Mind & Matter **22**(2), 203–226 doi: 10.5376/mm2024.203

Music Synchronizes the Bodies of Its Audience

Wolfgang Tschacher
University of Bern, Switzerland
and
Martin Tröndle and Christian Weining
Department of Cultural Studies
Zeppelin University, Friedrichshafen, Germany

Abstract

Synchronization and the bodily coordination of people in social interaction is by now a regular finding in psychotherapy research and social psychology. Recently, we have expanded the scope of synchrony research to empirical aesthetics and music. Studying audience members of public classical concerts, we hypothesized that the shared musical stimuli synchronize the physiological dynamics of listeners and, if so, the individual degree of synchrony is linked to a listener's aesthetic experiences, music appreciation, affect and personality traits. The same may be expected for synchronized movement. After data acquisition with over 900 participants, we can now report significant evidence of physiological synchrony (cardiac and respiratory measures, skin conductance response) as well as movement synchrony in classical audiences, and distinct patterns of association with self-rated subjective experience. We believe this shows how the experience of music is embodied in listeners' synchronies. We conclude this empirical review with suggestions how the embodiment approach may be situated in the philosophy of mind.

1. Introduction

The motto of this issue "from sound to soul" is a poetic statement on the impression music can create in the minds of listeners. Listeners often respond to music with emotions and aesthetic appreciation (Schindler *et al.* 2017) or the feeling of being moved (Menninghaus *et al.* 2015). People find it easy to distinguish between valences of the music they hear, and they can tell that (physical) sounds are (mentally) sad or joyful, angry or relaxed. In other words, music can induce aesthetic experiences in the minds of listeners, and this is likely the major reason why people attend concerts and consume music through numerous other channels. The

musicians' side of the coin is that music is also a means of expression of emotions, where joint music-making communicates togetherness and even increases social bonding (Stupacher *et al.* 2017). The interplay of impression and expression is the core of music therapy, where music perception and music-making are used as interventions to alleviate mental and neurological problems (Theorell 2014, Raglio *et al.* 2015).

What is the mechanism by which music creates emotions and affective responses in people? It was hypothesized that musical rhythms can entrain bodily rhythms in listeners (Trost *et al.* 2017) and thereby influence the physiological ingredients of experienced emotionality. A large body of research, in general laboratory-based studies, has shown that music can induce physiological responses in listeners (e.g. Salimpoor *et al.* 2009), which are experienced as pleasurable and can lead to salient physiological phenomena such as chills or tears (Mori and Iwanaga 2017). Related research has explored the effects of music in the central nervous system using EEG and brain imaging (e.g. Zatorre 2015) or biomarkers such as the hormone oxytocin (Harvey 2020).

In the field of musicology we perceive a close association between aesthetic experiences, emotions and cognitive appraisals (Meyer 1956) on the one hand and physical bodily responses on the other. The exploration of such psychophysiological associations are a traditional topic of music theory and pedagogy (Truslit 1950). The study of psychophysiological associations are also the objective of a relatively novel approach in the cognitive and the social sciences, called embodied cognition, 4E cognition, or in short, embodiment (Tschacher and Bergomi 2011, Newen *et al.* 2018). The 4E approach (Fig. 1) views the mind, i.e. "cognition", as Embodied (grounded in the body), Embedded (nested in the affordances of the respective environmental frame), Extended (using external resources, such as tools), and Enactive (cognition based on continuous sensorimotor loops).

Thus, the study of bodily responses to music is part of a larger field of research, which in psychology has explored the bidirectional influence of the body on the mind and, *vice versa*, the influence of the mind on the body. A large number of studies has addressed such influences in the context of motor activity, for instance by studying the facial affect hypothesis – the experience of joy leads to smiling, as well as, in reverse, activation of smile-related muscles in the face leads to the experience of joy (Strack *et al.* 1988). Studies have also focused on the bidirectional relationships between body movements and emotions – depression leads to changes in gait and, in reverse, a sad walking style activates the cognitive biases characteristic of depression (Michalak *et al.* 2015). The dualistic wording of "bidirectionality" in the context of embodiment warrants some closer reflection from the viewpoint of the philosophy of mind; we will return to this issue in Sec. 4.

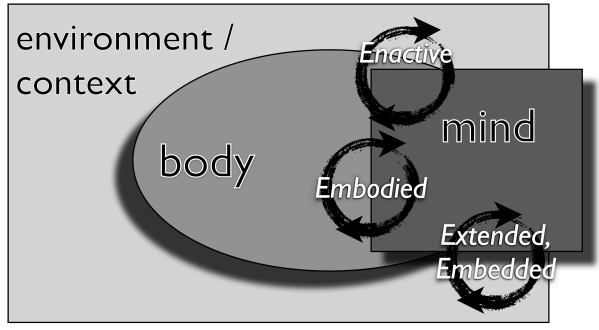

Figure 1. Schematic illustration of 4E cognition claiming relationships between mind, body and environment

Our empirical research on responses to music rests on the embodiment approach in that we collected data both on bodily variables and mental variables of music listeners in order to analyze if and how both types of data were linked (Tröndle *et al.* 2022). We obeyed two further guidelines in this series of studies.

First, a study design was chosen that optimizes ecological validity. The majority of studies on embodiment and on music-related empirical aesthetics are laboratory studies, often with student samples and prerecorded musical stimuli. Our data acquisition, however, was realized in concert venues open to the public, where professional ensembles played music pieces live. We aimed at recruiting our participants from the population of concert-goers. To keep up with this naturalistic setting, the recording of physiological and psychological data was prepared to be as unobtrusive as possible.

Second, among all genres of art, music by its nature is a temporal art form. In order to do justice to this property it seems more adequate to use longitudinal measures rooted in dynamical systems theory rather than just cross-sectional conventional designs and methods. Our core measures were therefore derived from time series recorded during the concerts, focusing on the temporal alignment of participants' responses, their synchrony (Moulder *et al.* 2018).

Why focus on synchrony? Since the turn of the century, a growing number of studies (Feldman 2006, Ramseyer and Tschacher 2006) has been conducted showing that people in interaction behave in coordinated ways, and this coordination or synchronization can be quantified, in the case of dyadic time series, using the cross-correlation function of the two time series. The cross-correlation function comprises the correlation and the lagged cross-correlations up to a chosen maximum lag, and the cross-correlation function "slides" over the whole time series, for example cov-

ering the duration of an entire music piece of 20 minutes. Thus there is a convenient algorithm by which all sorts of time series can be examined for signs of coordination and entrainment, i.e. synchrony.

Synchrony has been reliably demonstrated to arise in conversations staged among strangers, as well as in psychotherapy sessions, in romantic couples and quite generally in interpersonal communications of various kinds. Synchrony was assessed on the basis of time series of body movement (Galbusera *et al.* 2019), various physiological variables (Kleinbub 2017), eye movements (Tschacher *et al.* 2021) and prosodic voice qualities (Paz *et al.* 2021).

