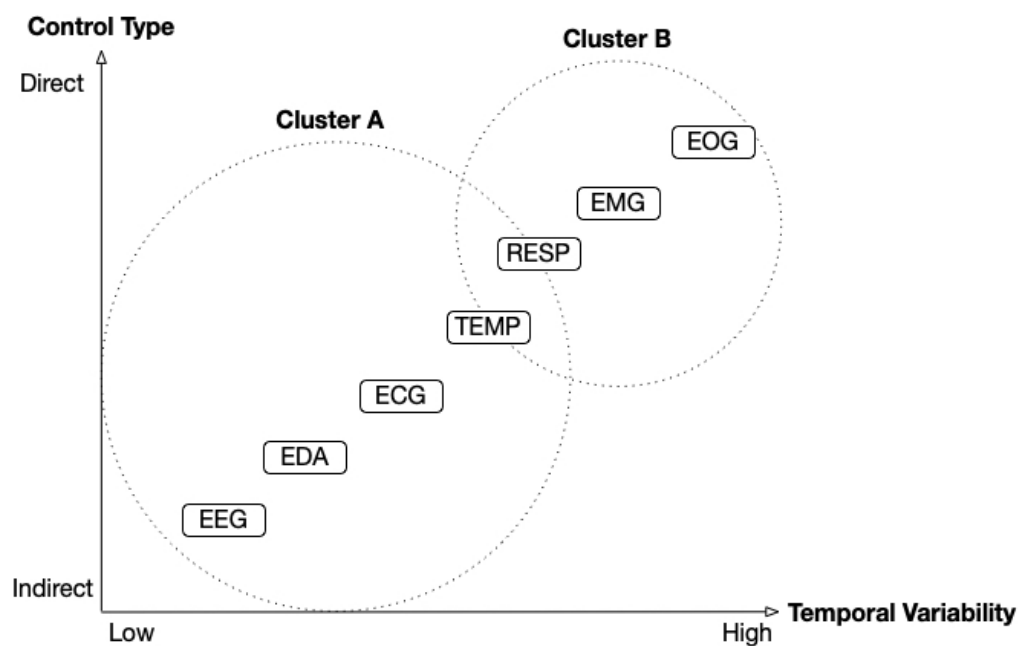


Figure 5.7: Distribution of Physiological Measures Across Two Axes: The horizontal axis represents the temporal variability of the sensor's response to stimuli, while the vertical axis indicates the level of direct control over the generated electrical potentials. Two distinct clusters, labeled A and B, are identified based on the sensor's type of control and response characteristics.

By integrating these two dimensions, the taxonomy offered a comprehensive framework for selecting sensor technology tailored to design interactions within a musical environment. It facilitated informed decision-making regarding sensor choice based on each interactive scenario's unique requirements, thereby enhancing interactive systems' effectiveness and responsiveness in capturing and interpreting users' physiological responses. Figure 5.7 depicts the proposed taxonomy for physiological sensing in IMS.

The horizontal axis of the taxonomy, representing temporal variability, spans from low to high degrees of variability. This dimension distinguishes between physiological signals that exhibit rapid fluctuations and those characterized by slower rates of change. For instance, a gaze sensor demonstrates high temporal variability as it captures the swift movements of the eyes during interaction. Conversely, an EEG sensor typically exhibits lower variability since it measures brainwaves, which tend to change at a slower pace.

On the other hand, the vertical axis of the taxonomy signifies the degree of control that subjects have over their physiological functions, ranging from direct to indirect control. This dimension quantifies the extent to which individuals can consciously manipulate their physiological states, thereby influencing sensor readings. For instance, humans generally possess direct and explicit control over muscle impulses, which can be captured by an EMG sensor. In contrast, control over skin conductivity, measured by an EDA sensor, tends to be more indirect and implicit, as it reflects emotional arousal or stress responses that may not be consciously controlled by individuals.

As illustrated in Figure 5.7, the physiological sensors are arranged diagonally, indicating an

interrelationship between the horizontal and vertical axes. This arrangement means that the speed of sensor responses correlates with the degree of direct control users typically exert over the measurements and their subsequent changes. In essence, the faster the sensor responses, the greater the likelihood that users have direct control over the measured physiological functions.

Within this arrangement, the taxonomy identifies two overlapping clusters where certain sensor technologies exhibit rapid responsiveness and direct user control characteristics. This overlap arises because some sensors can rapidly change their measurements due to sudden alterations in their measuring environment despite having a generally slow response rate. For instance, while a TEMP sensor typically demonstrates a slow response rate, a user can induce more immediate changes by blowing air into it, accelerating the sensor's reaction time.

Another dimension worth considering is body intrusion, which pertains to the physical obtrusiveness associated with a sensor. While this factor is pertinent in selecting physiological sensors for specific tasks, ongoing advancements in miniaturization are expected to make sensor technology increasingly ubiquitous and unobtrusive across various artistic applications.

Following the establishment of the initial taxonomy, a second taxonomy was developed to categorize physiologically-driven IMS. Illustrated in Figure 5.8, this taxonomy is structured into functional and empirical classifications (Aly et al., 2021).

The functional classification is adapted from a pre-existing taxonomy (da Silva, 2017), which is further subdivided into several dimensions aimed at elucidating physiological signals from both HCI and signal-processing perspectives. These dimensions encompass user controllability, perception, device intrusiveness, feature observability, and signal properties. By embracing this functional classification, the taxonomy furnishes a structured framework for categorizing physiologically-driven IMS according to their inherent functional attributes. This approach aids in achieving a thorough comprehension of the multiple dimensions that contribute to the design and implementation of IMS integrating physiological signals. More precisely, the dimensions of user controllability perception and device intrusiveness assess the perceived accuracy with which users can control the degrees of freedom in physiological signals and the ergonomic implications of using the physiological sensors, respectively. On the other hand, the dimensions of feature observability and inherent signal properties delve into the time and frequency-domain characteristics of the signal. These dimensions cover the typical time scales required for acquiring information from the sampled signal and the temporal stability of the signal's statistical features.

In physiological-driven IMS, the functional category is delineated into four dimensions: perceived user controllability, device obtrusiveness, information observability, and signal property. Each dimension offers a unique lens through which the interaction between users and physiological sensors can be understood. The functional categories are detailed as follows:

Perceived User Controllability:

- **Definition and Context:** From an HCI perspective, this dimension encapsulates the user's perceived precision in modulating a physiological signal under scrutiny (Wanderley and

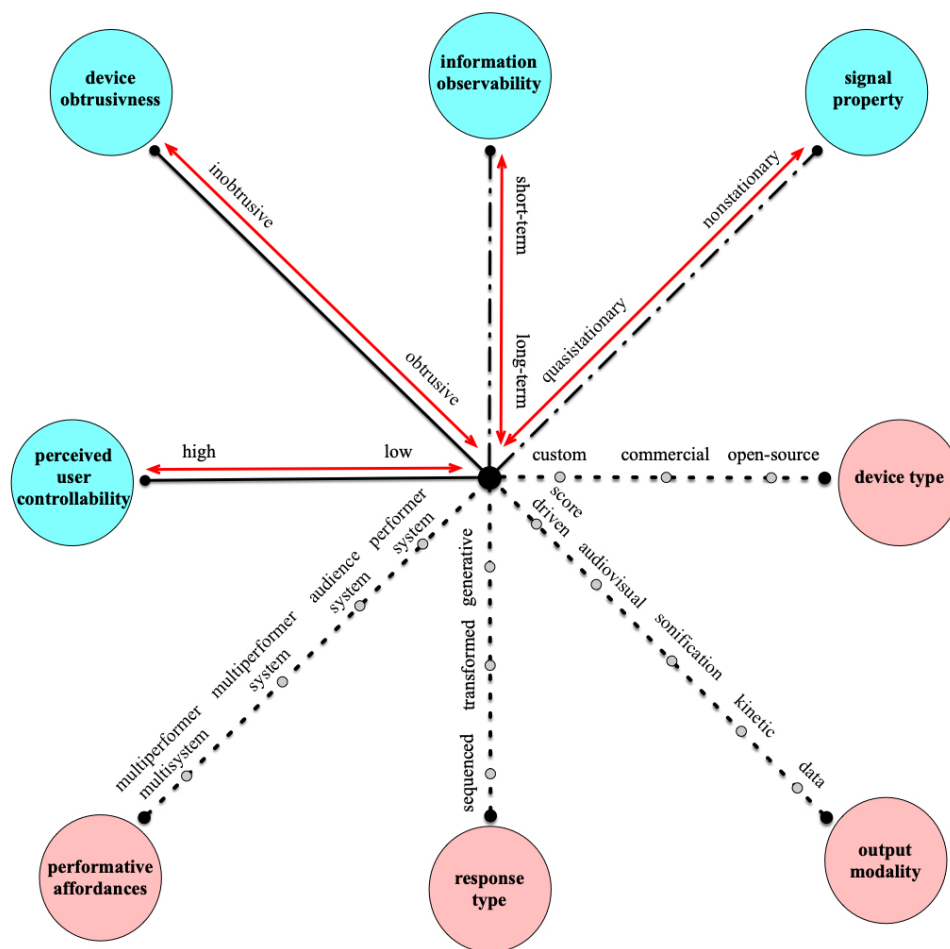


Figure 5.8: In the dimensional space, both the functional and empirical categories are distinctly delineated. The functional categories manifest in a shade of blue, contrasting with the empirical categories highlighted in red. Originating from the core of the star diagram, each radial line signifies a unique dimension. These lines are stylized to represent their corresponding knowledge domains: solid lines for human-computer interaction, dashed lines for signal processing, and dotted lines for interactive music systems. Within the taxonomy's framework, dimensions can be classified as either continuous or discrete. The continuous dimensions are marked by arrowed lines in red, with the ends of these lines demarcating qualitative extents.

Orio, 2002). It is not merely a metric of control but a reflection of the user's agency within the dynamics of the system's action-reaction continuum.

- **The spectrum of Controllability:** This dimension spans a continuum from high to low perceived user controllability. At the high end it includes voluntary muscular activities, including actions like arm muscle activation or limb movement. Physiological sensors such as the EMG, FLEX, and GYR are typically associated with this high degree of controllability. Conversely, EEG signals characterize the middle spectrum involving controlled movements, such as eye-opening and closing, as well as involuntary activity, such as the level of focus or relaxation, through measurements of alpha or beta waves, respectively. The lower end of the

spectrum includes involuntary action, such as electro-dermal, temperature, or cardiac activity (Tahiroğlu et al., 2008). physiological sensors like the ECG, EDA, and RESP typically fall under this category.

Device Obtrusiveness:

- **Definition and Context:** From an HCI standpoint, this dimension pertains to the user's tangible experience with a specific technological apparatus, encompassing both the sensor and its associated signal-processing device.
- **The spectrum of Obtrusiveness:** This dimension spans from obtrusive and unobtrusive. As the term suggests, obtrusive devices are those devices that users might find uncomfortable or intrusive (Hensel et al., 2006). These are often physically attached or worn, like headsets with electrodes for monitoring brain activity (Çiçek, 2015). In more extreme scenarios, these devices can be invasively implanted within the body (Filas, 2013). Such invasive techniques might involve needles or electrodes inserted into muscle tissue to glean information at the muscle membrane level (Rau et al., 2004). Conversely, inobtrusive devices capitalize on technological advancements, miniaturizing monitoring devices and enabling noninvasive capturing of physiological signals (van den Broek et al., 2009). An example is a noninvasive method of capturing body temperature monitoring through the use of infrared cameras.

Information Observability:

- **Definition and Context:** From a signal processing perspective, this dimension highlights the temporal scale at which we detect discernible changes in the biosignal data beyond mere residual noise.
- **Spectrum of Observability:** This dimension oscillates between short-term and long-term observability. Short-term observability pertains to physiological signals where information extraction occurs rapidly, within the millisecond range. For instance, an EMG reports information from muscle electrical activity and can exhibit abrupt changes even at the sample level. The typical sampling rates for such signals might range from 250 Hz to 1000 Hz. On the other hand, we characterize long-term observability by a slower rate of information extraction, often spanning several seconds. For instance, the EDA typically responds to stimuli within a 10 to 30-second range (Boucsein, 2012).

Signal Property:

- **Definition and Context:** This dimension is concerned with the stability of the signal's statistical properties over time.
- **The spectrum of Signal Property:** It ranges from quasistationary to nonstationary. Quasistationary signals exhibit relatively stable statistical properties, with only gradual changes over time. Body temperature measurements exemplify this, as human bodies do not undergo

rapid temperature fluctuations. In contrast, nonstationary signals manifest significant statistical variations over time, as seen in EEGs capturing sudden eye blinks or EMGs detecting muscular activity spikes (Escabí, 2005).

In the domain of physiological sensing technologies, it is essential to recognize the susceptibility of these devices to external disturbances. Given the dynamic nature of specific IMS applications, motion often emerges as a primary noise source. The sensitive nature of physiological signals, particularly in the millivolt range for devices like ECG and EMG, implies that even minor movements can result in electrode displacement, thereby introducing noise into the signals. Additionally, external forces can distort measurements; for example, EDA, which measures skin impedance, can be influenced by variations in electrode pressure. Electromagnetic disturbances, such as those from transformers or fluorescent lights, can overshadow the signals of interest or yield inaccurate readings. Environmental variables like air conditioning or heating can also impact specific control structures. Awareness of these factors is crucial when utilizing biosensing technologies to ensure accurate and reliable data capture and interpretation.

The empirical classification utilized in this study was designed to elucidate the potential expressivity of interactions within a musical system. This classification aids in categorizing IMS according to the compositional sonic architectures' structure, as previously outlined in the literature, particularly by (Drummond, 2009).

The empirical categories are divided into dimensions that offer an in-depth understanding of physiological signals from two distinct angles: the technological aspect, represented by the device type, and the inherent musical interactive attributes, which include output modality, response nature, and performative possibilities. As an example, the dimension of information observability in a physiological signal is characterized through a temporal scale on a continuous spectrum. Short-term and long-term observability endpoints bound this spectrum. Depending on the specific application domain, these varying durations can facilitate different rates of information acquisition. The discrete qualitative spaces within this dimension, symbolized by gray circles along the dotted trajectories, can be situated either along or within the boundaries of the dimensions' trajectories as illustrated in Figure 5.8.

In the context of IMSs, a system may align with a single type or span multiple types within these dimensions. For example, the output musical response of an IMS could be solely generative, sequenced, or it could incorporate both modalities across musical time as separate entities. It should be noted that a blended generative and sequenced response within the same temporal framework is considered unfeasible in this taxonomy. The empirical category provides a thorough framework for comprehending the intricacies of these systems. This category is further elaborated into four empirical dimensions: device type, output modality, response type, and performative affordances. Together, these dimensions offer insight into the interactions enabled by interactive systems and their role in the musical creation process.

Device Type:

- **Overview:** This dimension delineates the variety of physiological sensing devices utilized in each work, categorizing them into three classifications: custom, commercial, and open-source.
- **Historical Context:** In the initial stages of IMS development, custom devices equipped with physiological sensors predominated. These bespoke devices, developed for specific artistic endeavors, were a hallmark of early IMSs. However, post-2010 saw a surge in commercial mobile biosensing devices entering the consumer market. These devices are characterized by their ease of positioning, wireless data transmission capabilities, enhanced mobility, and cost-effectiveness, leading to their increased adoption. (Chabin et al., 2020). Commercial devices include g.MOBILab, Emotiv's EPOC, MindMedia's Nexus units, and Thought Technology's Infiniti. In recent years, there has been an emergence of open-source devices. These devices are praised for their flexibility in assembly, integration, and prototyping across various programming languages. They offer the added advantage of unrestricted access to biosignal data, facilitating greater collaboration and innovation within the research community. OpenBCI (Durka et al., 2012) and BITalino (Guerreiro et al., 2013) are exemplars in this category.

Output Modality:

- **Overview:** This dimension categorizes IMSs based on their output mechanisms, specifically focusing on actuators that convert electrical energy into other forms of energy such as acoustic, kinetic or visual.
- **Types:** The output modality dimension is divided into five types: score-driven, audiovisual, sonification, kinetic, and data. Score-driven outputs are characterized by an IMS's inherent understanding of a predefined compositional structure coupled with real-time tracking capabilities. Audiovisual outcomes encompass light-emitting diodes, liquid crystal displays, video projectors, and lasers. Sonification outputs directly correlate specific biosignal attributes with corresponding sound parameters. Kinetic effects involve devices like loudspeakers, piezo buzzers, electric motors, and solenoids, which engage the audience's tactile and kinesthetic senses. Conversely, data outputs involve collecting and analyzing biosignal data from performers to derive insights into specific musical tasks.

Response Type:

- **Overview:** Drawing from the classifications proposed by (Drummond, 2009), this dimension elucidates how an IMS reacts to its input (Rowe, 1992).
- **Types:** The response type dimension is divided into three categories: generative, transformative, and sequenced. Generative responses denote a system's capability for self-creation autonomously or influenced by external stimuli. Transformative responses encompass algorithmic processing models, including filtering, transposing, and granulation techniques. Sequenced responses involve the playback of pre-established musical instructions.

Performative Affordances:

- **Overview:** This dimension classifies the IMS based on the quantity and quality of participating agents.
- **Types:** The performative affordances dimension is segmented into four categories: human performer, audience, computational system agents, and configurations involving multiple agents. This dimension does not delve into the intricate algorithms or processes but focuses on the number and roles of agents interacting with the IMS. For instance, when non-expert performers, primarily from the audience, partake as agents in the IMS, they are designated as AUD (audiences).

5.5 Summary

“Acting Emotions 1” aimed to explore how physiological signals correlate with actors’ emotions during performances, evaluating sensor efficacy. “Acting Emotions 2” investigates actors’ interaction with sounds generated from their physiological data and how this impacts emotional expression by turning actors’ physiological responses into sound events and exploring real-time processing to synchronize auditory feedback with live performances. Through diverse mapping techniques, the aim is to foster emotional expression in acting. These experiments deepen understanding of the relationship between physiological responses and emotional expression in theatre while assessing the utility of physiological sensing technology for real-time interaction and emotional modulation.

A customized BITalino was developed in collaboration with its developers to meet research needs. The device needed seamless integration into stage environments, demanding compactness, robustness, incorporation of movement sensors, and Wi-Fi connectivity. In stage settings, unobtrusive tools are crucial to avoid hindering movement or drawing focus from the audience, preserving the essence of performances. This customized version addressed these requirements, ensuring suitability for stage use while facilitating physiological data collection during theatrical performances.

A software suite called Biosignal Processing Toolbox (BarT) was developed for the research. Engineered to perform various functions like data collection, recording, feature extraction, mapping, and real-time auditory representation of physiological signals, BarT emphasized proficiency in real-time environments. BarT was pivotal in implementing the experimental framework within theatrical settings, enabling dynamic interaction between actors’ physiological responses and auditory feedback.

Finally, a taxonomy was proposed for physiological signals within the framework of IMS developed for this study. The groundwork for this taxonomy drew inspiration from digital games and human-computer interaction studies. Following the establishment of the initial taxonomy, a second taxonomy was developed to categorize physiologically-driven IMS. The functional classification is subdivided into several dimensions to elucidate physiological signals from both HCI and

signal-processing perspectives. The empirical classification utilized in this study was designed to elucidate the potential expressivity of interactions within a musical system, aiding in categorizing IMS according to the compositional sonic architectures' structure.

The forthcoming Chapters 6 and 7 provide an in-depth examination of the experimental protocol, data collection, and analysis, as well as the results and discussions pertaining to each of the two experiments conducted within the scope of the present research.

Chapter 6

Acting Emotions 1: Physiological Correlates of Emotional Expression in Theatre

As highlighted in Chapter 1, theatre actors possess unparalleled expertise in modulating expressive behavior and non-verbal emotional communication, rendering them invaluable subjects for research. The chapter introduces “Acting Emotions I: A Study of Physiological Correlates of Emotional Valence in Theatre,” an experimental framework designed to examine the physiological underpinnings associated with actors’ emotional expression, focusing on valence and arousal. This study puts its emphasis on identifying physiological correlates of valence and arousal among a group of professional theatre actors whose adeptness in modulating expressive behavior and non-verbal emotional expressiveness is highly refined.

“Acting Emotions 1: Physiological Correlates of Emotional Valence and Arousal in Theatre” was designed to address the first research question: (Q1) “How do physiological signals correlate with the emotional states of actors during performances, and what are the variations in these physiological-emotional correlations across different individuals?”

One unique aspect of this study is the emphasis on participant-driven selection of the emotional repertoire, involving eliciting specific emotions. Following each experimental session, participants self-evaluated to determine the emotions they aimed to portray in order to ensure the robustness and validity of our experimental protocol; a comprehensive analysis was conducted, including assessments of inter-rater agreement, trajectories of continuous annotations, and a comparative evaluation of box plots across various emotional categories.

“Acting Emotions I” presents a comprehensive experimental protocol exploring the physiological aspects of emotional valence and arousal in these specialized performers. The experiment’s primary objective was to analyze the physiological concordance of valence and arousal across multiple actors. A key feature of the study was allowing participants to freely choose their emotional set from four categorical emotions and perform self-assessment post-experiment. The experimental protocol was validated through inter-rater agreement analysis, examination of continuous

annotation trajectories, and contrasting box plots for different emotional categories. The findings demonstrated that the participants successfully evoked the intended set of emotions, leading to statistically significant variations in distinct valence and arousal levels.

Emotions originate from various sources, prominently from physiological systems quantifiable through signals like electromyography and electrocardiography. Previous research in emotion recognition has primarily focused on the general population, often neglecting the unique context of theatre actors proficient in conveying acting emotions to their audience. To address this gap, 11 professional actors conducted a study to collect physiological data associated with emotion-driven acting. The objective was to explore the association between physiological signals and the expression of emotions. One of the outcomes of this experiment is the DECEiVeR (**D**atas**E**t **a**cting **E**motions **V**alence **a**rousal) dataset, comprising an extensive array of carefully collated physiological recordings to identify a specific set of five emotions.

Additionally, the experiment involved a preliminary analysis aimed at modeling the recognition of acting emotions from raw and processed temporal and spectral data and assessing the consistency of physiological data over time. The DECEiVeR dataset was designed to enhance the understanding of the complex relationship between physiological signals and emotional expression. It contributed significantly to acting emotion recognition and affective computing by illuminating the extent to which physiological signals could reflect emotions generated from internal stimuli. One final note is that the data collection and analysis were published in the renowned journal *Nature Scientific Data* (Aly et al., 2024).

6.1 The Correlation Between Emotions and Physiology

“Acting Emotions I” delved into the design and implementation of an IMS driven by physiological signals. By harnessing the nuanced emotional states of actors, the IMS aims to dynamically align and modulate design elements such as sound, thereby creating a more interactive stage environment. Furthermore, to ensure the robustness and reliability of this integration, this study comprehensively evaluates the performance of the employed sensors across various emotional categories. The overarching goal was to develop a theatrical experience that was more interactive and emotionally resonant for both performers and audiences. The main motivation of “Acting Emotions I” is to understand to which extent theatre actors can elicit an expected emotional set recurring only to mental imagery and if this proficiency is expressed in physiological signals.

A two-fold experiment was devised to validate the underlying hypothesis, comprising two distinct phases separated by a fifteen-day interval. This comprehensive experiment involved 11 professional theatre actors. It aimed to explore the physiological underpinnings associated with emotional valence and arousal (VA) dynamics during acting. Emotions were conceptualized as continuous numerical entities, with ‘valence’ quantifying the spectrum from positive to negative emotions and ‘arousal’ measuring the continuum from high to low, as depicted in Figure 6.1.

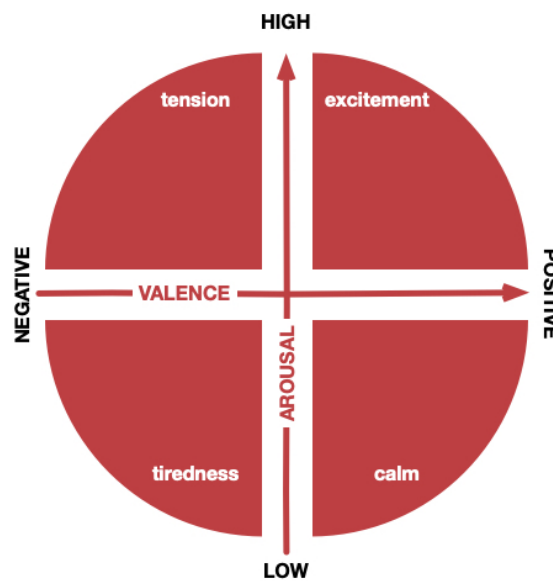


Figure 6.1: Drawing from this conceptual framework, we demarcated our emotional spectrum into a structured *set* comprising four cardinal emotions, each anchoring the extremities of the VA quadrants: High Valence & Low Arousal (HVLA); Low Valence & Low Arousal (LVLA); Low Valence & High Arousal (LVHA); and High Valence & High Arousal (HVHA). During the initial phase, participants were tasked with manifesting these four emotions under two distinct scenarios: a state of rest and a physically active state. Throughout this experiment, we meticulously captured data from fEMG, ECG, EDA, PZT, and motion metrics using an integrated IMU.

In the subsequent phase of the experimental procedure, participants viewed a playback video of their performance. They were then instructed to interact with a touch-sensitive application interface for each distinct emotion within the predefined emotional set, mirroring the two-dimensional VA space depicted in Figure 6.1. Their primary task was to trace and replicate the emotional trajectory they had intended during their performance. This introspective self-reporting mechanism aimed to provide insights into each actor's genuine intentions while acting a specific emotion. Furthermore, this self-assessment offered a deeper understanding of the actor's emotional journey and served as a crucial validation instrument, ensuring the appropriateness and relevance of the chosen emotional set for the study.

The primary significance of the study lies in formulating an experimental protocol for evaluating acting emotions within a predetermined emotional framework. Stemming from this experiment, a hardware-software ecosystem was designed to process physiological data and facilitate interactive annotations. A crucial outcome is creating a unique database capturing the nuances of acting emotions exhibited by theatre actors. Spanning nearly 14 hours of uninterrupted physiological recordings, this repository offers a rich resource of emotional dynamics and actor responses. It is a useful resource for subsequent inquiries in psychology and human physiology. It fosters advancements in the interdisciplinary fields of human-computer interaction and digital arts. The study paves the way for a deeper understanding of the human emotional spectrum within the theatre by bridging the gap between tangible physiological manifestations and the intangible realm

of emotions.

