The Influence of Musical Rhythm on Cardiovascular, Respiratory, and Electrodermal Activity

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von

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Abstract

Background. Athanasius Kircher, one of the first prominent figures to propose a connection between the distinct rhythm of the heart and the state of people's health, suggested the use of rhythmic stimuli to cure diseases. Since then, there have been various attempts to alter the heart rate by means of auditory stimuli, and for similar purposes. Be it in music or in rhythmical coordination tasks, interactions of periodic exogenous pulses and endogenous biological rhythms have been studied extensively. However, there are still limitations to understanding the regulating mechanisms in cardio-respiratory synchronisation.

Aims. Various listening and bio-feedback experiments are discussed, dealing with different aspects of the influence of rhythmical auditory stimuli on cardio-respiratory regulation, biological rhythm generation and coordination. A focus is on the interpretation of respective physiological adaptation processes and different relaxation strategies that might help musicians to deal with unwanted stress before, during, and after a musical performance. Different challenges inherent to empirical musicological and music-related biomedical research, and how they might be tackled in future experiments, are considered. The study itself aims to shed light on basic functions within the complex psycho-physiological regulatory mechanisms of subjects who are presented with auditory stimuli. In different experiments, the author investigates heart rate behaviour under fixed pulse respiration ratios and during voluntary breathing phases, the effects of rhythmical acoustic stimuli on subjects' cardio-respiratory regulatory mechanisms, and the influence of bio-feedback on the ability to actively adapt and deflect their own heart rate to and from a steady periodic rhythmical stimulus. A set of questionnaires accompanies the experiments, providing information about musical preferences, learning issues, stage anxiety biases, and similar parameters that might contribute to a more comprehensive understanding of how subjects react to certain acoustic stimuli.

Methods. Thirty-five volunteers participated in the investigation. Before the experiments took place, the subjects completed two questionnaires that covered age, gender, musical education and practises, daily rehearsal duration, musical preferences, and overall expressivity. According to their musical practises and education, they were classified as musicians or controls after the experiments had taken place. When the ECG electrodes, a respiration belt, EDA electrodes and headphones had been applied, the subject's ECG was monitored visually until a steady state was reached. The set of experiments started with a one-minute stimulus-reaction test to normalise the subject's overall state of arousal and identify their physiological parameters at rest. A thirty minute listening experiment followed, during which the subjects listened to a five minute musical sample three times, with five minute phases of silence before each musical sample was played. With every phase, the subject received different breathing instructions. After two phases of voluntary breathing, different pulse-respiration ratios had to be maintained with the help of visual ECG feedback. The subjects were instructed to listen attentively since a questionnaire about the musical and interpretational features of the musical sample had to be completed afterwards. This questionnaire contained questions about subjects' state of arousal, involvement, and preference. When it had been completed, subjects were instructed on how to raise their heart rate by imagining stressful situations, such as a concert or an exam. A fifteen-minute experiment followed, with the subject listening to 150 seconds of metronome beat (with its frequency constantly adjusted to the subject's obtained heart rate at rest), alternating with 150 second phases of silence. With every phase, the subject received different instructions on how to adapt or detach their heart rate (which was fed back visually and acoustically) to or from the metronome beat.

Results. MATLAB data acquisition and a proprietary software tool was used to analyse the recorded physiological data sets, according to potential activation, coordination, and synchronisation effects of heart, respiration and electrodermal activity with the respective musical or rhythmical stimuli. These analyses and the information gathered in the questionnaires provided the documentation of the different psycho-physiological reactions to stress upon which this study is based. Subjects in both the musicians and the control groups increased breathing frequencies when listening to both slow or activating music compared to silence. Differences in average respiration rate were higher in musicians compared to controls. Whereas the difference in electrodermal activity was small in controls, musicians showed an average increase of 10.1 % $\pm$ 3.492 from slow to fast music. However, the alterations of heart frequency while listening to activating or sedating music were not significant, although the questionnaires account for high subject involvements. The results of the second experiment showed that subjects were able to actively increase their heart rates (compared to their heart rates at rest) with the help of biofeedback; while, at the same time, their electrodermal activity increased. An external acoustic stimulus (a regular metronome click) did not significantly facilitate or counteract this ability. Regarding the coordination of heart and respiration, the analysis revealed that although the subjects' respiration rates increased significantly during the phase when activating music was played, their heart rates did not. Thus, in the complex cardio-respiratory regulatory system, the parameters of heart frequency and respiration frequency seemed to function relatively independently, although coordination and synchronisation effects might have been occurring. An investigation into heart rate variability suggested that heartbeats became more regular when the subjects listened to music. However, that the decrease of heart rate variability is time-dependent, namely that subjects' heart rates became more regular over the course of the experiment regardless of whether any music was played to them, cannot be

ruled out since the experimental setup did not always allow a control for habituation effects. Additional analyses revealed that the more severely subjects rated their stage anxiety, the higher were their average heart rates and respiration rates during the stimulus reaction test. An analysis of the results of an Affective Communication Test (ACT) revealed no significant differences between musicians and controls. However, the higher subjects scored in the test, the more intensely they rated their experience of the music.

Implications. The mechanisms though which auditory stimuli can influence biological rhythms are complex and cannot be easily modelled. For a durable understanding of the influences auditory stimuli have on the cardiovascular and respiratory cycle, studies have to investigate biophysical and psycho-physiological determinants (phase transitions, possible synchronisation and coordination effects, cardiac and respiratory arrhythmias and their causes, and psycho-acoustic impacts), group interactions, musical preferences and so on, in order to form a picture that might help improve the techniques used in applied music therapy, or develop relaxation techniques for musicians. Applied music therapy could be more beneficial if a reliable understanding of how rhythmic stimuli influence the cardio-respiratory system existed, and if there were medical standards in interpreting heart and respiration activity in phases of physical activity, such as musical performances.

