The Aesthetic Experience of Live Concerts: Self-Reports and Psychophysiology

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Abstract

Music listening can lead to strong aesthetic experiences. However, to gain deeper insights into such experiences, more empirical research outside of laboratory settings is required. The current exploratory study measured aesthetic experience (music-induced emotions and absorption) in combination with psychophysiology (facial electromyography and arousal measures) from 98 participants during three live concerts with a program of classical, romantic, and contemporary chamber music. One musical movement from the contemporary work was presented from a recording. Results firstly highlight two key components of the concert frame as influencing the aesthetic experience: a) the programming order led to a rise-and-fall trajectory of emotions with the less familiar contemporary work leading to higher negatively valenced emotions. Nonetheless, this experience was embedded in an overall highly appreciated concert, with b) the factor of liveness becoming apparent in lower engagement with the recorded than the live music. Secondly, the participants' reactions gave insights into how the multi-movement works were perceived; opening and closing movements elicited higher positively valenced arousal, contrasting the characteristics of an inner section, which evoked lower arousal and mixed emotions. This scheme differed between the classical and the romantic works in the third movements, reflecting a different trajectory of tension and relaxation in the respective styles. Finally, we show relations between physiological responses and self-reports reflecting both positive and negative aesthetic experiences. Overall, we demonstrate that the ecological validity of the current study is particularly informative for theoretical approaches on the aesthetic experience, with the frame as a crucial component.

Keywords: live music, aesthetic emotions, absorption, concert research

The Aesthetic Experience of Live Concerts: Self-Reports and Psychophysiology

Music listening can lead to strong aesthetic experiences (Panzarella, 1980; Gabrielsson, 2011). Whilst current frameworks of aesthetic experiences and emotions in music exist (Brattico et al., 2013; Brattico & Pearce, 2013; Hargreaves & North, 2013; Juslin, 2013), there is still a question of ecological validity in terms of stimuli and listening situations. So far, studies have typically been conducted in highly controlled laboratory environments, using only short musical works or excerpts (single movements or short clips). While such research may provide a good basis for understanding fundamental relationships between acoustic and musical characteristics, self-reports, and physiological responses, it is far from naturalistic forms and situations of music listening. In particular, typical lab approaches often do not include entire (multi-movement) pieces nor capture the supposedly crucial influence of the frame (Goffman, 1974) in which listening happens, despite situation and context being theoretically acknowledged as a key component in models of a visual aesthetic experience in art (e.g., Leder et al., 2004; Locher et al., 2016; Pelowski et al., 2016) and in the reciprocal feedback model in music (Hargreaves et al., 2005). In real life, the frame co-determines (among others) the intended function of the music, the works that are selected in order to achieve this function, the adopted listening mode (e.g., attentive or not) or what other behaviors are deemed appropriate in response to the music (Schäfer & Sedlmeier, 2009; Greb, Steffens, & Schlotz, 2018). Therefore, the current study aimed to explore the aesthetic experience of music listening in a real-world setting, namely in response to live performances of music in a concert hall including three string quintets by Ludwig van Beethoven, Johannes Brahms, and the contemporary composer Brett Dean.

The Concert Frame: Attentive Listening in a Set Course

To describe the relationship between situational factors and music-related behaviors, we adopt a term introduced by the sociologist Erving Goffman, i.e., the frame (Goffman, 1974). According to Goffman, frames contain components that are used by participants to

understand, interpret, and evaluate the present situation and to align their behavior accordingly. Therefore, these frame components can be expected to also influence aesthetic experience and appreciation. Recently, studies have started to acknowledge the influence of the context, situation, or frame by moving into real-world settings such as theatres (Ardizzi et al., 2020), movie theatres (Koustoulas et al., 2015), art museums (Pelowski et al., 2012; Pelowski et al., 2017; Tschacher et al., 2012), and live music venues (e.g., Baltes & Miu et al., 2014; Coutinho & Scherer, 2017; Eggermann et al., 2013; 2020 Scherer et al., 2018).

A classical concert, which is the highly ritualized product of social conventions and stylistic development of Western music (Heister, 1988; Hewett 2017), contains several relevant frame components. These include the programming (deliberately choosing popular/famous works from the classical canon and perhaps a less well known piece (Gilmore, 1993; Weber, 2003)), the multimodal nature of the event (one cannot only hear the music live, but also watch the musicians creating it in the moment), and the setting aimed at affording an undisturbed, attentive, even absorbed mode of listening (created by the typical concert-hall layout with seats facing a lit stage, optimal acoustics, and learned behavioral regimes that call for silent and still listening) (Heister, 1988; Small, 1998; Seibert, Toelle, & Wald-Fuhrmann 2020; Thorau & Ziemer, 2019). Accordingly, the concert frame signals to the audience that the works to be heard are of high artistic value, and that they therefore should be received with attention because they promise the listener a special experience.

Indeed, studies have shown that certain concert components enhance the music listening experience. Live performances of music tend to more frequently evoke strong (positive) responses (Gabrielsson & Lindström Wik, 2003; Lamont, 2011). Additionally, a live performance in a church venue was shown to induce higher emotional engagement, and feelings of wonder and tenderness compared to a video recording of the same performance shown in a lecture hall (Coutinho, & Scherer, 2017b). Attention has also been shown to be related to more intense, even absorbed experiences (Vroegh, 2018; Lange et al., 2017). Also,

when asked about their motivation to go to concerts, attendees typically refer to their hope for deep and meaningful experiences (Brown & Knox, 2016; Burland & Pitts, 2014; Holt, 2010). Although studies have begun showing the effect of attentive listening during live opera performances (Baltes & Miu, 2014; Scherer et al., 2018), no studies exist that explore the trajectory of an aesthetic experience with an intentional series of differing multi-movement works, which are a key component of classical concerts.

The Compositional Strategy: A Music Theoretical Perspective

While the concert frame determines the schematic nature of the concert on a global level, there is also the possibility to consider smaller units within the single compositions. To investigate these underlying compositional strategies in music, a music theoretical perspective can be taken on (Zbikowski, 2002). In a similar way to how linguistic research demonstrates that lower-level units group to higher-level structures – syllables group to words (with attentive listening, Ding et al., 2018), and words group to hierarchical sentence structures (Nelson, 2017) – such grouping is present also in music (for a review, see Patel, 2001) and systematic music theoretical methods further suggest categories to describe longer-term musical features. These longer-term features – such as themes and phrases which create sections - eventually constitute movements (i.e., separate parts in multi-movement works such as sonatas or symphonies). These categories are not only mere descriptions of the musical score, but have assigned functions that they fulfill for the listener within a given style (Caplin, 1998). Like the concert as such, compositions also follow certain trajectories which are typical for their respective style and genre.

Those familiar with European music between the 18th and the early 20th century (the so-called common practice period) in general have heard a comparable array of music – which follow a similar compositional strategy – many times; to the extent that an expectation of how a (full-length) work and its movements may sound is developed. This is the basic assumption of a theory on one of the most influential and discussed forms in classical music:

the sonata form (Hepokoski & Darcy, 2006). Themes and movements are presented in a pre-defined order and harmonic schema, following specific functions by raising or denying expectations to create a higher-level form. This convention is typically used in symphonies and sonatas as well as chamber music genres of the (Viennese) classical and romantic period, which are represented in the current study through Ludwig van Beethoven and Johannes Brahms works, respectively. The traditional sonata cycle follows a standard four-movement pattern, with different tempi for each movement (fast – slow – dancelike – fast) as well as a development of key areas and the resulting harmonic expectancy (tonic – non-tonic – tonic – tonic). Fast opening and closing movements frame two inner movements of a contrasting slow, song-like character, and a rhythmically pronounced dance-like character in triple meter (a Minuet or Scherzo). The aggregation of these movements has recently been described as the pairwise grouping of two movements towards a balanced symmetry of 2+2 (Hepokoski & Darcy, 2006, p. 338). However, empirical evidence whether this grouping is actually perceived by listeners or only part of a theoretical layout is still pending.