Synchrony is a characteristic not only of dyads but also of multi-person groups and of mass behavior. Unexpected synchrony can arise even in groups of strangers, as was observed when London's Millenium Bridge was inaugurated. Pedestrians were strolling in large numbers over the new bridge, where they involuntarily synchronized their gaits (Strogatz *et al.* 2005), so that the bridge got into danger of collapse due to resonance. Ritualistic behavior ranging from military parades to carnival parades, from political protest marches to sports audiences, often show synchronized properties that are either instructed or develop spontaneously by a process of self-organized pattern formation (Wunderlin and Haken 1984).

In the present context of musical performances, an interesting aspect of many rituals is that music, dancing, chanting, or singing are jointly present: music and synchronous movements are implemented in rituals to deepen the impact of rituals. Viewed from the angle of ritualistic behavior, the concert format may be considered a specific kind of ritual with an inherent synchronization tendency.

The current study was based on variables of the autonomous nervous system (ANS) of listeners, and additionally on measures of overt body movement. The ANS consists of two antagonistic branches, the sympathetic and the parasympathetic one, which have arousing and calming effects on the organism, respectively. For the sake of naturalistic empirical research, ANS activation, other than brain dynamics or endocrinal responses, can be comfortably accessed by minimally-invasive monitoring of cardiac, respiratory, and electrodermal variables. Furthermore, we used an unobtrusive method of motion capture to record the (often minimal) body movements of classical concert listeners during the presentations. Motion capture is possible based on video recordings of the audience, thus is entirely sensor-free.

To date, very few publications have addressed synchrony in music-making (Gill 2012, Müller and Lindenberger 2011), synchrony in music listeners (Czepiel *et al.* 2021) or the synchrony between musicians and listeners (Clayton *et al.* 2004, Hou *et al.* 2020). The mathematical model of musical gestures, initially proposed by Mazzola and Andreatta (2007), was extended by Mannone (2018) in terms of gestural similarity. This

model can be applied to gestures of musicians, the conductor, and listeners and their similarity, thus to instances of synchronization between the various gestures. A gesture can be formulated as a neutral mathematical form, that may include the composer's symbolic gestures written down in the score as well as the listener's receptive gestures, the whole concert system can be cast in the form of gesture similarity.

The physiological and movement synchrony in concert audiences has, to our knowledge, not been empirically studied in any systematic way before. Thus, until recently it was not known whether music presentations in concerts significantly generate synchrony in listeners, and in which way their supposed tendency to synchronize with the music may be associated with listeners' cognitive appraisals and emotional variables. These two general research questions are inherently linked to the embodiment approach in the context of music.

In line with the embodiment approach, we expected that the music dynamics will be embodied in listeners' bodily dynamics, the synchrony, and this synchrony will be linked with mental self-report. In the following, we will present the methods and results of a series of studies centered on the physiological and movement synchrony of listeners in concerts of classical music. All studies were organized in the context of the project "Experimental Concert Research".[1]

Two general hypotheses underly the reported studies. The first hypothesis (H1) stated that the recorded time series would show significant overall synchrony in the audiences because audience members are exposed to the shared music stimuli. (H1) thus addressed that the music was represented and embodied in the various physiological and motor signals of participants. The second hypothesis (H2) concerned the associations between self-report variables and these synchronies. It was expected that participants' affective states, personality, experiences and cognitive appraisals, as measured in pre- and post-concert surveys, would be associated with the synchronies arising during the concerts. (H2) was partially exploratory because no previous direct evidence pointed to which of numerous plausible associations would be realized.

2. Methods

2.1 Procedures and Samples

In this article, we review results generated in four waves of empirical data acquisition encompassing 18 live concerts with classical chamber music that spanned music from Viennese classic to contemporary art music.

[1] More details about this project can be found at `experimental-concert-research.org/?lang=en`.

Study 1. A concert was organized in 2016 in the Artlab concert hall of the Max-Planck-Institute for Empirical Aesthetics, Frankfurt, Germany (Seibert *et al.* 2019). The program consisted of six pieces with durations between two and five minutes: two romantic "Kunstlieder" by Franz Schubert (singer and piano), movements 2 and 4 of the "Piano Trio in G major" (piano, violin, viola) by Claude Debussy, the contemporary piece "La malinconia" for violin and viola by Salvatore Sciarrino, and the contemporary piece "Next to Beside Besides" for viola and snare drum by Simon Steen-Andersen.
Twenty-two listeners participated in study 1. Movement synchrony was computed of the musicians and the audience members. Self-reports on piece appreciation, liking of the interpretation, absorption/immersion, feeling connected with musicians and feeling connected with other audience members were collected based on ad-hoc Likert scales.

Study 2. A series of three concerts was organized in 2018, again in the Artlab concert hall at Frankfurt (Tschacher *et al.* 2023). Each concert lasted about 2 hours 15 minutes, with a 20 minutes break in between, presenting three string quintet pieces. First, Ludwig van Beethoven's string quintet Opus 104 in C minor, then Brett Dean's "Epitaphs for String Quintet", and finally Johannes Brahms' string quintet Opus 111 in G major. The pieces by Beethoven and Brahms had four movements each, the Dean piece five, and the performance represented different musical styles (Viennese classic, Contemporary, and Romantic).
138 persons participated in the concerts of study 2. Synchrony was computed on the physiological measures of all listeners recorded during the concerts (99 participants with usable physiological data). Self-reports based on general ad-hoc items of appreciation from 89 participants were sampled after each piece and after the end of each concert. After factorization of the items, five self-report variables were available for testing the associations with synchronies: piece-appreciation and piece-connection ("felt connected with musicians and other listeners"); concert-appreciation, concert-timing ("duration appropriate", "enough preparation time"), and concert-inconvenience ("annoyed by the measurements").

Study 3. In 2020, a further series of three concerts was performed in the concert venue Radialsystem in Berlin, Germany (Tschacher *et al.* 2023). The concerts were open to the public, and the program was the same as in study 2, except that only the first movement of the Beethoven piece was presented. The concerts had durations of about 1 hour 15 minutes.

132 attendees fulfilled inclusion criteria and provided written informed consent for participation. Physiological synchronies were measured in 123 participants, with between 9 and 50% missings due to technical reasons. Movement data were available of 130 participants. A full set of self-report data was obtained in surveys of participants before and after each concert (see description of self-report measures below).