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Martin Morgenstern

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Abbreviations

ACT	Active Communication Test
ANOVA	Analysis of variance
BP	Blood pressure
BRS	Baroreflex sensitivity
DBP	Diastolic blood pressure
ECG	Electrocardiogram
EDA	Electrodermal activity
EEG	Electroencephalogram
FEX	Fragebogen zur Erfassung der emotionalen Expressivität
fMRI	functional Magnetic Resonance Imaging
GSR	Galvanic skin response
HF	High frequency
HR	Heart rate
HRV	Heart rate variability
IgA	Immunoglobuline A
LF	Low frequency
NN50	Number of RR intervals for which successive RR intervals differed by at least 50 ms
PET	Positron emission tomography
pNN50	Percentage of absolute differences in successive NN values $> 50\ ms$ from the index RR interval
PRR	Pulse-respiration ratio
RR	Respiration rate
RSA	Respiratory sinus arrhythmia
S-IgA	secretory Immunoglobuline A
SBP	Systolic blood pressure
SD	Standard deviation
SDANN	standard deviation of sequential 5-minute RR interval means
SDNN	Standard deviation of Normal-to-Normal intervals
SR	Skin response
ULF	Ultra-low frequency
VLF	Very low frequency

Von der Straße her ein Posthorn klingt.
Was hat es, daß es so hoch aufspringt,
Mein Herz?

Wilhelm Müller

Musicology fills the gap

When we speak about *the effects of music*, we are often observing the secondary or transfer effects that music produces. Surely enough, when Bernardi, Porta, and Sleight (2006) noted that *Music can reduce stress and improve athletic performance, motor function in neurologically impaired patients with stroke or parkinsonism, or milk production in cattle*,[1] it was almost always a transfer function that the respective music triggered. It is not (only) the sound waves that may motivate cows to give more milk,[2] or innervate subjects to score better in a paper cutting-and-folding test. Rather, it is concomitant factors, such as the stimulating attention of the researcher or other socio-psychological circumstances that contribute to the findings, or are even their main cause. Studies in this field have, in many cases, not been controlled for transfer effects; this would seem necessary if the whole cause-and-effect interrelation is to be understood or even modelled.

[1]Bernardi et al. (2006, p. 445)

[2]The almost exclusively cited study in this field is by Sambraus and Hecker (1985); although it did not bear any significant differences in the milk production of the five cows that were investigated. Compare the findings of Campo, Gil, and Davila (2005) regarding the effects of music stimuli on animals' stress and fear levels.

In the work of Sambraus and others, a limited study of the effects of music has sometimes led to an oversimplified idea of how overall well-being or even dedicated bodily parameters might be directly influenced by an acoustic stimulus. Be it the questionable belief that just *one* piece by *one* particular composer was able to trigger certain abilities or skills,[3] or the idea that it was the musical piece played to cancer patients that would cause a decreased consumption of analgetics –[4] a connection can seldom be made directly. Often enough, experiments investigating the psycho-physiological effects of rhythmical stimuli, conducted on a seemingly basic level, produce contradictory results. So, even today, the researcher, having consulted dozens, maybe hundreds of studies in the respective area, might end up with the feeling that *Wir stehen selbst enttäuscht und sehn betroffen / Den Vorhang zu und alle Fragen offen.*[5]

It therefore is the aim of this study to draw a more integrated picture of how external rhythmical stimuli can influence endogenous periodic rhythms of the human body by firstly shifting the discussion back to a more basic psycho-physiological level, and then widening the picture to include potential secondary causes and effects that, for example, music therapists refer to, and which might even directly be invoked to improve a patient's prognosis. An important focus is therefore on how the mental attitude of a subject might have an uncontrolled influence on the results of a medical intervention, including inter-individual preferences, subconscious expectations, and other factors, such as laboratory or investigator effects on the outcome of the experiments into the broader investigation.

Musicologists have the responsibility to comply with the scientific standards of empirical research on the one hand, and incorporate much of the experience and usual practises of the humanities, where their *wissenschaft* is originally rooted, on the other. In this case, learning from bio-medical engineers, health professionals, cardiologists, psychotherapists and, at the same time, music historians and theorists, music therapists, and, last not least, professional musicians made the whole investigation extremely versatile. It nonetheless had to meet all the necessary requirements and standards of the respective faculties. To constantly consider the prerequisites of *the two cultures*[6] was highly challenging, but rewarding.

[3] cf. McCutcheon (2000); Fudin and Lembessis (2004)

[4] as proposed in Reinhardt (1999)

[5] Bertolt Brecht, *Der gute Mensch von Sezuan.* Suhrkamp, Frankfurt am Main, 1964.

[6] cf. Brockman (1995)

Part I

Exploring the effects of music

> *Music has the power to stimulate and to calm, to soothe and to inspire. Playing music undoubtedly benefits people. The elderly are stimulated, the depressed are encouraged, and the tired are invigorated.*[7]

In the first part of this study, different approaches to the vast field of how to interpret the effects of acoustic stimuli are outlined in a general survey, and some interconnections are considered. On the physiological level, cardiac, respiratory, and electrodermal effects are focused on. These parameters are later investigated in the second part. The importance of a coherent understanding of these parameters, and also of the processes at neural level,[8] is self-evident.

Plato, considering the idea that different kinds of art could excite corresponding emotions in the recipient and even lead him to immoral ways of living, warned that the first and foremost law of art should be objective beauty and ethical worthiness, not subjective taste or the pleasurable sensation that was a stimulus and its satisfaction.[9] Almost 2500 years later, the ideas of what art can initiate – and what it should cause – have changed. Nevertheless, the question remains as to whether and how music has, other than its pedagogical or educational functions, psychological and physiological effects.

Athanasius Kircher, one of the first prominent figures to propose a connection between the distinct rhythm of the heart and the state of people's health, suggested the use of rhythmic stimuli to cure diseases:

> Solte nun ein Medicus seyn/ der dise Harmony gründlich verstünde / und wüste / was alle Kranckheiten für absonderliche pulsus hätten / würde er durch widrige media,harmonicè applicirt / entweder zu oder davon thuend/den Leib gar bald wieder zur vollkommenen Harmony bringen. Weil aber dergleichen wenig gefunden werden/ist es kein Wunder/daß die medici in ihrer Cur so gar unglückselig sind.[10]

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[7] (Aldridge, 1993)

[8] Thaut (2007, p. vii) notes that *music has received an unprecedented research focus in the brain sciences over the previous two decades.* Effects of music on brain function are not investigated in the present study for practical reasons, but recent studies in the field are discussed in order to provide a necessary overview of current understandings of bodily regulatory systems.