Although listeners implicitly gain knowledge through exposure (Bigand & Poulin-Charronnat, 2006) and have implicit knowledge of tonal music (e.g., Koelsch et al., 2000; Tramo et al., 2001) – at least on a local phrase level – psychological research does not seem to provide perceptual evidence for such high-level features of musical form. Concerning whole sections, studies have shown that aesthetic pleasure does not change when the intended order of form parts was not always in place, i.e., comparing stimuli in original versus manipulated forms (Cook, 1987; Gotlieb & Konečni, 1987; Karno & Konečni, 1992). However, emotional characteristics and physiology related to the formal functions of whole movements from different musical styles has not been investigated.

In our concert, two instantiations of a sonata cycle (Beethoven and Brahms, both four movements) were contrasted by the four sequential movements of a “suite” (Dean, contemporary work). This allowed for investigating audience’s responses to the formal

structure of two different four-movement patterns: the cyclic organization of the sonata form and the sequential order of the suite.

Measuring the Aesthetic Experience

Although there are several dimensions that can encompass an aesthetic experience, we chose to focus on two components that have been previously identified as key components of an aesthetic experience with music (Brattico et al., 2013; Brattico & Pearce, 2013), that is music-evoked emotions and absorption.

The importance of absorption in the aesthetic discourse about classical music has been discussed in music history literature (Herbert 2011; Hoffding, 2018). Conceptualizing the aesthetic experience as a distinctive state of mind (Levinson, 2003, p. 7; Vroegh, 2018) that is related to the focused perception of sensory objects and differs from ‘everyday’ mental states, the state of absorption presents itself as a valuable measure for the aesthetic experience of music in a concert, where parameters are traditionally designed to optimize focus only on the music. These parameters include dimmed lights, an engineered room architecture for optimum acoustics (which influence perceived clarity of melodic lines, loudness and reverberation; Lokki et al., 2012; Lokki et al., 2011), as well as behavioral conventions of attentive listening such as (expected) total silence, and sitting still (Heister, 1983).

Emotions have also been shown to be part of aesthetic experience (Brattico et al., 2013; Brattico & Pearce, 2013; Menninghaus et al., 2019; Schindler et al., 2017). It is worth noting here the differentiation between perceived and felt emotions (Gabrielson, 2001; Schubert, 2013). While works of classical music are expected to have an expressive component and to be performed expressively, they do not necessarily evoke the same emotions that they might express, nor are they expected to (e.g., music may evoke mixed emotions such as being moved, Trost et al., 2012). Recent research has led to more standardized self-report tools to measure such evoked emotions, with some constructed to be applicable to art and non-art (e.g., nature) domains, such as AESTHEMOS (Schindler et al.,

2017), or shorter tools that apply to more specific domains such as classical music (GEMIAC, Coutinho & Scherer, 2017a).

In addition to self-reports, a non-obtrusive and continuous method to measure experienced emotions is using electromyography (EMG), cardiovascular and respiratory measures, and skin conductance (see Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000). Responses such as increased sweat gland secretion (measured by skin conductance), heart and respiration rate – activated by the sympathetic division of the autonomic nervous system in response to stimulating events – reflect increased felt arousal and engagement (Benedek & Kaernbach, 2010; Bradley & Lang, 2000; Cacioppo et al., 2000). Facial muscle activity is also considered a measure of behavior (Cacioppo et al., 2000) and can reflect mimicry of several discrete emotions (Wingenbach, 2020), and – to a certain extent – evoked emotions, e.g., the zygomaticus major (smiling) muscle and corrugator supercilii (frowning) muscle have been shown to reflect positive and negative valence, respectively (Bradley & Lang, 2000).

Most research on physiology and emotions during music listening concerns how the perceived emotion of the music is reflected in felt emotions, i.e., the emotion of the music is induced within the listener. Studies using either categorical (e.g., happy, sad) or dimensional (valence-arousal) emotion concepts show that ‘happy’ or arousing music (rated as inducing happiness or high arousal in listeners) evoked higher skin conductance amplitudes, faster breathing and heart rates compared to sad or music with low arousal (happy vs. sad: Etzel et al., 2006; Khalfa et al., 2002; Khalfa et al., 2008; Krumhansl, 1997; Lundqvist et al., 2009; high vs. low arousal: Egermann et al., 2015; Egermann et al., 2013; Gomez & Danuser, 2004). Higher smiling muscle activity was also associated with happy compared to sad music (Khalifa et al., 2008; Lundqvist et al., 2009).

Other research demonstrate how physiology may reflect emotions above and beyond the emotion of the music itself, such as pleasure, aesthetic chills, or perceived beauty. Music

rated as pleasurable, or reported as evoking chills during music listening, evoked higher skin conductance amplitudes, faster breathing and heart rates (pleasure: Salimpoor et al., 2009; Sammler et al., 2007; chills: Blood & Zatorre, 2001; Craig, 2005; Guhn et al., 2007; Rickard, 2004; Roy et al., 2009; Salimpoor et al., 2009). Pleasant music also reduces certain motor activity such as eye blink amplitude (Roy et al., 2009). Additionally, heart rate is found to be higher during music judged as ‘beautiful’ (though this effect is dependent on speed; de Jong et al., 1973). More recently, Omigie et al. (2019) found an interaction between the music judged as beautiful and its induced emotions: higher skin conductance was found in high energy beautiful music, whereas more smiling and higher respiration rate were associated with low tension and low energy beautiful music. However, there is limit on studies that show which kind of physiology may reflect more negative aesthetic experiences. Particularly in a live music situation, where full pieces of music are presented, one can expect a variety of music-evoked emotions.

The Present Investigation

This current study considers specific concert features and full-length musical trajectories of differing genres as an important element to influence effects on aesthetic experiences (here measured using behavioral responses and psychophysiological measures), thus making our approaches and hypotheses rather exploratory. To investigate the aesthetic experience of music in a real-world (as opposed to laboratory) situation, the current study tested 98 participants across three identical live concert evenings. The concert program comprised three string quintets in classical, romantic, and contemporary style with four movements each. Participants were asked to fill out short questionnaires on their aesthetic experiences, i.e., music-induced emotions (GEMIAC, Coutinho & Scherer, 2017a) and absorption (Vroegh, 2018) which were reported after each movement. Physiology was continuously measured throughout the whole concert.

Despite the exploratory nature of this ecological set-up, we nonetheless had a few hypotheses. We expected to (1) see how behavior and physiology may reflect the concert frame, e.g., its programming in form of differences between the classical, contemporary, and romantic works. We also expected to (2) observe compositional strategies of the works mirroring in audience responses, i.e., differences between movements due to their functions within a sonata cycle or suite. By choosing full pieces of music that were able to elicit an aesthetic experience on various levels – rather than choosing music that reflect one specific emotion (e.g., Khalfa et al., 2002; 2008) or that evokes primarily pleasurable emotions (e.g., Omigie et al., 2019; Salimpoor et al., 2009) – we additionally hoped to (3) extend typical laboratory studies on the relations between physiology and a wider range of positive and negative aesthetic experiences. This study will widen our knowledge on how people experience music aesthetically and emotionally based on self-reports and psychophysiology in the real-world setting of a live concert.