Study 4. In 2022, the project succeeded in conducting the planned final concerts, after an enforced moratorium due to the Covid-19 restrictions in Germany. Eleven concerts were organized, two initial concerts in the Pierre-Boulez-Saal, then nine in the Radialsystem, both venues located in Berlin, Germany. The musical program was as in study 3, and additionally the format and staging of the music was systematically varied from concert to concert (Wald-Fuhrmann *et al.* 2021).
The concerts were again publicly advertised, and over 700 attendees participated, of whom 690 provided usable physiological data. Pre- and post-concert surveys were performed to collect self-report information as in study 3. Physiological synchronies of all audiences were computed and associations obtained between synchrony and self-report measures (Tschacher *et al.* 2024).

2.2 Physiological Signals

Various physiological signals (Wright *et al.* 2022) are available to represent sympathetic and parasympathetic activity of the autonomous nervous system. Participants of studies 2 to 4 were equipped with sensors integrated in a glove to collect electrodermal activity (Fig. 2 left), and wore respiration belts to measure breathing. Devices were manufactured by biosignalsplux (PLUX Wireless Biosignals S.A., Portugal). Physiological data were acquired at 200 Hz sampling rate and were processed using the BioSPPy library (Carreiras *et al.* 2015) to extract the signals from the raw data of the devices.

Two cardiac signals were recorded, heart rate (HR, measured as beats per minute) and heart rate variability (HRV). HR is a result of sympathetic as well as parasympathetic activity where higher HR values denote bodily activation and reduced relaxation. HRV is the subjectively imperceptible variability of the intervals between subsequent heart beats; higher values predominantly reflect parasympathetic relaxation. Electrodermal activity and respiratory behavior were also used in the studies. Electrodermal activity (skin conductance response, SCR) is the activity of the sweat glands in the skin, denoting exclusively sympathetic arousal. Respiration provided the two signals RR and RESP for the studies: Respiration

Figure 2. Left: Assistant attaching sensors to a participant's hand. Right: A participant fills out questionnaires on a tablet device after a concert. Fotos: Phil Dera.

rate (RR) is the frequency of breathing cycles, which like HR represents both branches of the ANS; and high RR means arousal. The time series of respiratory behavior (RESP) was additionally analyzed in studies 3 and 4. RESP is based on the raw time series of the strain-sensitive belts, which contain information on the exact moments of a participant's inhalation and exhalation.

2.3 Self-Report Measures

Before and after each concert self-report questionnaires were filled out by each participant on iPad tablets (Fig. 2 right). This procedure was used in studies 3 and 4. Only a limited set of items were acquired in studies 1 and 2. The pre-concert survey acquired demographic data and contained standardized questionnaires for the assessment of affective states, personality traits and music-related habits. Affective states were measured using the PANAVA scale, short version (Schallberger 2005), which has three subscales: positive activation (PA), negative activation (NA), and valence (VA). Participants' personality traits were assessed by the "big five" personality test, short form (BFI-10, Rammstedt and John 2007), which is based on ten five-point Likert scales assigned to the five traits extraversion, agreeableness, conscientiousness, neuroticism, and openness.

After the concerts, participants were given the PANAVA again, and a number of items on music experience. Items were used to assess the experience and appreciation of the whole concert and the three presented pieces by Beethoven, Brahms and Dean. Piece-related experience items were derived from the Aesthetic Emotions Scale (AESTHEMOS, Schindler *et*

al. 2017). Concert evaluation ("please rate the following aspects of the concert") was assessed by additional 5-point Likert items addressing the musicians, the program, the selection and interpretation of pieces, and the atmosphere of the concert venue. Further items focused on aesthetic experiences and cognitive appraisals towards the music. For the purpose of summarizing all these aspects of experiences, emotions, and cognitive responses, this large item pool was factorized in each study using maximum-likelihood factor analysis with varimax rotation, which compresses the information of multiple items into factors. The content of each factor is explained in Sec. 3.

2.4 Motion Capture

Time series of participants were recorded in studies 1 and 3. For motion capture, the method of Motion Energy Analysis (MEA) was used, a method to derive movement from video recordings (Ramseyer and Tschacher 2011). MEA assesses the extent of body movement by gathering the number of pixel changes from frame to frame of a digital video. Pixel changes are quantified within a specific "region of interest" (ROI) of the video (Fig. 3). MEA generates time series of the pixel changes in the ROIs that have a sampling rate equating the recording speed (frames per second) of the camera. In study 1, time series of the ensemble members were recorded additionally.

Figure 3. Principle of motion capture from top-view video of a string quintet. The shaded areas define the five regions of interest within which all pixel changes are quantified to generate time series of each musician's body movement. The insert highlights the changed pixels at this moment in the video

2.5 Computation of Synchrony: Surrogate Synchrony and Synchrony Contribution

The general idea of synchrony computation is to assess the amount of coupling between two or more processes, which are here provided by the physiological and movement time series of participants in concerts. In previous research (Tschacher and Haken 2019) we developed a correlation-based algorithm, the surrogate synchrony approach (SUSY, available as an R-package; Tschacher 2022), which assesses the synchrony between two time series based on their cross-correlation function. The multivariate version of SUSY handles multiple time series, also published as an R-package (mvSUSY; Tschacher and Meier 2023).

The statistical synchrony approach of SUSY accounts for lags between people because they may respond differently with regard to musical stimuli (positive lags), or may also anticipate musical events (negative lags). The definition of synchrony includes a second step by which the cross-correlations are tested against a control condition of randomly generated surrogate time series. In SUSY, the cross-correlations are computed segment-wise; time series are cut into segments of, for instance, 30 seconds duration, and the cross-correlations within each segment of the two time series are computed across a certain range of lags, e.g. $+/-$ 5 seconds, so that all cross-correlations in a ten-seconds window are considered. Segment-size and range of lags are basic parameters of the SUSY algorithm.

To allow for aggregation of segment-wise cross-correlations, they are transformed using Fisher's Z transformation. A general measure of synchrony is then mean Z, aggregated inside each segment and then aggregated across all segments of the time series. In studies 2 to 4 we used exclusively the non-absolute values of Z, which allow to distinguish between in-phase ($Z > 0$) and anti-phase synchrony ($Z < 0$); anti-phase means that one person's values may be consistently high whenever the other person's are low. The cross-correlation range of ten seconds means that the psychologically significant moment of several seconds, the psychological "now", is covered. This timespan contains between three to seven musical bars, depending on the piece. Assuming that the phrase-length of music is commonly four bars, this range of lags in SUSY approximately covers a musical phrase.

The second step in SUSY consists of surrogate tests that establish a control condition for mean Z. We generate surrogate time series by randomly shuffling the sequence of all segments of a time series. From a dyadic time series with n segments, $n(n-1)$ different surrogates can be produced, each of which entails pseudo correlations between time series, as the sequence of segments in both time series is falsely arranged by the random mixing. The surrogate step finally generates a signature of syn-

chrony, namely the effect size ES, for non-absolute Z cross-correlations, defined as the difference between the "real" Z and the mean of all surrogate Z, divided by the standard deviation of the surrogate Z. Thus, ES is an effect size at the level of a single bivariate process, presented for example by the heart-rate time series of two participants in the audience of the same concert.