[9] *Oberstes Gesetz der Kunst ist nicht das subjektive Gefallen, der schwärmerische Taumel und das nur auf den Reiz und seine Befriedigung ausgehende Lustgefühl, sondern das objektiv Schöne, das ontisch Richtige und ethisch Wertvolle* (Hirschberger, 1980, Vol. 1, p. 132).

[10] (Kircher, 1988a (1650, p. 311))

However, effects of music on the human body have been reported from very early on. In cultic acts, often accompanied by a pulsating drum rhythm, different peoples had used sound as a stimulus (Gillis, 1966).[11] Besides war rituals, healing ceremonies played – and sometimes still play – an important role in the everyday life of indigenous people.[12]

But it is not only in the tradition of the autochthonous peoples that there seems to be an obvious desire to influence bodily health and performance by certain kinds of music, as two recent examples demonstrate. The first is taken from the European Committee for the Prevention of Torture and Inhuman or Degrading Treatment or Punishment (CPT), which demanded that *Psychiatric treatment [generally] should involve a wide range of rehabilitative and therapeutic activities, including access to occupational therapy, group therapy, individual psychotherapy, art, drama, music and sports.* [13] The second is from the American Civil Liberties Union (ACLU), who published documents in 2004 which suggested that prisoners had been forced to confess through the use of loud music.[14] In a clinical sense, both examples assign to music the potency to actively influence people's minds and bodies.

Music therapy characterises its manifold concepts *psychotherapeutically in its essence.*[15]. However, the physiological influences of music therapy on subjects have not as yet been investigated thoroughly. The *Kassel Theses* mention the use of music *for the reconstitution, preservation, and promotion of mental, somatic, and intellectual well-being*, but they do not go into further detail regarding the mechanisms of its effects. The effects of music therapy are still difficult to quantify, which contributes to the fact that in Germany and elsewhere, health insurance companies rarely or never pay for such therapies.

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[11] The fact that *Naturvolk* (primitive people) and *Kulturvolk* (civilised people) were perceived to be different well into the 20th century might allude to the intricacies of nomenclatures in functional (healing) music versus (cultural) music. However, this discussion is beyond the scope of the present study.

[12] *The Navahos spend more than a quarter of their time healing the sick.* (Touma, 1982, p. 289)

[13] (Europäisches Komitee zur Verhütung von Folter und unmenschlicher oder erniedrigender Behandlung oder Strafe (CPT), 2005, p. 60)

[14] *BAU [Behavioral Analysis Unit] personnel witnessed sleep deprivation, REDACTED and utilization of loud music/bright lights/growling dogs in the Detainee interview process by DOD [Department of Defense] representatives.* (FBI, 2004b, p. 4585) *On several occasions, I did hear loud music being played and people yelling loudly from behind closed doors of interview rooms but I could not say that detainees were present in those rooms.* (FBI, 2004a, p. 4499)

[15] *"...ihrem Wesen nach als psychotherapeutisch..."* (Bissegger et al., 2003)

In Germany, aside from *Music Medicine*, which is nowadays mostly associated with aiding the recovery of professional musicians, there are also smaller branches of research and therapy that deal with the psycho-physiological properties of music performance and consumption. There are often secondary uses of the results of such work. Sports science, for example, with its findings about heart rate variability and other cardio-respiratory characteristics in athletes, contributed to the development of wearable HRV measuring devices for fitness sports, commercial software and hardware for the analysis of bio data,[16] and a device that is able to play music continuously in a tempo defined by the actual running pace of its carrier (Bieber and Diener, 2003). Since music-medical questions play a rather minor role in these developments, they will not be examined much further in this study.

1 General psycho-physiological effects

In recent years alone, a vast amount of studies have been undertaken on various effects of music. Researchers investigated the effect of live music on anxiety levels in patients undergoing chemotherapy treatment (Ferrer, 2007) and on hospital patients in general (Moss, Nolan, and O'Neill, 2007), the psychological effects of music tempi during moderate exercise (Karageorghis, Jones, and Stuart, 2007; Yamashita, Iwai, Akimoto, Sugawara, and Kono, 2006) and during 400 metre sprinting (Simpson and Karageorghis, 2006). Investigations were made on interactive music as a treatment for pain and stress in children during venipuncture (Caprilli, Anastasi, Grotto, Abeti, and Messeri, 2007), the "Vivaldi effect", namely the increase of working memory in older adults by playing an excerpt of Vivaldi's "Fours Seasons" to them (Mammarella, Fairfield, and Cornoldi, 2007), and the effect of background stimulative music on the social behaviour in Alzheimer's patients (Ziv, Granot, Hai, Dassa, and Haimov, 2007). In more specific areas of research, the role of tempo entrainment in the psycho-phyiological differentiation of "happy" and "sad" music (Khalfa, Roy, Rainville, Dalla-Bella, and Peretz, 2008), and the effect of rhythmic auditory stimulation on gait performance in children with spastic cerebral palsy (Kwak, 2007) were investigated recently.

Regarding music therapy, its effect on schizophrenic patients (Ulrich, Houtmans, and Gold, 2007), in stress response to day surgery (Leardi, Pietroletti, Angeloni, Necozione, Ranalletta, and Gusto, 2007),

[16] cf. Hottenrott (2004)

on elderly people with depression (Hanser and Thompson, 1994)[17] or moderate or severe dementia (Takahashi and Matsushita, 2006), on the behavior profile and musical skills in young adults with severe autism,(Boso, Emanuele, Minazzi, Abbamonte, and Politi, 2007)[18] and in palliative medicine (Gallagher, Lagman, Walsh, Davis, and Legrand, 2006) were outlined.