Methods

Venue

The ArtLab is a special concert hall designed for empirical investigations. It comprises 46 comfortable seats with arm rests and a pull-out table, arranged in five rows. The room is engineered to ensure equal sound quality for all seats. It has a stage, sound system with speakers, microphones and video cameras on the ceiling. In front of the ArtLab is a large foyer, where participants were prepared for physiological data acquisition.

Participants

46 different participants responded a public advertisement for a chamber music concert for each of the three concerts. Some participant data were lost due to technical issues of server and user failures or data loss ($N = 31$). A resulting number of 98 physiology data

sets (Concert 1 (C1), $N = 36$; Concert 2 (C2), $N = 41$; Concert 3 (C3), $N = 21$) and 88 complete data sets (physiology and self-report data) were used for final analyses.

The gender distribution was similar across concerts (C1 = 15/17 female/male, C2 = 16/17, C3 = 9/12; 3 not stated). Age groups across concerts were also quite similarly distributed: participants were asked to choose their age group (within a five-year range, i.e., 18-22, 23-27, ... 95-99), where half of the participants in C1 marked their age as being between 18-50, in C2 between 18-55 and C3 between 18-40 years old. Most participants in all three concerts indicated their highest education level was a university degree ($N = 23, 25, 17$), a high school degree with German “Abitur” ($N = 8, 5, 4$) or a finished vocational/professional training (without “Abitur”; $N = 1, 4, 0$).

To evaluate musical sophistication, two sub-scales from the German version of The Goldsmiths Musical Sophistication Index (Gold-MSI, Schaal et al., 2014) were chosen: General Music Sophistication and Emotional Engagement with Music (Müllensiefen et al., 2014). The participants across the three concerts were very similar a) for the overall sophistication: C1 (mean (M) = 69.84, $SD = 22.01$), C2 ($M = 71.61$, $SD = 21.97$), C3 ($M = 70.76$, $SD = 19.33$) and b) for the emotion scale: C1 ($M = 33.53$, $SD = 4.75$), C2 ($M = 31.17$, $SD = 6.85$), C3 ($M = 33.24$, $SD = 5.45$).

Participants reported that they most often visit concerts comprising of classical music and opera. Half of the participants came to the concert with someone else (see supplemental material for details).

Materials

The chosen repertoire for the live performances of a string quintet was based on an artistic decision by musicologists and curators, reflecting the stylistic variety and order (including an interval) typical of present-day classical chamber music concert programming. The first string quintet played was from the Classical period, op. 104 in C minor (1817) by Ludwig van Beethoven, with four movements. From the second work, “Epitaphs” (2010) by

the contemporary composer Brett Dean, also four movements were presented – the fifth one was omitted for artistic reasons. The third work was from the Romantic period: the string quintet op. 111 in G major (1890) by Johannes Brahms, also comprising four movements.

The contemporary work by Dean is written as a suite with five movements, each of them musically independent from each other, and each paying homage to personal friends. This work generally has more complex/dissonant harmonic and rhythmic structures. Each movement emphasizes a characteristic set of acoustic features (Figure 1), some of them more challenging to the standard listening experience than others. For instance, timbre and intonation of the performance of the first movement – resulting from the realization of various harmonics in the score – can be described as more challenging to listen to than the more consonant and melodic third movement. The last (fourth) movement played in the concert has the character of a typical finale in terms of clear, engaging rhythm, and repetitive structures. Even though there is no standard musical form to label the overall work, there is a clear dramaturgical development from movement one to movement four, which closes with an effectual ending.

Beethoven's and Brahms' quintets are exemplars of the traditional sonata cycle (Hepokoski & Darcy, 2006), following the standard four-movement pattern as described above (Figure 1).

--- Figure 1 about here ---

The performing musicians were a string quintet from the Frankfurt am Main (Germany) area, working solely as professional orchestra and chamber musicians. The musicians were accordingly compensated for their time playing in all three concerts. As the main aim was to keep the three performances as comparable as possible, the musicians were instructed to achieve similarity across concerts, which was more likely to be ensured with a professional group of musicians that regularly play together.

The second movement of the work by Dean “II. Walk a little way with me” was presented as recording (Doric String Quartet, Brett Dean Viola, Chandos, 2015) via loudspeaker (with musicians still sitting on stage). The idea behind this decision was to have one stimulus presentation with the exact same acoustic properties across all three concerts and without the visual aspects and the live acoustics, which are (besides the frame) typical characteristics of laboratory situations. As one of the main aims of the study was to keep the setting as naturalistic as possible, it seemed most plausible for the concert to have the control comparison recording in the contemporary work – as this style typically can also include electro-acoustic elements – rather than in the classical work or the romantic work (which may lead to confusion if a recording of only one of the movements was played throughout a classical or romantic work).

Procedure

Participants were invited to arrive at the venue one or one and a half hour(s) prior to the beginning of the concert. Firstly, participants were informed about the study and signed required agreements to take part in the study, they were also handed a program that included the composer’s name, the work with year of composition, and the names of the movements (no further text was presented). They were then prepared for the physiological recording, which included the measurement of the (a) zygomaticus major (smiling) muscle activity measured by EMG with adhesive electrodes on the left side of the face (with a ground electrode placed on the mastoid), (b) respiration rate (RR), measured using a custom prepared respiration belt wrapped around the lower rib cage, (c) electrodermal activity (EDA) was measured with electrodes attached to the index and middle fingers of the non-dominant hand – from which phasic skin conductance (SC) could be inferred – as well as (d) blood volume pulse (BPV) measured with a plethysmograph clip – from which heart rate (HR) could be inferred. Electrodes were connected to a portable amplifier, the “biosignalsplux” system (<https://plux.info/12-biosignalsplux>; “plux” hereafter). The plux device recorded the data from

the incoming sensors and was attached with adhesive tape to the participants upper back, and remained there for the entirety of the concert. Data were sampled at a 1000 Hz rate. Concerts started at 7:30 p.m. Beethoven and Dean were performed in the first half; Brahms was performed in the second half. In between, a 20-minute break was taken outside the ArtLab concert hall foyer. Concerts ended approximately 9:45 p.m.

After each movement, a short break (roughly two minutes) was taken to fill out two short questionnaires on a tablet. The first questionnaire comprised eight items of state absorption taken from Vroegh (2018, p. 150 and p. 203) including liking, all evaluated on a 5-point Likert scale from very much to not at all. The questionnaire comprised items on altered awareness, such as “I was completely absorbed by the music,” “Time passed quickly,” on dissociation, such as “I did not notice the surroundings,” “I forgot being at a concert,” attention, such as “I focused completely on the music,” and control items, such as “My mind was wandering” and “I was totally bored.” The second questionnaire on the next page comprised the 14 “emotion classes” from the GEMIAC (Coutinho & Scherer, 2017a). This “checklist” contains a selection of affect and emotion categories, where each category was derived from a hierarchical cluster analysis, leading to so called emotion classes. Each class is represented by one item containing two terms: filled with wonder/amazed, moved/touched, enchanted/in awe, inspired/enthusiastic, energetic/lively, joyful/wanting to dance, powerful/strong, full of tenderness/warmhearted, relaxed/peaceful, melancholic/sad, nostalgic/sentimental, indifferent/bored, tense/uneasy, agitated/aggressive. The items were translated into German by taking the adjectives from a comparable assessment, AESTHEMOS (Schindler et al. 2017), and the intensity of each emotion as felt by participants were assessed on a 5-point Likert scale.