Audiences are of course multi-person settings, not dyadic. Therefore, we described the audience synchrony by the ensemble of all dyadic synchronies between all participants of the respective concert audience. Consequently, audience synchrony is the mean value of all dyadic synchronies, expressed by their effect sizes ES, within the audience. For example, in an audience of 50 participants, the permutation of all participants into dyads generates $50 \times 49/2 = 1225$ dyadic synchronies. For use in statistical models which test the association of individual self-reports and synchrony, we compute the contribution of each single participant A towards the overall audience synchrony of a concert. In the example of an audience of 50 participants, A's *synchrony contribution* is the mean of all the 49 dyadic synchronies that A has with each of the other participants of this concert. This can be expressed as the mean effect size of participant A, denoted $\langle \mathrm{ES}_A \rangle$.

The multivariate approach of mvSUSY comprises the coupling of multiple time series. Their synchrony can be assessed by aspects of the eigenvalue decomposition of the correlation matrix (Meier and Tschacher 2021, Tschacher *et al.* 1998). Based again on the segment-wise computation, an effect size can be derived to estimate the audience synchrony in analogy to dyadic SUSY (for details on mvSUSY see Meier and Tschacher 2021).

2.6 Statistical Analyses

A range of statistical models were computed to assess hypotheses (H1) and (H2). We first addressed the question whether synchrony was found among the audiences of concerts (H1), and secondly if and how the degree of synchrony was associated with participants' self-report ratings (H2).

The first objective of supporting the significant existence of audience synchrony was implemented by testing the synchrony contributions against the null hypothesis that there are no consistent signs of synchronization in the concerts. This can be accomplished using one-sample t-tests of synchrony contributions against the expectation that $\langle \mathrm{ES}_A \rangle$, $\langle \mathrm{ES}_B \rangle$, ..., $\langle \mathrm{ES}_N \rangle$ do not statistically deviate from zero, where $A, B, ..., N$ are all audience members of a concert.

The second objective was assessed using regression models to decide which of the self-report scales significantly predicted the measured synchronies $\langle \mathrm{ES}_A \rangle$, $\langle \mathrm{ES}_B \rangle$, ..., $\langle \mathrm{ES}_N \rangle$. As studies 2 to 4 comprised data from multiple concerts, hierarchical regression models were applied to disen-

tangle the variance of the individuals on level 1 of the datasets from level 2 of the respective concerts.

3. Results

3.1 Study 1

This study was considered a pilot test of the computation of movement synchronies of concert audiences, and four short pieces of the concert with durations ranging from 1:49 to 3:47 minutes were included in the analyses (Seibert *et al.* 2019). The synchronies within the audience of this concert were calculated based on all permutated dyads of participants; they were significant in three pieces and insignificant in the Sciarrino piece, partially supporting hypothesis (H1).

The synchronies between musicians were found very heterogeneous from case to case, with the highest synchrony in the Steen-Anderson piece. Synchronies between the movements of participants and of musicians were also computed; they were insignificant. Mixed models were used to detect associations between participants' movement synchronies and self-report items. Two items were significantly ($p < 0.05$) linked to movement synchrony, namely feeling connected with musicians and feeling immersed in the music. Counter to expectations, both were negatively linked to synchrony.

The synchrony computations in study 1 used a variant of surrogate synchrony; the effect sizes were based on cross-correlations taken as absolute numbers, so that no distinction was made between in-phase and anti-phase synchrony. The range of lags was four seconds, segment size was chosen at 30 seconds.

3.2 Study 2

As in study 1, three concerts were conducted in the Artlab, where audience synchronies were calculated for heart rate (HR), respiration rate (RR) and skin conductance response (SCR), separately for each piece (Beethoven, Dean, Brahms) and each concert (1, 2, 3). In study 2, synchrony was computed with non-absolute cross-correlations. Nineteen out of these 27 audience synchronies were significant; seven of the nine audience synchronies of concert 3 (with the smallest sample) were insignificant. This suggested again partial support of hypothesis (H1) on the basis of Bonferroni-adjusted effect sizes. A specialty of study 2 was that the time scale of the physiological measures was not in seconds but in natural units, namely musical bars ("beats"). Thus, for the computation of HR, RR, and SCR synchrony, the parameters were a range of lags of 6 bars and 20 bars segment size.

Concerning hypothesis (H2), several links between physiological synchronies in the audiences and self-report responses regarding the respective pieces were found. Hierarchical models showed that listeners' appreciation of pieces was positively linked to higher audience synchrony of SCR and RR. Addressing evaluations on the level of the whole concert, audience synchrony of RR was less expressed when listeners reported being bothered by the measurements. Exploratory questions were tested finding that audience synchronies in the Beethoven piece were significantly higher than in the other pieces of the concerts, in line with the reported higher appreciation of Beethoven and Brahms over Dean.

3.3 Study 3

The three concerts of study 3 were the first that the Experimental Concert Research project staged in the Radialsystem in Berlin. Audience synchronies (range of lags: 10 seconds, segment size: 30 seconds) were calculated, in addition to HR, RR and SCR also for respiration behavior (RESP) and body movement, and the project's complete set of questionnaires was implemented. Hypothesis (H1) was supported for 26 of the 27 audience synchronies (3 pieces times 3 concerts times 3 physiological signals). Movement synchronies of the audiences were likewise significant across all three concerts and in 8 of the 9 piece synchronies. RESP synchronies were never found significant, thus participants did not coordinate their breathing cycles, only their rates of breathing (RR).

Hypothesis (H2) at the piece level entailed positive links between the factor "inspiring" predicting HR synchrony in both Brahms and Dean. At the concert level, personality trait extraversion was negatively and agreeableness positively predictive of HR synchrony. Neuroticism was negatively and openness positively predictive of RR synchrony. HR synchrony was positively associated with the factor "immersion", and SCR synchrony negatively with the factor "in company", enhanced in people who especially valued attending the concert in company and meeting friends. Audiences' movement synchrony was not found associated with self-reports, and no links were found between affect and any synchrony, so that (H2) was rejected for affect and generally for movement synchrony.

3.4 Study 4

Eleven concerts were organized, constituting the final data acquisition of the Experimental Concert Research project, which included over 700 participants of these concerts almost all of whom provided physiological measures and self-report data. Audience synchronies (range of lags: 10 seconds, segment size: 30 seconds) were calculated for HR, HRV, RR and SCR, and for RESP across all concerts. Hypothesis (H1) was supported for all 12 physiological audience synchronies (3 pieces times 4 physiological

signals). (H1) was rejected for RESP across all concerts and pieces, as well as across all concerts per piece.