Studies, excluding those concerned with socio-cultural priming and which concentrate on physiological effects of music, with a special focus on animals have established the influence of classical and rock music on red blood cell rheological properties in rats (Erken, Kucukatay, Erken, Kursunluoglu, and Genc, 2008), the effect of Vivaldi's "Four Seasons" on stress and fear levels of hens (Campo, Gil, and Davila, 2005), the effect of harp music on heart rate, blood pressure, and respiratory rate in the African green monkey (Hinds, Raimond, and Purcell, 2007),[19] and the effect of auditory stimulation on renal sympathetic nerve activity and blood pressure in rats (Nakamura, Tanida, Niijima, Hibino, Shen, and Nagai, 2007). Even in plants, some effects of music and white noise were found.[20]

Other studies combined the effects of music with sociological, therapeutical, or other factors, and these have included, for example, the meaning of rap music for ethnically diverse college students (Iwamoto, Creswell, and Caldwell, 2007), the effect of aroma-therapy massage accompanied by music on the stress levels of emergency nurses (Cooke,

[17] It should be noted that a recent meta-study by Maratos, Gold, Wang, and Crawford (2008) suggests that although music therapy is accepted by people with depression and is associated with improvements in mood, the small number and low methodological quality of studies in this area make it impossible to be confident about its effectiveness.

[18] A meta-analysis by Whipple (2004), including 12 dependent variables from 9 quantitative studies, concluded that *all music intervention, regardless of purpose or implementation, has been effective for children and adolescents with autism.* She also discusses clinical implications and recommendations for future research.

[19] McDermott and Hauser (2007) investigated nonhuman primates, and how they reacted to music, and concluded that *there appear to be motivational ties to music that are uniquely human.*

[20] Creath and Schwartz (2004) investigated the effects of music, noise, and so-called "Vortex Healing" on okra (*Hibiscus*) and zucchini seeds. However, regarding the effect of healing energy on the sprouting process, the study, which reports results from Creath (2002), did not control for thermal conditions. Since the seeds were re-stacked for healing treatment, and the hand of the researcher touched the top of the stack for 30–40 minutes per day, temperature effects might have been the cause of the accelerated sprouting. The seeds might also have benefited from other factors, like sound wave vibration, ventilating air, etc.

Holzhauser, Jones, Davis, and Finucane, 2007), the effect of Bach's "Magnificat" on the emotions, immune, and endocrine parameters of patients with infectious lung conditions (le Roux, Bouic, and Bester, 2007), electrophysiological correlates of the processing of pleasant and unpleasant music, and neural correlates of the evoked emotions (Sammler, Grigutsch, Fritz, and Koelsch, 2007), and the means of rhythmic body movement when investigating auditory encoding (Phillips-Silver and Trainor, 2007).

In a number of ways, investigations into the effects of listening to music overlap with those that investigate the bodily effects of *making* music.[21] Regarding the neuro-physiology of musicians, Baeck (2002, pp. 452f.), for example, concludes that

> the brains of musicians have definite anatomical and functional characteristics which are not found in non-musicians and which are correlated with the age at which musical studies began. Indeed, maturation of the tissue fibres and intracortical neurophil continues up to the age of 7 years.[22] Consequently, musical training results in structural adaptation, probably plastic reorganization, i.e. changes in synaptic connections and/or neural growth processes. Whether these brain characteristics in musicians are due solely to cortical plasticity through training or to an innate structural property, or to both, however, is still an open question; after all, it is not known how the expression of neuroplastic processes is modulated by genetic or environmental factors.

Harrer and Harrer (1982) specify five general characteristics that may cause different vegetative alterations under the "effect of music":

1. The 'vegetative reagibility' of the subject, depending on physique, age, gender, life style, training condition, overall physical condition, and actual physical condition (fatigue, alcohol, coffee etc.).

2. The 'emotional reagibility' or receptivity.

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[21] This topic is not reviewed in detail here, although a survey of the relevant literature was undertaken when setting up the pilot study, which included a practical performance experiment (which was not included in the later set of experiments).

[22] The data of Schlaug, Jaencke, Huang, Staiger, and Steinmetz (1995) indicated *a difference in interhemispheric communication and possibly in hemispheric (a)symmetry of sensorimotor areas* in musicians who had begun musical training before the age of 7.

3. The overall attitude towards music.[23]
4. The actual attitude towards the presented music.[24]
5. The volume of the presented music.

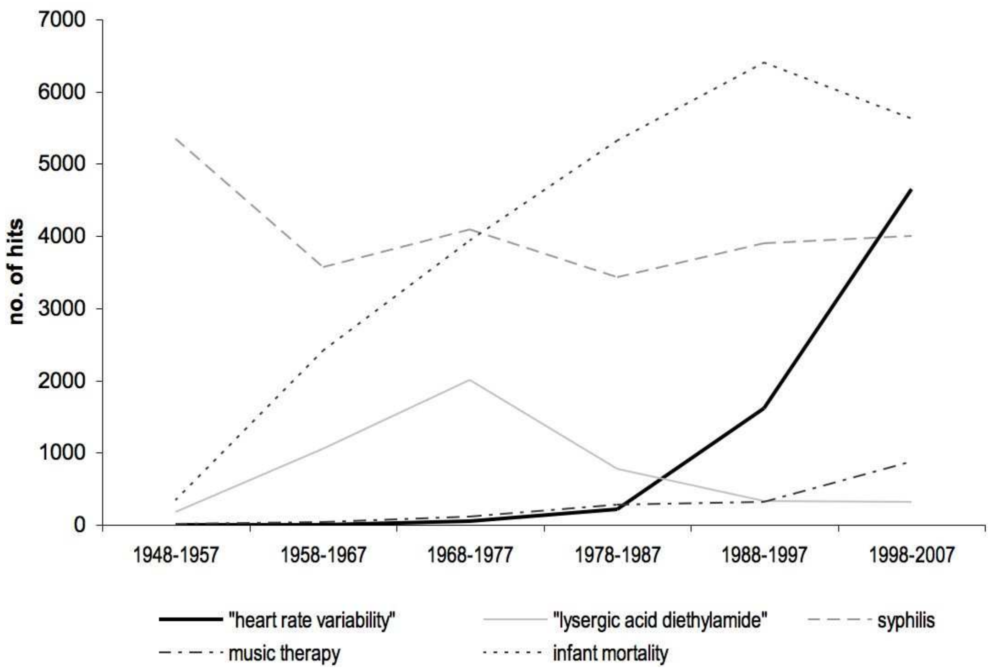

Figure 1: MEDLINE Keyword Search
Due to progress in the quality and availability of medical devices, political or socio-economic developments, or shift of interest within medical fields and professions, the amount of research on a certain topic varies, and with it, the number of studies. As an example, research about heart rate variability (HRV) profited from the recent development of more powerful recording devices, which can be comprehended by the number of hits in the MEDLINE database.