Additional questions were presented after each work and after the concert, for example on familiarity with this kind of music (options of: “Yes,” “No,” and “I am not sure”; see supplemental material). Participants were compensated with a free ticket to the concert,

including a complementary non-alcoholic/-caffeine refreshment during the interval. They did not receive any further monetary compensation.

The three concerts were conducted on three consecutive evenings. In order to have the concerts as comparable as possible, great care was taken to ensure factors of timing, performers, lighting, and temperature, which were kept the same across these three concerts.

Analysis of Physiological Measures

All signal processing was carried out using custom scripts written in MATLAB 2018b (The MathWorks). Plux data were transformed from raw to meaningful measures following the data sheets provided by the developer, i.e., EMG and BVP in millivolt, EDA in micro-Siemens, and respiration in percentage of displacement. Missing data (gaps of less than 50ms) were interpolated at the original sample rate.

Electromyography

To obtain a continuous measure of facial muscle activity over time, the EMG was band-pass filtered between 90 and 130 Hz, and the absolute value of the Hilbert transform of the filtered signal was extracted and then smoothed using the *conv2* function in MATLAB, as recommended (<http://www.fieldtriptoolbox.org/documentation>; Oostenveld et al., 2011).

Respiration and Heart Rate

The respiration signal was low-pass filtered by 0.6 Hz and demeaned. BVP signal was band-pass filtered between 0.8 and 20 Hz, and demeaned. For both signals, peaks in the raw signal were identified using a function that identified local minima and maxima in any given epoch, visual inspection was used to confirm that peaks were correctly identified. Finally, rate for each signal was estimated by taking a differential of the timings of maxima (inter-beat intervals) and the resulting rate time-series were interpolated to a regular sampling frequency to give continuous HR and RR. Data were kept at 1000 Hz sampling rate. Noisy HR data were additionally identified using Poincaré plots (Mourot et al., 2004a, Sosnowski et al.,

2005) and single work movements by single participants were excluded if more than 10 % of data were affected.

Skin Conductance

EDA was down sampled to 20 Hz and analyzed by means of Discrete Decomposition Analysis (CDA) from the *Ledalab* toolbox (Benedek & Kaernbach, 2010) performing optimization of four initial values and data smoothing using the gauss-method and a window width of 16 samples. This resulted in a mean amplitude of phasic skin conductance components (SC), which reacts in an event-related manner.

Measures

In order to get meaningful measures despite varying movement lengths, number of events per minute were used, in addition to mean rate and amplitude. For SC, the mean amplitude of phasic activity and number of events per minute were calculated; however, the number of events did not follow a normal distribution, so only the mean amplitude of phasic activity was taken for further analysis. For the EMG signal, mean amplitude did not give a meaningful measure, as the amplitude averaged out too much (most likely as the time across each movement was several minutes, as opposed to typical trials lasting a few seconds), so the number of events per minute was used instead. An event was defined by moments when the signal was higher than a threshold (the individual mean plus two times the standard deviation was used, i.e., being the threshold for a $p < .05$ value following a normal Gaussian distribution). For HR and RR, the mean per movement was calculated. This yielded in 4 physiological data points per participant per movement: mean HR (beats per minute, BPM), mean RR (breaths per minute), mean amplitude of phasic skin conductance, and mean number of EMG events per minute, although after manual data checks some participants HR and / or SC data was rejected, so some participants only had two or three physiological data points. In total, 98 data sets were used for EMG and RR, 88 for skin conductance, and 82 for HR data.

Acoustical Analysis

To compare acoustic variability between the concerts, acoustic features representing performance-based features (i.e., features not describing the music composition itself, but rather acoustic features that may vary from performance to performance, Beveridge & Knox, 2009; Goodchild et al., 2017) were obtained manually and computationally. Using the MIRToolbox (Lartillot & Toiviainen, 2007), RMS (a feature typically representing loudness perception) and spectral centroid (the feature most commonly used to represent timbre, or ‘brightness’; Alluri & Toiviainen, 2011; Grey & Gordon, 1978; Iverson & Krumhansl, 1993; McAdams et al., 1995) were extracted in 25ms time windows as is typical in MIR analysis (Tzanetakis & Cook, 2002). As a longer-term feature, tempo is not always successfully captured by computational methods (Lange & Frieler, 2018), and was therefore extracted manually using Sonic Visualiser (Cannam et al., 2010), by tapping in timestamps for each beat of the performances of each movement (yielding a vector of timestamps per beat and bar), calculating the inter-onset intervals (IOIs) between beats, and converting these to beats per minute. Loudness, timbre, and tempo values were averaged in time windows per bar to allow comparisons between concerts.

Statistical Analysis

Statistical analyses were carried out using *R* (R Core Team, 2014). All questionnaire items were recoded so that the highest number reflects highest intensity.

The *lme4* package within *R* (Bates et al., 2015) was used to construct linear mixed effects models (LMM). The significance of the fixed effects was tested with conditional *F*-tests using the *anova* function and the *lmerTest* package (Kuznetsova et al., 2017). Pairwise comparisons using the Tukey method were performed with the *emmeans* package (Lenth et al., 2018). Two (Pseudo-)R² values (marginal and conditional) were calculated with the *MuMin* package (Bartoń, 2015), which is designed for general and linear mixed effects models. The *randomForest* package in *R* (Liaw & Wiener, 2002) was used to construct

random forest regressions. 500 trees were fitted. The output gives the percent explained variance of each model and the importance of each variable in explaining the variance. The ‘importance’ of each predictor was indicated in %IncMSE, which shows the increase in mean squared error of predictions as a result of a variable being permuted. Because random estimations depend upon the computer’s random number generator, each model was replicated 100 times to examine the distribution of R^2_{oob} as well as the variable importance across replications. For multiple and forest regressions, reference values for interpreting R^2_{GLMM} and R^2_{oob} , respectively, can be taken from Cohen (1988), that is a small effect $R^2 = .02$, medium effect $R^2 = .13$ and large effect $R^2 = .26$. All statistical results of fixed and random effects can be found in supplemental material.

Acoustic Comparisons

Performance acoustic features were correlated per movement between concerts using the *corr.test* function from *psych* package in R (Revelle, 2019), adjusted for false discovery rate. All acoustic correlations of instantaneous tempo, timbre, and loudness between concert 1 (C1), concert 2 (C2) and concert 3 (C3; C1-C2, C1-C3, C2-C3) had r values above 0.6, with $p < .001$ (with most correlations at $r > 0.8$), meeting the criteria for a large effect size in correlation of $r > 0.5$ (Cohen’s q for correlation coefficients, Cohen 1988). This confirms that the concerts were similar enough acoustically to allow further statistical analysis (i.e., that measured self-report and physiology across concerts were in response to a stimulus that remained comparable over the concerts). Unsurprisingly, apart from the (recorded) Dean 2nd movement, most r values were all under .95, suggesting that the performances differ slightly from each other, reflecting the ‘live’ aspect of performances: that even highly practiced performances offer slight deviations in interpretation to offer a fresher performance, as well as exhibiting small human errors (Chaffin et al., 2007; Palmer, 1997)

Reliability of the Questionnaires

Intra-class correlation (two-way random effects model, type: consistency) was performed for the eight absorption items and revealed an average measure ICC of .535 with a 95% confidence interval from .491 to .577 ($F(1020,7140) = 2.151, p < .001$). The ICC for the 14 emotion items from the GEMIAC revealed an average measure ICC of .734 with a 95% confidence interval from .709 to .759 ($F(924,12012) = 3.766, p < .001$).