6.1.1 Participants

Eleven Portuguese professional actors (five females and six males, mean age = 36, standard deviation = 10.82 years) were recruited for this study on the physiological correlates of emotion expression in theatre. The recruitment process involved an open call disseminated through direct contact, targeting professional theatre companies and schools. All participants reported no history of neurological or psychiatric conditions. Informed consent was obtained digitally from all participants, who were briefed on the study objectives, data collection procedures, and confidentiality measures. The study adhered to the ethical guidelines set forth by the ethical rulebook of the University of Porto. No financial compensation was offered, and there were no instances of participant dropout. It is important to note that the study focuses on a specialized population segment, particularly within the context of the Portuguese acting profession. In Portugal, the acting profession is relatively rare, so a sample size of 11 participants reflects this specialized group. The study offers valuable insights specific to this context, contributing to the broader understanding of emotional expression in professional acting. The participants vary in age, and the study maintains a gender balance, adding diversity. While acknowledging limitations in broader generalizability, the findings are significant for understanding emotional elicitation in this specific professional group.

The study received retrospective approval from the Data Protection Officer of The University of Porto, Portugal, under approval number 11094042/2023. The Officer evaluated and concluded that the risks to the rights and freedoms of participants contributing to this dataset were very low. This assessment was based on several factors: participants voluntarily engaged in the study after making an informed decision, and the data is considered anonymous when considering reasonable means (human, technological, temporal and financial) that could potentially be used for personal identification. The dataset comprises exclusively physiological signal data, each linked to individual participants through unique identification numbers assigned for the study. These numbers are not connected to the participants' identities, ensuring the data's anonymity.

Informed consent for data sharing and participation was obtained from all participants. They received detailed information about the study's objectives, the methods used for data collection, and the measures taken to maintain confidentiality. Every participant was fully apprised of the nature of the research and how the collected data would be used, ensuring their participation was informed and voluntary. The study did not offer any financial incentives for participation.

6.1.2 Experiment Design

The study utilizes a framework for understanding emotional responses as explained in Section 4.1.3. Embracing a multi-dimensional perspective, emotional responses are depicted as dimensions rather than discrete states. The focus on emotion recognition is anchored in physiological

patterns, a methodology endorsed by current major theories that consider physiological responses integral to the emotional experience Coppin and Sander (2021).

Emotions in this study are quantified as continuous numerical values within a multi-dimensional space, following the circumplex model proposed by Russell Russell (1980). Specifically, the valence-arousal (VA) circumplex model, as depicted in Figure 6.1, arranges emotions along two orthogonal axes: valence and arousal. Valence measures the degree of positivity or negativity of the emotional state, while arousal quantifies the level of excitement or calmness. To operationalize these dimensions, the study defines four distinct emotional states located at the extremes of each quadrant: High Valence & Low Arousal (HVLA), Low Valence & Low Arousal (LVLA), Low Valence & High Arousal (LVHA), and High Valence & High Arousal (HVHA). A neutral emotional state is also included at the center of the VA space for comparative purposes. This methodological approach allows for a nuanced capture of emotional states by integrating both experiential and physiological dimensions, thereby offering a more comprehensive understanding than models that treat these aspects as separate or discrete.

6.1.3 Experimental Protocol

In preparation for the experiment, participants were instructed two weeks beforehand to engage in mental imagery exercises intended to evoke the five target emotions and a neutral state. This method contrasts with conventional approaches that often utilize emotionally charged content like images or videos to induce specific emotional states. Instead, the study adopted a participant-centric method, allowing individuals to utilize their cognitive abilities to elicit emotions. Various stimuli were suggested for these exercises, including film scenes, theatrical settings, personal memories, or other relevant events. This methodological choice aimed to facilitate a more authentic and personalized emotional experience by enabling participants to select scenarios they believed most effectively elicit each emotion, thus enhancing the ecological validity of the study.

Upon arrival on the day of the experiment, participants received oral instructions regarding the study procedures. The experiment occurred in a meticulously arranged theatre stage equipped with a black-box setup to regulate external light and sound interferences, ensuring an isolated and controlled environment. This venue selection was intentional, aiming to provide a familiar and professionally relevant space for the participants, all of whom were professional actors. The black-box theatre stage enabled precise control over lighting conditions, as depicted in Figures 6.2a and 6.2b. To emulate a theatrical environment and align with the study's focus on professional actors, lighting intensity was adjusted to specific levels, creating various moods and atmospheres conducive to emotional expression, as detailed in Figure 6.2. These choices were not merely aesthetic; they were integral to the study's methodology, enhancing participants' emotional engagement and performance and thus ensuring the validity and reliability of the collected physiological data. Physiological sensors were then affixed to specific locations on the participants' bodies, and each participant was comfortably seated on a chair strategically placed at the center of the stage-like setting.

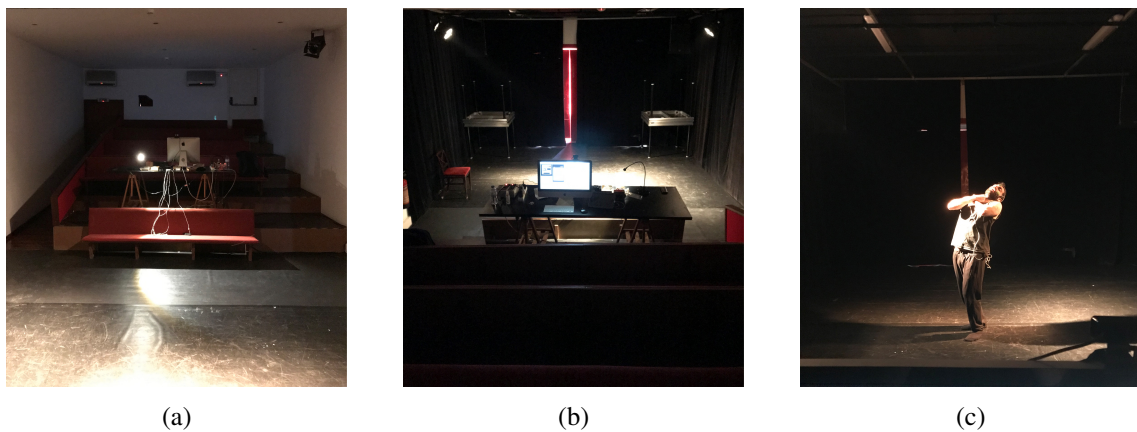


Figure 6.2: Overview of the Experimental Scenario: Panel (a) presents a stage perspective, detailing the spatial arrangement used for the experiment, along with the configuration of the biosignal acquisition system. Panel (b) provides an audience viewpoint, depicting the stage under meticulously controlled lighting conditions to facilitate emotional expression. Panel (c) offers an experimenter's perspective, capturing a participant in the act of eliciting one of the targeted emotional states on the stage.

A comprehensive explanation of the experimental protocol followed, detailing the sequence in which emotions would be performed, the time allocated for each emotion, and the intermission periods. The choice of time allocated for each emotional expression and the intermission periods was informed by existing literature, ensuring that the durations were scientifically rigorous and conducive to authentic emotional expression. This time, structuring aimed to balance the need for sufficient data collection with the participants' comfort and natural emotional trajectory. The concept of an emotional trajectory was fundamental, allowing participants to transition more comfortably between different emotional states. This assumption was based on the premise that emotions are not isolated experiences but are often part of a broader emotional landscape that individuals navigate. By allowing time for participants to return to a neutral emotional state during intermission periods, the study aimed to capture this natural emotional flow, thereby enhancing the ecological validity of the research. To ensure uniformity across the experiment, the name of the emotion to be performed was announced before each segment. The sequence of emotions remained consistent across all experimental sessions, with the total duration of the experiment estimated at approximately 40 minutes.

After the experiment concluded, the physiological sensors were meticulously detached from the participants to ensure their comfort and to preserve the integrity of the collected data. Following this, a feedback session was initiated, employing a specialized touch-responsive application designed to gather participants' subjective assessments. Within this digital interface, participants could recreate their emotional trajectory using a two-dimensional VA representation. This interactive feature was not merely a data collection tool but also a medium for participants to articulate their emotional experiences. By enabling them to adjust the positioning of points within the VA space, the application allowed for a nuanced expression of their perceived emotional states. The

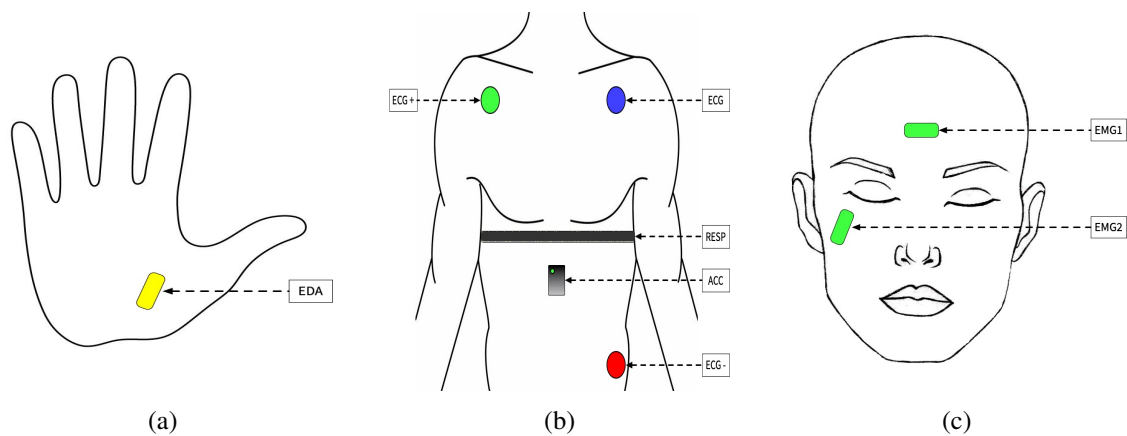


Figure 6.3: Sensor Placement Strategy Employed in the Study: Panel (a) illustrates the positioning of the EDA sensor on the non-dominant hand. Panel (b) identifies the locations for the ECG sensor in a Lead II configuration, the PZT sensor on the thorax, and a three-axis digital accelerometer sensor. Panel (c) details the placement of two EMG sensors: EMG 1 on the *corrugator supercilii* and EMG 2 on the *zygomaticus major*.

primary aim of this feedback mechanism was to obtain qualitative insights that could complement the physiological data, thereby providing a more comprehensive understanding of the emotional experiences under study. This approach was intended to evaluate the efficacy of the research methodology from the participants' perspective, adding another layer of validation to the study's findings. In addition to utilizing the touch-responsive application, participants were encouraged to share any further observations or insights. This open-ended component of the feedback session aimed to capture any nuances or specific experiences that might not be fully encapsulated by the VA representation, thereby enriching the dataset.

6.1.4 Data Collecting and Assessment

Data recording for the study utilized a BITalino Plugged kit alongside an R-IoT device. Please refer to Section 5.2 for hardware specifications. The R-IoT device enabled WiFi connectivity, facilitating seamless communication between the BITalino board and the data collection computer via UDP. Configured to stream OSC packets when connected to the UART of a BITalino (r)evolution device, the R-IoT transmitted all exported data, including IMU and BITalino readings. To safeguard the hardware components, the BITalino (r)evolution Plugged kit was enclosed in a custom 3D-printed case (see Figure 6.4a).

For data acquisition and management, custom software (for detailed software architecture, please refer to Section 5.3) was developed using the MaxMSP programming environment, as illustrated in Figure 6.4b. This software provided various functionalities, including listening to the UDP port connected to the BITalino hardware, parsing incoming data, real-time visualization of physiological signals, and formatting data for subsequent analysis (refer to Figure 6.4c). The software logged data in two formats: raw and resampled. In the raw format, data was logged at the board's native sample rate of 100 Hz, while the resampled format maintained a constant rate of

500 Hz or two milliseconds per sample. This resampling, aimed at generating high-resolution interpolated data, catered to potential future analyses. Both raw and resampled data were automatically saved in uniquely identified files corresponding to each recording session. Additionally, the software facilitated synchronized video and audio recording, enabling multi-modal analysis for future research.

The hardware setup for data recording comprised an Apple iMac with a 2.5 GHz Intel Core i5 processor, 20 GB DDR3 RAM, and a 21.5-inch screen. Video and audio data were captured using the iMac's built-in HD camera and microphone, ensuring consistent and high-quality multimedia recordings.

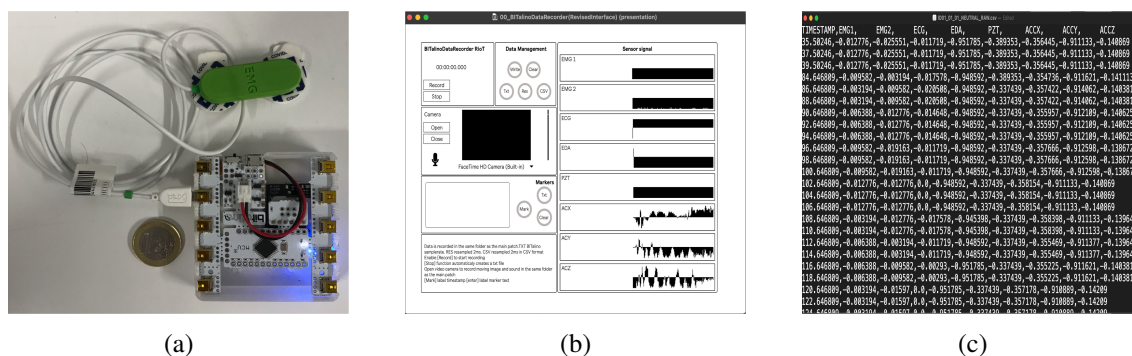


Figure 6.4: Overview of Experimental Instruments and Data Management: Panel (a) illustrates the strategic placement of various sensors on participants' bodies, connected to an (r)evolution Plugged kit board and a BITalino R-IoT device for WiFi connectivity. For durability and theatrical performance compatibility, the hardware components were housed in a 3D-printed enclosure, also shown in the image. A 1 euro coin is included for size comparison. Panel (b) features the custom-developed software interface used for data acquisition and analysis, capable of listening to the UDP port, parsing physiological signals, visualizing real-time data, and saving in both raw and resampled formats. Panel (c) details the data storage strategy, where sensor data is saved in a CSV file. Each participant and emotion is assigned a unique identifier, and the file is structured in columns to include timestamp, EMG1, EMG2, ECG, EDA, PZT, and three-axis acceleration data x , y , and z .

Following each session's conclusion, participants viewed a video recording of their performance to provide context for subsequent self-report assessments. Using a touch-responsive application, they recreated the emotional trajectory for each emotion within a two-dimensional VA space, as illustrated in Figure 6.1. This self-report assessment served multiple purposes: (i) It aimed to capture subtle nuances within each emotional state that might not be fully represented by physiological data alone; (ii) it sought to examine the separation or distinction between different emotions, providing an additional layer of data to evaluate the effectiveness of the emotional elicitation techniques used in the study, and (iii) this self-assessment was designed to identify any discrepancies between the emotions participants aimed to elicit and the emotions they experienced, thereby offering insights into the efficacy of the mental imagery techniques employed.

In addition to the VA space mapping, participants were asked to provide a brief textual description of the mental imagery they used to evoke each specific emotion. This qualitative data

enriched the study's dataset by offering context to the numerical and physiological data, potentially revealing patterns or commonalities in the imagery techniques that were most effective in eliciting specific emotional states.

"Acting Emotions 1" study provides a comprehensive exploration of the physiological correlates of emotional expression in theatre. The study sheds light on the dynamics of emotional valence and arousal during acting through meticulous experimental design, bespoke data acquisition software, and a controlled theatre environment. A significant contribution is the creation of a unique database containing nearly 14 hours of uninterrupted physiological recordings from professional actors, serving as a foundational resource for future research. Additionally, the study integrates experiential and physiological dimensions of emotions, offering a nuanced understanding. By employing a participant-centric approach that leverages mental imagery to elicit emotions, the research enhances ecological validity and lays the groundwork for further exploration of the interplay between physiological manifestations and emotional experiences in theatre.

6.2 DECEiVeR: Dataset Acting Emotions Valence Arousal

To facilitate diverse analytical approaches and ensure comprehensive data accessibility, the primary dataset, DECEiVeR (**D**atas**E**t **a**Cting **E**motions **V**alence **a**Rousal), is meticulously organized into five principal folders. The DECEiVeR is publicly accessible via the Figshare open access repository. The entire dataset is consolidated into a single archive file, which can be accessed at <https://doi.org/10.6084/m9.figshare.23579862>. These folders are: DECEiVeRraw, DECEiVeRresampled, DECEiVeRsession, DECEiVeRarousal, and DECEiVeRfeatures. Each of these folders serves a specific purpose:

- DECEiVeRraw: Contains the raw physiological data, logged at the board's native sample rate.
- DECEiVeRresampled: Houses the resampled data, maintained at a constant sample rate for high-resolution analyses.
- DECEiVeRsession: Includes files that pertain to individual experimental sessions, facilitating a session-wise approach to data analysis.
- DECEiVeRarousal: Focuses on data specifically related to the valence and arousal dimensions, allowing for targeted emotional analyses.
- DECEiVeRfeatures: Contains extracted features from the physiological signals, prepared for advanced statistical or machine learning analyses.

To assist further in navigating this extensive dataset, README files are included in each directory. These files provide detailed explanations regarding the data's organization, structure, and the types of files within each folder. Participant identification is standardized across all DECEiVeR

datasets. Each participant is assigned a unique identifier consisting of an "ID" followed by a two-digit number (e.g., ID01, ID02). This consistent naming convention aids in data traceability. For instance, a file named "ID01_01_01_NEUTRAL_RAW.csv" would indicate data from the first participant, collected during their first session while they were acting out the emotion categorized as 'neutral,' and the data is in its raw format. The dataset is depicted in Figure 6.5 and organized as follows:

The [DECEiVeR_Raw] directory serves as the repository for the raw, unprocessed physiological data collected from the 11 participants involved in the study. This data is meticulously organized according to the specific emotion each participant was instructed to enact. The physiological signals were captured at a sampling rate of approximately 100 Hz, resulting in a data volume of approximately 556 megabytes (MB). The directory is further segmented into five sub-folders, each dedicated to one of the five emotions under investigation. Within these emotion-specific folders, individual Comma-Separated Values (CSV) files are stored. These CSV files are structured to include nine distinct variables, each allocated to its own column, as follows:

- Column 1: Represents the time in milliseconds for each data sample acquired. This column serves as the temporal reference for aligning the physiological signals.
- Columns 2-9: Contain the sensor output values that have been transformed to a standardized range of -1 to 1. These columns capture data from various sensors, including EMG1, which measures the corrugator supercilii muscle activity; EMG2, which measures the zygomaticus major muscle activity; ECG, capturing electrocardiogram data; EDA, representing electrodermal activity; PZT, capturing piezoelectric transducer data, and three additional columns for the accelerometer data, capturing movement along the X, Y, and Z axes.

The [DECEiVeR_resampled] directory is designated for storing the resampled physiological data collected from the study's 11 participants. This resampled data has been adjusted to a uniform sampling rate of 2 milliseconds per sample, resulting in a total data volume of approximately 1.20 gigabytes (GB). The directory is systematically divided into five sub-folders, each corresponding to one of the five emotions that were the focus of the study. Within these emotion-specific sub-folders, individual Comma-Separated Values (CSV) files are maintained. Each CSV file is structured to include nine distinct variables; each allocated its column for clarity and ease of analysis. The columnar organization is as follows:

- *Column 1*: Captures the time in milliseconds for each resampled data point, with a temporal resolution of approximately seven milliseconds per sample. This column serves as the time reference for the resampled physiological signals.
- *Columns 2-9*: House the sensor output values, which have been transformed to a standardized range of -1 to 1. These columns include data from various physiological sensors, such as: EMG1, associated with the *corrugator supercilii* muscle activity, EMG2, associated with the *zygomaticus major* muscle activity, ECG, representing electrocardiogram readings, EDA, indicating electrodermal activity levels, PZT, capturing data from the piezoelectric

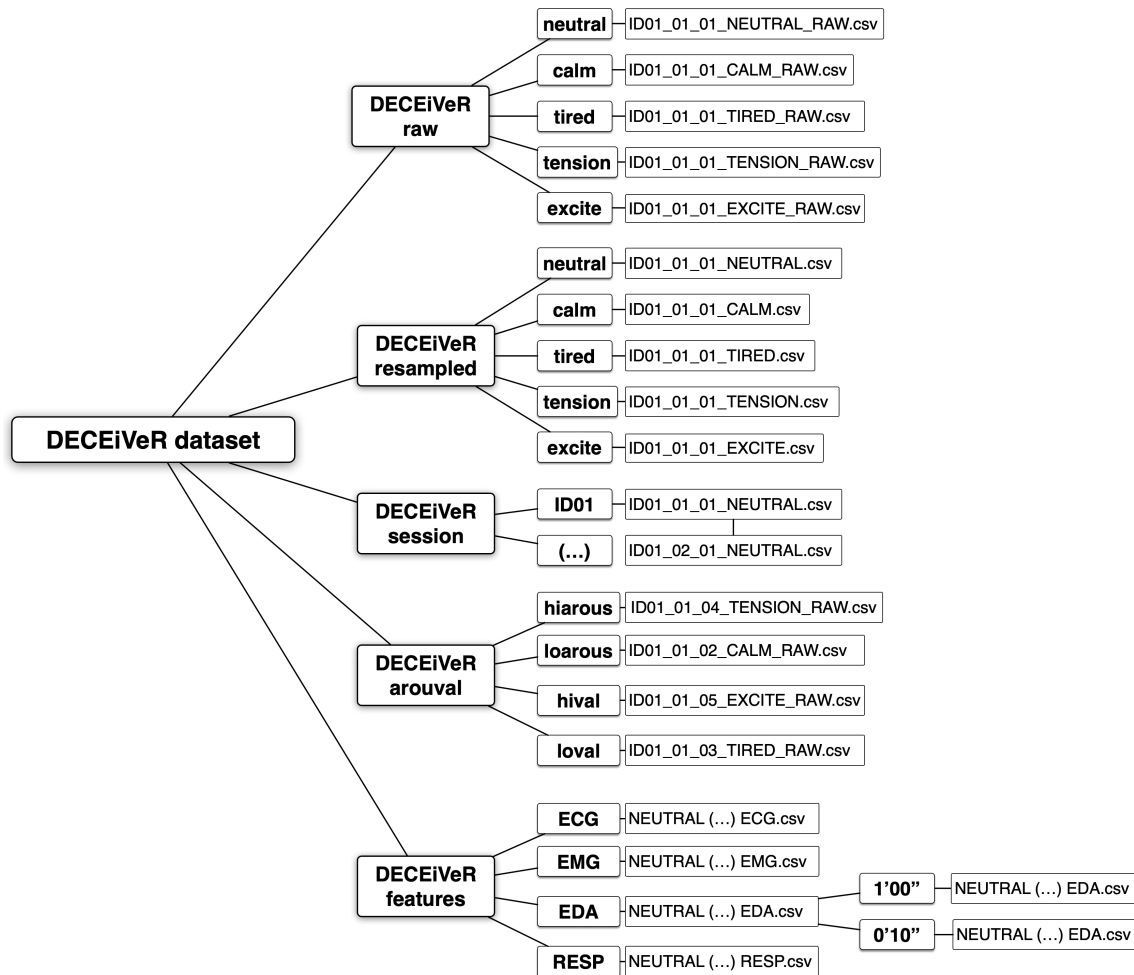


Figure 6.5: Tree diagram depicting the hierarchical organization of the DECEiVeR dataset. The root directory, labeled as [DECEiVeR dataset], encompasses five primary sub-directories: [DECEiVeR raw], [DECEiVeR resampled], [DECEiVeR session], [DECEiVeR arousal], and [DECEiVeR features]. Within [DECEiVeR raw] and [DECEiVeR resampled], five sub-directories are dedicated to different emotional states. Each of these emotional sub-directories contains individual files for each participant across both sessions. The [DECEiVeR session] directory is further divided into participant-specific sub-directories, each containing individual session files. The [DECEiVeR arousal] directory is organized based on emotional quadrants, specifically capturing high and low dimensions of arousal and valence. Individual participant files are included within these quadrant-specific sub-directories. Finally, the [DECEiVeR features] directory is segmented into sensor-specific sub-directories, each containing files categorized by emotion. Notably, the [EDA] sub-directory within [DECEiVeR features] diverges slightly by including two additional sub-directories: one representing a ten-second analysis window and another for a one-minute window, thereby accommodating different analysis approaches.

transducer, and three additional columns for accelerometer data, capturing motion along the X, Y, and Z axes

The [DECEiVeR_Session] directory is designed to house the resampled physiological data, segmented according to the two distinct sessions in which the data was collected from the 11 participants. This archive, comprising a total data volume of approximately 1.20 gigabytes (GB), is meticulously organized to facilitate session-specific analyses. Within the [DECEiVeR_Session] directory, 11 separate sub-folders are present, each uniquely corresponding to one of the study's participants. Inside these participant-specific folders, individual Comma-Separated Values (CSV) files are stored. These files are structured to include nine distinct variables, each allocated to its column, thereby aiding in the efficient analysis and interpretation of the data. The columnar arrangement is detailed as follows:

- *Column 1*: Records the time in milliseconds for each data point, sampled at a rate of 500Hz. This column serves as a temporal anchor, providing a uniform time reference for all the resampled physiological signals.
- *Columns 2-9*: House the standardized sensor output values, which have been transformed to fall within a range of -1 to 1. These columns include data from a variety of physiological sensors, such as EMG1, associated with the *corrugator supercilii* muscle activity, EMG2, associated with the *zygomaticus major* muscle activity, ECG, representing electrocardiogram readings, EDA, indicating electrodermal activity levels, PZT, capturing data from the piezoelectric transducer, and a three additional columns for accelerometer data, capturing motion along the X, Y, and Z axes

The directory is meticulously structured to house the resampled physiological data from all 11 participants, organized according to specific emotional dimensions of arousal and valence. This directory is further divided into four distinct sub-folders, each tailored to encapsulate a unique emotional dimension: [DECEiVeR_01_higharous]: This folder contains data logs that are specifically associated with states of high arousal, such as tension and excitement. The [DECEiVeR_02_lowarous] folder is dedicated to data logs that capture low arousal states, including calmness and fatigue. The [DECEiVeR_03_posvalence] folder houses data logs related to positive valence states, such as calmness and excitement. The [DECEiVeR_04_negvalence] folder contains data logs that are indicative of negative valence states, including fatigue and tension.