Regarding emotional responses to music, Juslin and Västfjäll (2008) generally note that

> the notion of musical emotions remains controversial, and researchers have so far been unable to offer a satisfactory account of such emotions. We argue that the study of musical

[23] *"Dabei kann sich die Untersuchungssituation (Labor, Apparate usw.) störend auswirken"* (Harrer and Harrer, 1982, p. 79).

[24] *"Bei lediglich verstandesgemäßer, kritischer Einstellung sind vegetative Veränderungen nur in geringem Maße nachweisbar oder fehlen ganz"* (Harrer and Harrer, 1982, p. 81).

> emotions has suffered from a neglect of underlying mechanisms. Specifically, researchers have studied musical emotions without regard to how they were evoked, or have assumed that the emotions must be based on the "default" mechanism for emotion induction, a cognitive appraisal. Here, we present a novel theoretical framework featuring six additional mechanisms through which music listening may induce emotions: (1) brain stem reflexes, (2) evaluative conditioning, (3) emotional contagion, (4) visual imagery, (5) episodic memory, and (6) musical expectancy. We propose that these mechanisms differ regarding such characteristics as their information focus, ontogenetic development, key brain regions, cultural impact, induction speed, degree of volitional influence, modularity, and dependence on musical structure.

The following chapters therefore start with an overview of the main areas of research, and the recent developments and results concerning the various effects of music on people. The effects are, of course, multiple, and although they are discussed individually, they are not separate phenomena. Finally, open questions and implication on future research are summed up.

1.1 Effects on the central nervous system

The basic functions of how music is perceived by the brain have been investigated with several neurophysiological and neuroimaging methods. Among others, Evers et al. (1999) performed a study of the middle cerebral artery, using functional transcranial Doppler sonography (fTCD) to evaluate changes in cerebral blood flow velocity during different periods of music perception, suggesting that musicians and non-musicians have different strategies to lateralise musical stimuli.[25] Ohnishi et al.

[25] In their study, Evers et al. name three major problems of earlier studies on the subject:

> First, differences between the subjects, such as musical experience, handedness and gender, have been neglected in some studies. Secondly, the character of music, its similarity to language and the attitude of the subjects towards it have not been considered in other studies. In these studies, the impact of simple musical elements such as intervals, chords and pitch or timbre discrimination on lateralization were examined primarily, and complex musical structures were not looked at. Thirdly, for most of the methods, analysis of dynamic short duration changes during music perception is not possible. The time period necessary to evaluate

(2001) used functional magnetic resonance (fMRI) to examine cerebral activity patterns associated with musical perception and suggested that such activity was associated with absolute pitch ability and the functional re-organisation produced by the early commencement of long-term training. Zatorre, Evans, Meyer, and Gjedde (1992); Blood, Zatorre, Bermudez, and Evans (1999) measured cerebral activation with positron emission tomography (PET); their findings suggest *that music may recruit neural mechanisms similar to those previously associated with pleasant/unpleasant emotional states, but different from those underlying other components of music perception, and other emotions such as fear*[26] however, some of their findings could not be reproduced by regional cerebral blood flow measurement with single photon emission tomography (SPECT).[27] Analysing EEG responses is another means of investigating the effects of music.[28] Based on their findings, Koelsch and Siebel (2005) developed a neuro-cognitive model of how music may be perceived, thus trying *to identify aspects of music perception that need future research.*[29]

Regarding potential implicated therapeutic interventions, the authors of the latest *Cochrane Review on Music for Pain Relief* (Cepeda, Carr, Lau, and Alvarez, 2006) searched relevant medical bibliography sources for randomised trials that evaluated the effect of music on any type of pain in children and adults, excluding trials that reported concurrent non-pharmacological therapies: 51 studies involving 1,867 subjects exposed to music and 1,796 controls were included. The report concludes that

> Listening to music reduces pain intensity levels and opioid requirements, but the magnitude of these benefits is small and, therefore, its clinical importance unclear.[30]

Average heart rate is one of the indicators for an overall sympathetic arousal of the central nervous system, and one of the easiest to be

functional changes is at least a few minutes for modern neuroimaging or neuropsychological testing.

[26](Blood, Zatorre, Bermudez, and Evans, 1999, p. 382)
[27]As noted by Evers, Dannert, Rödding, Rötter, and Ringelstein (1999, p. 76).
[28](Ogata, 1995)
[29](Koelsch and Siebel, 2005, p. 582)
[30]Bennet and Bennet (2008), in another recent example, claim in their general review of the literature that *music and the human mind have a unique relationship that is not yet fully understood.*

measured. If the subject is able to self-report bodily reactions, so-called "chills", a subtle nervous tremor caused by intense emotion,[31] are another indicator that has been investigated in recent years.[32] The quality and quantity of bodily reactions depends, among other factors, on the reagibility of the subject and the relationship of the stimulus to the listener, which differ between individuals. Grewe et. al. suggest that when analysing stimuli such as chills, there is also a learning process involved, and thus propose that

> it is not the music as a physical stimulus that manipulates our moods, but it is we using the music as a communicative offering to influence our feelings in a re-creative process. There may be some strong effects in music [...] which trigger chills directly. But even in this example, it seems to be a process mainly based on the heightened attention of the listener. The reason why we largely are not aware that we actively influence our feelings by listening to music is because this process is mostly implicit, based on associations, memories, and expectancies.[33]

However, as the analysis of the effects of music on the central nervous system already show, it is not always possible to differentiate strictly between certain effects on various biological parameters and regulation cycles. What follows will therefore allude to the main areas of research, without attempting to clearly separate them.