Factor Analysis

All items from the GEMIAC and the absorption scale were subjected to a factor analysis. The *fa* function (also from the *psych* package) was used with direct oblimin rotation, after determining the number of factors performing a parallel analysis. Five factors (latent variables) were identified (Table 1).

Table 1

Factor structure of the items from the GEMIAC and the absorption scale

Questionnaire	Items	Positive emotions	Engagement	Negative emotions	Mixed emotions	Dissociation
	<i>Proportion of variance explained</i>	<i>0.29</i>	<i>0.22</i>	<i>0.19</i>	<i>0.18</i>	<i>0.12</i>
GEMIAC	energetic/lively	0.82				
GEMIAC	powerful/strong	0.69				
GEMIAC	inspired/enthusiastic	0.69				
GEMIAC	joyful/wanting to dance	0.66				
GEMIAC	filled with wonder/amazed	0.62				
GEMIAC	enchanted/in awe	0.51			0.36	
Absorption	bored		-0.68			
GEMIAC	indifferent/bored		-0.67			
Absorption	concentrated		0.58			
Absorption	forgetting time		0.55			
Absorption	absorbed		0.54			0.37
Absorption	liking		0.47	-0.40		
Absorption	mind wandering		-0.31			
GEMIAC	tense/uneasy			0.89		
GEMIAC	agitated/aggressive			0.84		
GEMIAC	relaxed/peaceful			-0.43	0.41	
GEMIAC	nostalgic/sentimental				0.78	
GEMIAC	melancholic/sad				0.72	
GEMIAC	tenderness/warmhearted	0.30			0.51	
GEMIAC	moved/touched	0.42			0.46	
Absorption	forgetting being in a concert					0.73
Absorption	forgetting surroundings					0.70

Note. Factor loadings < .3 are omitted.

Effects of Work and Movement on Emotion and Absorption Items

To investigate effects of performances of different works and movements on the self-reports, LMMs were performed for each latent variable separately as the dependent variable, with the fixed effect of (a) Work (three works, with random intercept of Movement and Participant) or (b) Movement (12 movements, with random intercept of Participant).

Effects of Concert, Work, and Movement on Psychophysiology

To evaluate effects of concert, musical work, and movement on physiological measures, separate LMMs were fitted for each physiological measure with fixed effect of Concert (three concerts) or Work (three works with random intercept of Movement and Participant) or Movement (12 movements, with random intercept of Participant) separately.

Effects of Emotion and Absorption Items on Psychophysiology

Two approaches were chosen to investigate the relationships between ratings and physiological measures. Firstly, an exploratory approach using random forest regression was used to find the best predictors (based on importance values) within the self-reports for each psychophysiological measure. Random forests were fitted for each physiological measure with all rating items ($N = 22$) as predictors. Secondly – because the results from random forest regressions do not give an objective threshold for importance values – LMMs were fitted for each physiological measure with the latent variables as fixed effects (four physiological measures, with random intercept of Participant). Because one absorption factor and one emotion factor correlated (factors positive emotions and dissociation; $r = .57$), we made two models to avoid issues with multicollinearity. One model entailed the emotion related factors (positive, negative, and mixed emotions as fixed effects), the other the absorption related factors (engagement and dissociation as fixed effects).

Results

Self-Reports

Concert. Across all three concerts, participants liked the concert as a whole ($M = 4.10$, $SD = 0.69$) as well as the atmosphere ($M = 3.82$, $SD = 0.83$). They had the feeling they were actually visiting a concert (rather than being part of a study; $M = 3.81$, $SD = 1.01$), reporting low disturbance of the electrodes ($M = 2.17$, $SD = 1.0$). Reported duration of preparation of physiological set-up before the concert ($M = 3.98$, $SD = 0.81$), and of the concert itself ($M = 4.22$, $SD = 0.70$) was appropriate and participants could imagine visiting such a research concert again ($M = 4.64$, $SD = 0.64$).

Works. The quintets by Brahms and Beethoven were familiar for the majority of participants (only 19% and 29% respectively reported they were not sure if they knew it), which was not the case for Dean's work (98% reported not to know it). Mean liking ratings of the (whole) works were for Beethoven $M = 4.09$ ($SD = 0.88$), for Brahms $M = 3.99$ ($SD = 0.78$), and Dean $M = 3.25$ ($SD = 1.18$).

Differences Between Works and Movements in Self-Reports

Effects of Work and Movement on each latent variable can be seen in the significant F -tests resulting from the linear mixed models in Table 2.

Works. Compared to Brahms and Beethoven, Dean's work received lowest ratings of positive emotions (marginally missing significance to Beethoven) and mixed emotions (significantly lower than Brahms), but highest ratings of negative emotions (significantly higher than both other works). Brahms' quintet was rated highest on dissociation (significantly higher than Dean). No significant differences were found between works for engagement (pairwise comparisons are depicted in Figure 2; all statistics can be found in supplemental material).

--- Figure 2 about here ---

Table 2

Results of the conditional F-tests following the linear mixed effects models for each latent variable and the fixed effects of Work or Movement

	Work				Movement			
Latent variable	<i>F</i> (2, 9)	<i>p</i>	<i>R</i> ² (m)	<i>R</i> ² (c)	<i>F</i> (11, 815)	<i>p</i>	<i>R</i> ² (m)	<i>R</i> ² (c)
Positive emotions	3.781	.064	.058	.454	19.261	<.001	.131	.447
Mixed emotions	6.075	.021	.153	.589	53.013	<.001	.275	.576
Negative emotions	71.251	<.001	.339	.552	65.421	<.001	.360	.551
Engagement	0.867	.452	.007	.340	5.333	<.001	.043	.338
Dissociation	6.702	.016	.013	.477	3.310	<.001	.021	.479

Movements. In positive emotions, a difference occurred between the second and the outer movements of the classical and the romantic works: Beethoven's 3rd and 4th movements had significantly higher ratings compared to the 2nd movement. Brahms' 4th movement had significantly higher ratings compared to the 1st through 3rd movements (Figure 2). For Dean, the 4th movement had significantly higher ratings compared to the 1st and the 2nd in positive emotions.

In mixed emotions, a reversed pattern could be seen where Beethoven's and Brahms' 2nd movements had significantly higher ratings compared to the 1st, 3rd, and 4th movements. For Dean, the 1st movement had significantly higher ratings compared to the 4th movement.

In negative emotions, Dean's 1st movement was significantly higher than the 4th. No significant differences within the Beethoven and Brahms movements were found.

In engagement, Beethoven's 3rd movement was significantly higher than the 2nd, and Brahms' 4th movement higher than the 1st, 2nd, and 3rd, being the highest in the whole concert. Dean's 4th movement was significantly higher than the 2nd. There were no significant differences between movements within works for dissociation.

The part presented via loudspeaker, Dean's 2nd movement, received lowest ratings in engagement, which was significantly lower compared to Dean's 4th, Beethoven's 3rd and 4th and Brahms' 4th movement.

Psychophysiological Measures

Differences Between Concerts, Works, and Movements

Concert. LMMs with physiological measures as dependent variables and concert as independent variable revealed no differences between concerts (see supplemental material). Along with the very similar acoustic features across concerts, this confirms that the physiological data from three separate but comparable concerts do not differ significantly based on the mean values and can be treated as a single group. Therefore, no comparisons are made between concerts in the following analyses.

