Assessing real-world music listening in concerts

The most pleasurable music listening experiences occur in live concert settings (Gabrielsson & Wik, 2003; Lamont, 2011). One way to capture a listening experience in these contexts with minimal disruption is measuring peripheral responses (Ardizzi et al., 2020; Egermann et al., 2013). However, to date there is limited empirical evidence on how humans experience music in such naturalistic contexts (Brattico, 2021; Tervaniemi, 2023; Wald-Fuhrmann et al., 2021). Therefore, the overall aim of this thesis was to assess a more holistic understanding of a real-world music listening experience in audiences attending Western classical concerts, captured by aesthetic and peripheral responses. In the following, I first summarise the main findings of the empirical studies presented in Chapters 2-5. This summary is followed by a discussion on how the study results inform and extend the (neuro-)cognitive music science field's understanding of aesthetic and peripheral physiological responses of naturalistic music listening. Finally, some limitations and open questions are presented with suggestions for future research.

1 Summary

Empirical models of musical aesthetic experiences generally converge on three components: (1) inputs of music, context, and individual person (e.g., music preference), (2) processing mechanisms, and (3) an aesthetic response output (Anglada-Tort & Skov, 2020; Brattico et al., 2013; Hargreaves & North, 2010; Wald-Fuhrmann et al., 2021). Broadly speaking, research has mainly focused on the second component, with recent studies focusing on naturalistic music processing (Alluri et al., 2012; Burunat et al., 2014; Cheung et al., 2019; Di Liberto et al., 2020; Kern et al., 2022; Omigie et al., 2021). However, less is known about the 'input' components, such as the external environment (Tervaniemi, 2023). Therefore, we examined 'inputs' within a concert context, focussing on two broad aspects. As the concert yields an optimal situation to present full-length, naturalistic music, we first explored naturalistic music itself: the global/local structural and acoustic features of music (Chapters 2-3). Second, next to the auditory experience, the visual aspect of seeing the musician in a musical performance was explored (Chapters 4-5). An additional focus was the 'output', evaluating whether and how physiological responses (Chapter 2 and 4) and synchrony of physiological responses (Chapter 3 and 5) reflect aesthetic responses to music, such as liking (Chapter 2 and 4), emotion (Chapters 2-3), and engagement (Chapters 2 and 5).

Chapter 2 presented an initial glimpse into aesthetic experience trajectories over an entire concert program. So far only two studies have empirically and quantitatively assessed the trajectory over the entirety of an evening performance - within the context of an opera (Balteș & Miu, 2014; Scherer et al., 2019a). Chapter 2 extends their findings to a music concert of instrumental pieces. Across three

concerts, audiences were presented with a professionally curated concert program, consisting of a Classical period piece (by Ludwig van Beethoven, 1770-1827), a contemporary classical piece (by Brett Dean, b. 1961), an interval, and finally a Romantic period piece (by Johannes Brahms, 1833-97), all for string quintet. The first and last compositions were common practice period (CCP) pieces, with conventional musical structures, tonal harmony, and regular metres. The middle piece was a contemporary classical piece with non-tonal harmony and irregular meter. The audience reported their experiences on liking, absorption, and emotion response scales. Peripheral responses of skin conductance, heart and respiration rate, and facial muscle activity of individual concert attendees were also collected. First, despite highly negative ratings for the middle contemporary piece, liking ratings for the concert in its entirety was overall high (on average 4.1 out of 5). These high liking ratings suggest that the high positive ratings of the first and last piece may offset the negative ratings for the middle contemporary piece. Second, people's emotional responses were related to the overall structure of the multi-movement works: outer movements yielded more positive responses compared to inner, calmer sections that followed the traditional composition conventions of their time. This is in line with the idea that listeners' emotional trajectories across long-term musical works might reflect tension-resolution across music (Balteș & Miu, 2014). However, there was no manipulation of the order of pieces and their internal structure. Therefore, these first two findings regarding concert programming and emotions responses reflecting musical form can only be cautiously interpreted. Future studies with varied piece and movement order would be required to corroborate initial interpretations offered here. Third, specific physiological responses reflected the overall concert listening experience: heart rate (HR) dropped over time, reflecting an overall calming effect of a concert, but rose at the climactic ending of the final piece. Physiological arousal responses (increased SC and RR) were related to increased ratings of feeling energetic, agitated, and feeling joyfulness, while EMG zygomaticus major (smiling muscle) decreased with liking. These results objectively show that certain experience can be reflected in physiological responses in real-world music listening settings. The findings point to potential components that can be further explored to extend some of the exploratory results found here.