Hypothesis (H2) was partially supported concerning affectivity (measured pre- and post-concert): HR synchrony was linked to a pre-to-post reduction of negative affect, whereas SCR synchrony was linked to an increase of positive affect. As for personality traits, extraversion was negatively and openness positively predictive of HR synchrony, and neuroticism was negatively predictive of HRV synchrony. Concert experience was related in various ways with synchronies: the factor "diffuse distraction" (thoughts unrelated to music; listening with half an ear) was associated with lower synchrony of HR, HRV and SCR. The factor "emotional listening" (give myself over to the music; bathing in the sound; music got under my skin) was negatively associated with synchrony of HR, HRV, and RR. Positive associations with HR synchrony were found for participants high on "structural listening" (focusing on the musical structure and on how melodies, rhythm, harmony were composed) and between HRV synchrony and "sound" (focusing on the sounds, locating sounds in specific instruments). Furthermore, a number of piece-specific associations were found, among them the negative link between "moved me" and RR synchrony in Brahms.

4. Discussion

We structure this section into three parts, beginning with a discussion of the outcomes of the reviewed four waves of empirical studies of bodily synchronies in concert attendees. We then address how these findings on the embodiment of music listening may relate within the context of the philosophy of mind. We conclude with considerations of a self-organizing systems approach where the mind is considered an emergent property of a complex physical system.

4.1 Embodiment and Audience Synchronies

Hypothesis (H1), claiming that bodily synchronies are established in concert audiences, was convincingly supported. This means that audience members of classical music resonated with the music on different levels of their embodied arousal and activity, by collective variations of heart rate, respiration rate, electrodermal activity, heart-rate variability as well as overt body movements. The traditional setting of classical concerts demands that the audience remains seated, people are dispersed across the seating area of the concert venue in subdued lighting (especially in studies 3 and 4, when Covid regulations had enforced physical distancing between people), and there is little or no visual contact, let alone communication, between audience members.

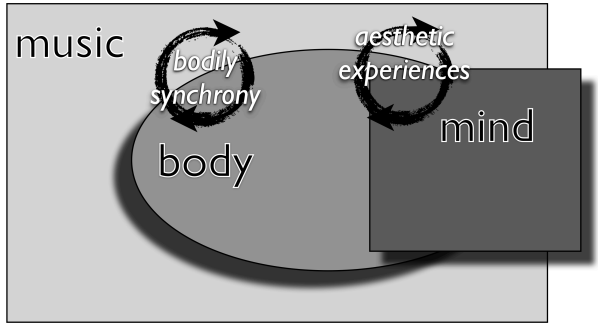

Figure 4. Schematic illustration of 4E cognition applied to the audience synchrony studies.

This implies that the measured synchrony did not arise owing to interpersonal interactions but was almost exclusively induced by the shared musical stimulation. Whereas in concerts of popular music the synchronization of audiences will likely be enhanced additionally by dancing and singing in the crowd, this is hardly the case given the classical concert format. We may therefore conclude that the music in the concerts studied here became embodied in listeners purely due to their listening to the music and watching the ensembles perform. The acoustic dynamics of the presented music has entrained listeners' sympathetic and parasympathetic dynamics and body movement. These findings relate to the circular loop "bodily synchrony" in Fig. 4.

The synchrony effect we generally found was, however, not present in respiration behavior measured in studies 3 and 4. Thus the music did not systematically determine the phases of inhalation and exhalation; there was no phase coupling between listeners' respiration and, hence, between listeners' respiration and the music. The reason may be that synchrony was computed over longer periods of time such as whole pieces, always lasting longer than ten minutes. Synchrony of breathing phases may therefore have been smeared, although they may nevertheless have been present in specific salient moments of the music (Sato *et al.* 2017), that is on another time-scale (Nozawa *et al.* 2023). Studying the synchrony in specific short excerpts such as peak moments is therefore a goal of future research.

Hypothesis (H2) is directly related to the topic of embodiment – is there a relationship between physical stimuli (music as acoustic process), bodily processes (physiological and movement synchronies) and mental processes (aesthetic experiences, perception, emotions and affectivity)? These relationships would therefore address the enactive aspect of 4E cognition (cf. Fig. 1) and are illustrated in Fig. 4 as the loop "aesthetic experiences". Results of studies 1 to 4 showed several such relationships in

pointing to associations between bodily synchronies and personality, affect changes, aesthetic emotions and experiences, and cognitive appraisals.

The results regarding (H2) were not always consistent across the different concerts and studies. We expected that the set of experiences of "immersion" would be positively associated with synchrony – if one is more in-sync with the music one should also feel more moved by and immersed in the music. This was a finding in study 3, but not in the pilot study 1 nor in study 4, where an aspect of immersion as "emotional listening" was investigated. Thus it seems necessary to reconsider our expectation, and possibly accept that diving deep into the music may even mean a disruptive process ("the music got under my skin") and thus reduce rather than enhance one's being and staying synchronized with the other attendees.

In all four studies, we followed a strict quantitative path, which should be complemented by qualitative analyses in later research. For example, we studied movement of audience members (studies 1 and 3) and of the performers (study 1) using motion capture, which does not represent the qualitative expression of movements. The qualitative meaning of movement as a musician's "gesture" (Berry 2009) or a listener's emotional facial expression must be elucidated more closely by methods that go beyond motion capture.

4.2 Embodiment as Mind-Matter Research

The explicit research on the relationships between mind and body has started in (social) psychology in the 1990s, then often called ecological psychology, situated cognition, enactivism, and currently embodied cognition. Its core tenets are postulates such as "cognition is embodied, not just information processing", "there is a bidirectional relationship between mind and body" or "enactive cognition rests on circular exchanges between physical environment, body and mind", and similar.

Empirical researchers commonly consider these to be credible postulates, which they study in quantitative datasets (Tschacher and Dauwalder 1999, Tschacher and Bergomi 2011). The implicit assumption of such studies is that mind, body and environment must be discriminable entities. If embodiment researchers then become aware of the philosophy of mind or the field of consciousness studies (Blackmore and Troscianko 2018), they will have to realize that the majority of philosophers would disagree.

Mind and body as discriminable entities are criticized by most philosophers as originating from dualistic Cartesian theory, because "entity" would imply that mind and body are ontologically different, consistent with René Descartes' *substance dualism*. The interaction between mind and body would additionally imply a site where mind-body interaction

takes place (such as Descartes' pineal gland, or the liaison cortex of Popper and Eccles 1977). Yet this site has not been discovered to date, and it is also said to contradict the causal closure of physics and the energy conservation law (however, see Cucu 2024).