Works. The LMMs for Work show significant differences for SC, EMG, and HR response, but not for RR (Figure 3; Table 3). Dean received significantly higher physiological responses than Brahms for SC, HR, and EMG. Beethoven had significantly higher HR responses compared to Dean and Brahms.

--- Figure 3 about here ---

Table 3

Results of the conditional F-tests following the linear mixed effects models for each psychophysiological measure and the fixed effects of Work or Movement

	Work					Movement				
Measure	<i>F</i>	df	<i>p</i>	<i>R</i> ² (m)	<i>R</i> ² (c)	<i>F</i>	df	<i>p</i>	<i>R</i> ² (m)	<i>R</i> ² (c)
EMG	5.54	2, 8.99	.027	.018	0.258	4.559	11, 1065	<.001	0.032	0.260
RR	1.18	2, 9.01	.35	.002	0.577	2.488	11, 1066	.004	0.010	0.578
HR	36.88	2, 9.05	<.001	.018	0.946	25.338	11, 700	<.001	0.020	0.947
SC	4.24	2, 8.96	.051	.024	0.633	11.922	11, 871	<.001	0.050	0.632

Movements. The LMMs for Movement show significant effects for SC, EMG, and HR response, but not for RR (Figure 3). SC is significantly higher in Dean's 1st movement than in Dean's 2nd and 3rd movements, Brahms' 1st through 3rd movements, and Beethoven's 1st and 2nd movements. SC is also significantly higher in Dean's 4th is than in Brahms' 1st through 3rd movements. SC was lowest in Brahms's 1st movement overall, but increases over the four movements, with SC in the 3rd and the 4th movements being significantly higher than the 1st and 2nd movement. HR increases over the four movements also in Brahms, with HR significantly higher the 4th movement than in the 1st and 2nd movements (but still significantly lower than all Beethoven movements). EMG in Dean's 1st movement is significantly higher than Beethoven's 1st, 2nd and 4th, also Brahms' 1st through 4th movement. EMG in Dean's 4th movement is also significantly higher than Beethoven's 1st and Brahms' 1st and 3rd movements.

Dean's 2nd movement presented via loudspeaker did not lead to striking differences in physiology compared to the live played music.

Relations Between Psychophysiological Measures and Self-Reports

The random forest regressions revealed higher importance values in SC for feeling energetic, joyful, indifferent, powerful, inspired, agitated and feelings of tenderness ($R^2 = .064$; Figure 4), where SC activity increases with feeling energetic, joyful, indifferent and agitated, and decreases with feeling powerful, inspired and feelings of tenderness. Importance values for HR were high for feeling inspired and forgetting about being in a concert (the situation) and surroundings ($R^2 = .138$), where HR increases with feeling inspired but decreases when participants report they forgot being in a concert and the surroundings. Higher importance values in RR were seen for feelings of tenderness, feeling indifferent, energetic and powerful ($R^2 = .106$), where RR increases with feeling energetic and indifferent but decreases with feelings of tenderness and feeling powerful. In EMG, importance values were

high for feelings of tenderness, feeling relaxed, moved, inspired, and liking (where EMG activity decreases with these feelings; see supplemental material), although the explained variance is low ($R^2 = .004$).

--- Figure 4 about here ---

Linear models with the latent variables revealed that SC activity was predicted by mixed and negative emotions (explained variance: $R^2(m) = .015$, $R^2(c) = .61$; beta estimates, standard errors and significance levels are depicted in Figure 5), and dissociation ($R^2(m) = .012$, $R^2(c) = .62$), i.e., SC activity decreased with higher mixed emotions, and increased with higher negative emotions and dissociation. HR was predicted by positive emotions ($R^2(m) = .001$, $R^2(c) = .94$), i.e., increased with higher positive emotions. RR was only marginally predicted by mixed emotions ($p = .086$), i.e., decreased with higher mixed emotions. EMG was significantly predicted by negative emotions ($R^2(m) = .010$, $R^2(c) = .28$), showing that EMG activity increased with higher negative emotions.

--- Figure 5 about here ---

Discussion

This study investigated aesthetic experiences with music in a live concert context, measured by self-reports of music-induced emotions (GEMIAC, Coutinho & Scherer, 2017) and absorption (Vroegh, 2018), in combination with physiological measures (skin conductance, zygomaticus major muscle activity, heart rate, and respiration rate). We saw how these measures reflect attentive listening in the concert as a dynamic experience (1) on a global level across three works from different musical periods as well as (2) within works on a structural level (between individual movements). We also (3) extend previously found associations of physiological responses with music-evoked emotions as well as positive and negative aesthetic experiences occurring in a real-world concert setting.

The Concert Experience

A concert frame is characterized by presenting a number of works in an intended order, where we observed a rise-and-fall trajectory of emotions (Balteş & Miu, 2014): Positive and mixed emotions started high for the performance of the classical work, dipped during the contemporary work, and rose again for the romantic work. The negative emotions (tense, agitated) were significantly higher in the contemporary work compared to the classical and romantic works. This shows, on the one hand, that the less familiar work by Dean seemed to be a suitable counterpart to the other two more familiar works, evoking emotions of different valence and arousal (also seen in higher SC and EMG activity) and therefore, extending the range of music-evoked emotions in the concert. On the other hand, the work by Dean did not significantly differ in engagement from the other two works, and the concert lead to an overall positive experience (high overall liking, averaging at 4.10 out of 5). This finding is relatively important, as it supports the idea of general programming in classical concerts to include new works and placing it between well-known canonic works to increase its chance of being ‘audience-friendly’ (Blackburn, 2016; Gotham, 2014).

In terms of physiology, HR decreased constantly over the course of the concert, from (on average) 72 BPM in Beethoven’s 1st movement to 68 BPM in Brahms’ 2nd movement. The HR decrease may indicate the general relaxation of the body in the evening (because of a physiological increase in parasympathetic activity) complemented by a calming and relaxing concert experience. Only in the last two movements of the romantic work, HR significantly increased again, but it did not rise to the level of the beginning (i.e., is still significantly lower than Beethoven’s 4th movement), potentially reflecting the exciting climactic ending of the Brahms and the awareness of the imminent end of the concert. However, there was the limitation that the order of the works was the same across the concerts. This ecological choice meant that it was not possible to see if this physiological trajectory was evoked by the music (which is relatively unlikely, given that the works exhibited an alternation of movements with

different arousal potentials, not a generally decreasing trajectory), the concert frame, or by other unspecific factors.

In a similar way to how the self-report measures were most contrasting in the contemporary work, the physiology in the work by Dean also stood out from the other works: SC in Dean's 1st movement was significantly higher than for the first two movements of both the classical and the romantic works, suggesting that increased skin conductance as evoked by unexpected harmony on a phrase scale (Steinbeis et al., 2006) or single melodic line (Egermann et al., 2013) can be generalized to long-term dissonance across a whole piece. Additionally, the 1st and 4th movements by Dean led to overall significantly higher EMG responses of the zygomaticus muscles (compared to all but Beethoven's 3rd movement). Although inconsistent with positive valence judgments increasing zygomaticus muscle activity (e.g., Kirsch et al., 2016), our results are supported by the finding that dissonant (compared to consonant) music elicits significantly more zygomaticus major activity, potentially reflecting "grimacing" or ironic laughter (Dellacherie et al., 2011). The assumption that zygomaticus major activity is not merely involved with smiling (i.e., reflect pleasure, liking, or other positively valenced reactions and evaluations) is further supported by Wingenbach et al. (2020), who recently showed that the zygomaticus major muscle in facial mimicry was also associated with negatively valenced emotions such as fear and disgust, the latter already indicated in a music related setting (Vrana, 1993).