Each sub-folder contains individual Comma-Separated Values (CSV) files, structured to include nine distinct variables. Each variable is allocated its column, facilitating a streamlined and efficient data analysis process. The columnar organization within these files is as follows:

- *Column 1*: Captures the time in milliseconds for each sampled data point, with a sampling rate of 500Hz. This provides a consistent temporal framework for all the resampled data.
- *Columns 2-9*: House the transformed sensor output values, standardized to fall within a range of 0 to 1. These columns include data from various physiological sensors, such as

EMG1, associated with the *corrugator supercilii* muscle; EMG2, associated with the *zygomaticus major* muscle; ECG, representing electrocardiogram readings; EDA, indicating electrodermal activity, PZT, capturing piezoelectric transducer data, and three additional columns for accelerometer data, capturing motion along the X, Y, and Z axes

6.3 Protocol Validation

For protocol validation, measurements were obtained by analyzing self-reports (Aly et al., 2022). Notably, the emotional elicitation in this study was participant-driven, occurring without the influence of any external stimuli. Following the methodology outlined by (Xue et al., 2021), continuous annotation trajectories were registered, as depicted in Figure 6.6. These self-reports align well with each category's intended emotions, confirming the efficacy of the participant-driven approach. For instance, the emotion category of Calm falls within the High Valence, Low Arousal quadrant, while Tiredness aligns with Low Valence, Low Arousal. Similarly, Tension corresponds to Low Valence, High Arousal, and Excitement to High Valence, and High Arousal.

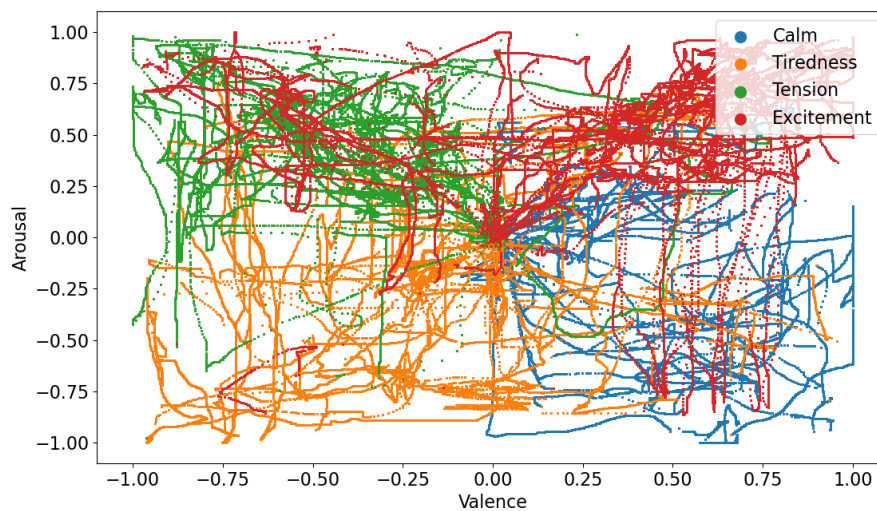


Figure 6.6: Trajectories of the continuous self-reports.

The self-reports for each emotion exhibit considerable variability but remain within the expected quadrant, as evidenced by Figure 6.6 and the boxplots in Figures 6.7 and 6.8. This suggests that participants successfully induced the expected degrees of valence and arousal for each emotion. However, outliers were observed across categories. For example, in the category of Excitement, notable variability was observed, extending to both low and high valence as well as low and high arousal.

To evaluate the reliability of the self-reports, the study employed the analysis of the inter-rater agreement, a well-established method in emotion recognition literature (Yannakakis and Martínez, 2015; Melhart et al., 2019). Following the methodologies outlined by (Yannakakis and Martínez,

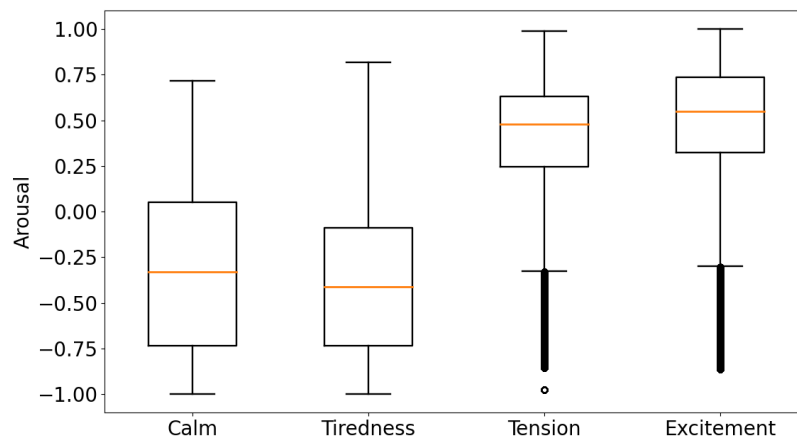


Figure 6.7: Arousal self-reports.

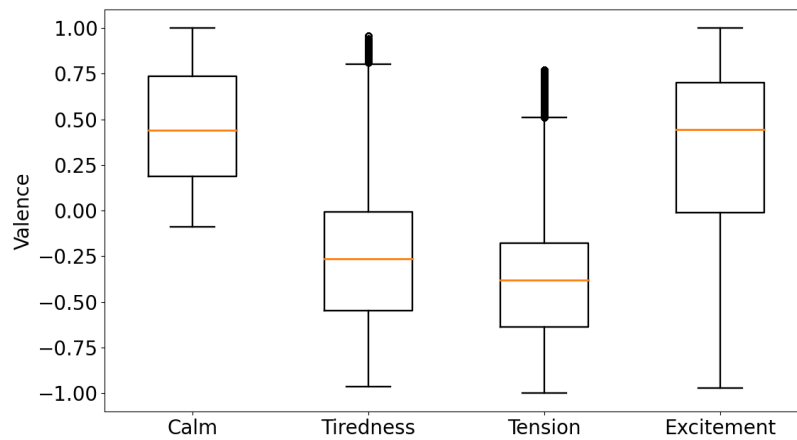


Figure 6.8: Valence self-reports.

Table 6.1: Inter-rater agreement among the annotations for the same emotion type with a time window of 5 seconds. Scale $\in [0, 1]$, for random and total correlation.

	Calm	Tiredness	Tension	Excitement
Valence	0.073	0.022	-0.008	0.031
Arousal	-0.046	-0.007	0.252	0.277

2015; Melhart et al., 2019), Krippendorff's α was calculated for the data. This calculation used the average value of valence and arousal annotations in consecutive 3/5-second time windows. The results of this calculation are available in Table 6.1. A key observation from the data is the higher level of agreement among participants for the categories of Tension and Excitement, specifically in terms of arousal. This finding aligns well with the existing literature. For instance, in (Melhart et al., 2019), Krippendorff's α ranges from negative values to approximately 0.3 in correlation. In (Yannakakis and Martínez, 2015), the range is between 0.15 for arousal and 0.41 for valence.

Thus, the results of this study fall within the expected range set by the state-of-the-art methodologies (Melhart et al., 2019; Yannakakis and Martínez, 2015). It is worth noting that some of the lower values in Krippendorff's α can be attributed to the unique nature of the videos rated by the participants. Even though the emotion categories, such as High Valence, Low Arousal, remain constant, the videos may contain moments of higher valence at different time windows. This variability could contribute to the lower agreement rates observed in specific categories. Overall, the study's approach to assessing reliability through inter-rater agreement and calculating Krippendorff's α provides a robust framework for understanding the nuances in participant responses. This not only validates the reliability of the self-reports but also offers insights into areas where variability exists, thereby enriching the overall analysis.

The results reveal some of the study's premises: actors have specialized skills in controlling their expressive behavior and non-verbal emotional expressiveness. The resulting analysis of the self-reports reveals an agreement when actors are summoned to elicit and act emotions on stage. The majority of the participants reported a consistent trajectory on each emotion. The identified outliers reveal a tendency for the excitement and tiredness emotions to bleed into HVLA and LVHA. We do not know if the outliers result from a deviation of one or more participants or if there are specific emotions that actors feel the need to explore in a more all-around emotional space. However, according to Figure 6.6, tension is the more concentrated emotion, and it seems that actors tend to narrow and focus the emotional space for this specific emotion. On the other hand, emotional calm is accomplished in the expected quadrant but with a more spread distribution inside it.

6.4 Data Analysis and Validation

In addition to the raw log files from the sensor data, a statistical description and feature-based annotation of the biomedical sensor data are provided. Feature extraction is essential in signal processing, reducing data size while preserving relevant information. Higher-level analysis systems, such as emotion classifiers, often rely on this set of features to train their models. For feature extraction, BioSPPy (Milivojević et al., 2017), a Python toolbox for biosignal processing, was utilized. BioSPPy bundles various signal processing and pattern recognition methods to analyze biosignals.

Extracting these features employed a segmentation strategy that used 60-second time windows with 10-second overlaps. This approach, informed by previous research, aims to facilitate

the effective validation of the collected data (Gibson et al., 2010; James and Hesse, 2004). The segmentation into 60-second windows with 10-second overlaps allows for a more granular analysis, enabling extracting the most relevant features from each segment and enhancing the robustness and reliability of any subsequent analyses.

Within each of these 60-second time windows, a comprehensive set of 11 descriptive statistics undergoes calculation. These statistics, which include metrics like minimum and maximum values, mean, difference, variance, root-mean-squared (RMS), standard deviation (SD), root-mean-squared standard deviation (RMSSD), kurtosis, skewness, and interquartile range (IQR), provide a thorough understanding of the data's distribution and variability. A detailed presentation of these statistical descriptors is available in Table 6.2.

Table 6.2: Synopsis of the 19 Statistical Descriptors Categorized into Temporal and Spectral Domains

Domain	Statistical descriptors
Temporal	Minimum and maximum value, mean, difference, variance, root-mean-squared (RMS), standard deviation (SD), root-mean-squared standard deviation (RMSSD), kurtosis, skewness and interquartile range (IQR).
Spectral	Total energy, spectral centroid, spectral skewness, spectral kurtosis, spectral slope, spectral decrease, spectral roll-off, spectral variation.

Table 6.4: Summary of Sensors Employed in the Study and the Fourteen Features Extracted from the Corresponding Signals.

Sensor	Extracted features
ECG	Heart rate is the number of heartbeats per minute (HR min and HRmax). The period between successive heartbeats (IBI). Interbeat intervals from which artifacts have been removed (NNi). Standard deviation (SD) of NN intervals (SDNN). Filtered data to remove noise (RR). Intervals that differ by more than 50ms (RRi). The standard deviation of the average NN intervals for each 5 min segment (SDANN). Percentage of successive RR intervals that differ by more than 50 ms (pNN50). The number of adjacent NN intervals that differ from each other by more than 50 ms (NN50). The integral of the density of the RR interval histogram is divided by its height (TRindex).
EDA	Tonic level of electrical conductivity of skin (SCL). Phasic change in electrical conductivity of skin (SCR). Phasic rate, rise, and half-recovery.
EMG zygomaticus	Statistical, temporal and spectral features (see Table6.2).
EMG corrugator	Statistical, temporal and spectral features (see Table6.2).
PZT	Statistical, temporal, and spectral features (see Table6.2). Respiration rate. The interval of respiration peaks.

In addition to these statistical descriptors, the extraction process includes spectral features. A

total of ten spectral descriptors—total energy, spectral centroid, spectral skewness, spectral kurtosis, spectral slope, spectral decrease, spectral roll-off, and spectral variation—undergo extraction. These spectral descriptors offer valuable insights into the frequency domain characteristics of the physiological signals and are instrumental in understanding the nuances of emotional valence and arousal. Table 6.4 presents a comprehensive list of these spectral descriptors organized by the type of sensor used for data collection.

The study undertook a preliminary analysis to address three critical questions: the capability of *raw* physiological data to capture and recognize the emotions under scrutiny, the effectiveness of *feature-based* physiological data in distinguishing the emotions under examination, and the temporal stability of physiological measurements across two spaced sessions. The data for the first two inquiries aimed to identify the sensor that provides the highest differentiation of emotions, considering both raw and feature-based data. The final evaluation focused on the variability of physiological responses across the two sessions for each participant and emotion, shedding light on topics related to calibration and reproducibility. The overarching goal of these analyses was to explore the potential of physiological data in revealing internally elicited emotions, offering valuable insights for developing robust models for emotion understanding and recognition.

In order to address the first question, the study concentrated on identifying significant statistical differences in the raw signal data across different emotional pairs, following methodologies outlined in previous research (Krishnan and Athavale, 2018). In the study, the t-test, a statistical method extensively utilized for comparing the means of two distinct groups, played a crucial role. The primary objective of the t-test was to discern whether the physiological responses associated with various emotional states exhibited significant mean differences. By applying the t-test to the raw sensor data, the study aimed to compare the physiological responses across pairs of emotions, scrutinizing the data for any statistically significant disparities. The t-test culminates in a p-value, a statistical metric ranging from 0 to 1. Researchers typically set threshold values to determine significance levels, with $p \leq 0.001$, $p \leq 0.01$, and $p \leq 0.05$ representing high, moderate, and low significance, respectively (Fisher, 1970). A lower p-value indicates a stronger contradiction of the null hypothesis, which posits that there is no significant difference between the groups under comparison. In the context of this study, the null hypothesis would imply that there is no significant difference in the physiological responses between the different pairs of emotions. The study established specific thresholds to interpret the p-values and determine the level of statistical significance. A p-value less than or equal to 0.001 was considered highly significant, suggesting strong evidence against the null hypothesis. A p-value less than or equal to 0.01 but greater than 0.001 indicated moderate significance, while a p-value less than or equal to 0.05 but greater than 0.01 shows a lower yet still notable significance level. To facilitate a quick and intuitive understanding of the results, the study employed a color-coding scheme in Figure 6.9. In this visual representation, green highlighted areas where the differences in physiological responses between emotional pairs were highly significant, yellow indicated moderate significance, and red marked areas of lower significance. Through this meticulous application of the t-test and the subsequent interpretation of the results, the study aimed to validate the physiological data's capability in capturing



Figure 6.9: Significance levels derived from t-tests conducted on the raw physiological data across different emotions, employing a color-coded scheme to distinguish between low (red), moderate (yellow), and high (green) significance. In the series of sub-figures, **(b)** and **(b)** pertain to the results from both EMG sensors, **(c)** showcases the findings from the ECG sensor, **(d)** represents the EDA sensor's outcomes, and **(e)** illustrates the PZT sensor's results. The final sub-figure, **(f)**, consolidates the t-test analysis results for an individual sensor, categorizing them according to the arousal and valence dimensions. Together, these visual representations elucidate the statistical significance of the t-test results, shedding light on the intricate relationships between the sensors' data and the emotions under investigation in the study.

and distinguishing the nuanced differences in emotional responses, laying a solid foundation for future explorations in emotion recognition and analysis.

The analysis of the results reveals a distinction in performance across the various sensors in differentiating the five emotional states under investigation. Specifically, the EMG2 and PZT sensors are superior in distinguishing between all five emotions. It is crucial to highlight the significant influence that the placement of the EMG sensor has on the effectiveness of recognizing acting emotions. The EMG1 sensor, strategically positioned to monitor the zygomaticus muscle activity, demonstrates less satisfactory performance in differentiating the five emotions under study when compared to its counterpart, EMG2. On the other hand, the PZT sensor showcases good performance, capturing variances across both the valence and arousal dimensions effectively. In contrast, the EMG2 and ECG sensors show enhanced differentiation for arousal or valence, respectively. The EMG2 sensor had an excellent performance in differentiating emotions based on

arousal, whereas the ECG sensor distinguishes emotions based on valence. This divergence in performance underscores the unique strengths of each sensor, highlighting their potential contributions to the comprehensive understanding of emotional states in the context of acting emotions. The findings from this analysis served as a valuable resource, guiding sensor placement and selection to optimize emotion recognition and analysis based on physiological recordings in a theatre context.

To investigate the ability of feature-based physiological data to capture and differentiate the various emotions under study, an assessment was conducted to determine the most effective features from Tables 6.2 and 6.4 in distinguishing the four emotions. This involved analyzing the density and peaks in the data, with the results visualized through violin plots in Figure 6.10. Violin plots serve as a powerful tool for data visualization, combining aspects of box plots and kernel density plots to provide a comprehensive view of the distribution of a dataset. The primary purpose of a violin plot is to depict the distribution of data across different categories, highlighting the probability density of the data at different values. This allows for a clear and concise visual representation of the data's distribution, making it easier to identify patterns, trends, and potential outliers. The central feature of a violin plot is its symmetrical, elongated shape, which represents the distribution of the data. The width of the plot at different points corresponds to the density of the data at those values, with more comprehensive sections indicating higher density and narrower sections indicating lower density, providing a visual cue as to where the data are concentrated, helping to identify modes in the distribution. Violin plots are particularly useful when comparing data distribution across categories or groups. By placing multiple violin plots side by side, one can easily compare the distributions, identify differences and similarities between groups, and draw inferences about the underlying data. In the context of the study on emotion recognition using physiological signals, violin plots were employed to showcase the distributions of features extracted from various physiological sensors, as highlighted in the previous discussion on feature-based physiological data analysis. The plots, as presented in Figure 6.10, provide a visual representation of how different features behave across various emotional states, offering insights into which features and sensors contribute most significantly to emotion differentiation.

The preliminary analyses, encompassing various features, yielded mixed results. Most features did not exhibit a clear distinction between the emotions, making it challenging to discern specific patterns in the data for most of the sensors. However, an exception was noted in the case of the PZT sensor. Three features extracted from this particular sensor demonstrated a superior performance, showcasing a more pronounced differentiation across the four emotions. In contrast, the selected features from the ECG sensor managed to display a subtle distinction between the emotions, albeit not as prominently as the PZT sensor. This slight differentiation, while not as definitive, still contributes valuable insights into the emotional states under study. The results from this investigation underscore the importance of careful feature selection and highlight the potential of specific sensors and features in enhancing the accuracy and effectiveness of emotion recognition systems. The findings suggest further research and refinement in feature extraction and selection processes to better capture and distinguish between complex emotional states.

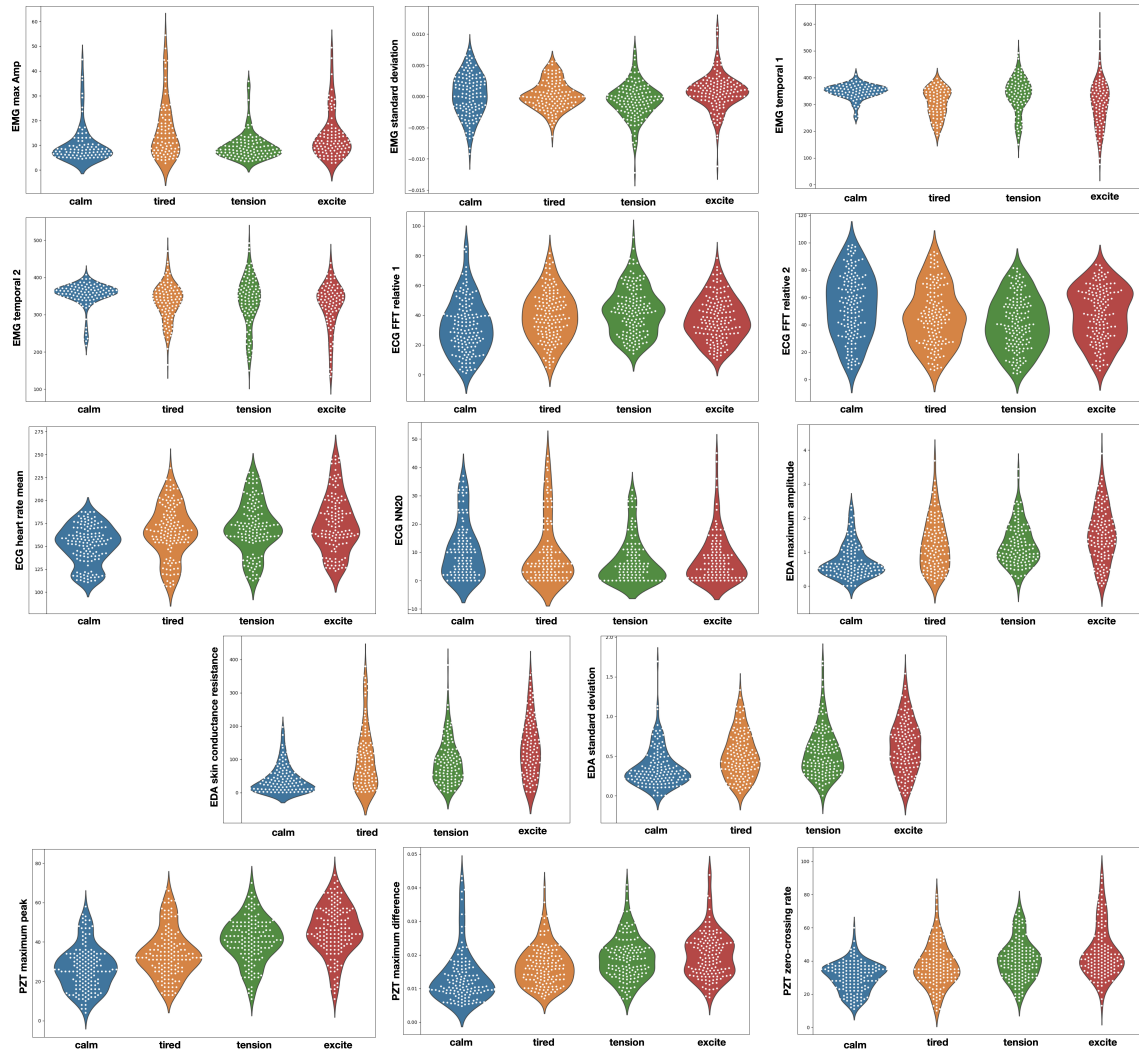


Figure 6.10: General view of the "Violin" plots for the distribution of the values of the selected feature across different types of four emotions. For an in-depth examination of the individual results pertaining to each sensor, readers are directed to the images provided in the Appendix section of the document. These images offer a comprehensive visual representation of the data, allowing for a nuanced understanding of how each sensor performed across different sessions and conditions. The detailed visual aids complement the textual analysis presented in the document's main body, providing a holistic view of the study's findings. By scrutinizing the images in the Appendix, readers can gain valuable insights into the variability and consistency of the measurements obtained from each sensor, further enriching their understanding of the study's outcomes. This additional layer of information is crucial for those seeking to delve deeper into the specifics of the data, ensuring a thorough and well-rounded comprehension of the study's findings.

The findings from the three tests conducted provide valuable insights that require further exploration. Initially, the results underscore the necessity of a calibration phase, which is imperative to fine-tune the analysis to the specific characteristics of the subject under investigation. This step becomes particularly crucial when developing classification models to interpret complex emotional data, ensuring that the models are finely tuned to the nuances of individual responses. Furthermore, the feature selection process from the raw data emerges as a critical component in comprehending the dataset. The dataset's DECEiVeR features folder is proof of this, offering a comprehensive assortment of features meticulously extracted from the raw signal. This repository is a rich resource for conducting more granular and in-depth investigations into the physiological responses associated with emotional states.

On a more subjective note, the research sheds light on the varying expectations associated with different methods of emotion induction. A notable distinction arises when comparing the responses elicited through visual or auditory emotional content to those generated from internal emotional elicitation. In scenarios where participants are highly proficient in expressing emotions, such as theatre actors, the responses tend to deviate from the predictable patterns observed in non-trained populations. These skilled individuals will likely exhibit a broader and more nuanced range of emotional expressions, challenging conventional expectations and highlighting the complexity of emotion recognition in such contexts.

In the final phase of the investigation, the focus shifted to examining the temporal persistence of the measurements across different sessions, with a specific emphasis on evaluating the reliability of the measurements for each participant between sessions. In this context, reliability refers to the consistency and stability of a specific measurement over time, particularly in terms of physiological measures (Lee, 1977). To assess this reliability, the study employed the Intraclass Correlation Coefficient (ICC), a statistical measure used to evaluate the degree of consistency or agreement between different measurements. The ICC is particularly useful when measurements are repeated across different sessions or under varying conditions, making it an apt choice for this study. It provides a value between 0 and 1, where higher values indicate a higher level of agreement or consistency between the measurements, and lower values suggest less reliability.

The use of ICC in this context aimed to quantify the reliability of the physiological measures obtained across different sessions, providing a robust statistical basis for evaluating the temporal persistence of the measurements. By doing so, the study sought to ensure that the physiological data collected were reliable and consistent over time, thereby enhancing the validity of the results obtained. Incorporating the ICC into the evaluation process added a layer of rigor to the study, ensuring that the measurements' reliability was not only assessed qualitatively but also quantified through a well-established statistical measure. This approach helped to bolster the credibility of the physiological measures used in the study, providing a solid foundation for the subsequent analysis and interpretation of the participants' emotional states.