1.2 Effects on mood and behaviour

Ziv, Granot, Hai, Dassa, and Haimov (2007) examined the effect of background music on the behaviour of Alzheimer's patients, and found both a significant increase in positive social behaviors and a significant decrease in negative behaviors related to agitation when music was played.

Regarding the effects of music in therapeutic interventions, a meta-analysis by Whipple (2004) indicates benefits in the use of music in intervention for children and adolescents with autism, regardless of purpose or implementation. However, the majority of studies so far have only been performed with small sample sizes, and rather brief intervention times.[34]

[31] cf. Panksepp (1995)

[32] (Grewe, Nagel, Kopiez, and Altenmüller, 2007)

[33] Grewe et al. (2007, p. 313)

[34] "Reports published to date in the field have usually exploited brief music therapy

More importantly, long-term studies sometimes lack control groups, and can not exclude type II errors.[35] Boso, Emanuele, Minazzi, Abbamonte, and Politi (2007) is a typical example and included eight young adults with severe autism in 52 weekly music therapy sessions lasting 60 minutes. Clinical and musical ratings were done after 26 and 52 weeks, and compared to baseline prior to the intervention. Apart from the ability to execute complex rhythmic patterns, there were significant improvements in both ratings compared to baseline, but no significant improvements over the last 26 weeks, suggesting a plateauing response. Since there was no control group, the researchers could not rule out transfer effects, and they stated that

> the beneficial effects of active music on clinical variables measured in our patients with autism during the first six months are likely to rely on the high level of absorption and the high degree of personal interaction that active musical engagement may induce.[36]

In fact, many behavioral effects that are attributed to music could actually be transfer effects, or attributed solely to experimental procedures.[37]

Fiske (1996) concludes that mood states following music listening are the result of an inividual's unique past experiences, and he differentiates between aesthetic response and listener mood state response to music, the latter occuring

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interventions – typically daily sessions over 1 week – without focusing on the possible behavioral and social effects of long-term therapeutic programs in ASD" (Boso et al., 2007, p. 710)

[35] "False negative" or β error: the error of failing to reject a null hypothesis when it is, in fact, false. Cf. Bortz (1993, p. 107).

[36] (Boso et al., 2007, p. 712)

[37] For example, there were a number of methodological shortcomings in Escher and Evequoz (1999) who stated that *Unter entspannender Musik (Bach, Vivaldi, Mozart) ergab sich eine signifikante Verringerung der Herzfrequenz und auch eine Verbesserung der Herzfrequenzvariabilität* (Escher and Evequoz, 1999, p. 951). In their study, the researchers aimed to investigate the moderation of the sympathetic nervous system by music in young adults via the means of a long-term ECG analysis. They compared average heart rates prior and post treatment, which consisted of listening to "relaxing music" in a reclined posture. Having found a significant decrease in heart rate, they did not attribute the effect to posture, nor did they involve controls. Even more, heart rate variability (HRV) was assumed to have "improved" (that is, *pNN50* – the number of pairs of adjacent NN intervals differing by more than 50 ms, divided by the total number of all NN intervals – had increased) while this effect can be exclusively ascribed to the decreased average heart rate.

> as a result of individuals projecting their many past experiences and beliefs (with the inherent emotional content) onto their experience of the tonal rhythmic events presented in music.[38]

For a vast number of studies investigating the well-established effects of music on arousal, mood and also certain skills and bodily abilities,[39] Husain, Thompson, and Schellenberg (2002, p. 153) may be cited as representative:

> [...] we do not yet have a full account of the temporary effects of music listening on spatial abilities. Some researchers continue to posit a direct link between music and spatial abilities (Gruhn & Rauscher, 2002; Shaw, 2000), but we believe that the available evidence favors an explanation that we call the "arousal-mood" hypothesis. Arousal and mood represent different but related aspects of emotional responding. Although the use of these terms in the literature varies, mood typically refers to relatively long-lasting emotions [...], which may have stronger consequences for cognition (thinking and reasoning) than for action [...] Arousal typically refers to the degree of physiological activation or to the intensity of an emotional response [...]. Self-report measures of arousal include adjectives that make reference to physiological states and intensity (e.g., vigor, activity, wakefulness), whereas measures of mood include adjectives that make reference to feelings and evaluation (e.g., sad, happy, discouraged, depressed, gloomy). Arousal and mood correspond closely to activation and valence, respectively [...] According to the arousal-mood hypothesis, listening to music affects arousal and mood, which then influence performance on various cognitive skills.

Magee and Davidson (2002) showed that there are significant positive effects of music therapy on mood states in patients with neurological impairments. A meta-analysis by Standley and Whipple (2003) showed that music therapy had a significant impact on the mood states of children receiving medical treatment.

Almost all studies in this field to date suggest more randomised controlled trials (short-term or long-term) to further investigate the di-

[38] as also noted in Lesiuk (2005, p. 174)

[39] see p. 23 for a more thorough analysis of literature on the effects of music on skills and cognitive function

rect effects music may have on mood and behaviour, and to be able to control for confounding variables.[40]

1.3 Effects on the cardiovascular system

According to early research, listening to music of different styles and tempi can result in changes of heart rate, blood pressure, and respiration rate.[41] However, there has also been strong evidence that simply listening to music may not alter any of these variables.[42]

In his review of the literature, Biedermann (1993, p. 449) provides an overview of the research done in the 1970s and 1980s:

> Numerous research studies have investigated the effects of music listening on physiological processes. Of these studies, heart-rate has been the most commonly investigated parameter by far (Dainow, 1977). Music research in laboratory settings has attempted to clarify the interactive relationship between bodily and musical rhythms, but has produced variable results (Hodges, 1980).
>
> Within medical settings, the therapeutic effects of music have been noted in several studies (Standley, 1981) [...] Some other studies in medical settings, however, have failed to demonstrate significant heart-rate differences while listening to music (Davis-Rollans and Cunningham, 1987; Updike and Charles, 1987; Zimmerman, Pierson, and Marker, 1988).
>
> The diversity of individual responses while listening to music has led some researchers to attempt to isolate those factors which may influence physiological measures. Researchers have noted the influence of personal factors in the listener which may influence heart-rate responses, including: reactions to variables in the experimental situation itself (Dainow, 1977), and the listener's relationship to the music – e.g., familiarity (Landreth and Landreth, 1974), preference (Davis and

