Rehearsals, Risks and Resilience: Stress, Acoustics, and Youth Orchestra Performance

Matthias Bertsch[1], Christoph Reuter[2], Tristan Leitz[1], Marik Roos[2]

[1] *University of Music and Performing Arts Vienna, Centre for Music Physiology, E-Mail:Bertsch@mdw.ac.at*

[2] *SInES Lab of Systematic Musicology, University of Vienna, E-Mail: christoph.reuter@univie.ac.at*

Introduction

Young orchestral musicians face complex challenges that extend beyond technical skill. The demands of high-level ensemble performance often expose them to elevated stress levels, inconsistent acoustic environments, and significant physical strain–all of which may compromise health and artistic performance. Prolonged exposure to high sound pressure levels, combined with the psychological pressures of public performance and career preparation, raises growing concerns about the long-term well-being of these emerging professionals [1,2,3,4,5]. Traditional training environments often fail to address the physiological and psychological resilience required for sustained performance excellence. In response, the EU-funded project The Future of Youth Orchestra - Addressing Physiological and Psychological Needs in Young Orchestral Musicians (www.tfoyo.eu) was initiated as an interdisciplinary pilot project. Coordinated by an interdisciplinary consortium – including De Unges Orkesterforbund (NUSO, Norway), Landesjugendorchester Hamburg (LJO, Germany), and the Austrian Society for Music and Medicine (ÖGfMM, Austria) – the project brings together expertise in music physiology, psychology, and acoustics.

Its primary aim is to enhance young musicians' health literacy and resilience through targeted interventions in hearing protection, physical preparation, and mental training. The project integrates 360° soundscapes, audiometric profiles, immersive VR training, standardized questionnaires, and continuous biosignal tracking. Further information and open-access educational resources are available on the project website (https://tfoyo.eu).

Study Design and Participants

The TFOYO-Project combines science, education, and artistic collaboration and was conducted as a mixed-methods research project involving two youth orchestras: the LJO (N=67) and the NUSO (N=69). A total of 136 musicians, aged 14 to 27 years (mean ≈18.3), participated in the study, which took place during a 10-day orchestral summer camp in Bodø, Norway (August 3-11, 2024), a 3-day fall camp in Hamburg and culminated in a professional concert at Hamburg's Elbphilharmonie (October 5, 2024). The participants covered a full range of orchestral instruments, including upper strings (N=55) lower strings (N=32), brass (N=21), woodwinds (N=19), percussion (N=6), keyed instruments, and harps.

Hearing Health and Acoustic Environment

Educational lectures – including an interactive Kahoot quiz – were used to raise awareness about hearing health. Participants were informed about the risks of hearing damage, acoustic facts related to maximum safe exposure times, and various hearing protection options. Emphasis was placed on treating the ears as a musician's most valuable instrument.

In addition, personal audiometric screenings and real-time documentation of sound exposure levels helped increase awareness and encouraged more responsible hearing protection practices.

Spatial Sound Exposure Mapping

During the piece "Festivity" composed by Ingebjørg Vilhelmsen in 2023, calibrated measuring microphones (1000 Hz at 114 dB_{SPL}) were used to measure the respective sound level at the musicians' ears at 16 positions in the orchestra. These measurements allowed for an interactive sound exposure map over the entire duration of the piece to be created. In this map, users can click on the positions of the individual musicians and the conductor and follow the corresponding levels evolving between 45 and 100 dB_{SPL}, thus hearing what the musicians hear at their respective positions (see Fig.1). The acoustic measurements are also documented with immersive 360° imagery, providing a comprehensive auditory and visual impression of the sound environment within the orchestra. This approach not only supports a better understanding of individual auditory exposure but also promotes awareness and encourages safer listening practices among young musicians.