The study aimed to assess the consistency of measurements for four distinct emotions across two sessions involving the same participants and utilizing identical measures. To achieve this, the intraclass correlation coefficient (ICC), specifically a two-way mixed model with an absolute-

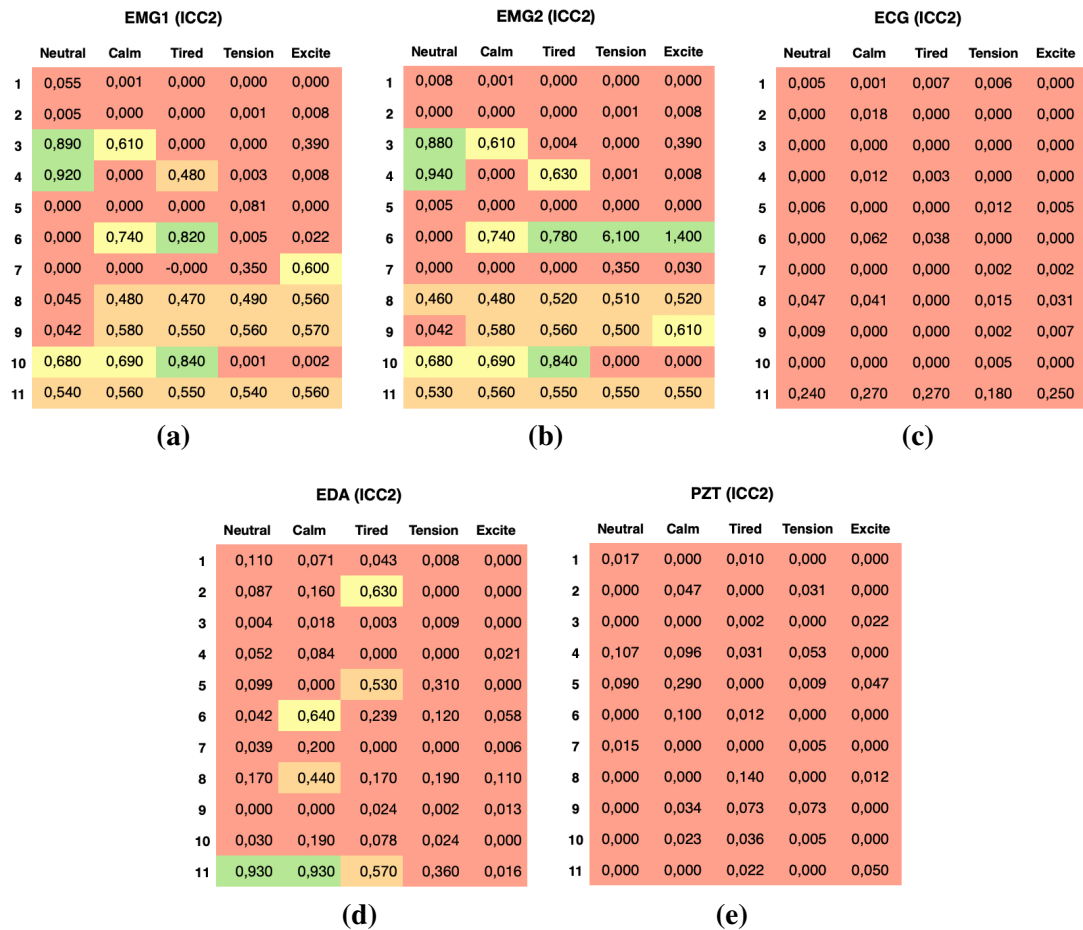


Figure 6.11: Panel (a) and (b) display the ICC reliability measurements for both EMG sensors, indicating the consistency and agreement of the measured muscular activity between sessions. Panel (c) illustrates the ICC reliability measurement for the ECG sensor. Panel (d) represents the ICC reliability measurement for the EDA sensor. Panel (e) showcases the ICC reliability measurement for the PZT sensor. Overall, the ICC reliability measurements provide valuable information about the consistency and stability of the physiological measurements across sessions, highlighting the reliability of the sensors in capturing and measuring specific physiological responses related to emotions.

agreement metric, was employed as outlined by (Fisher, 1970). The ICC, a widely recognized index, varies from 0.0 to 1.0, providing a quantitative measure of reliability (Cicchetti, 2001). The interpretation of ICC values follows specific guidelines, with ICC values ≥ 0.75 indicating "Excellent" reliability, values between 0.60 and 0.75 indicating "Good" reliability, values between 0.40 and 0.60 indicating "Fair" reliability, and values < 0.40 indicating "Poor" reliability.

The results of this reliability assessment are visually represented in Figure 6.11, showcasing the ICC values across all databases. Data analysis reveals that the EMG sensors demonstrated a higher degree of reliability across sessions, with a substantial number of ICC values ≥ 0.75 . This finding suggests a strong consistency in the measurements obtained from these sensors, highlighting their potential for reliable emotion recognition. On the other hand, the performance of the HIGH ICC set, comprising EMG1 and EMG2, was categorized as medium-high, falling within the "Good" reliability range, indicating a high level of consistency in the measurements obtained from these sensors across the two sessions. Conversely, the LOW ICC set, which includes the ECG and PZT sensors, exhibited lower reliability. This discrepancy in performance between the two sets of sensors can be attributed to the nature of the physiological responses they measure. The EMG sensors, which measure muscular movements, are subject to conscious control by the participants, resulting in more consistent and reliable measurements. In contrast, the ECG and PZT sensors, which measure aspects of the autonomic nervous system, are less susceptible to conscious control, leading to more significant variability and lower reliability in their measurements.

In the domain of artistic studies (the application context of our study), the conducted statistical analysis and results offer guidelines that can play a pivotal role in enlightening creatives as they design their theatrical performances. For instance, understanding the best typology of sensors associated with specific emotions (or emotional dimensions) can provide invaluable insights for artists aiming to evoke emotional responses beyond classification. Furthermore, assessing sensor response consistency over time for each emotion is critical. It allows artists to gauge the reliability of their chosen sensor in conveying intended responses. Current evaluation provides valuable directions for art directors to ensure some degree of consistency across multiple performances, thus contributing to the enduring quality of the artistic work.

6.5 Outcomes of Acting Emotions 1

The code used for the experiment is publicly available in the platform and cloud-based service for software development and version control GitHub.

<https://github.com/DECEIVER-dot/BITalino-Toolbox>.

The code for these applications was developed in MaxMSP, with all required packages listed in the requirements.txt file. This repository includes three applications developed in MaxMSP, facilitating direct communication with an IRCAM R-IoT module embedded in a BITalino board. These applications offer diverse functionalities, such as biosignal data recording, Bluetooth connectivity, and interactive annotation while viewing video recordings of experiments. It's important to note

that the software is tailored for the MaxMSP programming environment and relies on external libraries for specific functionalities.

The first application facilitates seamless communication via a USB connection with the IRCAM R-IoT module on the BITalino board. It enables users to record biosignal data directly into a CSV file format, offering two different sample rates. The recorded data is saved in its raw form without normalization or interpolation. However, it's essential to note that the current software version does not include data normalization or interpolation functionalities.

The second application extends the capabilities of the first one by incorporating Bluetooth connectivity as an alternative communication method. Users can connect the IRCAM R-IoT module on the BITalino board and the computer via Bluetooth using this application. It offers the same data recording functionalities as the USB version, but please note that motion data is not recorded with this version of the application.

The third application is developed for interactive annotation while simultaneously viewing video recordings of experiments. Developed within MaxMSP, it requires the installation of external libraries for the Mira interface, which enhances interaction capabilities. Furthermore, this application operates optimally when paired with an iOS device. Researchers or experimenters can utilize this tool to annotate video recordings in real time, ensuring accurate and synchronized annotation of events or observations during experiments.

The code implementation in Python utilized the BioSPPy library, known for its versatility in biosignal processing. BioSPPy offers a wide array of algorithms tailored for processing and analyzing physiological signals, encompassing electrocardiography, electrodermal activity, electromyography, and more. By abstracting complex processing tasks, BioSPPy streamlines the extraction of pertinent information from biosignals, empowering researchers and developers to focus on analysis. It boasts modules for signal processing and feature extraction, including HRV, EDA, and EMG analysis. As an open-source library, BioSPPy facilitates easy installation via Python package managers like pip or conda. Its modular design and intuitive API cater to users of all levels, from novices to seasoned researchers. For comprehensive documentation, code examples, and further details, visit the official BioSPPy GitHub repository at <https://github.com/PIA-Group/BioSPPy>.

The RStudio code, available at <https://posit.co/download/rstudio-desktop/>, facilitates tests and interclass correlation analysis. With this code, users can conduct a range of statistical tests and calculate interclass correlation coefficients using the R programming language. It's important to adjust file naming and location based on individual computer file structures. Additionally, the code includes necessary external libraries for test execution.

6.6 Summary

The experiment “Acting Emotions 1” delved into the domain of emotional expression among theatre actors, emphasizing the physiological aspects of emotional valence and arousal. Positioned at

the intersection of cognitive science, theatre studies, and sound, this study provides valuable insights into the intricate relationship between physiological responses and emotional experiences.

Central to this research is the “Acting Emotions 1” experimental framework, designed to unravel the physiological correlates of emotions in theatre actors. This unique framework emphasizes actors’ proficiency in modulating expressive behavior and non-verbal communication, rendering them indispensable subjects for such investigations. Employing a robust methodological approach, the study integrates a two-fold experimental procedure to evaluate actors’ capacity to evoke specific emotional states through mental imagery and the discernibility of these states in their physiological signals.

A notable aspect of the study is its participant-driven approach to selecting the emotional repertoire. Drawing upon their expertise, actors engage in self-evaluation following experimental sessions, offering subjective insights that contextualize the collected physiological data. This method enriches the dataset with nuanced emotional dimensions. It bolsters the study’s ecological validity by grounding the research in authentic acting contexts.

The study holds multifaceted significance. Firstly, it devises an innovative experimental protocol customized for the intricacies of theatrical performance, effectively capturing the nuanced intricacies of emotional expression within a controlled setting. Secondly, it pioneers the integration of an IMS powered by physiological signals, advancing the creation of immersive and adaptive stage environments. This integration unlocks novel avenues for artistic expression and sets a foundation for future interdisciplinary investigations.

The data gathered through meticulous physiological measurements and self-assessments undergoes rigorous processing and analysis, employing advanced statistical tools like ICC. This thorough analysis elucidates the consistency and reliability of physiological measurements across sessions and emotions, establishing a robust statistical framework for the study’s conclusions.

The research yields insights, emphasizing the importance of meticulous calibration and thoughtful feature selection when analyzing physiological data to capture the nuances of emotional expression accurately. It underscores the significance of recognizing the subjective nature of emotional responses, particularly in populations adept at emotional regulation, such as actors. This comprehension is vital for developing affective computing systems and tools attuned to human emotions’ intricacies.

Additionally, the study offers invaluable guidance for future research endeavors. It underscores the significance of sensor selection, highlighting the superior reliability of EMG sensors in capturing consistent physiological responses across sessions. This insight holds particular relevance for researchers and practitioners in emotion recognition and human-computer interaction, providing a clear pathway for optimizing sensor deployment in forthcoming studies.

The experiment “Acting Emotions 1” offers practical insights for directors and performers in artistic performance. Understanding the physiological correlates of emotions can inform more nuanced performances and audience engagement strategies. Knowledge about specific sensors consistently capturing certain emotions can guide the design of interactive performance elements, enhancing the emotional resonance of theatrical productions.

In conclusion, “Acting Emotions 1” is a study and a comprehensive exploration of emotion and physiology in theatre. It bridges the gap between tangible and intangible physiological manifestations of emotions, paving the way for a deeper understanding of the human emotional spectrum. The research contributes significantly to affective computing, psychology, and performing arts, offering insights and directions for future inquiries. As the curtain falls on this project, the stage is set for a new era of interdisciplinary research unraveling the complex narrative of emotions and their physiological echoes.

Chapter 7

Acting Emotions 2: A Case Study of Beckett's Theatre

The second experiment, “Acting Emotions 2: A Case Study of Beckett's Theatre” explores the influence of the “corporeal turn” on Samuel Beckett's approach to theater, tracing its evolution through material, organic, and atmospheric phases as referred to in Section 1.4. The experiment, “Acting Emotions 2”, was conceived to tackle the second and third research questions: (Q2) “How do actors experience and interact with sounds generated from their physiological data, and how does this impact their emotional expression in performances?” and (Q3) “How does integrating physiological data into theatre sound design redefine traditional theatrical narratives and storytelling techniques?” This experiment explored the experiential and expressive dimensions of actors' interactions with sound generated from their physiological data.

The experiment provides guidelines to facilitate the seamless integration of physiological sensors into theatrical settings, aiding theater practitioners in harnessing the potential of physiological sensors to deepen emotional expression. Additionally, the research provides guidelines for selecting the most apt physiological sensors for specific emotional tasks, guiding actors and directors toward optimizing performances to an emotional resonance. While acknowledging that individual physiological responses and specific actor roles might limit the applicability of the findings, the study lays out a framework for incorporating physiological-driven sonification into theatrical practice. This framework aims to contribute to the understanding of emotional expressions on stage and provides invaluable resources for the theater community.

7.1 Context And Background For Acting Emotions 2: A Case Study of Beckett's Theatre

In theater, conveying emotions demands a equilibrium between reality and mastery of technique. Within this context, two key concepts emerge: *acting emotions* and *task emotions*. Though these concepts appear distinct at first glance, their synergistic interaction plays a vital role in delivering compelling performances on the theatrical stage.

Acting emotions pertain to the emotions that actors depict during a performance, aiming to render the characters they portray as believable and relatable to the audience. The challenge for the actor lies in transcending their identity, allowing the audience to connect with the character rather than the performer. This process necessitates a comprehension of the character's inner world, including their motivations, psychological makeup, and emotional reactions to diverse scenarios (Konijn, 2000, pp. 55-56). Conversely, *task emotions* refers to the emotions that actors experience amid their performance (Konijn, 2000, p. 155). These emotions are intrinsically linked to the demands and complexities of the acting process rather than the emotions of the character portrayed. For example, an actor might experience a surge of adrenaline, a sense of anticipation, or the thrill of challenge while delivering a complex monologue or engaging in intense interactions with fellow performers during pivotal scenes. The intricate interplay between *acting emotions* and *task emotions* holds significant implications for theatrical performance. While *acting emotions* encapsulate the character's emotional landscape, *task emotions* infuse the performance with the requisite vigor and intensity, rendering the portrayal of character emotions more authentic and compelling. Furthermore, *task emotions* can act as a conduit, aiding actors in navigating transitions between varied emotional states with fluidity and genuineness. They offer a wellspring of authentic emotional experiences that can be channeled into portraying the character's emotions, ensuring a seamless and convincing transition. This study explores emotions within the theatrical domain and underscores the significance of both *acting emotions* and *task emotions* in comprehending the nuances of an actor's craft. Building on this foundation, the study explores Samuel Beckett's (1906-1989) *corporeal turn*, highlighting a paradigm emphasizing an embodied and experiential approach to theater.

The corporeal turn marks a significant methodological shift, placing the body at the forefront of theatrical acting, as highlighted by Palmstierna (2017). This transformative approach unfolds through a tripartite progression, encompassing material, organic, and atmospheric phases.

- The material phase challenges traditional aesthetics, creating a palpable tension between physical action and spoken word, actively subverting the conventional aesthetic object.
- Progressing to the organic phase, there is a reconstitution of the aesthetic object. This phase is characterized by a vibrant interplay of flux and transformation, with a pronounced emphasis on visual and auditory patterns.
- Culminating in the atmospheric phase, the aesthetic object transcends mere representation, evolving into an immersive experience.

The corporeal turn advocates for a more embodied engagement with theatrical performance, shifting the focus from intellectual or semantic interpretations to a sensory, visceral interaction with the theatrical event. It encourages audiences to navigate the delicate balance between sensation and cognition, challenging traditional theatrical and academic boundaries. This approach calls for a more integrative and experiential engagement with drama and its reception. Within this intersection of acting emotions and the corporeal dimensions of theater, the study explores new

territories in theatrical expression, reflecting on the actor's body as a potent medium of expression in contemporary theater. To address this intersection of acting emotions and the corporeal dimensions, the study conducts a systematic case study on a theater stage involving an actor performing a set of five emotions inspired by Beckett's characters: neutral, calm, tiredness, tension, and excitement. The research questions formulated for this study aim to unravel the intricate relationships between sonification, the body, emotion, and theater, thereby shaping the methodology and guiding subsequent analyses.

Building upon the following research questions, the study aims to investigate the complex relations of sonification, body, emotion, and theater, shaping the methodology and subsequent analyses.

- How can sonification techniques effectively translate and enhance the emotional expressions of the body when acting in theatre?
- How does the relationship between sonification models – namely, parameter-mapping (PMS) and model-based sonification (MBS) – and physiological data from the actor's body redefine traditional theatrical narratives?
- How is the actor's experience of the sound generated from their physiological data, and how does it influence their emotional expression and agency when acting?

To tackle the research questions presented, the study embraced a real-world theatrical case study as its central methodology, incorporating the dynamic environment of a theatre stage and its performative elements such as lighting, set design, and sound. The research harnessed signal processing techniques to transform real-time physiological data, including cardiac and muscular activity, into auditory experiences via diverse sonification modules. The primary focus was on translating the actor's physiological responses into sound, utilizing various mapping techniques to facilitate this process.

However, it is crucial to acknowledge that the unique nature of individual physiological responses, coupled with the specific roles portrayed by the actor, might challenge the generalizability of the findings. Despite this, the study succeeds in providing valuable guidelines for the implementation of this technology within theatrical settings, offering a robust methodological framework for the integration of physiology-driven sonification in theatrical contexts. The ultimate goal is establishing a seamless connection between physiology and sound, exploring various sonification approaches to enhance the theatrical experience. This study contributes to the broader understanding of how physiological data can be leveraged to augment emotional expression on stage, providing a novel perspective on the intersection of technology, physiology, and theatre.

7.2 Experiment Setup

This study deployed a comprehensive array of sensors and instruments for the detailed capture and analysis of various physiological signals. Two EMG sensors were strategically positioned on the

biceps brachii, the key muscle in forearm flexion, to record the electrical activity during muscle contractions. Furthermore, an ECG sensor, configured in the Lead II position, was used to observe the heart's electrical activity, a vital metric for evaluating cardiovascular health. Additionally, a PZT sensor was affixed to the thorax to monitor respiratory movements. This sensor translated the mechanical pressure of respiratory motions into electrical signals. The EDA sensor, placed on the participant's non-dominant hand, measured fluctuations in the skin's electrical conductance, often linked to changes in emotional or physiological states.

These sensors were all connected to a modified BITalino board, as described in the previous Section 5.2. The BITalino board was crucial in aggregating and transmitting data from different sensors, supported by its WiFi communication capabilities. The toolbox components outlined in Section 5.3 were utilized for data processing and analysis. This toolbox was all-encompassing, including functionalities for data collection, signal manipulation, feature identification, mapping, and the capacity to provide a real-time auditory representation of the physiological signals. This comprehensive approach was pivotal in ensuring a thorough and intricate analysis of the physiological data, crucial for the experiment's success. The recording setup for the data comprised an Apple MacBook Pro 15" powered by an I7 processor and equipped with 16 GB of RAM. This machine was connected to a Motu M2 audio driver, establishing an audio link with a Yamaha MG16 mixing desk. The audio output was then relayed through a Public Address (PA) system consisting of two Electrovoice speakers, each delivering a power output of 150W.

Expanding further on this setup, integrating these diverse tools and sensors facilitated a multi-dimensional approach to physiological data analysis. The combination of EMG and ECG sensors provided a holistic view of muscular and cardiac activities. In contrast, the PZT and EDA sensors offered insights into respiratory patterns and psycho-physiological responses. This setup enabled a nuanced understanding of the physiological processes during the experiment and allowed for the exploration of complex interactions between these various physiological systems.

Before delving into the subsequent sections, readers are encouraged to view a video that documents this work. The video is accessible online and can be watched by clicking [here](#).

7.3 Experiment Design

The experimental case study focused on five emotional states: neutral, calm, tiredness, tension, and excitement. Each state was associated with a character from Beckett's works, selected for their distinct physiological attributes. These characters served as ideal frameworks for expressing emotional states through physiological signals.

The experiment involved three primary participants: an actor, an artistic director, and a sound designer (the author). The actor played a central role, equipped with various physiological sensors to capture cardiac rhythms, muscle activity, respiratory rates, and skin conductance. Guided by the artistic director, the actor delivered nuanced performances crucial for collecting and analyzing physiological data.



Figure 7.1: The sensors are attached to specific points on the body, which are likely chosen for their relevance to the type of data being collected. For example, electrodes on the chest can be used for an electrocardiogram (ECG) to measure heart activity, while those on the back and arms might be for electromyography (EMG) to record muscle activity.

The experiment spanned five days and took place on a theater stage. Each session lasted three hours, dedicated to exploring one of the emotional states. The stage was arranged with a chair positioned at the center, serving as the focal point for the actor's performances. A mirror was placed in the upper left corner to enrich the theatrical environment and potentially influence the actor's emotional expression. The stage lighting, created using two crossed zoom profilers, was carefully designed to provide adequate visibility and enhance the mood appropriate for each session.

The research adopted a qualitative approach, investigating the correlation between physiological responses and sound within the theater setting. This ecological methodology facilitated an authentic exploration of the character's actions and emotions. The study aimed to go beyond mere application of sonification techniques; it aimed to critically evaluate every aspect of the process, from data collection to analysis and presentation of results. This comprehensive assessment was essential for understanding the efficacy of our methods and their influence on conveying emotional states through physiological signals and sound interaction within a theatrical framework.

The inclusion of theatrical elements such as the mirror and specific lighting aimed to cultivate an environment conducive to eliciting deeper emotional responses from the actor, thereby enriching the physiological data. The objective was to establish a symbiotic relationship between the actor's performances and the physiological signals, where each element informed and enhanced the other. This integration resulted in a nuanced interplay of sound and emotion, effectively capturing the essence of each character and emotional state.

The subsequent subsections will offer detailed insights into the strategies employed for portraying each emotion under examination. They will provide an in-depth explanation of the mapping techniques and sound strategies utilized in the study. The subsections encompass a thorough

examination of how the actor prepared for and enacted these emotions, capturing their physical and psychological essence. The discussion will delve into the subtleties of each emotion and elucidate how they were translated into expressive performances. In each grid of sequential snapshots depicting an actor's performance, a link to the Figshare repository for the videos is provided.

Furthermore, the subsections will elaborate on the mapping techniques that connected the actor's physiological data to the corresponding sound parameters. This section will outline how different physiological responses triggered and modulated various aspects of the sound, directly correlating the actor's emotional state with the auditory output.

The sound strategies section will elucidate the creative and technical processes involved in crafting the soundscapes for each emotion. This includes the selection of specific sounds, their arrangement, and the rationale behind these choices, offering insight into how the sound design enhances and complements the actor's performance. This comprehensive overview aims to provide a clear understanding of the integrated approach utilized in this study, which combines acting, physiological interpretation, and sound design to create a cohesive and impactful theatrical experience.

7.3.1 The Material Body: Implicit and Explicit Gestures

The "Material Phase," a term grounded in the broader conceptual framework of *The Corporeal Turn*, signifies a pivotal period in Samuel Beckett's artistic progression. Spanning nearly a decade, from 1953 to 1962, the Material Phase represents a definitive departure from conventional theatrical conventions, emphasizing the linguistic and corporeal dimensions of performance. The aim is to unravel and disrupt the semantic constructs frequently inherent in language, primarily achieved through "mis-movements."

Mis-movements, far from peripheral, hold significant importance in the Material Phase, serving as both tactical devices and thematic signifiers. A character might proclaim, "I am going," while paradoxically remaining motionless, thereby instigating a dissonance between the spoken word and physical action, between expectation and reality. Crucially, this isn't merely a spectacle of incongruities; rather, it's a deliberate maneuver intended to disrupt the audience's cognitive frameworks that govern narrative comprehension and meaning-making processes. This notion can be interpreted as an *assault on words*, a strategic subversion of the textual to highlight the corporeal and formal aspects of theater. This assault aims to disturb and emancipate, challenging the perceived authority often associated with traditional interpretations of theater. By eroding or diluting semantic foundations, new avenues for aesthetic exploration are opened, laying the groundwork for the more intricate frameworks that would emerge in subsequent phases of the Corporeal Turn.

The performance is encapsulated in a series of still images arranged in a grid, labeled from A to D horizontally and numbered from 1 to 5 vertically, following a sequential pattern that suggests a progression of time or actions as depicted in Figure 7.2.

In the first column, labeled 'A,' the actor initiates each sequence with a starting position revisited at the beginning of each subsequent snapshot series, suggesting a return to a baseline or



Figure 7.2: Grid of sequential snapshots depicting an actor's performance to convey a neutral emotional state within a theatrical context. The series is labeled across the top from A to D and down the side from 1 to 5, organizing the frames into a 4x5 matrix. Video link for the "Acting 2" Neutral: <https://tinyurl.com/msvw5ymx>

neutral starting point. The snapshots depict the actor engaging in a minimalistic motion, embodying the concept of 'going without going anywhere,' which evokes a sense of motionless journeying or effort without progress. As we move rightward to columns 'B' and 'C,' there is an apparent evolution or continuation of movement. These represent different stages of the actor's interaction with a chair on the stage—a prop central to the performance. The actor's interaction with the chair is methodical as if each motion is an exploration of the theme, ranging from sitting to standing, leaning, and perhaps attempting to move the chair, all under a focused spotlight that adds to the theatricality of the experiment. The final column, 'D' captures a culmination of the sequence—either the actor is standing, having interacted with the chair, or returning to it. The repetition of these actions, observed in the varying 'D' snapshots, appears to conclude the individual cycles of the performance, only to begin anew in the next 'A' snapshot. The lighting and shadows are crucial in accentuating the actor's motions, casting elongated shadows that dramatize the stillness and movement. The stark contrast between the illuminated actor and the dark background emphasizes the isolation of the actor's actions, aligning with the neutral emotion intended to be expressed. Throughout this series, the performance embodies patience and persistence, as indicated by the description of the actor steeping the chair and the repeated attempts, metaphors for trial, endurance, and the human condition. The neutral state being acted out is not one devoid of action. However, it is one of controlled, deliberate non-expression, allowing viewers to project their interpretations onto the performance without being guided by overt emotional cues. The actor's disciplined restraint throughout the sequences requires careful observation to discern the nuances of neutrality in a performance context.

In the 'neutral state' scene, the focus was on exploring implicit gestures, where the actor's physiological state had a significant yet not all-encompassing influence on the auditory output. To achieve this, an ECG sensor was implemented to monitor the R-to-R peak interval, a critical component for measuring cardiac rhythms. This interval was linked to two key parameters within a granular sound synthesis engine: the initiation of each sound grain, timed precisely with the onset of each heartbeat, and the duration of the grains, reflecting the time between successive R-to-R peaks. Furthermore, an EDA sensor was used to capture more subtle physiological changes. It was utilized to compute average values across time windows of ten and 30 seconds. These averages, representing variations in EDA, were then mapped to adjust the pitch frequencies of two ambient pads. These pads, evolving concurrently and echoing the qualities of string instruments, dynamically responded to the nuances in the physiological data.

By extending this approach, additional layers of interaction were introduced. The ECG and EDA sensors influenced the primary auditory parameters and contributed to a more complex sound texture. For instance, fluctuations in electrodermal activity could trigger subtle changes in timbre or introduce harmonic elements, further enriching the auditory landscape, creating an immersive and responsive environment where the actor's physiological state became a living, breathing part of the sonic narrative, blurring the lines between the performer and the performance. Such a setup offered a novel way to experience and interpret the interplay of human physiology and technology in creating art.