[40] Barton (2008, p. 26), for example, states that *music therapy is a relatively new field to the medical profession and has just begun expanding into different areas of the hospital such as the emergency department. Future research is [therefore] recommended [...]*

[41] Hyde (1927); Ellis and Brighouse (1952); Meyer (1956); Zimny and Weidenfeller (1963); Landreth and Landreth (1974); Gembris (2000); Gomez and Danuser (2004)

[42] (Davis-Rollans and Cunningham, 1987; Zimmerman, Pierson, and Marker, 1988; Landreth and Landreth, 1974)

> Thaut, 1989; DeJong, van Mourik, and Schellekens, 1973), and level of musicianship (DeJong et al., 1973).
>
> Other researchers have isolated specific elements within the music which may influence heart-rate (Edwards et al., 1989). Although many of the music and physiology studies have compared the relative effects of musical stimuli according to the general classifications of "stimulative" or "sedative", research has shown that these descriptors do not necessarily lead to predictable physiological changes (Taylor, 1973). Several authors have suggested the need for greater definition of musical stimuli during music research, based on individual reactions to specific pieces of music (Hanser, 1985; Hodges, 1980).
>
> Another factor which may influence listener's heart rate is the principle of entrainment.[43]

Entrainment principles have been observed during physiological research utilising music or its rhythmical parameters in various forms. In his own study, Biedermann (1993) used two different tempo conditions of music, where one should have elicited entrainment of heart rate to music. The conditions yielded no significant difference. One thing the analysis did show, however, was *that inter-individual heart-rate responses differed significantly during these conditions ($p < .002$), and indicated diverse individual responses to the same stimuli* (Biedermann, 1993, p. 451): Biedermann had used music under non-realistic circumstances which increased the probability of uncontrolled psychological "side-effects" (the tempo of the samples was manipulated).

1.3.1 Heart frequency alteration

Einthoven's tele-cardiogram[44] made it possible to analyse the pulse and correlate it directly with the behaviour of the proband. In the following years, studies using that apparatus attributed alterations of heart rate to muscular exercises, noise, psycho-sensoric activity, posture, or the subject's emotion.[45] Since an active music performance required a number of these parameters to shift, and therefore could not be excluded

[43]Bason and Celler (1972, p. 279) found *entrainment of the sinus rhythm with external auditory stimuli* under specific circumstances, and they attribute it to *neural coupling into the cardiac centres of the brain.*

[44]cf. Einthoven (1906)

[45]cf. Smith (1981)

as sources of irritation, many researchers restricted their studies on the effects of music to the *listening* process. These experiments involved one or two subjects, but later on, long-term studies were made with members of symphony orchestras. One of the first researchers who used the Einthoven apparatus in the field of music research was Ida Hyde.[46]

In 1952, Ellis and Brighouse summed up earlier results in this field of research, and thus established a starting point for various other studies to come which dealt with the influence of music on heart and respiration activity.[47] They recorded the pulses of subjects before, during, and after they listened to a musical piece, and – contradicting the results of many other physiologists – could *not* determine significant differences of heart rate. Landreth and Landreth (1974) suggested higher experimental standards for future research. They criticised Ellis and Brighouse's method of recording just minute-long pulse frequencies. Landreth et al. therefore recorded heart rates continually, and by doing so could correlate them with the presence or absence of certain learning processes. They also suggested complementing and verifying heart rate measurement with the recording of other vital functions, namely EEG, electrodermal activity, or respiration rate,, and they increased the number of subjects in follow-up studies, and controlled the subjects' activities before the experiments and in the recreational intermissions.

Zimny and Weidenfeller had been able to show that playing three different kinds of musical samples (stimulating, neutral, and calming music) had no significant effect on the heart rates of subjects. They suggested that galvanic skin response (GSR) was a better criterion for measuring those effects.[48] Finally, Dorney summed up the results of research on music's effects on heart activity,[49] and concluded that music was able to intensify physiological *arousal*, but inter-individual differences posed a problem for the reliable interpretation of the experiments. It was only later on that the general conception of how acoustical stimuli might influence bodily parameters in various other ways than via a mere direct

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[46] *It was interesting to see that meals, certain foods, smoking, vitiated air, fatigue, familiarity and repetition, and excited and depressed states of mind all exerted an influence upon the effects produced by the music, and these varied for different individuals.* (Hyde, 1927, p. 181)

[47] (Ellis and Brighouse, 1952)

[48] (Zimny and Weidenfeller, 1963, p. 313). Boucsein (1992, p. 372f.) added that *consideration should be given to the use of different EDA parameters as markers for the various emotional states, as for example in research on emotional expression, where EDR amplitude is correlated with the inner emotional involvement, while HR is more likely to reflect overt emotions.*

[49] (Dorney, 1992)

entrainment of rhythmical pulses was widened by the concept of how music could alter states of mood and arousal.

1.3.2 Changes in heart rate variability

Recent enhancements in analysis have promoted heart rate variability (HRV) as an important clinical parameter in patients who had been suffering or were suffering from myocardial infarction, cardiac insufficiency, diabetes, or MODS (*Multiple Organ Dysfunction Syndrome*).[50] A pathologically reduced HRV after a myocardial infarction, for example, suggests an increased mortality of the patient.[51] In other fields, various HRV parameters are predicted to be of diagnostic relevance as well. However, many investigators are unaware of the statistical complexity this measure poses,[52] or over-interpret its diagnostical value.[53]

Klein, Cnaani, Harel, Braun, and Ben-Haim (1995) suggested that a decreased HRV may be a characteristic of panic disorder (PD) and proposed it as a diagnostic marker, not clearly recognising the fact that PD patients have higher baseline heart rate.[54] The significant difference in average heart rate of subjects and controls is also not discussed in necessary detail in an otherwise meticulously conducted study by Yeragani et al. (2002), which suggests that major depression is associated with decreased cardiac vagal function, using non-linear measures like LLE (*largest Lyapunov exponent*), although the "Task Force"[55] had stated that *in physiological studies comparing HRV in different well-defined groups, the differences between underlying heart rate should [...] be properly acknowledged*, indicating that time- and frequency domain measures

[50](Lombardi, Malliani, Pagani, and Cerutti, 1996; Stein and Kleiger, 1999; Pumprla, Howorka, Groves, Chester, and Nolan, 2002)

[51](Stauss, 2003)

[52]The general observation that *the more variable are successive beat intervals the healthier is the person* (Fallen, 2000, p. 339) has in some cases also led to wrong ideas about how regulatory mechanisms function.