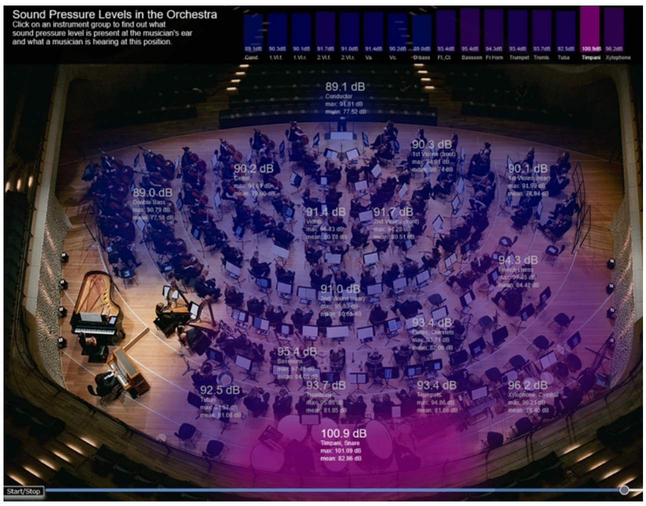

Figure 1: Interactive display of the sound pressure levels in the orchestra on the final chord of the work "Festivity"): The sound levels at the musicians' ears are between 90 and 100 dB_{SPL} (Interactive version available at: https://muwiserver.univie.ac.at/tfoyo)

Audiometric Screenings

Over 80 participants completed personal audiograms, which provided baseline data for identifying early signs of hearing loss. A clinical audiometer (Zeisberg CA350) was used to measure the hearing thresholds of most participating musicians, including 50 string players, 11 woodwind players, 16 brass players, and 1 percussionist. The results showed that the hearing of the young musicians was generally healthy in most cases. However, some early signs of hearing loss were observed – particularly among brass players (see Fig. 2). Nota bene: The percussionist's hearing threshold was exceptionally good, likely due to the use of individually customized hearing protection. All hearing thresholds can be explored by hovering over their instruments in the interactive orchestra setup at: https://muwiserver.univie.ac.at/tfoyo/audiometrie

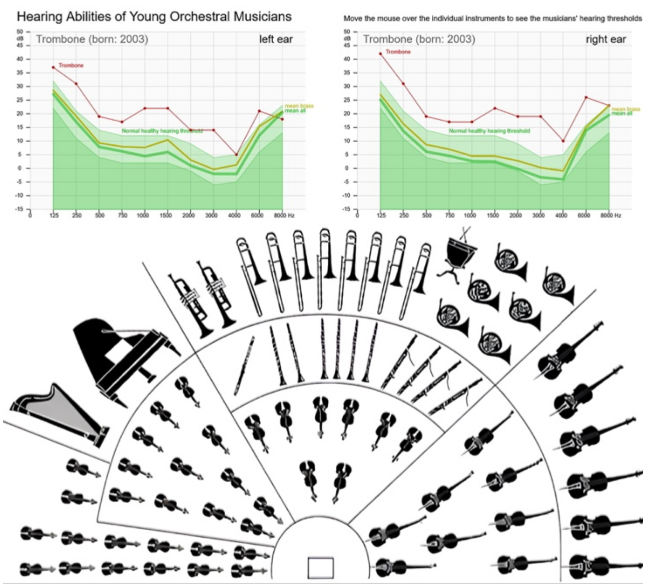

Figure 2: Audiograms of young orchestra musicians. The hearing thresholds of most musicians show a normal, healthy pattern and fall within the light green area of the diagram. In cases of higher sound exposure (e.g., among brass players), early signs of hearing loss become apparent (red curves). (Interactive version available at: https://muwiserver.univie.ac.at/tfoyo/audiometrie)

Physiological Monitoring

Smartwatch-Based Data Acquisition

Fifteen EmbracePlus smartwatches by Empatica – an advanced wearable sensor platform designed for continuous, high-resolution physiological monitoring – were assigned to 10 string players and 5 wind players. The devices recorded 24/7 data (whenever worn) of their biophysiological parameters. Aggregated per-minute data includes stress and energy indicators such as EDA (Electrodermal Activity), MET (Metabolic Equivalent of Task), pulse rate, step count, temperature, and wear detection, as well as accelerometer-based metrics. Only available at rest are PRV (Pulse Rate Variability, Respiratory Rate, Sleep Detection). [6] In addition, the device records high-resolution raw data streams as follows: Electrodermal Activity (EDA): 4 Hz; Blood Volume Pulse (BVP): 64 Hz; Skin Temperature: 1 Hz and Tri-axial Accelerometry: 64 Hz.