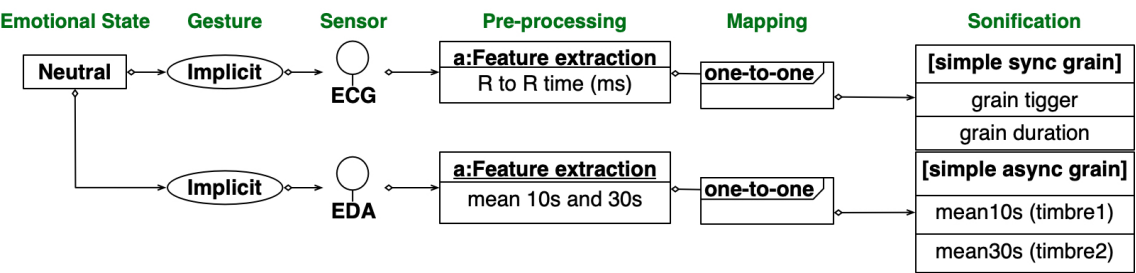


Figure 7.3: Presents the methodological framework utilized for the 'neutral' scene. This study incorporated an ECG and an EDA sensor focusing on implicit gesture typologies. Specifically, the R to R peak time derived from the ECG was associated with a granular synthesizer, while the mean value across two time windows determined the timbre of two ambient pads. <https://tinyurl.com/ycbsjs3d>

The provided image is a composite of snapshots taken from "Acting Emotions 1," a study in theatrical emotion portrayal. Here, the actor explores the concept of calmness, captured across a 4x8 grid of images.

Each row, labeled from A to D and column numbered 1 to 8, represents a sequence of moments from a four-minute performance. Starting from A1, the actor begins standing, with each subsequent snapshot in the 'A' column mirroring this initial pose, suggesting a reset or a return to a foundational calm state at the start of each new sequence. As the viewer's eye moves across the rows to columns 'B,' 'C,' and 'D,' we observe a progression of actions—subtle shifts in posture and positioning that convey a deliberate and controlled exploration of the stage space. The snapshots depict the actor engaging with the environment and the chair—sometimes standing beside and interacting with it. These interactions are not haphazard; instead, they seem to be carefully choreographed to create patterns with the body that exude a sense of calmness.

The lighting plays a crucial role in the composition of each snapshot, focusing on the actor and casting a spotlight that follows their movement, creating a visual rhythm that aligns with the described rhythmic breathing. While the breathing rate is not visible in the stills, it is implied that this aspect was central to the performance, perhaps guiding the actor's movement and timing and giving life to the calmness that permeates the scene. The image sequence captures a performance where the actor's body language and controlled breathing coalesce to create a portrait of calm. Each frame speaks to a moment of repose or a gentle transition, all part of a larger, fluid symphony of serenity enacted on stage.

In the "calm" scene, a PZT sensor was employed to facilitate the exploration of hybrid gestures, combining elements of both explicit and implicit signals as a mode of interaction. This approach allowed for a more nuanced and dynamic control of the auditory experience. The PZT sensor provided data from which three features were extracted: the peak value, the difference between peaks, and the variance in signal strength. Each feature played a distinct role in manipulating the sound produced by the sample granular synthesizer. Specifically, the peak value was used to determine the starting point of the sample playback, ensuring that the sound generation was in sync with the physiological rhythms captured by the sensor. The difference in peak val-

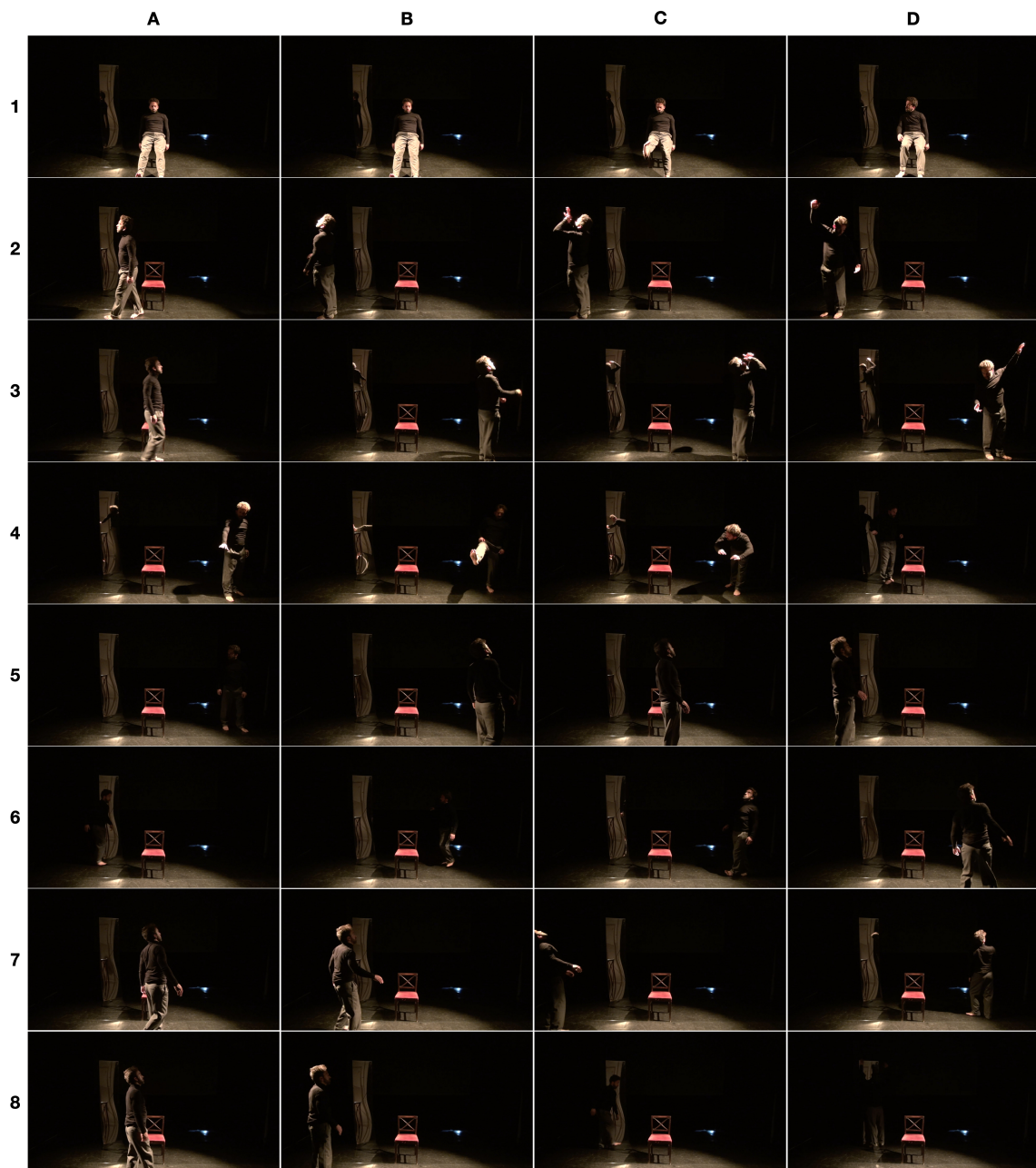


Figure 7.4: Showcases a grid of sequential snapshots from 'Acting Emotions 1,' illustrating an actor's interpretation of a Calm state during a four-minute performance. The snapshots follow a sequence from A1 to D8, arranged in a 4x8 matrix. The actor navigates the theatrical stage with poised serenity, embodying a tranquil demeanor. Body patterns emerge subtly through the actor's movements. Though not visible in the images, the breathing rate punctuates the rhythm of the performance, underscoring the calmness of the enacted emotion. Video link for the "Acting 2" Calm: <https://tinyurl.com/289bzudp>

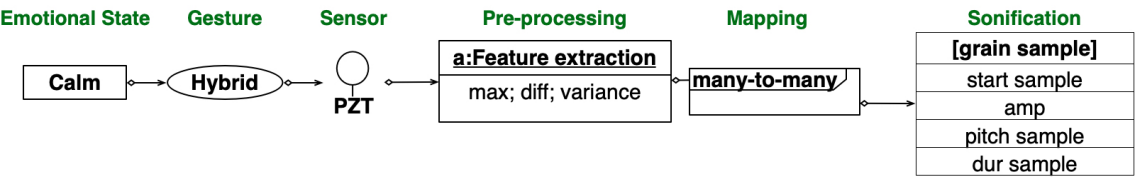


Figure 7.5: Illustrates the methodological approach used for the 'calm' scene, where a PZT sensor was implemented to focus on a hybrid gesture approach. Notably, the average time obtained from the EDA sensor readings was linked to various parameters in a granular sampler. <https://tinyurl.com/26bh4m2n>

ues was utilized to modulate the amplitude of the sound, adding layers of dynamic variation and intensity to the auditory output. Lastly, the variance in the PZT signal was crucial in defining the duration of each sample, allowing the sound to evolve organically in response to the subtle changes in the sensor's readings. A rich and responsive sound landscape was created by mapping these extracted features to specific parameters within the granular synthesizer. This setup reflected the physiological state conveyed by the PZT sensor and allowed for a deeper, more immersive interaction between the performer and the sound environment. The result was a unique auditory experience that seamlessly blended the explicit and implicit aspects of human gesture and physiological response.

7.3.2 The Organic Body: Explicit and Hybrid Gestures

The "Organic Phase," articulated within the overarching paradigm of Beckett's "Corporeal Turn," marks a significant evolution in the playwright's exploration of aesthetic forms. While the Material Phase was fundamentally preoccupied with disrupting linguistic semantics through 'mis-movements,' the Organic Phase shifts the focus to the visual and auditory patterns inherent in performance (Palmstierna, 2017, p.124). This phase embraces a diverse set of vehicles, of which mis-movements continue to be a part, to engage with the audience in ways that stretch beyond textual meanings to the formal aspects of the theatrical experience.

One of the most salient features of the Organic Phase is its intricate choreography of characters' movements. No longer are these actions arbitrary or merely disruptive; they are meticulously designed to constitute visual patterns that serve as aesthetic objects in their own right. This takes Beckett's already nuanced focus on the body to a heightened level of complexity. Instead of merely contradicting the text, the characters' bodily movements are orchestrated to interact synergistically with other elements like lighting, sound, and set design, creating an immersive, cohesive aesthetic experience.

Figure 7.6 depicts an array of snapshots capturing an actor's embodiment of tiredness, part of an experimental performance piece titled "Acting Emotions 1." It is structured into a grid pattern, with each row labeled from A to D and each column numbered from 1 to 8, documenting the sequential flow of a four-minute enactment.

In column A, the actor initiates the sequence, demonstrating the onset of exhaustion. The actor's posture and interaction with the chair convey an increasing heaviness as if each action is

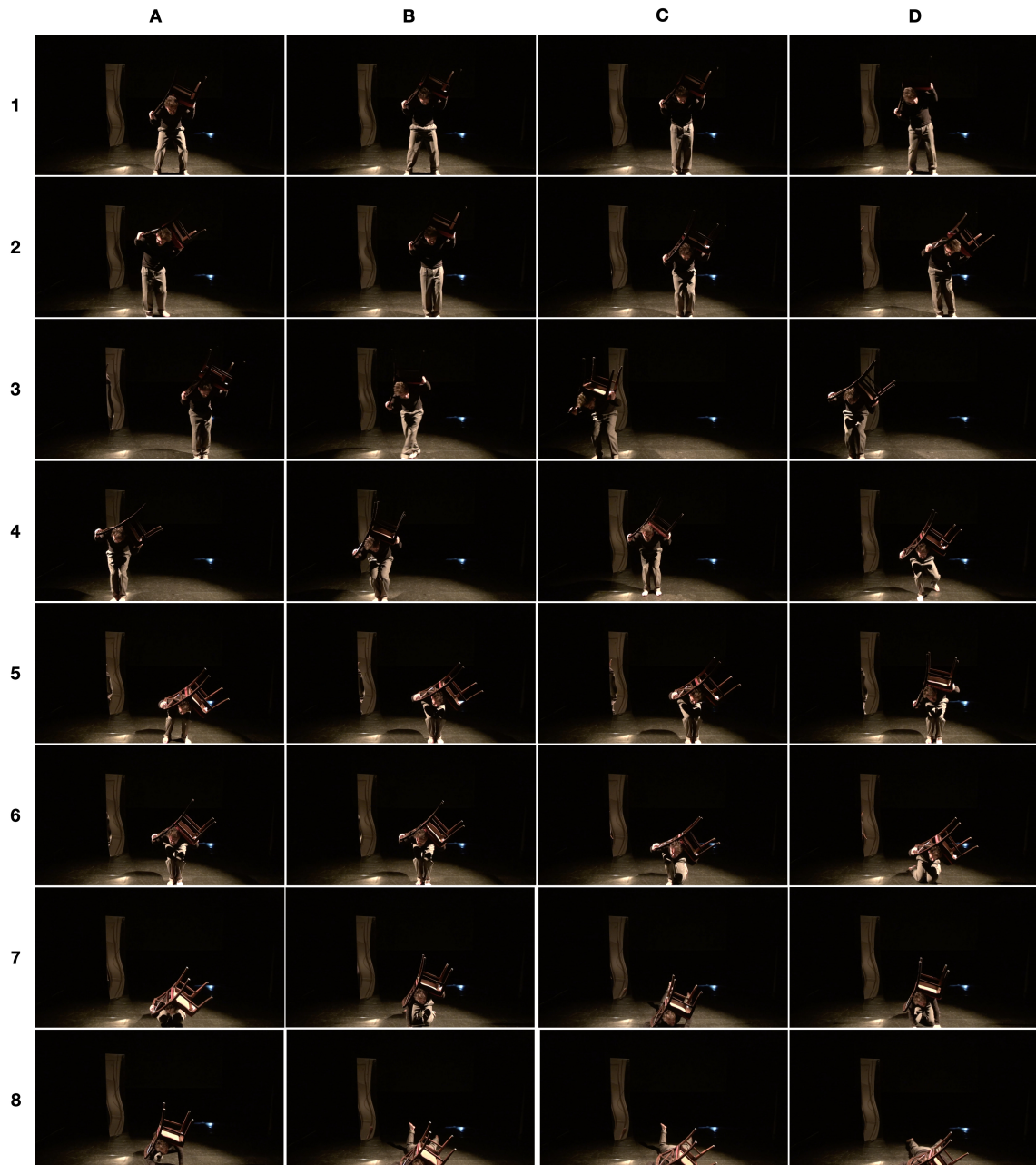


Figure 7.6: Depicts the actor's acting emotional tiredness, illustrated in a 4x8 grid sequence of a performance depicting the weight of weariness through interaction with a chair, symbolizing life's burdensome struggles against the inevitable. Video link for the "Acting 2" Tiredness: <https://tinyurl.com/44ctrxv5>

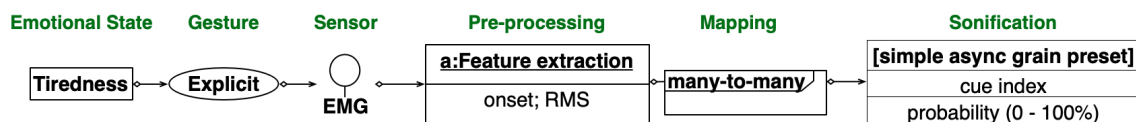


Figure 7.7: Illustrates the methodological structure applied in the 'tiredness' scene. Here, two EMG sensors were employed, emphasizing explicit gesture-based interactions. Key features like onset and RMS, derived from the EMG readings, were linked to specific predetermined cues. These cues were instrumental in dynamically altering synthesizer settings and influencing the likelihood of sound generation.

a monumental effort. This progression continues across the B and C columns, where the actor's movements with the chair grow more strenuous, reflecting the thematic concept of the burden of weariness. By column D, the snapshots suggest the actor's struggle reaching a peak, with each lift and drag of the chair seeming to resonate with the existential weight of the performance's underlying message: the absurdity of life's toils against the inevitability of death. The snapshots do not just portray physical tiredness but also allude to emotional and philosophical exhaustion. The lighting in the performance space is minimal, stark against the dark background, and focused sharply on the actor and the chair, the primary elements in this narrative. The light symbolizes the scrutiny of life, highlighting the actor's solitary labor against the weight of existence. The chair, an ordinary object, takes on an extraordinary significance—it symbolizes life's burdens, the weight each person carries, and the tiredness that accumulates through the persistent effort to hold it up. Throughout the performance, the actor's body becomes a canvas displaying the weariness of the human condition. Every gesture, lift, bend, and pause is imbued with a sense of heavy resignation. The performance becomes a visual metaphor for the Sisyphean struggle inherent in human existence, with the chair's weight a constant reminder of the unyielding pressures of life. The snapshots together offer a narrative of tiredness that is both literal in the actor's fatigue and symbolic of the broader human experience, inviting the audience to contemplate the profound and often absurd struggle against the relentless march of time and fate.

In the "tiredness" emotional state scenario, two EMG sensors were positioned on the biceps brachii of both arms — the right and the left. The left arm's muscular potentials were utilized to trigger a granular synthesizer equipped with preset capabilities. Simultaneously, the root-mean-squared (RMS) value of the muscular potential energy from the right arm was employed to modulate the synthesizer, adding a probabilistic layer to sound generation based on the average intensity of the EMG signal. This approach underscored the intricate relationship between physical muscle activity and sonification events, particularly emphasizing explicit gestures.

The explicit gesture demonstrated through muscular movement granted the actor a unique level of control. For example, increased muscular exertion directly translated to heightened levels of sound activity, creating a dynamic and interactive auditory experience. This setup provided a tangible link between the actor's physical state and the resulting soundscape and highlighted the capacity for intentional, deliberate actions to influence artistic expression. Extending this concept, the differential use of the left and right arms for triggering and modulation introduced an

element of asymmetry and balance in the interaction. The actor could experiment with various levels of muscular engagement in each arm to explore a wide range of auditory outcomes, from subtle textural changes to dramatic shifts in the sound landscape. This dual-sensor approach allowed for a deeper exploration of the actor's physicality as a means of artistic expression, offering a compelling way to sonically represent the nuances of the "tiredness" emotional state. This innovative method effectively bridged the gap between physical exertion and auditory representation, enriching the overall sensory experience of the performance.

Figure 7.8 is a collection of photographic frames arranged in a 4x7 grid, each capturing a moment from "Acting Emotions 1," where an actor delves into the emotional state of tension. The sequence of snapshots, labeled A1 through D7, follows the actor through a meticulously choreographed performance, where his movements and stillness are pivotal to the theatrical narrative.

At the onset in column A, we see the actor interacting with a chair, leaning in as if to listen closely to the inanimate object. This gesture sets the tone for the entire series, where the actor seems to be in a constant state of alertness, trying to attune to the space around him. As the actor moves from frame to frame, his body language suggests a heightened sensitivity to the environment, reflective of the internal state of tension he aims to convey. The auditory component, described as fragments of text by Samuel Beckett, plays when the actor moves, adding a layer of complexity to the performance. The fluctuating volume challenges the actor to listen more intently, to stretch his senses to catch the elusive words. The snapshots in columns B and C capture the actor in motion, reflecting the moments when Beckett's text is audible. In contrast, the images in column D, with the actor in stillness, suggest the moments when the sound recedes and the effort to listen intensifies. The actor's exploration extends to the floor and the backstage area, suggesting a search for meaning or clarity beyond the immediate visible space. The tension is not just in the physical attempts to listen but also in the thematic undercurrent of looking for something that remains just out of reach, whether it is the sound, a meaning, or an existential answer. The lighting in each frame is stark and focused, much like a spotlight on the actor's solitary figure, emphasizing the isolation that often accompanies intense concentration or anticipation. The contrast between light and shadow in the images reinforces the theme of tension—the sharp delineation between knowing and not knowing, hearing and straining to hear. Overall, the sequence depicts not just a performance of tension but an immersive experience where the actor, the text, and the silence around it all coalesce to form a tangible manifestation of the emotional state being explored. The actor's performance becomes a visual and auditory metaphor for the human condition's inherent tensions: the quest for meaning, the struggle to perceive the intangible, and the sometimes Sisyphean effort to find clarity in a world that often whispers its truths.

In the exploration of the "tension" theme, a hybrid gesture methodology was employed, integrating an ECG sensor to leverage the time interval between two consecutive R-to-R peaks. This interval was used to determine the musical tempo for a Brownian motion algorithm, generating a unique piano composition. Concurrently, a 3-axis magnetometer was utilized to gather motion data. This data was then fed in real-time into an Artificial Neural Network (ANN) model, trained to recognize specific body poses of the actor and dynamically interact with various sound elements.



Figure 7.8: A Theatrical Exploration of Tension in a 4x7 Snapshot Grid, capturing an actor's performance characterized by attentive listening to the space and sounds around, juxtaposed with the struggle to discern faint text by Samuel Beckett, embodying the tension of searching without finding. Video link for the "Acting 2" Tension: <https://tinyurl.com/4nuhbwej>

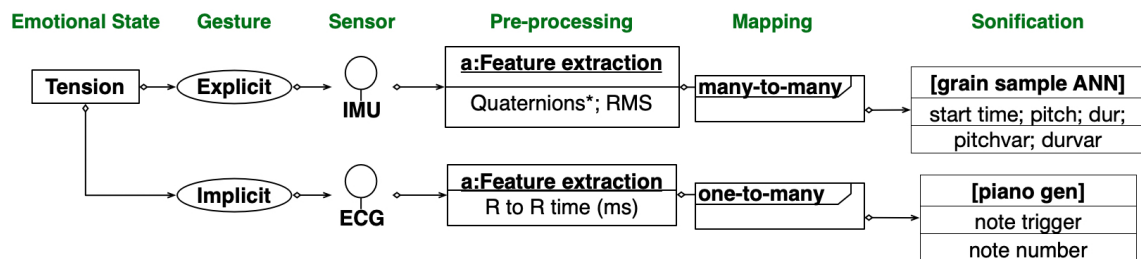


Figure 7.9: Illustrates the methodological blueprint implemented in the 'tension' scene. This part of the study integrated an Inertial Measurement Unit (IMU) and an Electrocardiogram (ECG) sensor, emphasizing hybrid gesture types. Key quaternion features from the IMU were mapped to control multiple parameters of the synthesizer. Simultaneously, the timing between R-to-R peaks from the ECG sensor was utilized to sequence through musical notes. Video link for the Acting 1 Excitement: <https://tinyurl.com/44ctrxv5>

The methodology is depicted in Figure A.7d.

This setup allowed the actor's pose to exert sophisticated control over the sound parameters. It marked a shift from the traditional one-to-one mapping, where a single action corresponds to a single sound response, to a more complex one-to-many approach. In this innovative approach, each distinct pose could simultaneously influence a diverse array of sound parameters. Expanding on this, the integration of the ANN model added a layer of machine learning and artificial intelligence to the interaction, allowing for a more intelligent and responsive system, capable of adapting to the actor's movements and poses in a nuanced and evolving manner. Using the ECG sensor to control the tempo introduced an element of physiological responsiveness, linking the actor's emotional or physical state directly to the musical output. This method created a more immersive and interactive experience. It opened up interesting creative avenues for artistic expression, where the convergence of the actor's movement and physiological signals culminated in a rich, dynamic soundscape. This approach exemplified the potential of blending traditional musical composition techniques with sensing technology to create a novel, engaging auditory experience.

Building on this, the use of quaternion features from the IMU enabled a sophisticated interpretation of spatial orientation and movement, translating physical gestures into complex sound modulations. This method not only facilitated a nuanced interaction between the actor's movements and the resulting sounds but also allowed for a dynamic and responsive auditory landscape. The ECG sensor's role in determining the progression of musical notes added an additional layer of physiological interactivity, effectively syncing the actor's heart rhythm with the musical composition. This innovative approach highlighted the potential of using advanced sensor technology and gesture recognition in creating immersive and expressive soundscapes that respond in real-time to both the physical and emotional state of the performer.

7.3.3 The Atmospheric Body: Explicit Gestures

The Atmospheric Phase represents the pinnacle of Beckett's Corporeal Turn, creating what can be an encompassing aesthetic experience. This phase contrasts its forerunners: the Material Phase, which focused on subverting semantic meaning, and the Organic Phase, which prioritized form. The Atmospheric Phase seamlessly fuses these aspects, evolving beyond simple representation to bloom into an experience that engages multiple senses, challenging the conventional bounds of theatre. In this phase, the body transcends its role as a standalone performer. It becomes intricately woven into a complex tapestry of theatrical elements, including lighting, sound, and set design. The body is no longer just a performer following a script or choreography; it becomes an integral component of a multidimensional aesthetic composition. This integration includes choreographed movements, gestures, and poses synchronized with other sensory elements to create a distinct 'atmosphere.' This approach departs from earlier phases where the body often played conflicting roles. It is a dynamic element contributing to a unified and fluid aesthetic narrative. The concept of 'atmosphere' is central to the Atmospheric Phase. It represents a comprehensive engagement with the audience, encompassing visual, aural, and deeper emotional connections. The body acts as a bridge, a sensory medium between the performance and the audience. Every choreographed movement is designed for visual impact and to harmonize with the sounds and lighting, offering a layered, immersive sensory experience. This complex interaction extends beyond passive viewing, inviting the audience to become active participants in this aesthetic journey, marking a significant shift from traditional forms of audience engagement.

Figure 7.10 is a grid of snapshots capturing an actor's facial expressions while portraying the emotion of excitement. Each row, labeled A to D and numbered 1 to 7, presents a series of expressions varying slightly from one to the next, suggesting a sequence the actor follows to elicit specific sound cues through an artificial neural network.

In this experimental performance, the actor's facial expressions are not merely for visual storytelling but are integral to the soundscape of the piece. The neural network, trained on four distinct expressions linked to individual sounds, allows for a live synthesis of audio that responds to the nuances of the actor's performance, implies a complex, responsive system where the actor's excitement is not just conveyed through his physical visage but is also amplified and echoed through the generated sounds. The interpolation between the trained points suggests a nuanced control over the audio output, where the actor, by transitioning between expressions, can create a fluid and evolving auditory experience. It is a kind of aural painting with the face as the brush and the soundscape as the canvas, blending technology and performance in a way that blurs the lines between the two. Through his performance, the actor becomes a conductor of sound, with each contortion and twitch contributing to the overall experience. The excitement is thus a multi-sensory emotion, experienced visually through the actor's expressions and aurally through the accompanying sounds. This approach to performance showcases the actor's skill in controlling and conveying emotion and highlights the potential of machine learning to augment and extend the expressive power of human actors.