Chapter 3 explored responses to more specific and localised musical features using the same string quintet concert data set used in Chapter 2. Previous studies that assessed responses to musical events have done so in a hypothesis-driven approach, i.e., manipulating or locating arousing musical features/self-reported chills and assessing the corresponding physiological responses. As the stimuli used here were non-manipulated naturalistic music, Chapter 3 presented one of the first studies to explore physiological responses to music in a data-driven approach. Moments of systematic

physiological responses were first identified and then musical features at these moments in time were evaluated. Systematic physiological responses were operationalised as moments of high synchrony calculated with inter-subject correlation (ISC), based on the assumption that commonalities between time-locked signals enhance signal-to-noise ratio in stimulus processing (Hasson et al., 2004; Nastase et al., 2019). Musical features were extracted by computational acoustic-based and theoretical score-based methods. Moments of high physiological synchrony revealed higher skin conductance and faster respiration, i.e., indices of activation of the sympathetic nervous system. These synchronised arousal responses were linked to music with faster tempo, suggesting that faster music had evoked higher emotional arousal. The link between faster music evoking higher arousal was confirmed by significant correlations between faster tempi and self-reported high arousal emotions. Additionally, high synchrony moments across three concert audiences occurred at structurally important locations in the music, namely transitions between musical sections, sudden changes in the tempo or key, and when thematic material was repeated, but in an unexpected and altered presentation. In summary, synchrony methods offer a way to assess interindividual music listening experiences in non-experimental, naturalistic paradigms, and here we show that specific musical events may evoke common responses across audience members.

A crucial part of a concert performance is that it engages the listener not only in an auditory experience, but also a visual one. **Chapter 4** explored differences when participants experience audio-only (AO) and audio-visual (AV) musical performances. It is well known that visual information of performer movement enhances the emotional intention (Dahl & Friberg, 2007), expressivity (Davidson, 1993, p. 199; Wanderley et al., 2005), and appreciation of music (for a review, see Platz & Kopiez, 2012). However, knowledge of whether such results extend to a concert setting (Coutinho & Scherer, 2017) is limited. Additionally, there are opposing results as to whether additional sensory information increases (Chapados & Levitin, 2008) or decreases (Vuoskoski et al., 2016) physiological responses during music listening. To examine this further, audiences were presented with audio-visual (AV) and audio-only (AO) versions of piano performances (same music in both conditions). Results presented in Chapter 4 revealed that audio-visual information enhanced the aesthetic experience of the music. For peripheral physiological responses, two main patterns were observed. First, heart rhythm related to activation of the sympathetic nervous system ("fight-or-flight" system) increased during AO performances. The most likely explanation is that the lack of visual information made sound onsets more surprising (Jessen & Kotz, 2011). Second, responses related to motor activity (respiration rate, i.e., respiratory muscles, and facial muscle activity) were higher in the AV performance, suggesting that seeing a musician's

movements may have evoked motor mimicry in the audience. However, certain inconsistencies in the statistical models for respiration and muscle activity, further research, with larger sample sizes, is required to confirm results found here. Third, we found the smiling muscle was positively related to aesthetic experience, showing support for the embodied aesthetic theory (Cross, 2011; Freedberg & Gallese, 2007). Overall, results demonstrate that physiological responses may reflect multiple responses, showcasing a more holistic, realistic experience of a music performance.

While **Chapter 3** and **Chapter 4** explored musical features and modality in isolation, **Chapter 5** presented a study exploring these two variables together, that is, assessing responses to between AO/AV modalities across pieces and at musical structural boundaries. Synchrony measures of physiological responses were calculated as a way to assess engagement with music over time (Dauer et al., 2021; Kaneshiro et al., 2020). Building on work from **Chapter 4**, stimulus-response synchrony and inter-subject synchrony were assessed both in the time and phase domain (Kaneshiro et al., 2020; Weineck et al., 2022). In the time domain, HR/RR responses were correlated either with the spectral flux of the acoustic signal (stimulus-response correlation, SRC), or across participants (inter-subject correlation, ISC). In the phase domain, coherence between heart/respiration phase angles and phase angle of spectral flux at heart (1 Hz)/respiration (0.3) Hz frequencies (stimulus-response phase coherence, SRPC) were calculated as well as the coherence between heart/respiration phase angles across participants (inter-subject phase coherence, ISPC). Only time domain measures were significantly higher compared to control (circular-shifted) data. Musical engagement – as indexed by cardiorespiratory synchrony and self-reported immersion in music – was greater in the AV condition, both at a global and time-resolved level. ISC of HR was the most robust synchrony measure, supporting the idea that engagement is not reflected in neural synchrony (Kaneshiro et al., 2020; Ki et al., 2016; Madsen et al., 2019), but also in cardiac synchrony (Pérez et al., 2021). Despite the significance of time domain measures during music listening, we found no significant effect of phase synchrony. This might relate to the interaction between participants. Typical Western classical concert etiquette requires audience members to limit movements and interactions. Contrastingly, phase synchrony has previously been found when participants move to and interact with each other when playing and listening to music (Gugnowska et al., 2022; Hartmann et al., 2019). Therefore, questions arise whether the relevance phase coherence is context dependent. Perhaps phase is less relevant in context with less interaction, such as a Western classical concert, but might be more relevant in contexts where listeners can move and interact, for example in pop and rock concerts. Thus, to gain more insight in synchrony dynamics in real-world music listening, future studies from more wide-ranging genres are required.