Data were transmitted in real-time to a secure online database known as the Care Lab, and were later downloaded and subsequently processed using custom-written R scripts, as the system itself does not provide built-in research analysis tools. However, the Care Lab offers online surveillance and real-time monitoring of users. The data do not rely on opaque "black box" algorithms, as commonly found in other commercial health monitoring devices. Thus, this comprehensive dataset enabled detailed tracking of stress responses, activity levels, and recovery patterns throughout the rehearsals, daily routines, and concert performances of the young musicians.

Physiological measurements were analyzed during key phases of the project–such as specific interventions, rehearsals, and the final concert at the Elbphilharmonie. Time markers were used to synchronize the physiological data with audio and video recordings, enabling precise contextual analysis. Biometric signals such as electrodermal activity (EDA) and pulse rate were plotted over performance times to identify stress responses during specific musical moments (e.g., solos, tutti passages, or climactic sections). Individual curves were further aligned with annotated musical scores and subjective self-reports to allow for a multimodal interpretation of the data.

Stress Response Visualization

Having a clear activity protocol is crucial for analyzing specific data. However, averaging the data across all participants allows for a general overview of physiological activation, especially since the musicians followed similar daily schedules. For example, acceleration data revealed the musicians' busy routines, such as "running" between meals at the hotel and rehearsals in Bodø. There was little downtime, and many participants showed late-night activity–likely influenced by the bright midnight sun in Bodø. Overall activity and stress levels can also be derived from averaged pulse data, as illustrated in Figure 3.

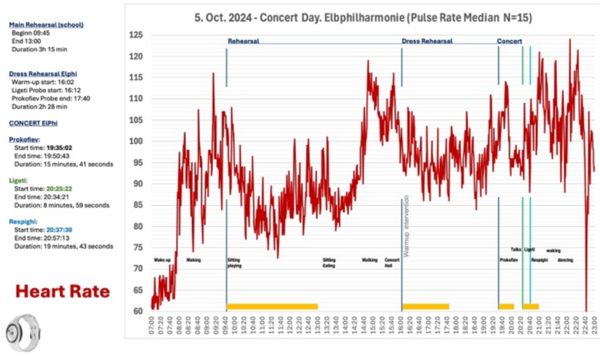

Figure 3: Physiological trajectories across the day: Rehearsal to performance. Averaged pulse rate of 15 musicians on concert day in Hamburg. The pulse data reveals an initial spike in the morning as musicians hurried to rehearsal, followed by a relatively calm rehearsal session. In contrast, the dress rehearsal at the Elbphilharmonie triggered heightened arousal, marked by a significant peak just before entering the hall. A warm-up on stage at the start of the rehearsal lowered the average pulse rate from approximately 115 to 95 bpm. Notable spikes were also observed before and at the start of the concert. A temporary decrease occurred during a "boring" speech, followed by a sharp rise in the second half of the performance. Post-concert peaks were attributed to a celebratory gathering.

It is an inherent challenge to visualize the enormous amount of data. For this reason, several R scripts were developed to display the minute-by-minute values of pulse rate and wrist temperature, along with a sliding 30-second window of each individual's electrodermal activity (EDA). Approximately 8,000 plots were animated and synchronized with the musical score and video recordings using exact time codes. These visualizations were compiled into videos rendered in 4K resolution. Links to the YouTube videos are available on the project website tfoyo.eu The structure of the visualization is illustrated in Figure 4.

Figure 4: Combined visualization output: A composite video shows pulse rate, wrist temperature, and real-time EDA values alongside the musical score and an audiovisual performance timeline. Links to the YouTube recordings of the Elbphilharmonie concert are available on the project website.

Visualizing a single individual player over specific time periods is less complex and can provide clear insights. Electrodermal activity (EDA), pulse rate, and wrist temperature are valuable indicators of stress, particularly for observing the activation of the sympathetic and parasympathetic nervous systems via the vagus nerve. Stressors typically lead to an increase in EDA. Pulse rate often shows a brief drop in response to a sudden shock, followed by an increase under sustained stress. As stress levels rise, peripheral vasoconstriction causes the hands to become colder, resulting in a drop in wrist temperature. Conversely, a relative increase in temperature is a strong indicator of relaxation and parasympathetic activation (see example in Fig. 5).