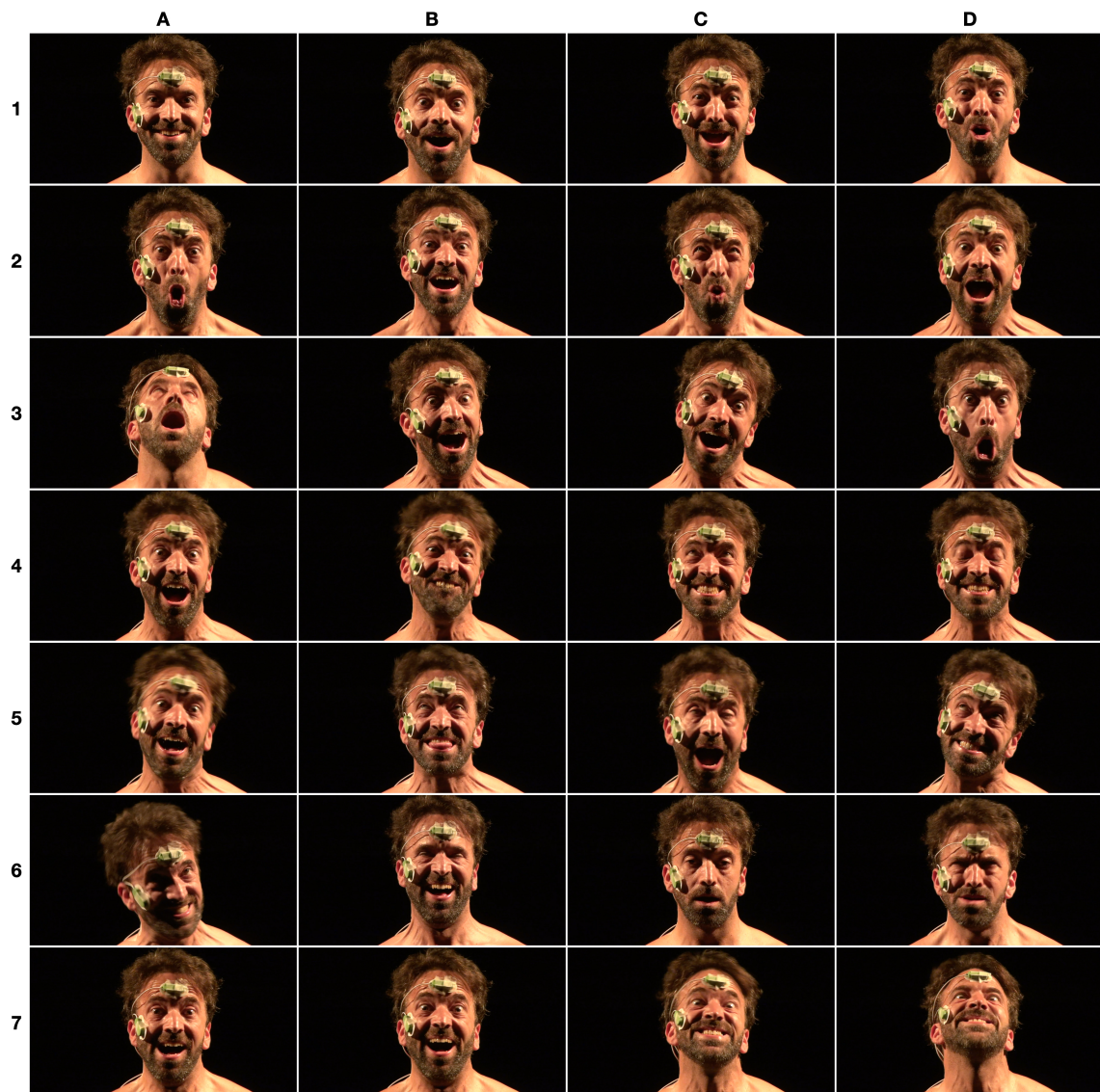


Figure 7.10: Illustrates the actor's exploration of excitement through facial expressions, mapped to a responsive soundscape via an artificial neural network, as captured in a 4x7 grid of performance snapshots. Video link for the "Acting 2" Excitement: <https://tinyurl.com/bd2ny54x>

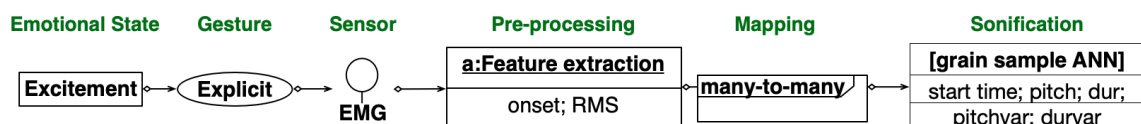


Figure 7.11: Illustrates the methodological approach adopted for the 'excitement' scene. An Artificial Neural Network (ANN) was employed to leverage onset and RMS features for identifying marked facial expressions, which in turn were correlated with specific sound events.

In the final exploration of “excitement,” the actor’s facial expressions were pivotal, monitored through two facial electromyography (fEMG) sensors positioned on the corrugator supercilii and zygomaticus major muscles. The first sensor, fEMG1, activated a predefined sonification path by engaging preset memories of a granular synthesizer. In contrast, the second sensor, fEMG2, influenced the synthesizer’s probability function, alternating between producing dense and more sparse sound patterns. Interactive machine-learning techniques were incorporated into the interaction design to enhance this setup. A robust and responsive sonification system was developed by recognizing and learning from extreme facial expressions indicative of excitement. This system was not just reactive but adaptive, improving its response over time as it learned to interpret the nuances of the actor’s expressions better. Building on this, the integration of machine learning allowed for a progressively refined interaction between the actor’s emotional expressions and the resultant soundscapes. Over time, the system could distinguish subtle variations in facial expressions, leading to a more nuanced and dynamic auditory response. This approach bridged the gap between physical expression and digital sound synthesis, creating a responsive and engaging performance environment. The result was a rich, layered experience where the actor’s facial movements did not just trigger sounds but shaped them, transforming the actor’s expressions into a live, evolving musical instrument. This innovative use of technology exemplified the potential for new forms of expressive, interactive art that merge human emotion with digital creativity.

7.4 Results and Discussion

In this section, the qualitative findings of the research are explored, highlighting dialogues, open deliberations, and on-stage experimentations of diverse alternatives. After each session, participants engaged in discussions centered on the artistic outcomes, focusing on the technical nuances of the methods introduced and their relevance in a theatrical setting. Critical insights were extracted from the analysis of video recordings following the four research inquiries outlined in Section 1. The following questions were formulated based on the initial meeting with the participants, including the actor and artistic director. These questions aim to guide the development of a script for creative dialogue on stage.

How might the process of transforming data from physiological sources into sound enhance emotional expression in acting?

The study was guided by four key variables: gesture typology, sensor selection, mapping strategies, and sonification techniques. Among the three gesture typologies explored, it was observed that implicit gestures yielded greater theatrical richness compared to explicit gestures, resulting in a more pronounced mimetic experience. For example, in the “neutral” scene, the actor’s manipulation of a sound with an imperceptible source facilitated the portrayal of solitude on stage. Sonification played a pivotal role in enhancing the actor’s presence and emotional expression within the theatrical context. In the depiction of a “neutral” state, the resynthesized heartbeat sound heightened the perception of a motionless body, thereby intensifying the actor’s sense of

potency and presence. Conversely, explicit gestures tended to produce a more conventional and predictable mimetic theatrical performance, as evidenced in the "tiredness" scene, where the direct correlation between movement and sound diminished the element of theatrical surprise. Hybrid gestures, comprising both explicit and implicit elements, proved effective when utilized together. For instance, in the "tension" scene, hybrid gestures were employed to manipulate a granular voice synchronized with the actor's respiration cycle and the fluctuation of musical notes from a virtual piano, leading to a seamless integration of gestural expressions.

In terms of mapping strategies, the study revealed that one-to-many and many-to-many mappings held significant potential for theatrical applications. These strategies introduced a deliberate disconnection between specific sounds and discrete gestures or theatrical elements, thereby enhancing the dramatic depth of characters, particularly those reminiscent of Beckett's works. Complex mappings and Interactive Machine Learning (IML) facilitated intricate and continuous connections between biosignal features and the parameters governing sound synthesis. This underscored the remarkable versatility and adaptability of these strategies in capturing the nuances of physiological responses and artistic expressions. This was exemplified in the "excitement" scene, where a complex interplay between facial expressions and sound events allowed for creative exploration on stage.

In the exploration of sonification techniques, each approach demonstrated its own set of advantages and disadvantages. For example, in the "neutral" scene, a grain-synth module was adopted, synthesizing a heartbeat sound with customizable frequency and amplitude control. Conversely, the "tension" scene incorporated a grain-sample module, enabling the manipulation of voice recordings triggered by the actor's body posture. Algorithmic sound generation, primarily through the piano-gen module, introduced a musical dimension to the scenes, proving particularly effective in conjunction with implicit gestures. For instance, in the "tension" scene, the mapping of ECG R-to-R peak time intervals to the piano-gen module generated a musical output intricately intertwined with the actor's performance.

How can sonification techniques effectively translate and enhance the emotional expressions of the body when acting in theatre?

The application of sonification, which involves translating data into sound, introduced innovative interactive dynamics between the human body and auditory feedback. Parameter-mapping sonification (PMS) and Model-Based Sonification (MBS) offer distinct merits and obstacles in sonification approaches.

The PMS method facilitated a mimetic interaction during direct one-to-one mapping. The actor perceived this as similar to adjusting controls, like dials or sliders, on an audio module but mediated through muscle movement. In contrast, adopting a one-to-many mapping approach led to an interaction that was less mimetic but more intuitive and expressive for the actor.

The MBS approach further enriched this interaction. Essentially, this method handled multiple simultaneous inputs, particularly from a 3-axis magnetometer, and correlated these inputs with varied outputs in the sonification algorithm. A particularly intriguing observation occurred when

the actor, during his trajectory, momentarily suspended movement between two adjacent training sets, resulting in a sonification that was not deliberately coded but naturally existed between points A and B, as illustrated in the “tension” scene.

Overall, mappings characterized by higher complexity and a certain degree of unpredictability, such as the one-to-many in PMS, tend to contribute to more expressive sonifications and a richer narrative discourse.

Does the actor perceive sound generated from their physiological data as an augmentation of their current emotional state? Conversely, does the actor feel overshadowed or restricted by this process, despite its origin from their biological signals?

In scenarios that heavily emphasized explicit gestures, the actor reported experiencing feelings of subjugation and restriction. With immediate control exerted over the sound, the actor developed anticipations regarding the desired auditory feedback. Explicit gestures compelled adherence to a predetermined sequence to elicit a particular sound, suggesting that more direct gestural control might foster a predominantly imitative actor response.

On the other hand, implicit gestures fostered a more ambiguous yet intriguing relationship between the actor's body, emotional expression, and sound. This gesture typology demonstrated significant potential for enriching and elevating the actor's performance, particularly in portraying Beckett's characters. The actor's feedback highlighted that implicit gestures are highly interactive, distinct from the traditional mimetic approach to acting.

The sensor's nature significantly influenced the actor's approach to the sonification. An illustrative example is using the EDA sensor despite its sensitivity to external factors and the constraints it imposed on the actor's movement. Surprisingly, the actor found this sensor particularly engaging, especially in conjunction with the ECG (another implicit gesture). This pairing allowed the actor to simultaneously perceive the evolution of their own heartbeat and arousal levels during the performance.

How does the relationship between sonification paradigms—specifically parameter-mapping and model-based sonification—and physiological data from emotional body expressions redefine traditional theatrical narratives?

The study acknowledges the inherent challenges in generalizing insights by focusing on a single actor. Some methodologies aimed to facilitate broader applicability, such as incorporating a calibration phase to account for individual biosensor baselines and varying external factors like lighting conditions and ambient temperature. Regarding temperature, it is pertinent to note that sensors like the EDA are intrinsically sensitive to body temperature fluctuations, influenced by both arousal levels and environmental temperatures. Challenges were identified in maintaining the integrity of the EDA sensor during experimentation. Within a theatrical production framework, allocating sufficient time to implement such methods is crucial. Due to the intricate technical setup, working with physiological-driven interactions demands meticulous efforts from all participants.

Moreover, reproducing a specific emotional state after technical disruptions poses a creative challenge. The ecological experiment has illustrated that setup conditions in a real-world theatrical scenario differ from in-vitro lab experiments.

The experiment “Acting 2” investigated sonification’s role within theatrical settings, emphasizing the interplay between biosensory technology, machine learning, and creativity. The main objective was to determine the ability of sonification to enhance and extend the actor’s on-stage presence, thereby offering an auditory representation of nuanced emotional and physiological states.

Distinct interaction modalities were identified through the implementation of PMS and MBS sonification models. The PMS methodology facilitated a direct, mimetic engagement, whereas the MBS framework yielded a complex, multi-dimensional interactivity by processing multiple inputs. Integrating IML and regression techniques enabled a sophisticated and adaptable framework for real-time data-to-sonification synthesis mapping, thereby enriching the theatrical experience.

However, the findings also underscored the inherent dichotomy of gesture control: the equilibrium between enabling and constraining an actor’s creative expression. Despite offering prompt auditory feedback, explicit gestures risked constraining the actor’s organic expression, leading to a predominantly imitative engagement.

The exploration of physiological sonification in theatrical performance has unveiled several promising creative avenues for future research. Investigating optimal sensor placement for capturing physiological signals in live theatrical settings could enhance the actor’s comfort and data quality. Further exploration of explicit, implicit, and hybrid gesture typologies and their impact on actor expression and interaction with sonification systems is warranted. Integrating machine learning (ML) techniques can enable real-time adaptation and learning within physiological sonification systems. These adaptive systems could respond to an actor’s emotional dynamics and provide more nuanced auditory feedback. In the theatrical realm, the collaboration between theater practitioners, physiology researchers, and theatre sound designers can yield innovative approaches to physiologic sonification. Engaging with actors, directors, and sound designers in the development process can result in more effective and artistically compelling sonification strategies and extend the findings to accommodate larger theatrical productions. These future research directions hold the potential to advance the field of physiologically-driven IMS in the theatre, offering new tools and insights for both artistic expression and scientific exploration.

7.5 Summary

The second experiment, “Acting Emotions 2: A Case Study of Beckett’s Theatre” explored the influence of the “corporeal turn” on Samuel Beckett’s approach to theater, tracing its evolution through material, organic, and atmospheric phases. This experiment offers guidelines to facilitate the integration of physiological sensors into theatrical environments, aimed at assisting theater practitioners in leveraging the potential of such sensors to enhance emotional expression on stage.

In the experimental performance, the actor embodied five Beckett-inspired characters, assigning each one an emotional cue from the studied emotional set: neutral, calm, tiredness, tension, and excitement.

In the “neutral”, the emphasis lay on exploring implicit gestures, primarily through the ECG and EDA sensors, where the actor’s physiological state wielded a significant, though not all-encompassing, influence on the auditory output. The ECG’s R-to-R peak interval underwent direct sonification, mapped to a sound algorithm that synthesized the heartbeat into an audible element. Meanwhile, the EDA sensor captured nuanced physiological changes across ten and 30-second intervals, modulating the pitch frequencies of two ambient pads. Within the “calm” scene, a PZT sensor facilitated hybrid gestures, blending explicit and implicit signals. Three features—peak value, peak difference, and signal strength variance—manipulated sound via a sample granular synthesizer. For the “tiredness” scenario, EMG sensors on both biceps brachii triggered a granular synthesizer, with the left arm’s muscular potentials initiating sounds and the right arm’s RMS value modulating them. This method underscored the intricate relationship between muscle activity and sonification, accentuating explicit gestures. In exploring “tension,” an ECG sensor and a 3-axis magnetometer drove a Brownian motion algorithm for piano composition, complemented by an ANN trained to recognize the actor’s body poses. This setup granted nuanced control over sound parameters through the actor’s pose, transitioning from traditional mappings to a sophisticated one-to-many approach, enriching the interaction between movement and sound. In the “excitement” scene, facial expressions transcended visual storytelling to become integral to the soundscape. A neural network trained on four expressions synthesized audio responsive to the actor’s nuances. This sophisticated, adaptive system resonated visually and sonically with the actor’s excitement, crafting a fluid, evolving auditory journey merging technology and performance in a boundary-blurring fusion.

Various sonification techniques were explored, each with distinct advantages and drawbacks. For instance, a grain-synth module in the “neutral” scene allowed customizable heartbeat synthesis, offering precise control. Conversely, the “tension” scene integrated a grain-sample module for voice manipulation triggered by body posture. Algorithmic sound generation via the piano-gen module added a musical dimension, especially effective with implicit gestures. The PMS method enabled mimetic interaction, akin to adjusting audio controls with muscle movement. In contrast, one-to-many mapping enhanced intuitive interaction. The MBS approach managed multiple inputs, correlating with varied outputs. An intriguing observation occurred when the actor suspended movement, resulting in natural sonification between training points.

The actor reported some restrictions in scenarios emphasizing explicit gestures and anticipating specific auditory feedback. Explicit gestures led to a predetermined sequence, suggesting direct gestural control fosters imitation. Implicit gestures fostered ambiguity, enriching performance, especially in Beckett’s characters. They offered interactive possibilities distinct from mimetic acting. Sensor choice influenced the actor’s approach; for instance, despite sensitivity and movement constraints, the EDA sensor engaged the actor, especially when paired with the ECG. This combination allowed the simultaneous perception of heartbeat and arousal evolution

during the performance, highlighting the sensor's impact on gestural expression.

The exploration of physiological sonification in theatre opens avenues for future research. Optimizing sensor placement for live settings could improve comfort and data quality. An investigation of explicit, implicit, and hybrid gestures' impact on actor expression and interaction with sonification systems is needed. Integrating machine learning enables real-time adaptation to actors' emotional dynamics, enhancing auditory feedback. Collaboration between theatre practitioners, physiologists, and sound designers can innovate physiologic sonification. Involving actors, directors, and sound designers in development can refine sonification strategies for larger productions. These directions advance physiologically-driven IMS in theatre, offering tools for artistic expression and scientific study.

Chapter 8

Conclusions and Future Work

The chapter begins by outlining the study's key findings, which include the establishment of a taxonomy for constructing physiologically-driven IMS and a retrospective analysis of physiological sensors in interactive music. Following this, a proposed experimental protocol delves into scrutinizing the physiological connections with emotional valence and arousal during acting performances. The experiment yields a comprehensive dataset of physiological recordings. In collaboration with an actor and an artistic director, a techno-artistic project is conceptualized to probe the potential of Samuel Beckett's theatre. This endeavor culminates in developing a prototype for a physiologically-driven IMS, complemented by creating a novel software toolbox dedicated to creatively sonifying physiological signals in theatrical contexts. These innovations herald new horizons for artistic exploration and expression.

8.1 Key Findings

This research delved into the intricate relationship between emotional expression in acting and theatre sound, bridging a gap in understanding and application. The pivotal contribution of this thesis lies in the analysis of emotional expressions in theatre, mainly through auditory dimensions. The findings and contributions are multifaceted:

- **Empirical and Functional Taxonomy:** From the research stemmed an empirical and functional taxonomy designed explicitly for the IMS application driven by physiological signals. This taxonomy is a step forward in the precise and nuanced design of IMS, offering a structured framework for future developments in the field.
- **Historical Overview of Physiological Sensors in Interactive Music:** The thesis presents a comprehensive historical analysis of the use of physiological sensors in interactive music, spanning from 1965 to 2023. This extensive overview charts the evolution of technology in this domain and sets the stage for understanding current trends and future possibilities.

- **Experimental Protocol for Emotional Valence and Arousal in Acting:** A significant aspect of this research was the design and implementation of an extensive experimental protocol. This protocol was meticulously crafted to analyze the physiological correlates of emotional valence and arousal in acting. Complementing this was the development of a sophisticated software toolbox designed for recording, parsing, and storing physiological data, which stands as a testament to the intersection of technology and artistic expression.
- **DECEiVeR Dataset (DatasEt aCting Emotions Valence aRousal):** A key contribution of this study is the creation of a comprehensive dataset, encompassing approximately seven hours of continuous physiological recordings, meticulously curated to facilitate the recognition of a set of five emotions. This dataset is a significant resource for the field, offering an extensive and valuable tool for future research in emotion recognition and physiological responses in theatrical settings.
- **Software Toolbox for Creative Sonification** Within the scope of their research, a software suite named **Biosignal Processing Toolbox (BarT)** was developed. This toolbox was engineered to execute various functions, including data collection, data recording, feature extraction, mapping, and the real-time auditory representation of physiological signals. A key specification for BarT was its proficiency in a real-time environment, encompassing the entire process from feature extraction to the utilization of machine learning techniques, ultimately leading to sonification.
- **Techno-Artistic Project:** In collaboration with an actor and an artistic director, a techno-artistic project was conceived to explore the potential of Samuel Beckett's theatre. This experiment culminated in the creation of a prototype for a physiologically-driven IMS. Accompanying this was the development of a novel software toolbox dedicated to the creative sonification of physiological signals in the theatrical context, thereby opening new avenues for artistic exploration and expression.

8.2 Conclusions

This present section aims to interpret and clarify the results. It delves into the implications of the findings, discussing their relevance, significance, and potential impact. The section will also address the limitations of the research, providing a reflection on the study's constraints and their effects on the outcomes. Furthermore, it proposes areas for future research, suggesting directions that can build upon the current study's insights. Specifically, it will discuss three main results following the research questions.

1. **(Q1) Emotional Expression Through Physiology with Theatre Actors:** This section delves into how physiological signals can function as a medium for emotional expression within a theatrical framework. The intricacies of capturing and interpreting these signals in relation to actors' emotional expressions will be explored. Moreover, the challenges inherent in

designing an experimental protocol to assess the physiological correlates of emotional expression in theatre actors will be discussed. These challenges encompass addressing issues such as the variability in actors' physiological responses, the complexity of gauging emotions through physiological measures, and ensuring ethical treatment of participants during emotionally charged performances. The experiment yielded a dataset comprising a comprehensive array of physiological recordings meticulously curated to facilitate the recognition of a specific set of five emotions. This dataset includes preliminary analyses on modeling the recognition of acting emotions from raw, low- and mid-level temporal and spectral data, as well as examining the reliability of physiological data over time. It offers valuable insights into acting emotion recognition and affective computing by demonstrating how physiological signals capture emotions evoked during acting performances.

2. **(Q1)** The Design of a Software Toolbox for Rapid Prototyping Sound Interactions with Physiological Signals: This part will discuss developing and implementing a software toolbox designed for rapid prototyping of sound interactions with physiological signals. It will focus on how this toolbox facilitates the quick development of prototypes to explore new modes of musical interaction, incorporating multimodal data connected to the body. Additionally, the discussion will highlight how this tool makes the process more accessible and integrated, allowing for a broader exploration and experimentation in the context of theatre and performance art. The aim is to understand the impact of this toolbox on the creative processes in theatre production, specifically in terms of efficiency, innovation, and artistic expression.
3. **(Q2 and 3)** The Theatrical Implications of Designing a Physiological-Driven Interactive Musical System for Theatre: This part delves into integrating physiological data with sound in theatrical settings. We will explore how transforming physiological data into sound can enhance emotional expression in acting and the effectiveness of these techniques in translating and amplifying the emotional expressions of the body. Critical questions will be addressed: Does the actor perceive sound generated from their physiological data to augment their current emotional state? Conversely, does the actor feel overshadowed or restricted by this process, despite its origin from their physiological signals? These inquiries will aid in understanding the complex interplay between physiological feedback and actor performance, offering insights into such a system's potential benefits and drawbacks in a theatrical context.

8.3 Emotional Expression Through Physiology

This research contributes to theatrical studies and affective computing by introducing a peer-validated experimental protocol that assesses emotional expression in theatre actors without relying on emotionally charged imagery. This protocol serves a dual purpose, catering to the research and theatre communities.

For the research community, especially in areas like affective computing, the protocol offers a method to evaluate emotional expression solely through mental imagery, devoid of external emotive stimuli. This approach permits an intrinsic assessment of emotional states independent of external influences. By focusing on mental imagery, the research delved into the internal emotional processes of individuals, which is a departure from traditional methods that often rely on external cues to gauge emotions. This shift towards an internalized perspective of emotional assessment could contribute to cognitive and emotional psychology research, providing insights into how emotions are formed and experienced from within.

In the theatre community, this methodology provides a window into the subtleties of emotional expression as reflected in physiological signals. It augments the existing understanding of the role of the body in theatrical performance, shedding light on how actors' physical states are intricately linked with their emotional portrayals. This understanding is crucial for actors and directors as it highlights the importance of internal emotional processes in enhancing the authenticity and depth of performances. It suggests that actors harness their mental imagery to evoke emotions, which can lead to more convincing and impactful performances.

The protocol's effectiveness was demonstrated by its ability to evoke specific emotions using only mental imagery, as evidenced by statistically significant variations in valence and arousal levels. This underscores the power of mental imagery in eliciting distinct physiological responses that align with particular emotional states, thereby validating the effectiveness of the experimental design. This finding is particularly significant as it suggests that mental imagery can be a powerful tool in actor training, helping individuals to access and express emotions in a controlled and conscious manner.

The research also offers two crucial insights into the dynamics of emotional expression and physiological response in theatre actors, expanding the understanding beyond the norms observed in the general population. Firstly, it confirms that physiological signals in theatre actors indicate emotional states similar to those of the general populace. These signals, captured through physiological sensors, reveal subtle emotional shifts not detectable through other methods like motion capture or facial emotion recognition. This highlights the sensors' proficiency in detecting slight emotional changes, which could have significant implications for affective computing and emotion recognition technologies. These technologies could be refined to become more sensitive and accurate in detecting nuanced emotional states, which could have wide-ranging applications in human-computer interaction, mental health monitoring, and personalized entertainment.

Secondly, the study observes inconsistencies in actors' emotional expressions over repeated scenarios. Data analysis suggests a correlation in certain aspects over time, with facial EMGs showing consistency across sessions, indicating retention of voluntary signals such as facial expressions. Conversely, PZT data, reflecting involuntary responses like breathing, did not show this consistency. This disparity highlights the complexity of emotional expression in theatre actors and the necessity for bespoke research approaches for specialized groups like actors. It suggests that actors develop unique mechanisms to control and modulate emotional expressions. This could be explored further for insights into emotional regulation and expression in high-pressure or public

performance settings.

Furthermore, the study uncovered variances in actors' methods to attain similar emotional objectives. The data analysis indicated a lack of uniform correlation among individuals, suggesting that each participant utilized their unique strategy to achieve and maintain the targeted emotional state. For instance, in conveying the emotional state of tiredness, actors did not consistently rely on respiration, a typical indicator of fatigue. Instead, some participants opted for alternative strategies, such as employing specific body postures that effectively communicated tiredness. This observation is crucial, mainly when designing physiologically driven IMS. It implies that each system must be individually calibrated, as physiological responses and the means of expressing emotions vary significantly from one person to another.