Finally, as it has been theorized that aesthetic experiences in music may be more intensely evoked by a combination of auditory and visual information (Cohen, 2008; Huron, 2008), enhanced in a live performance by adding a sense of creativity and uniqueness to the experience (Auslander, 1999; Brown & Knox, 2016; Holt, 2010; Minor et al., 2004; Packer & Ballantyne, 2010), we expected that the recorded music would evoke less intense positive aesthetic experiences compared to the live music. The current study found that the music presented as a recording – rather than live – was rated the lowest for engagement compared to

four other movements, showing that participants were less concentrated and absorbed and liked it less, probably due to the absence of a main factor of liveness, i.e., the possibility to watch the musicians creating the music in the moment (Seibert et al., 2020). Despite being also in line with other studies comparing a live performance with an audio-visual recording (Coutinho and Scherer, 2017b), the comparison of live and recorded music did not reveal striking significant differences in other self-reports or physiological responses. This result gives rise to the assumption that the situation moderated the aesthetic experience which points to the frame (Goffman, 1974) being a key component in modeling the aesthetic experience (Leder et al., 2004; Locher et al., 2016; Pelowski et al., 2016). This is further supported by the fact that Coutinho and Scherer (2007) compared responses from a live performance in a typical concert venue (church) and the recorded performance in a university lecture hall, i.e., that the difference in emotion may have been due to the lecture hall vs. concert frame, rather than necessarily due to the recorded or liveness *per se*. However, the limitation here is that only one movement was presented as a recording, and only from the contemporary work. This compromise was made to keep a more “naturalistic” approach as only the contemporary style could entail electro-acoustic elements. Nonetheless, this could be manipulated in future studies to confirm the role of engagement in a live concert setting.

Effects of Compositional Trajectory

While the performances of the classical and the romantic works hardly differed as whole works in self-reports and physiological responses, similarities as well as differences between movements were evident in these two genres. This could reflect the individual compositional style and strategy of the composers, and thus the overall organization of the work.

Based on the self-report data, participants seemed to perceive three sections of these forms of a sonata: an opening section (Beethoven’s and Brahms’ 1st movements), an inner section (Beethoven’s and Brahms’ 2nd movements, and Brahms 3rd movements), and a closing

section (Beethoven's 3rd movement, Beethoven's and Brahms' 4th movement). The inner sections evoked higher mixed emotions (lower arousal emotions such as being moved, nostalgic, melancholic) and lower positive emotions, while the closing sections evoked lower mixed and higher positive emotions (such as energetic, joyful, inspired) as well as higher engagement. This reflection of the formal structure of the works is depicted in Figure 6.

--- Figure 6 about here ---

In a similar way that storytelling is perceived in a linear trajectory (Simony et al., 2016), Webster describes a musical "plot" (Webster, 1991, p. 182) and analytically differentiates between the complementary perspectives of cyclic integration (thematicism, tonal organization, p. 194) and the so called through-composition. The idea of the through-composition focuses on aspects of gestural phenomena and rhetoric (p. 123), which imply an audience that is capable through anticipation, expectation, and involvement to conceive the work as a whole. Czerny (1848, pp. 33-81) has already suggested that the composition of a sonata cycle incorporates the concept of unity within and throughout its movements, by means of compatibility of affect (tempo, character) and unity of keys (see also Ratner, 1980, p. 322). Within a sonata form, the question arises, how listeners perceive the overall trajectory of the four movements. Hepokoski & Darcy (2006), for example, proposed a binary-based (2+2) structure, which is mainly based on the symmetrical tonal development from the tonic to a non-tonic key (movements one and two) and its resolving return to the tonic (movements three and four), indicating a higher contrast between the second and the third movement.

The current results can relate to this musical theoretical discourse, albeit more related to the emotional content of the movements (e.g., Balteş & Miu, 2014): in the classical and romantic works used in this study, there are sections of contrasting emotion/arousal, forming a third section emphasizing the non-tonic space (associated with more tension) of the inner movements between the outer movements in the tonic key. This is in line with Tovey (1956), who has described the 'emotional content' of a sonata cycle and observed that the individual

movements raised emotional issues which cannot be resolved without the other movements (p. 230). These results show that the reported felt emotions reflect the character/function of the movements, related to previous work showing matched relationships between felt and perceived emotions (Evans & Schubert, 2008).

Evidence for the different groupings between the classical and romantic works can also be seen in physiology, specifically in the 3rd movements of both works. While the four movements of the classical work do not show much physiological variation, the last two movements from the romantic work show a significant increase in HR and SC, probably reflecting the structure of the romantic work, in which the normative key-order scheme is changed: the third movement is not yet in the tonic key, thus serves as a preparation of the climax and helps establishing a clear area of return and relaxation (tonic key) only with the very last movement (Hepokoski & Darcy, 2006, p. 340). This interplay of tension (non-tonic) and relaxation (tonic) is a typical stylistic feature of tonal music of the common practice period and affects general expectation and prediction in listeners on all levels (Sears, 2018; Huron, 2006).

These responses within the sonata form specifically occur in the exemplars of the common practice period, but were not present in the contemporary work by Dean. As expected, the linear trajectory of the “suite” led to a very different sequence of emotion and tension ratings. Here, an increase in positive and a decrease in negative emotions from the 1st to the 4th movement of the contemporary work was observed, suggesting that liking may increase with familiarity in musical style (Szpunar et al., 2004) even in complex music (Madison & Schiölde, 2017). Again, the ratings fit to the overall trajectory of the composition, which cannot be elaborated further in this context. Nonetheless, it has to be noted that contemporary music also plays with expectation, tension and relaxation, but in a more diverse way, and it is very well possible for future studies to draw on schemata that are less common compared to the sonata form, and also in the contemporary style. Taken

together, the (music-)theoretical approaches fit with the findings of this study, and suggest that there might be at least an implicit perception of inner coherence between movements within the sonata form.

Relations Between Self-Reports and Physiology in an Aesthetic Context

By operationalizing a musical aesthetic experience with emotions and absorption (Brattico et al., 2013; Brattico & Pearce, 2013), this study investigated the aesthetic experience of not only positive (e.g., Salimpoor et al., 2019), but negative and mixed valence emotions in response to contemporary, classical, and romantic music performances in combination with continuously acquired psychophysiological measures. Therefore, our analysis was somewhat exploratory, and we conducted two separate analyses with two kinds of predictors for the physiological responses: the single items from each scale and the latent variables obtained from the factor analysis (independent of a specific musical work).

The models from the random forest regressions with single self-report items from the GEMIAAC and absorption scales show small to medium effects, while linear mixed effects models with the estimated five latent variables predicting physiology did not reveal noteworthy effects (all $R^2 < .02$). This means that the results from the random forest regression (i.e., single items) were more successful in explaining the variance in the physiology measures. These results could be due to the fact that latent factors were grouped by valence (where positive and negative emotion factors were both high arousal), whereas physiology tends to also respond to differences in arousal (Baumgartner et al., 2006; Bradley & Lang, 2000; Egermann et al., 2013; Gomez & Danuser, 2004). Indeed, our current results support these studies, by showing the strongest relations we found showed typical arousal reactions, e.g., SC and RR increased with high arousal emotions of feeling energetic and agitated, while SC also increased with joyfulness. SC, RR, and EMG responses decreased with lower arousal emotions such as feelings of tenderness.