Such data-driven insights can support future approaches to stress management and resilience training in high-pressure musical environments.

Limitations EmbracePlus Data

In addition to occasional missing values – such as when the smartwatch is not worn correctly – several factors can influence data quality. EDA is sensitive to motion artifacts; when the wrist is in motion, the signal may contain noise or be dominated by artifacts. Aggregated values for pulse and temperature tend to be more reliable but are still subject to external influences such as physical activity or ambient room temperature, which may affect interpretation beyond stress-related changes.

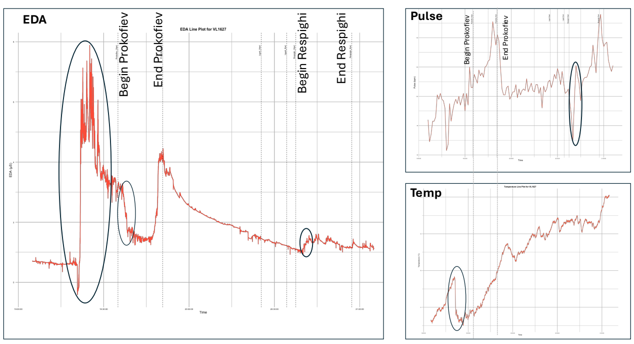

Figure 5: The electrodermal activity (EDA, left graph), pulse rate (top right), and wrist temperature (bottom right) of first violinist VL1627 during the concert at the Elbphilharmonie are shown. The physiological data align with the musician's self-reported experiences: – a) "Large stress before concert" – A sharp EDA spike appears before entering the stage, indicating strong anticipatory stress. – b) "It took half of Prokofiev to get over my tension" – EDA levels gradually decline, but only toward the end of Montagues and Capulets, suggesting prolonged tension. – c) "At the end of the 1st movement of Respighi… that was a big moment of shock" – A pronounced EDA spike with a simultaneous drop in pulse and temperature reflects acute stress, likely triggered by the fear of miscounting repetitions at the movement's end.

Intervention Modules

Warm-Up and Mental Coaching

During the camp days – as well as on stage before concerts – structured physical warm-up routines were introduced to reduce musculoskeletal strain and improve posture, core stability, and focus. These were complemented by mental training techniques such as breathing exercises, relaxation, and visualization. As the intervention groups for BodyFit and Mental Training (each consisting of three sessions) are not the main focus of this paper, further details can be found on the project website.

Virtual Reality Exposure Training (VRET)

A subset of participants also experiences VRET, which simulates high-stress performance environments, helping musicians build coping strategies in a controlled, immersive setting. VRET offers a controllable stress induction environment – a rare asset in music research [7]. Further information can be found on the project website.

To evaluate whether VR training induces physiological stress in musicians, selected participants wearing stress-monitoring smartwatches were tracked and analyzed. Here, a multimodal triangulation approach was used: integrating subjective reports with objective physiological data to validate performance stress experiences.

As shown in Figure 6, there are clear physiological stress markers in the synchronized data, although some artifacts may result from hand movements while playing or handling instruments.

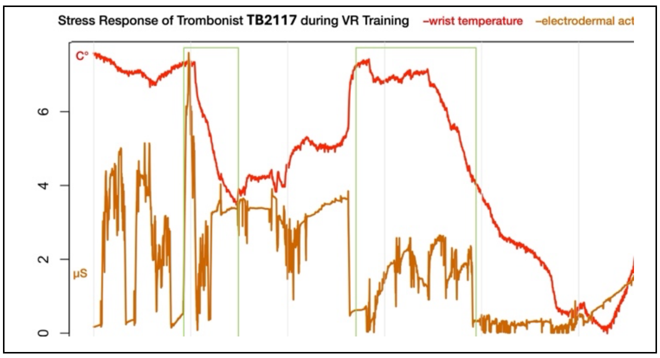

Figure 6: Wrist temperature (red line) and electrodermal activity (EDA, orange line) during a Virtual Reality training session. The temperature drops notably at 18:44 when the musician performs his concert solo excerpt virtually in the Elbphilharmonie and begins with a wrong note. An earlier drop at 18:35 occurs while watching his colleague improvise with the Big Band – triggering anticipatory stress, as he feared he might also have to improvise, despite being a classical player. In both cases, the hands become cold and EDA increases, indicating sympathetic nervous system activation.