In a theatrical context, where multiple IMSs might be in use, this necessity for personalization becomes even more critical. Each system should be precisely tuned to align with the individual actor's physiological patterns and emotional expression strategies. This personalization ensures that the IMS responds accurately to each actor's unique physiological cues, enhancing the performance's authenticity and impact. The disparity observed in the study, particularly between facial EMGs, which showed consistency in voluntary signals like facial expressions, and PZT data, which did not show consistency in involuntary responses such as breathing, further underscores the complexity of emotional expression in theatre actors. It highlights the need for bespoke research approaches when dealing with specialized groups like actors and suggests that actors may develop distinct mechanisms to control and modulate their emotional expressions. Understanding these unique mechanisms can provide valuable insights into emotional regulation and expression in high-pressure scenarios or public performances, thereby enriching the field of affective computing and theatrical studies.

Additionally, a significant contribution to the experiment was the creation of the DECEIVER dataset, which sheds light on the methods actors use to express and communicate emotions. This dataset, now accessible to the public, comprises over four hours of continuous physiological data, providing a unique perspective on emotional expression among trained theatre actors. Its value is further enhanced by the inclusion of replicated data gathered after a two-week interval. It offers a reliable means to evaluate the consistency of the actors' emotional expressions, making the DECEIVER dataset a valuable tool for researchers and professionals in fields like theatre, psychology, and affective computing, as it presents comprehensive data for thorough analysis and research.

Notably, the dataset has gained recognition in the academic community, published in Nature Portfolio, specifically in Nature Scientific Data, a prestigious international journal renowned for its scientific contributions. The decision to feature the dataset in this journal stems from its revelation of novel forms of emotional expression unique to specialized individuals, such as theatre actors. The nomenclature DECEIVER captures the essence of the dataset – it reflects the subtle art of deception that actors employ to captivate and sustain the audience's interest and curiosity, a fundamental aspect of theatrical performance. This acknowledgment by a leading journal underscores the dataset's significance and the groundbreaking insights it offers into the nuanced world

of emotional expression in theatre.

The dataset's utility in exploring how actors articulate and project emotions is particularly noteworthy. The dataset could be used to develop new training methods for actors, helping them to understand and harness their physiological responses to enhance their emotional expression. It could also create more emotionally engaging and interactive theatrical experiences, where the audience's responses could be integrated into the performance in real time.

The research contributes to our understanding of emotional expression in theatre actors, offering new methodologies and insights that have implications for the research and theatre communities. The development of the DECEIVER dataset and the novel experimental protocol contributes to the field, providing tools and data that could transform our approach to studying and understanding emotional expression in theatre.

8.4 Designing Physiological Driven Interactive Music Systems for Theatre

The study's exploration of physiological sensors in theatre sound design offers a different perspective on how we experience and interact with theatrical performances. This innovative approach, framed by four key variables – gesture typology, sensor selection, mapping strategies, and sonification techniques – opens creative avenues in theatre and, more specifically, in sound design.

The research defined three distinct gesture typologies – implicit, explicit, and hybrid – each uniquely shaping the theatrical experience. Implicit gestures, characterized by subtle sound manipulation by actors, foster a richer and more immersive experience. This method enables actors to naturally express emotions, leading to performances that deeply resonate with the audience. For example, actors' control over inaudible sound sources in scenes of neutrality can more effectively convey solitude on stage, surpassing traditional methods in emotional depth. In contrast, explicit gestures tend to produce more predictable performances. A clear instance is scenes depicting tiredness, where the straightforward link between movement and sound can diminish the audience's sense of surprise.

By combining explicit and implicit elements, hybrid gestures have proven particularly effective in complex scenes, such as those depicting tension. These gestures allow for the manipulation of various sound elements, resulting in a dynamic and captivating performance.

This gesture typology offers valuable insights into physiologically driven IMS design. The inherent characteristics of each gesture type lead to distinct sound interactions, providing a framework for actors and sound designers to create nuanced soundscapes. The actor in our experiment, "Acting Emotions 2," utilized this taxonomy to craft and develop his character, creating a dramaturgy rooted in gestures. For instance, when the character navigates the theatrical space, he moves to a specific area on the stage. In this space, sound is activated by the actor's motion, which is detected through the EMG, and his movement dynamics, which are captured by the IMU sensor. This integration of gesture and sound enhances the storytelling and adds a layer of interactivity and physicality to the performance.

The actor's exploration of these gesture typologies underscores the potential for creative expression and character development within the realm of theatre. Adopting a gesture-based approach to dramaturgy, the actor infused his performance with a unique blend of motion and sound, bringing a new dimension to his character's journey through the theatrical space. This approach demonstrates the transformative power of integrating physiological sensors and gesture typologies in theatre, offering a fresh perspective on character development and narrative construction.

Selecting sensors like EMG and EDA sensors is crucial in capturing an actor's physiological responses and converting them into sound feedback. This technology fosters a more profound link between the actor's emotional state and their performance, thereby creating a sound environment that is both responsive and interactive. For instance, in a tension-filled scene, using a sample granulator module enabled sound modulation based on the actor's posture, thereby infusing additional depth into the performance.

In terms of sensor-sound interaction, various sound design elements were considered. In the initial phase, simple raw sounds, such as basic oscillators, were effective when the actor first interacted with the system. These basic signals, including sine oscillators and filtered noise generators, established a clear connection between the physiological signal and the corresponding sound event. As the experiment progressed into the middle phase, more complex sound generators like granulators offered a richer interaction with sound. An intriguing instance was observed during the second experiment's scene, where a recording of Beckett's voice was manipulated in response to muscle tension, allowing the character to audibly interact with his writer by controlling the sound with muscle strength, creating a captivating theatrical moment.

At a higher level, extracting temporal features from sensors like the EDA facilitated a connection to musical rules. For instance, the median values from 10- and 30-second time windows determined which musical rules would be activated. The EDA sensor proved particularly effective in controlling ambient sounds. This layered approach to sensor-sound interaction, progressing from simple to complex systems, not only allowed for a gradual adaptation and exploration for the actor but also enriched the overall auditory experience of the performance. The experiment demonstrated sophisticated integration between technology and theatrical expression by meticulously calibrating the sound design to respond to various physiological cues. This methodology illustrates how physiological sensors can be harnessed to create a dynamic and immersive soundscape, enhancing the actor's performance and the audience's experience.

The research underscored the effectiveness of both one-to-many and many-to-many mapping strategies in theatrical settings. These mapping approaches deliberately separate specific sounds from theatrical elements, deepening the dramatic impact and encouraging more inventive exploration on stage. Such strategies are exceptionally beneficial in scenes that demand intricate emotional expressions, as they facilitate a more subtle and layered delivery of the story.

In addition to these strategies, the mapping approach emerged as a crucial aspect of our study. In specific scenarios, a one-to-one mapping provided significant theatrical value. For instance, in a scene from "Acting Emotions 2," the actor utilized his breathing to trigger a recording of a woman's voice. This direct linkage created a transparent relationship between the actor's respira-

tion and the resultant sound, enhancing the scene's emotional impact. However, when a one-to-many mapping was employed, it was less effective theatrically. During these moments, the actor experienced a sense of detachment as it became challenging to discern which sound parameter was being manipulated. This observation underscores a vital consideration in designing such systems: the need for a clear and discernible connection between the actor's actions and the sound output.

This clarity is crucial for the actor, who requires precise control over their performance. In contrast, the audience may not need to fully understand the connection between the actor's movements and the sound; the actor on stage benefits from having a more transparent and controllable interaction with the sound system. Therefore, when designing physiologically driven interactive systems for theatre, it is crucial to balance creating an engaging experience for the audience and ensuring that the actors maintain a sense of control and connection with the sound elements. This balance enhances the theatrical experience, allowing actors to confidently explore and express complex emotions while immersing the audience in the narrative.

The integration of physiological sensors into theatre sound design brings with it a host of both technical and creative challenges. Achieving precision and reliability in the sensors is as crucial as ensuring their seamless integration into live performances. Striking the right balance between technical accuracy and artistic expression is essential for successfully implementing this technology in a theatrical context. As we look to the future, incorporating physiological sensors in theatre sound design offers exciting research and creative innovation opportunities. With ongoing technological advancements, we can anticipate the development of more sophisticated sensor technologies capable of capturing a broader spectrum of physiological responses. Such progress promises to lead to more detailed and responsive sound designs, significantly amplifying the emotional resonance of theatrical performances.

The decision to incorporate this technology into theatre productions requires careful consideration. The time invested in calibration, interaction design, sound control, and working with the public address systems, along with collaboration with the artistic director and actors, indicates that this system needs to be integrated from the early stages of production. The system should be in place from the outset, allowing actors to engage with it during the initial production phases. This early involvement is crucial for adapting the system to each actor's unique method of emotional expression, ensuring that the sound design accurately mirrors their performance style. Such personalization is vital not only for the authenticity of the performance but also for the comfort and creative freedom of the actors.

Moreover, using physiological sensors in theatre impacts actor training and skill development. Actors can utilize feedback from these systems to refine their mastery of physiological responses, enhancing their ability to portray complex emotions and narratives. This interaction could lead to developing new acting techniques and methodologies, pushing the boundaries of traditional theatrical expression.

Incorporating physiological sensors in theatre sound design is not just a technological addition but a holistic process that intertwines with the creative flow of the production from its inception. It demands careful planning and integration, considering each actor's unique characteristics and

needs, as well as the overall artistic vision of the performance. As this technology evolves, it has the potential to revolutionize how performances are delivered and how actors train and develop their craft, marking a significant evolution in the art of theatre.

Physiological sensors for developing theatre sound design offer a transformative approach to performance art. It enriches actor performance, deepens audience engagement, and enhances the narrative discourse of theatre productions. The potential for innovation and the benefits of the theatrical experience are immense. This approach promises a future where theatre and performance art become more immersive, interactive, and expressive forms of storytelling, captivating audiences in entirely new ways.

8.5 Software Toolbox for Sound Interactions with Physiological Signals

The Biosignal Processing Toolbox (BarT) developed in our study is a testament to the evolving intersection of technology and art, particularly within the realm of theatre. BarT's capabilities encompass a broad spectrum of functionalities, making it an indispensable tool in the world of interactive media art. The design of BarT, with its focus on real-time operations, addresses the need for seamless and immediate interaction between physiological signals and their artistic representation.

The initial phase of BarT's operation, centered on capturing, assessing, and interpreting physiological data, lays the groundwork for the more complex stages of the process. This phase is critical as it establishes a solid foundation of accurate and reliable data, which is essential for the effectiveness of the subsequent stages. Following this, BarT transitions into a phase where it systematically incorporates algorithms to embed the physiological signals within the structure of IMSs. This embedding is a crucial step in bringing the physiological data to life in an artistic context, allowing for creation of dynamic and responsive soundscapes that can interact with actors in real-time.

The structure of BarT is particularly noteworthy, featuring Max/MSP abstractions and intuitive graphical user interfaces designed for efficient data analysis and visualization. These GUIs enable both researchers and artists to interact with the data in a user-friendly manner, making it accessible to a wide range of users. Moreover, the specialized sonification modules within BarT are a crucial feature, offering a spectrum of sound generation capabilities, from basic granular synthesizers to advanced granular synthesis mechanisms employing neural networks.

This diversity in sonification options allows artists to choose the most appropriate sounds for their specific project or performance, giving them the flexibility to create unique and engaging auditory experiences. BarT's ability to manage a variety of physiological signals, such as EMG, ECG, and EDA, adds to its versatility. The unique characteristics and processing requirements of each type of biosignal provide distinct opportunities and challenges for sonification. For instance, EMG signals can create soundscapes that mirror the actor's physical movements, adding a layer of physicality to the performance. ECG signals can sonify the emotional undercurrents of a theatrical

performance, potentially syncing the rhythm of the sound with the actor's heartbeat. EDA signals, reflecting emotional arousal, can alter the soundscapes in response to changes in the actor's emotional state, providing a direct link between the performer's internal experience and the external auditory expression.

This detailed toolbox aims to provide a comprehensive understanding of the potential of each signal type, offering insights into how they can be creatively utilized in theatrical and broader interactive media art contexts. By understanding the nuances and capabilities of each physiological signal, artists and researchers can push the boundaries of traditional artistic expression, creating experiences that are not only immersive and interactive but also profoundly resonant on an emotional level.

BarT, therefore, is not just a tool; it is a bridge that connects the physiological with the artistic, opening up new possibilities for how art can be experienced and interacted with. Its development marks a contribution to integrating technology in art, particularly in how physiological data can enhance the audience's experience. BarT paves the way for a new era of interactive and immersive art forms by providing a platform for real-time processing and sonification of physiological signals.

As we continue to explore and refine the capabilities of BarT, it plays a pivotal role in the future of interactive and immersive art. Its potential for innovation and creativity is valuable, offering artists and researchers new ways to explore the intersection of physiology and art. BarT's development clearly indicates the exciting directions in which interactive media art is headed, promising a future where art is seen heard and felt in a more profound and connected way. This future of art, powered by tools like BarT, holds the promise of more personal, engaging, and emotionally impactful experiences than ever before.

While developing the Biosignal Processing Toolbox and integrating physiological sensors in theatre promotes advancements in interactive media art, this study has notable limitations that must be acknowledged.

Firstly, the complexity of real-time data processing poses a significant challenge. The need for immediate and accurate interpretation of physiological signals requires sophisticated algorithms and robust hardware capabilities. Any lag or error in processing can disrupt the synchronization between the actor's physiological responses and the corresponding auditory feedback, potentially diminishing the impact and coherence of the performance.

Secondly, the customization and calibration of the system for individual actors present logistical challenges. Each actor's unique physiological responses necessitate a personalized setup, which can be time-consuming and requires a deep understanding of both the technology and the actor's specific characteristics. This individual calibration process may limit the scalability and ease of implementation in more extensive or diverse theatre productions.

Thirdly, relying on advanced technology, such as BarT and BITalino boards, might impose financial and technical constraints, especially for smaller theatre companies or independent artists. The cost of acquiring, maintaining, and updating such technology can be prohibitive, potentially limiting access to a broader range of users and stifling wider adoption in the field.

Furthermore, there is a learning curve associated with the use of this technology. Actors and production teams must be trained to use and interact with the system effectively. This requirement for specialized knowledge and skills can be a barrier to entry for some, hindering the integration of this technology into mainstream theatrical productions.

The study also faces the challenge of ensuring the comfort and unobtrusiveness of the sensors during performances. If the sensors are noticeable or restrictive, they can impede the actors' movement and expressions, thus affecting the authenticity and fluidity of the performance. Finding the right balance between technological integration and the natural dynamics of a theatrical performance remains a key concern.

Moreover, ethical considerations regarding the use of physiological data need to be carefully managed. Privacy, consent, and the potential misuse of sensitive biometric data must be addressed, ensuring that this technology aligns with ethical guidelines and respects the rights and dignity of the actors involved.

Finally, while the toolbox offers a range of sonification options, the artistic interpretation of physiological data can be subjective. Translating physiological signals into sound is an interpretive process that may only sometimes accurately or effectively convey a performance's intended emotional or narrative elements. This subjectivity can lead to consistency in how audiences interpret and engage with the performance.

In conclusion, while integrating physiological sensors and developing BarT fosters the intersection of technology and theatre, these advancements come with inherent limitations. Addressing these challenges will further refine this technology and broaden its application to interactive media art and theatrical performance.

8.6 List Of Publications

Biosensing in Interactive Art: A User-Centered Taxonomy (Aly et al., 2019). A user-centered taxonomy of bio-sensor technology is presented to provide a comprehensive view of the utilization of bio-sensing technologies for controlling parameters in the virtual domain of digital interactive systems. By adopting this user-centered perspective on bio-sensing technology, the objective is to expand existing taxonomies beyond the technical specifications of the sensors. This approach aims to facilitate a flexible and intuitive utilization of such technology by interactive artists, promoting its seamless integration into creative processes.

Appropriating Biosensors As Embodied Control Structures In Interactive Music Systems (Aly et al., 2021). A scoping review examining the integration of biosensors as control mechanisms in IMSs. Drawing on transdisciplinary perspectives spanning biomedicine, musical performance, and interaction design, we establish a taxonomy for biosensor-driven IMSs. Through compiling and categorizing a comprehensive catalog of 70 biosensor-driven IMSs published between 1965 and 2019, we identify representative historical trends. Notably, our analysis critically

assesses the hypothesis that biosensing technologies are diversifying the range of control structures within IMSs. Our findings confirm that this hypothesis aligns with the historical progression of biosensor-driven IMSs. Based on these insights, we identify future challenges for innovating control modalities across human and machine interfaces, with the aim of reshaping the agents involved in interactive music creation and fostering new corporealities in extended performative contexts.

Acting emotions: physiological correlates of emotional valence and arousal dynamics in theatre (Aly et al., 2022) Professional theatre actors are highly specialized in controlling their own expressive behaviour and non-verbal emotional expressiveness, so they are of particular interest in fields of study such as affective computing. We present Acting Emotions, an experimental protocol to investigate the physiological correlates of emotional valence and arousal within professional theatre actors. Ultimately, our protocol examines the physiological agreement of valence and arousal amongst several actors. Our main contribution lies in the open selection of the emotional set by the participants, based on a set of four categorical emotions, which are self-assessed at the end of each experiment. The experiment protocol was validated by analyzing the inter-rater agreement (> 0.261 arousal, > 0.560 valence), the continuous annotation trajectories, and comparing the box plots for different emotion categories. Results show that the participants successfully induced the expected emotion set to a significant statistical level of distinct valence and arousal distributions.

Acting Emotions: A Comprehensive Dataset Of Elicited Emotions (Aly et al., 2024) Emotions entail physiological systems assessable through techniques such as electromyography and electrocardiography. Previous studies on emotion recognition have predominantly centered on general population samples, neglecting the unique context of theatre actors who possess remarkable skills in emotive portrayal, known as acting emotions. A study involving 11 professional actors was conducted to gather physiological data on acting emotions and explore the correlation between physiological signals and emotional expression. The contribution of the research is the DECEiVeR (DatasEt aCting Emotions Valence aRousal) dataset, meticulously curated to facilitate the recognition of a specific set of five emotions. Additionally, a preliminary analysis was conducted to model the recognition of acting emotions using raw, low- and mid-level temporal and spectral data, along with examining the reliability of physiological data over time. The dataset aims to deepen understanding of the intricate interplay between physiological signals and emotional expression, offering valuable insights into acting emotion recognition and affective computing by elucidating the extent to which physiological signals capture emotions elicited from internal stimuli.

8.7 Limitations

The study was taken in the intersection of technology and artistic expression in exploring the relationship between emotional expression in acting and theatre sound, mainly through the lens of physiological sensors and IMS. However, this journey had its limitations. A primary constraint

lies in the scope of physiological sensors employed. Focusing predominantly on specific sensors like ECG and EDA, the study may have yet to capture the entire gamut of physiological responses accompanying the rich tapestry of human emotions. This limitation points to the need for incorporating a broader array of sensors, such as EEG, in future research, potentially unveiling a more comprehensive understanding of emotional expressions in theatre.

Moreover, the study's participant pool, pivotal in drawing insights, might have had its constraints. If the number of participants was limited or needed more diversity in terms of cultural backgrounds and acting experiences, this could potentially limit the generalization of the findings. The intricate nuances of emotional expressions, which often vary across different cultural and experiential backgrounds, suggest that future research could benefit from a more diverse and expansive participant base.

While meticulously crafted, Acting Emotions 1 experimental settings also present a limitation. The controlled environment of these settings, essential for scientific rigor, may only partially mirror the dynamic and often unpredictable nature of live theatre performances. This gap between the experimental setup and real-world scenarios could affect the direct applicability of the findings in actual theatre settings, highlighting an area for future research to bridge.

The study's focus on low and mid-level data analysis, though insightful, left the realm of high-level analysis relatively uncharted. The complex patterns that might emerge from a more in-depth analysis of the multimodal data remain a potential treasure trove for future studies, particularly those employing advanced machine learning techniques. This more granular level of analysis could significantly enhance our understanding of the physiological underpinnings of emotional expressions in theatre.

Technological constraints inherent in the physiological sensing and IMS tools used in the study also pose a noteworthy limitation. These tools, while cutting-edge, might have limitations in terms of accuracy, responsiveness, and the ability to capture the subtle nuances of emotional expressions. As technology evolves, so will the capabilities of these tools, offering promising prospects for future research. The study's interdisciplinary approach, merging the realms of acting and sound in theatre and technology, was ambitious. However, the depth of integration across these disciplines might have its limitations. A deeper, more comprehensive interdisciplinary exploration could yield richer insights and understandings, paving the way for a more nuanced fusion of these fields.

Subjectivity in emotional expression and perception also presents a limitation. Emotional experiences and expressions are profoundly personal and varied, and the study's methodologies for categorizing and interpreting these emotions might only encapsulate part of the spectrum of human emotional experiences.

Finally, potential experimental design or data analysis biases could have influenced the study's findings. Future research efforts might focus on more robust experimental designs and analytical methodologies to mitigate these biases, ensuring the validity and reliability of the findings. In summary, while the study made significant strides in understanding the interplay between emotional expression, theatre sound, and technology, these limitations provide valuable insights and

directions for future research endeavors. They underscore the need for broader sensor arrays, more diverse participant pools, adaptation to real-world settings, deeper data analysis, technological advancements, more profound interdisciplinary integration, and refined methodologies to advance this intriguing field of study further.

8.8 Future Work

Building on the comprehensive insights from this research, which explored the interplay between emotional expression in acting and theatre sound through a multifaceted lens, numerous opportunities for future work emerge. These opportunities not only extend the scope of the current research but also open new avenues in the field of Interactive Music Systems (IMS), physiological sensing in artistic contexts, and the broader realm of techno-artistic collaborations.

- **Expanding the Empirical and Functional Taxonomy for Diverse IMS Applications** Developing an empirical and functional taxonomy tailored for IMS applications based on physiological signals is a valuable contribution. Future work could explore the application of this taxonomy across various artistic domains, such as dance, visual arts, and multimedia installations. The adaptability and effectiveness of the taxonomy in these different contexts could be examined, potentially leading to its refinement and expansion. Additionally, investigating the taxonomy's application in therapeutic settings, like music therapy, could open new research pathways, offering insights into the therapeutic benefits of IMS.
- **Advancing Historical Analysis Beyond 2024** The comprehensive historical analysis of physiological sensors in interactive music, spanning nearly six decades, lays a solid foundation for understanding the evolution of technology in this domain. Future research should extend this analysis beyond 2024, capturing the latest technological advancements and trends. This continuous historical documentation would provide invaluable insights into technological progress in interactive music, offering a predictive lens for future innovations and applications.
- **Diversifying Experimental Protocols in Acting Across Cultures and Styles** The meticulously crafted experimental protocol for analyzing emotional valence and arousal in acting presents an extensive framework for future studies. Subsequent research could focus on applying this protocol across various acting styles, cultural contexts, and theatre genres. Such a diversified approach would enhance the understanding of physiological correlates of emotions in different acting traditions and practices. Additionally, comparative studies between actors with varying experience levels or different cultural backgrounds could reveal intriguing aspects of emotional expression and perception in theatre.
- **Leveraging the Physiological Recordings Dataset with Advanced Analytical Techniques** Creating a comprehensive dataset consisting of seven hours of physiological recordings is a significant achievement. Future research should leverage this dataset using advanced data

analysis techniques like machine learning and deep learning for more nuanced emotion recognition and pattern analysis. The dataset could also be made publicly available, inviting the global research community to contribute their analyses and interpretations, enriching the field with diverse perspectives and findings.

- **Advancing Data Analysis to Higher Levels** While the current study made significant strides in low and mid-level analysis of multimodal data (including ECG, EDA, and other signals), there lies an untapped potential in conducting high-level analysis to extract more complex patterns from this data. Our approach, as outlined in the introduction, was aligned with the initial objectives and scope of the study. However, as the literature in this field suggests, comprehensive machine-learning experiments aimed at inferring higher-level patterns in such datasets warrant a focused and dedicated effort. Such an analysis, while beyond the aims and resources of our current study, is a critical area for future research. Our dataset provides a robust foundation for this endeavor. Future work can leverage this dataset to conduct in-depth analyses using advanced machine-learning techniques. This step will be instrumental in uncovering richer, more complex insights from the physiological data gathered, potentially revolutionizing the understanding of emotional valence and arousal in theatrical settings.
- **Statistical Analysis and Sensor Effectiveness** An essential aspect of the present work involved conducting statistical analysis to identify the most effective sensors for specific emotion recognition tasks. This analysis was crucial in determining how these sensors accurately capture the emotional valence and arousal dimensions reported by the professional actors participating in our experiments. The insights gained from this analysis provide valuable guidelines for researchers in emotion recognition, psychology, and interactive music systems. The contributions lay a strong foundation for subsequent studies that could include applying sophisticated machine-learning techniques to further explore and validate the DE-CeiVeR dataset's utility in psychology, machine learning, and other related areas. By doing so, future research can build on findings to develop more nuanced and accurate systems for emotion recognition, enhancing the interplay between technological and artistic expressions.
- **Exploring New Techno-Artistic Collaborations and Software Toolbox Applications** The techno-artistic project, focused on Samuel Beckett's theatre and the accompanying software toolbox for creative sonification, represents a novel intersection of technology and artistic expression. Future work could explore similar collaborations in other theatrical genres or even extend to other forms of performing arts, such as opera or ballet. The software toolbox could also be further developed to include more sophisticated features, such as real-time interactive capabilities. It could be tested in live performance settings to evaluate its impact on performers and audiences.

- **Investigating Longitudinal and Cross-Disciplinary Impacts** A longitudinal study to observe the evolving impact of technological integration in theatre over time could offer profound insights. This could involve tracking how audiences' reception and performers' adaptation to technology-enhanced performances evolve. Additionally, cross-disciplinary studies, collaborating with fields like psychology, neuroscience, and human-computer interaction, could deepen the understanding of technology's emotional and cognitive impacts in theatrical settings.
- **Addressing Ethical Considerations and Privacy Concerns** Addressing ethical considerations and privacy concerns becomes paramount as research in this field progresses, especially involving physiological data and interactive systems. Future studies should prioritize developing guidelines and best practices for ethical data collection, storage, and usage, particularly in artistic contexts involving personal and emotional expressions.
- **Contributing to Educational and Training Programs** The insights and tools developed through this research could significantly contribute to educational and training programs in theatre, music, and technology. Developing workshops, courses, or seminars that integrate these findings could foster a new generation of artists and technologists adept at blending artistic expression with technological innovation.