Although most people in everyday life and using everyday language may think and behave like substance dualists, this approach is in serious disrespect among philosophers and largely ruled out. If philosophers' critical stance is true, the bidirectionality of embodiment can at best mean that the body influences the mind, but it cannot in reverse also mean that the mind influences the body – the possibility of mental causation is commonly rejected. Apparently, empirical psychology is at odds with a majority of philosophers.

A large fraction of philosophers has responded to the problems of dualism by reverting to epistemological or *property dualism*, which says that mind and body may not be ontologically different but only possess different properties. The mind may be a property of the brain (and body) and supervene on the brain (and body). Most proponents of this approach would still negate the possibility of mental causation.

Another related concept is that of *dual-aspect monism*, which regards mind and body as different aspects of a single underlying psychophysically neutral substance (Atmanspacher 2024). There is also a phenomenological dual-aspect approach on the "Leib-Körper" duality (Fuchs 2017). According to dual-aspect theories, mind and body are complementary aspects of an underlying reality that is neither mental nor bodily, which means they are correlated in principle, but definitely not linked in terms of a bidirectional causation.

A further option is to proceed without dualism altogether and adopt pure monism, either idealist or physicalist. Serious idealists are probably almost extinct at present (not counting the radical constructivists of systemic psychotherapy, or contemporary postmodern philosophy; Pluckrose and Lindsay 2020), but *physicalism* (physicalist monism) is a major approach in the philosophy of mind. Physicalism usually states that all mental processes are actually nothing but brain processes, and subjective experience and selfhood is an illusion (for an overview see Blackmore and Troscianko 2018). Eliminative physicalism proposes that even such illusions of subjectivity will fade away with time when "folk psychology" has finally waned.

Now, what is a proper position for embodiment? It is quite obvious that none of the monisms can serve as a philosophical fundament for embodiment research, since monism questions the very existence either of "mind" or of "matter" as such. If according to physicalism everything in reality is physical, then nothing is "embodied" because everything is just nothing-but-body. Empirical findings on mind-body associations would be nothing more than illusory. The analogous problem arises when radi-

cal constructivism is accepted: the "body" is just a construct of the mind, hence the mind cannot be "embodied". Physicalism entails that among the two loops in Fig. 4 only the loop "bodily synchrony" is logically possible, but the enactive loop of "aesthetic experiences" is ruled out. For idealism, both loops are void.

Therefore, the embodiment approach clearly demands some version of dualism. Dual-aspect monism appears compatible with the embodiment approach at first glance, yet the enactive loop may end up empirically tautological: if mind and body are just epistemically different kinds or aspects of the same neutral entity, what ultimately remains of the enactive loop is some sort of correlation. If property dualism is of the epiphenomenal type, and downward causation from a supervening mind is considered unfeasible, embodiment would make no sense because the supervening mind cannot inform or influence the body or brain. Substance dualism is of course well compatible with embodiment, and all empirical findings on mind-body interactions would be informative for and consistent with this strong version of dualism.

4.3 Embodiment and Self-Organization

A dualism in which mind is a new quality emerging from a complex system would be compatible with Haken's synergetics, a comprehensive interdisciplinary theory of self-organization in complex open systems far from thermodynamic equilibrium (Haken and Portugali 2016). "Far from equilibrium" means that the complex system is not a closed system but is driven by environmental "control parameters". This constellation leads to the emergence of macroscopic patterns, called "order parameters" in synergetics. The loop-like dynamics that governs this process of emergence is the "slaving principle". The initial formation of a still incomplete order parameter acts back on the complex system and leads to an accelerated full pattern formation.

In the case of the control parameter kept constant, the resulting order parameter presents a stable dynamics with properties of an attractor – the order parameter is stationary due to the continuous influx of energy originating in the environment of the open system. If, however, the control parameter is not maintained, the self-organization process is self-limiting as it leads to a depletion of the system-external control parameter. Thus there is another, second loop in the self-organizational dynamics by which the control parameter drives the complex system towards pattern formation, which then in return negatively feeds back on the control parameter and depletes it. A "restated second law" of thermodynamics was formulated (Schneider and Sagan 2005, p. 328), saying that the system

> will use all avenues available to counter and degrade the applied gradients [i.e. the control parameter]. ... As the applied gradients

> increase, so does the system's ability to oppose further movement from equilibrium.

In other words, the system produces those patterns that are best capable of reducing the control parameter (Tschacher and Haken 2007).

In this sense, we propose on the basis of the theory of synergetics that the notion of two loops may provide an analogy of brain dynamics (Haken and Tschacher 2010) and mental intentionality (Tschacher and Haken 2007). This is illustrated in Fig. 5: A complex system is given by the body and brain system from which the mind emerges (loop 1). Additionally, the environmental control parameter is represented by gradients that dwell in the environment of the body and mind. In psychological terms, these gradients are motivational forces or affordances. Those mental states emerge that are best capable of consuming the affordances, which means that mental states are intentional insofar as they are about the affordant aspects of the environment (the "aboutness" of intentionality).

This conceptualization would allow for the emergent mind to feed back on its physical substrate (the body-brain system) in two ways: first in agreement with the slaving principle (loop 1) and second by influencing (i.e. reducing) the affordances that have instigated the self-organized emergent process in the first place (loop 2). Concerning the consistence of this model with the empirical embodiment approach, mind-body bidirectionality would remain a feasible concept and thus be in accord with an emergent *synergetic dualism*.

In conclusion, there may be an emergentist concept of the mind-body relationship that is compatible with contemporary empirical findings of embodiment studies. The mind-body relationship constitutes the "hard

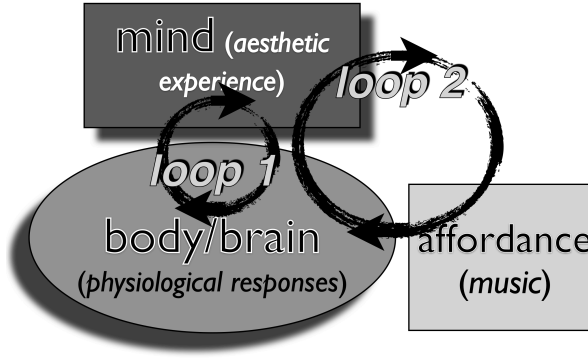

Figure 5. Schematic illustration of mind emerging in a self-organizing system. In synergetic concepts: body/brain = complex system; mind = order parameter; affordance = control parameter.

problem" of the philosophy of mind (Chalmers 2002). Like all the proposed solutions to this problem – in our opinion – the emergentist concept comes with a downside because the emergence of mind from matter in loop 1 is merely claimed but not explained. This is reminiscent of the downside of dual-aspect monism, where the monistic entity is merely proposed but not accessible.[2]

One possible answer to the hard problem of grounding embodiment research in philosophy may lie in pointing to the fact that there is a scientific discipline called "psychology". Since its initiation by Wilhelm Wundt in Leipzig in the 1880s, psychology has unearthed reliable empirical findings on how the psyche influences (physical) behavior and how environment and behavior exert reverse influences back on the psyche. This research on finding laws bridging the gap between mind and body has progressed successfully over many decades, with numerous different philosophical backgrounds, and often without any.