Survey Results

Pre- and post-intervention online surveys, along with physiological and acoustic assessments, were conducted from June to October 2024. To gather health information of the participants and to assess the impact of interventions, validated pre/post self-report questionnaires covered four aspects:
1. Hearing Health – Assessed awareness of acoustic risks and hearing protection behavior.
2. Physical Health – Based on Gembris et al., focused on posture, tension, pain, and body awareness [6].
3. Psychological Health – Included: (a) *Stressverarbeitungs–fragebogen* (SVF-78), Erdmann et al. [8]
(b) *Leistungsmotivations-Inventar* (LMI), Schuler et al. [10];
(c) *Dysfunctional Practice Behavior Scale*, Roos [9].
4. Music Performance Anxiety Inventory (MPAI-A) [4].

Health is crucial in orchestral training but often overlooked: 98% of young musicians report neck pain, 77% play through it, and only half feel taken seriously when they speak up. Despite anxiety being widespread – 55% worry about under-practicing while 73% feel uneasy when they can't practice – 40% never wear ear protection during rehearsals.
Aspiring professionals showed significantly more dysfunctional habits ($t = 3.881$, $p < .001$, df=82, d=.851) and higher pre-concert anxiety ($t = 2.869$, $p = .007$). Participants reporting more pain post-intervention improved their practice behavior ($r = .442$, $p < .001$). In the BodyFit group, pain reduction was correlated with intervention enjoyment ($r = .552$, $p = .003$). MPAI scores rose before the concert in general but stayed constant in the Mental Training group, suggesting mental training prevented the typical pre-concert anxiety spike.
A unified "*Musical Busyness*" score (based on concert / rehearsal/practice frequency) revealed a negative correlation with age ($r = –0.225$, $p = .031$): younger musicians were more musically active. High busyness was associated with more positive self-affirmation ($r = .282$, $p = .007$), less use of negative coping ($r = –.213$, $p = .043$). It was also associated with more dysfunctional practice behavior ($r = .263$, $p = .012$), which includes ignoring pain, neglecting other needs or obligations, and experiencing anxiety during periods without practice.

Conclusion and Future Directions

The TFOYO project demonstrates a pioneering integration of high-resolution physiological monitoring, spatial acoustic analysis, and targeted interventions to address the health and performance challenges of young orchestral musicians. Using the EmbracePlus smartwatch, we identified distinct stress trajectories during rehearsals and concert performance, with sustained elevations in electrodermal activity and heart rate indicating persistent sympathetic arousal – particularly during high-stakes concert segments. These findings closely align with participants' self-reports of tension, fatigue, and pressure during solos or climactic passages.
Our multimodal approach – combining hearing protection, structured warm-ups, mental training, and Virtual Reality Exposure Training (VRET) – proved both feasible and beneficial. VR simulations of real-life venues, coupled with sensor-based stress tracking, offer an innovative, immersive framework for training under performance-like conditions.
Acoustic measurements confirmed considerable variation in sound exposure across orchestral positions, underscoring the need for individualized hearing protection and seating awareness. Educational efforts improved earplug adoption and health literacy though consistent use remains a challenge. Beyond immediate outcomes, the project's sustainable impact is strengthened by an assortment of freely accessible educational tools held on tfoyo.eu. These include warm-up videos, hearing-health infographics, and interactive learning modules designed for implementation in youth orchestras and music schools across Europe.
This study offers a scalable blueprint for integrating health-promoting practices into music education, with implications for injury prevention, performance preparation, and long-term career sustainability. While limitations such as self-selection and non-randomized groups should be addressed in future studies, the findings highlight the value of merging objective data with pedagogical strategies.
TFOYO delivers a new support for interdisciplinary, evidence-based music training – one that nurtures both artistic excellence and bolsters the well-being of the next generation of musicians.

7. References

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