Another reason why the single items predicted the physiology better than the latent variables could be because the music in the current study was not chosen to represent one “basic” emotion (Baumgartner et al., 2006; Etzel et al., 2006; Khalifa et al., 2002, 2008; Krumhansl, 1997; Lundqvist et al., 2009) or separate locations on the arousal and valence dimensions (Dillman Carpentier & Potter, 2015; Eggermann et al., 2015; Gomez et al, 2004); rather they were chosen for their potential to evoke diverse and dynamic aesthetic experiences due to their quality as being widely appreciated compositions (for at least two of the works). Therefore, music-induced emotions that cannot be expressed by the music – such as feeling inspired, moved, or even bored – were investigated.

The results reveal that feeling inspired – considered a positive emotion – was associated with a decrease in EMG and SC, but an increase in HR, supporting previous research that heart rate is positively related to the experienced valence of the music (Sammler et al., 2007). Feeling powerful was associated with decreased SC and RR, suggesting that it may be related to a calm state of mind. Interestingly, we found that feeling indifferent/bored was associated with increased SC and RR. We also found that being moved and liking ratings were associated with a decrease of smiling muscle activity, which somewhat contradicts what we were expecting (Bradeley & Lang, 2000; Kirsch et al., 2016). An explanation for the current findings might be that idea that more positive musical judgments are associated with motor inhibition indices, such as smaller eye blink amplitudes (Roy et al., 2009), slower response times, and a higher amplitude of a motor inhibition N2/P3 component in an electroencephalography (EEG) event-related potential brain response (Sarasso, 2019). According to this perspective, positive aesthetic emotions and judgements inhibit muscle activity, maximising attentional resources on the perception of the aesthetic object. However, as mentioned above, the negative relationship with EMG activity of the smiling muscle and positive feelings/liking, also could be due to the activation of EMG muscles reflecting a negative experience, such as a grimace (e.g., Dellacherie et al., 2011; Wingenbach et al.,

2020). As we only took measurements from one facial EMG muscle, our current findings are not conclusive as to whether a negative experience is result of an *inhibition* of this muscle during more positive emotions or an *activation* in response to negative felt emotions but it could be possible that both mechanisms were at play here.

The physiology seemed to reflect two absorption items as well: HR decreased with the items forgetting about being in a concert and the surroundings, which is in line with the above made conclusion that the overall concert experience is reflected in HR – mirrored in items of dissociation, i.e., the exclusion of other content from the phenomenal field (Butler, 2004; Vroegh, 2018).

Although we show how physiology may be linked to emotions (on general arousal-valence dimensions) and absorption, a limitation of these measures is that they do not directly index emotions without being associated with self-reports on emotions and feelings. Hence, this study is an attempt at formulating more general conclusions on which emotions and physiological responses occur during a classical concert in response to different kinds of music. Further research may need to reduce this set of emotions and include continuous ratings to track the relations between continuous changes in rating behavior and physiology.

Conclusion

This exploratory study considered the aesthetic experience – as operationalized by music-induced emotions and absorption – in combination with physiology across whole multi-movement works of music of varying styles framed in a typical classical concert setting. Conducting research in a frame where the music is placed for optimum attention (e.g., dimmed lights, expected total silence) we observed firstly, (a) a rise-and-fall trajectory of emotions – with the contemporary work leading to higher negatively valenced emotions – embedded in an overall highly liked and appreciated concert and (b) that the movement presented as a recording had lower engagement than movements performed live. These results

tentatively highlight the programming and “liveness” as components of the concert frame which may influence the aesthetic experience – though it remains to be more systematically manipulated in future studies to confirm this effect. Secondly, investigating the experience of whole works yielded novel insights into the perception of a (cyclic) multi-movement work. Emotional and – in part – physiological responses mirrored the functions across movements in familiar classical and romantic works representing variations of the sonata form, contrasting the unfamiliar contemporary work (in the form of a suite), which did not follow such a trajectory. Thirdly, by selecting naturalistic music for their potential to evoke diverse aesthetic experiences, we extend previous results by showing that physiological responses reflect a range of music-evoked emotions relating to both positive and negative aesthetic experiences. To elaborate on these findings, it seems exploratory research is required in combination with more controlled studies to further understand the interplay between compositional conventions and musical expectations, between the score and the act of performance in a specific frame, and the resulting live concert experience (Toelle & Sloboda, 2019; Wald-Fuhrmann et al., submitted).

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Figure captions

Work	Ludwig van Beethoven String Quintet in C minor op. 104	Brett Dean 'Epitaphs'	Johannes Brahms String Quintet No. 2 in G major, op. 111
Stylistic period, date of composition	Classical (1817)	Contemporary (2010)	Romantic (1890)
Overall musical form	Sonata form	Suite	Sonata form
Movements			
Title or tempo description Musical characteristics (tonality and key area, meter, timbre, etc.)	1 Allegro con brio C minor – tonic 3/4	'Only I will know'. Gently flowing, with intimate intensity. 4/4 infused by 5/8 and 6/8. Unique texture through the use of overtones and bowing techniques.	Allegro non troppo, ma con brio G major – tonic 9/8
	2 Andante cantabile con variazioni E-flat major – non-tonic 2/4	'Walk a little way with me'. Moderato scorrevole. * Subsequent sections with varying meter and tempo.	Adagio D minor – non-tonic 2/4
	3 Menuetto Quasi allegro C minor (Trio in C major) - tonic 3/4	'The philosopher'. Quasi cadenza – suddenly flowing and floating. No meter in the beginning, then steady pulse, no clear pulse in the end.	Un poco allegretto G minor (Trio in G major) – non-tonic 3/4
	4 Finale. Prestissimo C minor – tonic 2/2	'György meets the Girl Photographer'. Fresh, energetic. Steady pulse of 1/16 notes with changing accents, engaging rhythm.	Vivace ma non troppo presto – Animato G major – tonic 2/4
	5	(not presented in the concert)	

Figure 1. Program and description of the works. * Presented via loudspeakers. The term 'work' describes the specific performance of that piece as experienced by the participants of the current study.

Figure 2. Differences (estimated marginal means) between musical works (upper row) and movements (lower row) in emotion and absorption ratings (latent variables). Pairwise comparisons with mean (black circle), 95% confidence intervals (CIs; blue (light grey) bars) and “emmeans” statistics depicting the significance of comparisons (overlapping red (dark grey) arrows mean no differences).

Figure 3. Differences between works (top row) and movements (bottom row) in psychophysiological measures; for details see Figure 2.

Figure 4. Importance values (%IncMSE = percent increase in mean squared error of predictions; values in their original units) for each emotion and absorption item and physiological measure. “e_” = GEMIAAC, “a_” = absorption scale, “_m” = liking rating per movement.

Figure 5. Beta estimates from the linear mixed effects models for all latent variables. *** $p < .001$, ** $p < .01$, * $p < .05$.

Movement	Classical – Beethoven			Section	Romantic – Brahms			Movement
	Physiology	Emotions Absorption	Tonal structure		Tonal structure	Emotions Absorption	Physiology	
1			tonic	opening	tonic		- HR, - SC	1
2		mixed	nontonic	inner	nontonic	mixed		2
3	(+ EMG)	positive, engagement	tonic		nontonic	mixed		3
4		positive	tonic	closing	tonic	positive, engagement	+ HR, + SC	4

Figure 6. Grouping of movements in the classical and the romantic works.