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Appendix A

Appendix

Title	Year	Author	Control	Device Type	Output modality	Response Type	Performative Affordances	Perceived Controllability	Device Obtrusiveness	Information Observability	Signal Property
[Item 1] Music for a Solo Performer	1965	Alvin Lucier	EEG	Custom	Sonification Kinetic	Generative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[Item 2] Spacecraft	1967	Richard Teitelbaum	EEG	Custom	Score driven	Generative Transformative	Multi-performer System	Low	Obtrusive	Long-term	Quasistationary
[Item 3] In Tune	1968	Richard Teitelbaum	EEG	Custom	Score driven	Generative	Multi-performer System	Low	Obtrusive	Long-term	Quasistationary
[Item 4] Ecology of the skin	1970	David Rosenboom, Richard Teitelbaum	EEG	Custom	Score driven	Generative Transformative	Multi-performer System	Low	Obtrusive	Long-term	Quasistationary
[Item 5] DIMI-T "Electroencephalophone"	1970	Erikki Kurenniemi	EEG	Custom	Score driven	Generative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[Item 6] Envrionetic synthesizer	1970	Woody Vaukka, Richard Lowenberg	EEG	Custom	Score driven	Generative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[Item 7] DIMI-S "Sexophone"	1971	Erikki Kurenniemi	EDA	Custom	Score driven	Generative	Multi-performer System	Mid	Obtrusive	Mid-term	Quasistationary
[Item 8] Corticalart I and II	1971-1973	Roger Lafose, Pierre Henry	EEG	Custom	Score driven	Transformative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[Item 9] Brain Wave Music	1974	David Rosenboom, Richard Teitelbaum	EEG	Custom	Score driven	Transformative	Multi-performer System	Low	Obtrusive	Long-term	Quasistationary
[Item 10] On Being Invisible I pt.1	1976-77	David Rosenboom	EEG	Custom	Score driven	Transformative Sequenced	Performer System	Low	Obtrusive	Long-term	Quasistationary
[Item 11] Clocker	1978	Alvin Lucier	EDA	Custom	Score driven	Transformative	Performer System	Mid	Obtrusive	Mid-term	Quasistationary
[Item 12] The Graphic Method Bicycle	1979	Dick Raaymakers	ECG, RESP, EMG	Custom	Score driven	Transformative	Performer System	Mid and High	Obtrusive	Mid-term	Quasistationary Nonstationary
[Item 13] HeartBeatsmb	1981	Chris Janney, Sara Rudner	ECG, EMG	Commercial Transkinetics inc.	Score driven	Generative	Performer System	Mid and High	Obtrusive	Mid-term Short-term	Quasistationary Nonstationary
[Item 14] Kagami	1991	Atau Tanaka	EMG	Commercial BioMuse	Score driven	Transformative Sequenced	Performer System	High	Obtrusive	Short-term	Nonstationary
[Item 15] Synesthesia	1992	Rita Addison et al.	ECG, RESP, EMG	Custom	Audio-visual	Sequenced	Multi-performer System	Mid and High	Obtrusive	Mid-term Short-term	Quasistationary Nonstationary
[Item 16] The Mnemonic Body	1995-2001	Alan Dunning, Paul Woodrow	EEG	Commercial IBVA Brain Machines	Audio-visual	Generative	Audience System	Low	Obtrusive	Long-term	Quasistationary
[Item 17] The Madhouse	1995-2001	Alan Dunning, Paul Woodrow	EEG	Commercial IBVA Brain Machines	Audio-visual	Generative	Audience System	Low	Obtrusive Inobtrusive	Long-term	Quasistationary
[Item 18] Dérive	1995-2001	Alan Dunning, Paul Woodrow	EEG, ECG, TEMP	Commercial IBVA Brain Machines	Audio-visual	Generative	Audience System	Low and Mid	Obtrusive Inobtrusive	Mid-term Long-term	Quasistationary Nonstationary
[Item 19] Body Degree Zero	1995-2001	Alan Dunning, Paul Woodrow	EEG, EMG	Commercial IBVA Brain Machines	Audio-visual	Generative Transformative	Audience System	Low and High	Obtrusive Inobtrusive	Long-term Short-term	Quasistationary Nonstationary
[Item 20] Conductor's Jacket	1998	Teresa Marrin-Nakra, Rosalind Piccard	EMG	Custom	Score driven	Sequenced	Performer System	High	Obtrusive	Short-term	Nonstationary
[Item 21] etheLife	1999	Greg Turner	ECG	Custom	Audio-visual	Transformative Sequenced	Performer System	Mid	Obtrusive	Mid-term	Quasistationary Nonstationary
[Item 22] BIOS - Bidirectional Input/Output System	2002	Thomas Tiet, Sven Hahne, Jaanis Garanes, Norman Müller	EEG	Custom	Audio-visual	Generative Transformative	Performer System	Low	Obtrusive	Long-term	Quasistationary Nonstationary
[Item 23] Sensors Sonic Sights	2003	Atau Tanaka, Cecile Babiolo, Laurent Dailieu	EMG	BioMuse	Audio-visual	Generative Transformative	Multi-performer System	High	Obtrusive	Short-term	Nonstationary

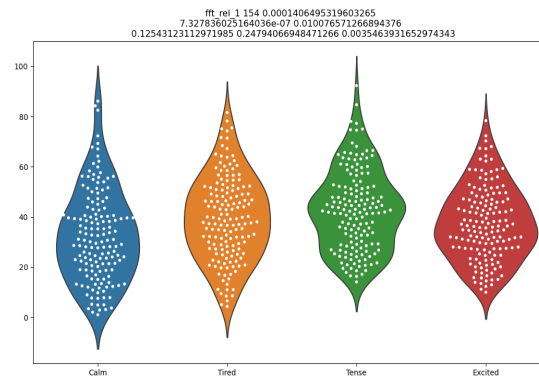
Figure A.1: A catalog of 70 physiological-driven IMS artworks, ranging in publication dates from 1965 to 2019, compiled and categorized according to the proposed taxonomy. Part 1.

Title	Year	Author	Control	Device Type	Output modality	Response Type	Performative Affordances	Perceived Controllability	Device Obtrusiveness	Information Observability	Signal Property
[Item 24] Sitting Breathing Beating (NOT) Thinking	2004	Adam Overton	EEG, EMG, RESP	Custom	Score driven	Generative	Performer System	Low and Mid	Obtrusive	Long-term Short-term	Quasistationary Nonstationary
[Item 25] Diamir	2007	Miguel Angel Ortiz, Benjamin Knapp, Michael Arcen	EDA	Commercial ThoughtTec	Score driven	Generative Transformative	Performer System	Mid	Obtrusive	Mid-term	Quasistationary
[Item 26] Carne	2008	Miguel Angel Ortiz	EMG	Custom	Score driven	Transformative	Performer System	High	Obtrusive	Short-term	Nonstationary
[Item 27] S&V	2009	Miguel Angel Ortiz	ECG	Custom	Score driven	Generative Transformative	Multiperformer System	Mid	Obtrusive	Mid-term	Quasistationary
[Item 28] The Multimodal Brain Orchestra	2009	Sylvain Le Goux, Jonas Manzoli, Paul FMJ Verschure	EEG	Commercial g.Tech	Audio-visual	Generative	Multiperformer System	Low	Obtrusive	Long-term	Quasistationary
[Item 29] The subCoach	2009	Mats J. Sivertsen	EEG	Commercial Emotiv EPOC	Audio-visual	Generative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[Item 30] Music Sensors and Emotion	2009	SARC	EMG	BioMuse	Score driven	Generative Transformative	Performer System	High	Obtrusive	Short-term	Nonstationary
[Item 31] Dentre	2010	Miguel Angel Ortiz	EEG, ECG	Custom	Sonification	Generative	Performer System	Low and Mid	Obtrusive	Long-term Mid-term	Quasistationary
[Item 32] Mind Pool	2010	Kiel Long, John Vines	EEG	Commercial Emotiv EPOC	Kinetic	Generative	Audience System	Low	Intrusive	Long-term	Quasistationary
[Item 33] The Brain Noise Machine	2010	Greg Kress	EEG	Commercial Neurosky EEG	Kinetic	Generative	Audience System	Low	Intrusive	Long-term	Quasistationary
[Item 34] Stahlhelm	2010	Christoph DeBebeck	EEG	IMEC	Kinetic	Generative	Audience System	Low	Intrusive	Long-term	Quasistationary
[Item 35] Unsound	2011	Miguel Angel Ortiz	ECG, EDA	BioMuse	Audio-visual	Generative	Audience System	Mid	Obtrusive Intrusive	Mid-term	Quasistationary Nonstationary
[Item 36] MoodMixer	2011	Grace Leslie, Tim Mullen	EEG	Commercial Neurosky EEG	Score driven	Generative Sequenced	Audience System	Low	Non-obtrusive	Long-term	Quasistationary
[Item 37] DECONcert	2011	Steve Mann, James Fung, Ariel Garten	EEG	Commercial ThoughtTec	Score driven	Transformative	Audience System	Low	Non-obtrusive	Long-term	Quasistationary
[Item 38] Music for Flesh I and II	2011	Marco Donnarumma	MMG	Open source Xbi Sense	Score driven	Generative Transformative	Performer System	High	Obtrusive	Short-term	Nonstationary
[Item 39] Hypo Chryson	2011	Marco Donnarumma	MMG	Open source Xbi Sense	Score driven	Generative	Performer System	High	Obtrusive	Short-term	Nonstationary
[Item 40] The Warren	2011	Joel Eaton	EEG	Custom	Score driven	Generative Transformative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[Item 41] Music for Sleeping and Waking Minds	2011	BioMuse Trio	EEG	BioMuse	Score driven	Generative	Multiperformer System	Low	Obtrusive	Long-term	Quasistationary
[Item 42] Brain Pulse Music	2012	Masaki Banoh	EEG, ECG	Commercial Neurosky EEG	Audio-visual	Transformative	Performer System	Low Mid	Obtrusive	Long-term Mid-term	Quasistationary Nonstationary
[Item 43] The Escalation of Mind	2012	Vaeolod Tiran	EEG	Commercial Emotiv EPOC	Audio-visual	Generative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[Item 44] Clasp Together (beta)	2012	Harry Whalley, Panos Mavros, Peter Furniss	EEG, ECG, ACC	Commercial Emotiv EPOC	Score driven	Sequenced	Performer System	Low to High	Obtrusive	Pervasive	Quasistationary Nonstationary
[Item 45] Omnious	2012	Marco Donnarumma	MMG	Open source Xbi Sense	Score driven	Generative Transformative	Performer System	High	Obtrusive	Short-term	Nonstationary
[Item 46] The Moving Forest	2012	Marco Donnarumma	MMG	Open source Xbi Sense	Score driven	Transformative	Performer System	High	Obtrusive	Short-term	Nonstationary

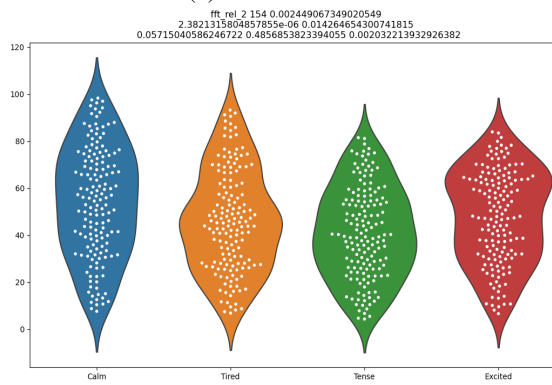
Figure A.2: A catalog of 70 physiological-driven IMS artworks, ranging in publication dates from 1965 to 2019, compiled and categorized according to the proposed taxonomy. Part 2.

Title	Year	Author	Control	Device Type	Output modality	Response Type	Performative Affordances	Perceived Controllability	Device Obtrusiveness	Information Observability	Signal Property
[item 47] [Radical] Signs of Life	2013	Marco Domarumma	PPG, MMG	Open source Xth Sense	Score driven	Generative Transformative	Performer System	Low	Obtrusive	Short-term	Quasistationary
[item 48] Alpha Lab	2013	George Khut, James P. Brown	EEG	Commercial Myndplay	Score driven	Generative	Audience System	Low	Obtrusive	Long-term	Quasistationary
[item 49] (un)Focused	2013	Alberto Novello	EEG	Commercial Emotiv EPOC	Audio-visual	Generative	Multi-performer System	Low	Obtrusive	Long-term	Quasistationary
[item 50] The Space Between Us	2014	Joel Eaton, Wei Wei Jin, Eduardo Reck Miranda	EEG	BioMuse	Score driven	Generative	Multi-performer System	Low	Obtrusive	Long-term	Quasistationary
[item 51] Conductor	2014	Jeff Crouse, Gary Gunn, Aramique	EEG	Commercial Neurosky EEG	Audio-visual	Generative	Audience System	Low	Obtrusive	Long-term	Quasistationary
[item 52] eeg-deer	2014	Dmitri Morozov	EEG	Modified Neconimi	Audio-visual	Generative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 53] Fragmentation: a brain-controlled performance	2014	Alberto Novello	EEG	Commercial Emotiv EPOC	Audio-visual	Generative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 54] Activating Memory	2015	Eduardo Reck Miranda, Joel Eaton	EEG	Commercial iG Tech	Score driven	Sequenced	Multi-performer System	Low	Obtrusive	Long-term	Quasistationary
[item 55] state.scape	2015	Mirjana Pipo, Svetozar Mucic, Bernhard Hecke	EEG	Commercial Emotiv EPOC	Audio-visual	Generative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 56] Deep Profundis	2015	David Mancini, Simona Lisi	EEG	Soundmachines, Neurosky	Score driven	Generative Transformative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 57] Vessels	2015	Grace Leslie	EEG, ECG, EDA	Muse	Score driven	Sequenced	Audience System	Low	Obtrusive	Long-term	Quasistationary
[item 58] Eyes Awake	2015	Grace Leslie, Carolyn Chen	EEG	Muse	Score driven	Sequenced	Audience System	Low	Obtrusive	Long-term	Quasistationary
[item 59] Emotion in Motion	2015	Benjamin Knapp, Javier Iainovich, Brennan Bortz	EEG, EDA	Custom	Data Recording	Sequenced	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 60] Choreography and Composition of Internal Time	2016	Tzoma Nacuato, John MacCallum	EEG	Custom	Score driven	Generative Sequenced	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 61] Behind Your Eyes, Between Your Ears	2016	George Khut	EEG	Muse	Audio-visual	Generative	Audience System	Low	Obtrusive	Long-term	Quasistationary
[item 62] Corpus Nil	2016	Marco Domarumma	EMG, MMG	Open source Xth Sense	Score driven	Generative Transformative	Performer System	High	Obtrusive	Short-term	Nonstationary
[item 63] E.E.G. Kiss	2016	Karen Lancel, Herman Maat	EEG	IMEC, Muse	Audio-visual	Generative Sequenced	Audience System	Low	Obtrusive	Long-term	Quasistationary
[item 64] Noor: a Brain Opera	2016	Ellen Pearlman	EEG	Commercial Emotiv EPOC	Score driven	Sequenced Transformative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 65] Synchronian	2016	Tzoma Nacuato, John MacCallum	EEG	Custom	Score driven	Generative Transformative	Performer System	Low	Obtrusive	Long-term	Quasistationary
[item 66] Tangente	2017	Tzoma Nacuato, John MacCallum	EEG	Custom	Score driven	Generative Sequenced	Performer System	Mid	Obtrusive	Mid-term	Nonstationary
[item 67] Harmonic Dissonance	2018	Mathias Oostrik, Suzanne Dikler	EEG, EDA	Commercial Emotiv EPOC	Audio-visual	Generative	Multi-performer System	Low	Obtrusive	Long-term	Quasistationary
[item 68] Atlas Zu tai	2018	Marco Domarumma	MMG	Open source Xth Sense	Score driven	Generative Transformative	Multi-performer System	High	Obtrusive	Short-term	Nonstationary
[item 69] Eingeweide	2018	Marco Domarumma	MMG	Open source Xth Sense	Score driven	Generative Transformative	Multi-performer System	High	Obtrusive	Short-term	Nonstationary
[item 70] Vreugt	2019	Cagri Erdem, Katja Henriksen Scha, Alexander Rebus Jenius	EMG	Commercial Myo	Score driven	Generative Transformative	Performer System	High	Obtrusive	Short-term	Nonstationary

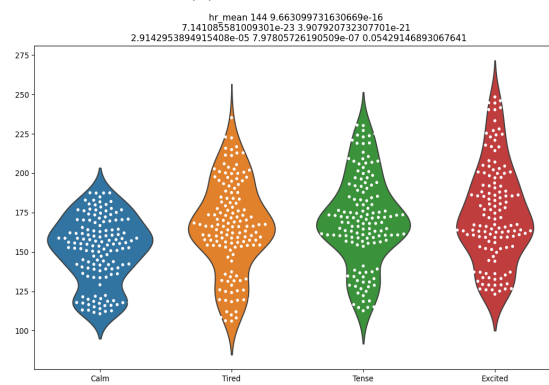
Figure A.3: A catalog of 70 physiological-driven IMS artworks, ranging in publication dates from 1965 to 2019, compiled and categorized according to the proposed taxonomy. Part 3.



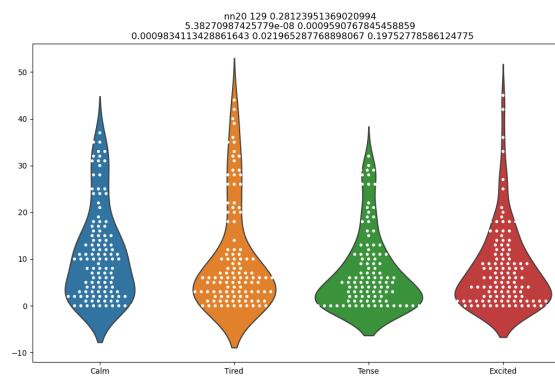
(a) ECG FFTREL1



(b) ECG FFTREL2

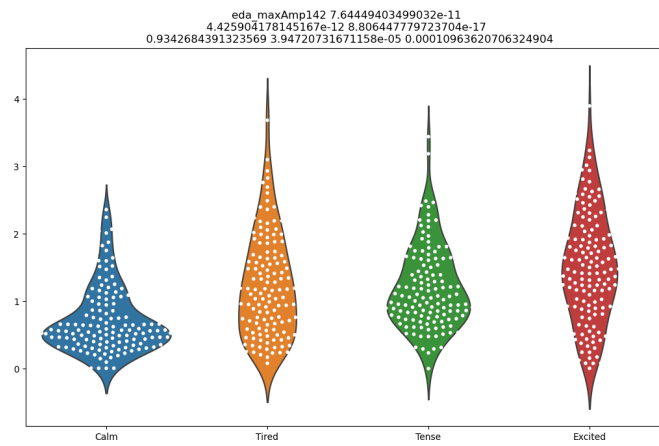


(c) HRMEAN

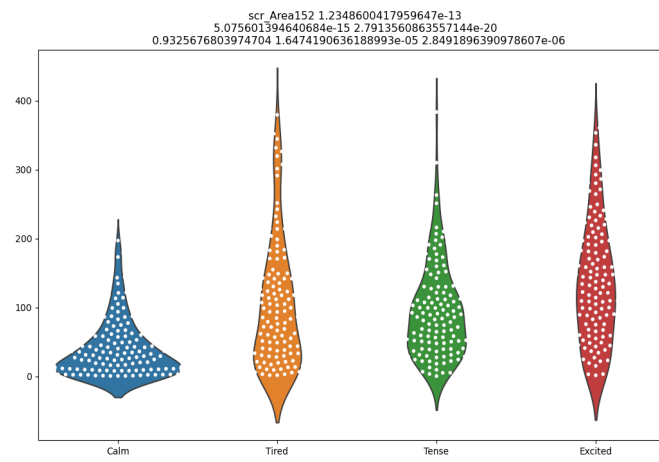


(d) ECG NN20

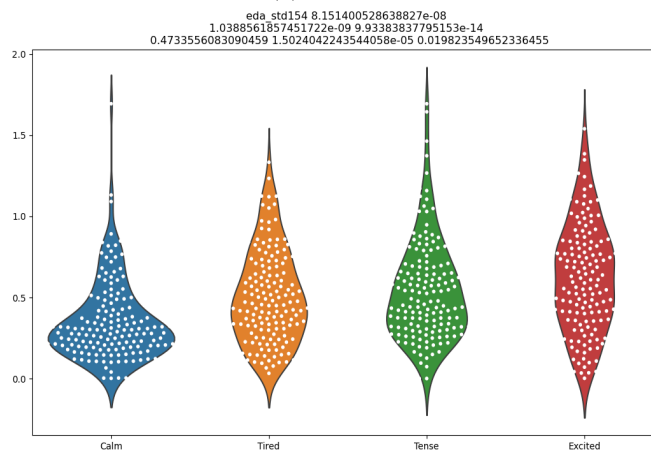
Figure A.4: ECG Spectral Features



(a) EDA MAXAMP

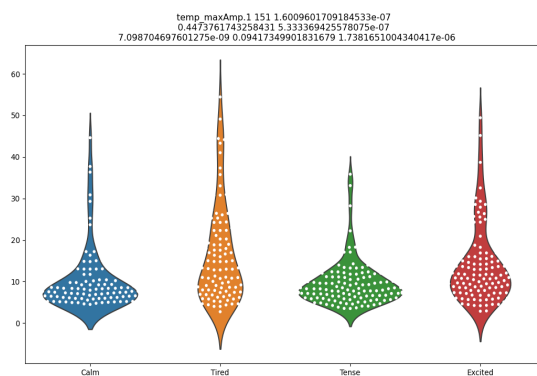


(b) EDA SCR

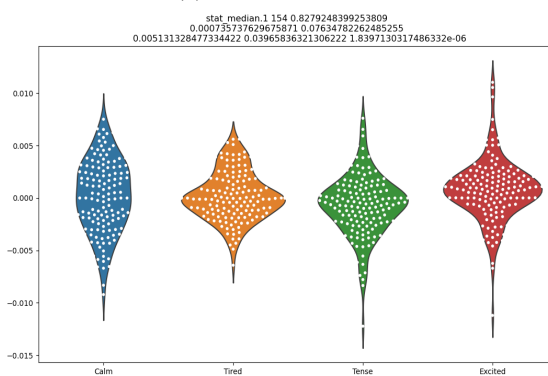


(c) EDA STD

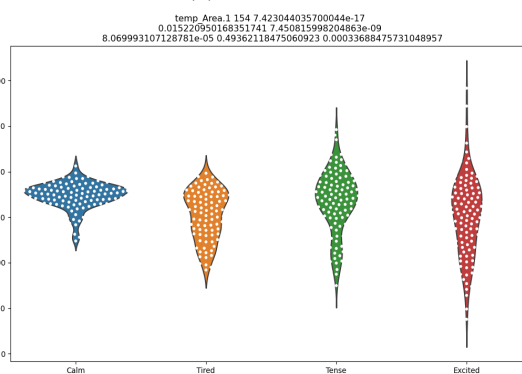
Figure A.5: EDA Features



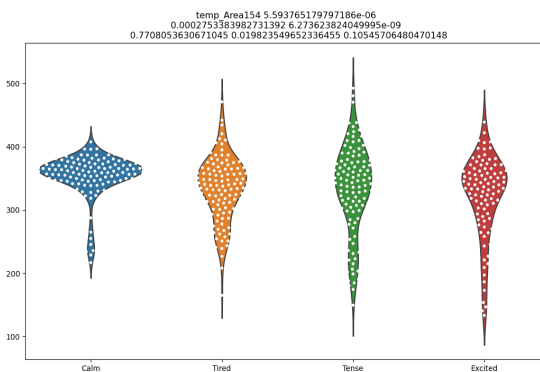
(a) EMG MAXAMP



(b) EMG STD

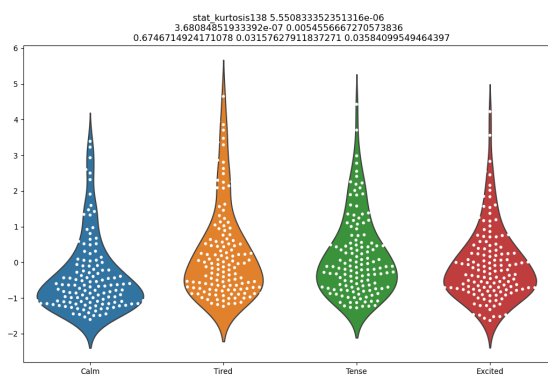


(c) EMG TEMP1

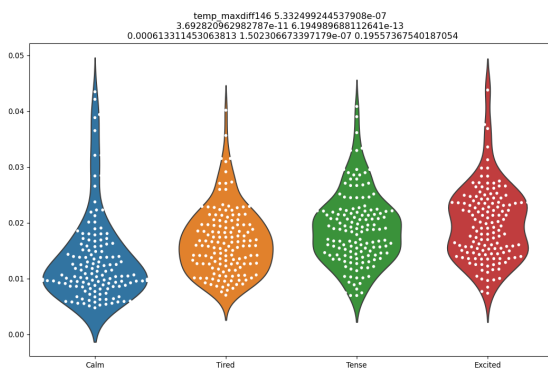


(d) EMG TEMP2

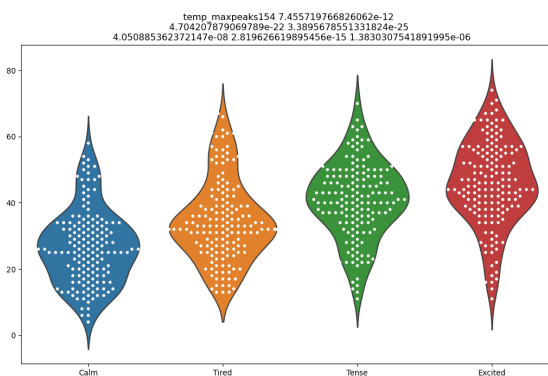
Figure A.6: EMG Features



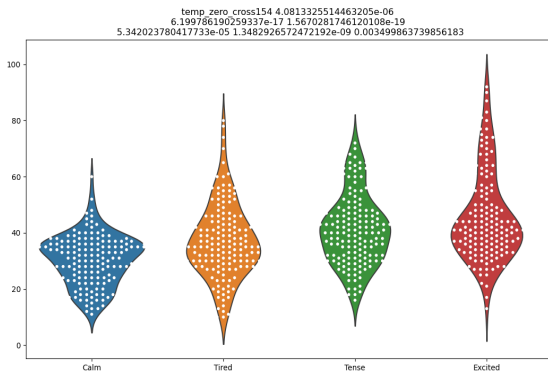
(a) PZT KURT



(b) PZT MAXDIFF



(c) PZT MAXPEAK



(d) PZT ZEROCROSS

Figure A.7: PZT Features