Concerning our present goal of a better understanding of the mind-body associations in music listeners, the recent embodiment research has provided evidence to indicate that music synchronizes bodily rhythms, and that the degree of this synchrony is associated with aesthetic experiences. It may be feasible and advisable to continue in this empirical-psychological tradition even in the face of unresolved and possibly unresolvable philosophical issues.

Acknowledgments

The authors wish to thank the Artlab, Pierre Boulez Saal and the Radialsystem Berlin for their support of the Experimental Concert Research (ECR) project. Folkert Uhde set up the musical program and designed the concerts. We are grateful for funding by Volkswagen Foundation and Aventis Foundation. Thanks go to ECR research assistants who were indispensable for data collection and guiding participants through the concert evenings.

References

Atmanspacher H. (2024): Psychophysical neutrality and its descendants: A brief primer for dual-aspect monism. *Synthese* **203**, 25.

Berry M. (2009): The importance of bodily gesture in Sofia Gubaidulina's music for low strings. *Music Theory Online* **15**(5).

Bishop L. (2018): Collaborative musical creativity: How ensembles coordinate spontaneity. *Frontiers in Psychology* **9**, 1285.

Blackmore S. and Troscianko E.T. (2018): *Consciousness: An Introduction* (3 ed.), Routledge, London

[2]The authors are grateful for consultations with Hermann Haken on these topics.

Carreiras C., Alves A. P., Lourenço A., Canento F., Silva H., Fred A. *et al.* (2015): BioSPPy – Biosignal Processing in Python. https://github.com/PIA-Group/BioSPPy/ [Online; Accessed Nov 7, 2023]

Chalmers D.J. (2002): The puzzle of conscious experience. *Scientific American* **273** (6), 90–100.

Clayton M., Sager R., and Will U. (2004): In time with the music: The concept of entrainment and its significance for ethnomusicology. *ESEM Counterpoint* **1**, 1–45.

Cucu A. (2024): Turning the table: How neuroscience supports interactive dualism. *Mind and Matter* **21**, 219–240.

Czepiel A., Fink L.K., Fink L.T., Wald-Fuhrmann M., Tröndle M., and Merrill J. (2021): Synchrony in the periphery: Inter-subject correlation of physiological responses during live music concerts. *Scientific Reports* **11**(1), 22457.

Feldman R. (2006): From biological rhythms to social rhythms: Physiological precursors of mother-infant synchrony. *Developmental Psychology* **42**, 175–188.

Fuchs T. (2017): *Ecology of the Brain: The Phenomenology and Biology of the Embodied Mind*, Oxford University Press, Oxford.

Galbusera L., Finn M.T.M., Tschacher W., and Kyselo M. (2019): Interpersonal synchrony feels good but impedes self-regulation of affect. *Scientific Reports* **9**, 14691.

Haken H. and Portugali J. (2016): Information and selforganization: A unifying approach and applications. *Entropy* **18**(6), 197.

Haken H. and Tschacher W. (2010): A theoretical model of intentionality with an application to neural dynamics. *Mind and Matter* **8**, 7–18.

Harvey A.R. (2020): Links between the neurobiology of oxytocin and human musicality. *Frontiers in Human Neuroscience* **14**, 350.

Hou Y., Song B., Hu Y., Pan Y., and Hu Y. (2020): The averaged inter-brain coherence between the audience and a violinist predicts the popularity of violin performance. *NeuroImage* **211**, 116655.

Kleinbub J.R. (2017): State of the art of interpersonal physiology in psychotherapy: A systematic review. *Frontiers in Psychology* **8**, 2053.

Mannone M. (2018): Introduction to gestural similarity in music. An application of category theory to the orchestra. *Journal of Mathematics and Music* **12**(2), 63–87.

Mazzola G. and Andreatta M. (2007): Diagrams, gestures and formulae in music. *Journal of Mathematics and Music* **1**(1), 23–46.

Meier D. and Tschacher W. (2021): Beyond dyadic coupling: The method of multivariate Surrogate Synchrony (mv-SUSY). *Entropy* **23**.

Menninghaus W., Wagner V., Hanich J., Wassiliwizky E., Kuehnast M., and Jacobsen T. (2015): Towards a psychological construct of being moved. *PLoS One* **10**, e0128451.

Meyer L.B. (1956): *Emotion and Meaning in Music*, University of Chicago Press, Chicago.

Michalak J., Rohde K., and Troje N.F. (2015): How we walk affects what we remember: Gait modifications through biofeedback change negative affective memory bias. J*ournal of Behavior Therapy and Experimental Psychiatry* **46**.

Mori K. and Iwanaga M. (2017): Two types of peak emotional responses to music: The psychophysiology of chills and tears. *Scientific Reports* **7**, 46063.

Moulder R.G., Boker S.M., Ramseyer F., and Tschacher W. (2018): Determining synchrony between behavioral time series: An application of surrogate data generation for establishing falsifiable null-hypotheses. *Psychological Methods* **23**, 757–773.

Müller V., and Lindenberger U. (2011): Cardiac and respiratory patterns synchronize between persons during choir singing. *PLoS ONE* **6**(9), e24893.

Newen A., De Bruin L., and Gallagher S., eds. (2018): *The Oxford Handbook of 4E Cognition*, Oxford University Press, Oxford.

Nozawa T., Sas M.I., Dolan D., Rajpal H., Rosas F., Timmermann C., Mediano P.A., Honda K., Amano S., Miyake Y., and Jensen H.J. (2023): Swinging, fast and slow: Multiscale synchronisation dynamics reveals the impact of an improvisatory approach to performance on music experience. [*PsyArXiv Preprint*] https://doi.org/10.31234/osf.io/cqxya

Paz A., Rafaeli E., Bar-Kalifa E., Gilboa-Schectman E., Gannot S., Laufer-Goldshtein B., Narayanan S., Keshet J., and Atzil-Slonim D. (2021): Intrapersonal and interpersonal vocal affect dynamics during psychotherapy. *Journal of Consulting and Clinical Psychology* **89**(3), 227–239.

Pluckrose H. and Lindsay J. (2020): *Cynical Theories: How Activist Scholarship Made Everything About Race, Gender, and Identity – and Why This Harms Everybody*, Pitchstone Publishing, Durham.

Popper K.R., and Eccles J.C. (1977): *The Self and Its Brain*, Springer, Berlin.

Raglio A., Attardo L., Gontero G., Rollino S., Groppo E., and Granieri E. (2015): Effects of music and music therapy on mood in neurological patients. *World Journal of Psychiatry* **5**, 68–78.

Rammstedt B. and John O.P. (2007): Measuring personality in one minute or less: A 10-item short version of the Big Five Inventory in English and German. *Journal of Research in Personality* **41**(1), 203–212.

Ramseyer F. and Tschacher W. (2006): Synchrony: A core concept for a constructivist approach to psychotherapy. *Constructivism in the Human Sciences* **11**, 150–171.

Ramseyer F. and Tschacher W. (2011): Nonverbal synchrony in psychotherapy: Coordinated body movement reflects relationship quality and outcome. *Journal of Consulting and Clinical Psychology* **79**(3), 284–295.

Salimpoor V.N., Benovoy M., Longo G., Cooperstock J.R., and Zatorre R.J. (2009): The rewarding aspects of music listening are related to degree of emotional arousal. *PloS One* **4**(10), e7487.

Sato T.G., Shiraki Y., and Moriya T. (2017): Audience excitement reflected in respiratory phase synchronization. *2017 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, Banff, AB, Canada, pp. 2856–2860.

Schallberger U. (2005): Kurzskalen zur Erfassung der Positiven Aktivierung, Negativen Aktivierung und Valenz in Experience Sampling Studien (PANAVA-KS). Accessible at `https://www.psychologie.uzh.ch/dam/jcr:00000000-4a5f-c2e5-0000-000006e4f6b9/PANAVA_05.pdf`.

Schindler I., Hosoya G., Menninghaus W., Beermann U., Wagner V., Eid M., and Scherer K. R. (2017): Measuring aesthetic emotions: A review of the literature and a new assessment tool. *Plos One* **12**(6), e0178899.

Schneider E.D. and Sagan D. (2005): *Into the Cool. Energy Flow, Thermodynamics, and Life*. University of Chicago Press, Chicago.

Seibert C., Greb F. and Tschacher W. (2019): Nonverbale Synchronie und Musik-Erleben im klassischen Konzert. *Jahrbuch Musikpsychologie* **28**, e18.

Strack F., Martin L., and Stepper S. (1988): Inhibiting and facilitating conditions of the human smile: A nonobtrusive test of the facial feedback hypothesis. *Journal of Personality and Social Psychology* **54**(5), 768–777.

Strogatz S.H., Abrams D.M., McRobie A., Eckhardt B., and Ott E. (2005): Crowd synchrony on the Millennium Bridge. *Nature* **438**(7064), 43–44.

Stupacher J., Wood G., and Witte M. (2017): Synchrony and sympathy: Social entrainment with music compared to a metronome. *Psychomusicology: Music, Mind, and Brain* **27**(3), 158–166.

Theorell T. (2014): *Psychological Health Effects of Musical Experiences. Theories, Studies and Reflections in Music Health Science*, Springer, Berlin.

Tröndle M., Greenwood S., Ramakrishnan C., Uhde F., Egermann H., and Tschacher W. (2022): Integrated methods: A call for integrative and interdisciplinary aesthetics research. In *Oxford Handbook of Empirical Aesthetics*, ed. by M. Nadal and O. Vartanian, Oxford University Press, Oxford, pp. 369–382.

Trost W., Labbé C., and Grandjean D. (2017): Rhythmic entrainment as a musical affect induction mechanism. *Neuropsychologia* **96**, 96–110.

Truslit A. (1950): Musik und Bewegung. *Schweizerische Musikzeitung* **90**, 1–5.

Tschacher W. and Haken H. (2007): Intentionality in non-equilibrium systems? The functional aspects of self-organized pattern formation. *New Ideas in Psychology* **25**, 1–15.

Tschacher W. and Haken H. (2019): *The Process of Psychotherapy: Causation and Chance*, Springer, Berlin.

Tschacher W. and Dauwalder J.-P., eds. (1999): *Dynamics, Synergetics, Autonomous Agents – Nonlinear Systems Approaches to Cognitive Psychology and Cognitive Science*, World Scientific Publishing, Singapore.

Tschacher W. and Meier D. (2023): mvSUSY: Multivariate Surrogate Synchrony. R package version 0.1.1, https://wtschacher.github.io/mvSUSY/

Tschacher W., Greenwood S., Ramakrishnan S., Tröndle M., Wald-Fuhrmann M., Seibert C., Weining C., and Meier D. (2023): Audience synchronies in live concerts illustrate the embodiment of music experience. *Scientific Reports* **13**, 14843.

Tschacher W., Greenwood S., Weining C., Wald-Fuhrmann M., Ramakrishnan S., Seibert C., and Tröndle M. (2024): Physiological audience synchrony in

classical concerts linked with listeners' experiences and attitudes. *Scientific Reports* **14**, 16412.

Tschacher W., Scheier C., and Grawe K. (1998): Order and pattern formation in psychotherapy. *Nonlinear Dynamics, Psychology and Life Sciences* **2**, 195–215.

Tschacher W. (2022): SUSY: Surrogate Synchrony. R package version 0.1.1, https://wtschacher.github.io/SUSY/

Tschacher W. and Bergomi C., eds. (2011): *The Implications of Embodiment: Cognition and Communication*, Imprint Academic, London.

Tschacher W., Greenwood S., Egermann H., Wald-Fuhrmann M., Czepiel A., Tröndle M., and Meier D. (2023): Physiological synchrony in audiences of live concerts. *Psychology of Aesthetics, Creativity, and the Arts* **17**(2), 152–162.

Tschacher W., Rees G.M., and Ramseyer F. (2014): Nonverbal synchrony and affect in dyadic interactions. *Frontiers in Psychology* **5**, 1323.

Tschacher W., Tschacher N.P., and Stukenbrock A. (2021): Eye synchrony: A method to capture mutual and joint attention in social eye movements. *Nonlinear Dynamics, Psychology and Life Sciences* **25**, 309–333.

Wald-Fuhrmann M., Egermann H., Czepiel A., O'Neill K., Weining C., Meier D., Tschacher W., Uhde F., Toelle J., and Tröndle M. (2021): Music listening in classical concerts: Theory, literature review, and research program. *Frontiers in Psychology* **12**, 1324.

Wright S.E., Bégel V., and Palmer C. (2022): *Psychological Influences of Music in Perception and Action*, Cambridge University Press, Cambridge.

Wunderlin A. and Haken H. (1984): Some applications of basic ideas and models of synergetics to sociology. In *Synergetics – From Microscopic to Macroscopic Order*, ed. by E. Frehland, Springer, Berlin, pp. 174–182.

Zatorre R.J. (2015): Musical pleasure and reward: Mechanisms and dysfunction. *Annals of the New York Academy of Sciences* **1337**, 202–211.

Received: 17 February 2024
Revised: 02 May 2024
Accepted: 27 May 2024

Reviewed by Nataša Crnjanski and Maria Mannone