[53]McCraty, Atkinson, Rein, and Watkins (1996, p. 172), for example, referred to some of the findings of Ori, Monir, Weiss, Sayhouni, and Singer (1992), and investigated the effects of music on autonomic activity and immunity using a relatively simple HRV power spectral density analysis, which just demonstrated *an increase in autonomic spectral power in all experimental conditions where there was an increase in S-IgA.*

[54]Although the study acknowledges that PD patients *showed significantly higher HR than control subjects.* (Klein et al., 1995, p. 22)

[55](Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996, p. 364)

of HRV might vary according to mean heart rate.[56] The design of many similar studies investigating HRV in risk groups is limited for ethical reasons.[57]

However, a relocation of researchers' interests in cardio-respiratory synchronisation due to the absence of a clear diagnostic relevance outside the mentioned diagnoses and some unsolved questions regarding methods and physiological interpretation, as Cysarz proposed it,[58] cannot be confirmed by studies in recent years. HRV, its clinical diagnosis capability and its potential application as a diagnostic measure of overall fitness, are still of much interest to investigators in all fields. Sport science, for example, uses HRV to quantify training effects in athletes, and in the adjustment of stress tests.[59]

[56] Panina, Khot, Nunziata, Cody, and Binkley (1995), for example, stated that *the disparity between the behavior of mean HR and HRV measures implies that these variables are governed by different mechanisms that remain to be investigated.*

[57] cf. Shea, Kamath, Fleming, .Streiner, Redmond, and Steiner (2008)

[58] (Cysarz, 2003, p. 3)

[59] Cf. Hottenrott (2004). With regard to the notion of 'stress', as used in the context of the present study, it may be useful to quote Boucsein (1992, p. 284f.) in detail:

> The use of the term 'stress' in psychology covers a wide range of phenomena, from simple over- or understimulation, via frustrative experience, to life-challenging situations. Therefore, it is not easy to treat stress as a clearly unitary concept, especially with respect to activation or emotional experience. Most researchers would accept that stress results in distressing experience of high intensity [...], since only a minority of studies have been concerned with the concept of eustress (i.e., experience of stress in a positive emotional context). Despite these problems of delineation, stress can be generally defined as a state of high general activation and negatively tuned but unspecific emotion, which appears as a consequence of stressors acting upon the subject. They are subjective and/or objective challenges exceeding a critical level with respect to intensity and/or duration. Stress reactions are regarded as having properties to reestablish homeostasis by using physiological and psychological levels as well. If this goal cannot be attained by the subject, fundamental psychophysiological changes are expected. However, it remains debatable whether long-lasting neuroendocrine changes [...] develop as a consequence of continuous short-lasting psychophysiological and endocrine reactions which can be elicited in laboratory stress situations. Experimental evidence for this comes from animal research [...] but cannot be performed with human subjects for ethical reasons. Modelling stress in laboratory settings, however, serves as a tool to observe the course of corresponding psychophysiological processes under experimentally controlled conditions. Therefore, the investigation of the characteristic course of psychophysiological parameters over time can be regarded as a major aim in this area of research [...] Thus, continuously

However, an exact physiological interpretation of a modified HRV parameter is still difficult. Higher HRV cannot be equated with improved health status or higher fitness. Accordingly, the interpretation of test results is still arguable. Until today, there are no common standards of measuring and interpreting endurance tests; the only guidelines in regard to measuring and interpreting HRV, compiled by an international task force in 1996, only refer to measuring HRV at rest.[60] Longitudinal multicentre studies that would investigate the potential long-term effects of training or exposure to stress on heart rate variability are still rare,[61] and no firm conclusions can be drawn from their results.[62]

Besides, HRV is a measure with a high inter-individual variation, and it fluctuates most in young, healthy, and endurance-trained subjects. Predictions about a diagnostic value of HRV in these subjects seem to be not yet reliable.[63] This may be the reason why this parameter has, until now, not been generally utilised in investigating. There are no relevant studies using HRV as a monitoring parameter during musical performances, or in assessing the physiological effects of music therapy.[64] Could it perhaps be used to develop and evaluate relaxation techniques, as Vestweber and Hottenrott (2002), for example, tried in the field of high performance sports activity?

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observing this time course may form a specific paradigm with respect to comparisons of simple group means in research on phasic changes in expressed emotion research [. . .] Tonic electrodermal parameters, such as the EDL or the NS.EDR freq. [...] may be regarded as the most suitable measures to continuously monitor ANS activity-elicited by stress, since EDA is solely determined by the activity of the sympathetic branch of the ANS which is predominant in stress states.

[60](Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996)

[61]Aubert, Seps, and Beckers (2003)

[62]Cf. (Achten and Jeukendrup, 2003). Therefore, Vestweber and Hottenrott (2002) were still promoting single case studies, rather than the effects of group statistics to clarify basic questions of interpretation.

[63]For a discussion of the general limitations of these findings, see, for example, Bernardi et al. (2000).

[64]A study by Chiu, Lin, Kuo, Chiang, and Hsu (2003) reveals a number of methodological shortcomings, notably that they ignored the recommendations of the Task-Force mentioned earlier.

1.3.3 Blood pressure alteration

Blood pressure (BP) is one of the parameters studied when investigating cardiac control mechanisms.[65] Like heart rate, it continuously fluctuates over time[66] under the influence of control mechanisms aimed at maintaining cardiovascular homeostasis. These fluctuations are, as Parati, Mancia, Rienzo, and Castiglioni (2006, p. 676) put it,

> generated by external perturbations and by neural control mechanisms opposing their effects in the attempt to bring BP back toward a reference "set point" [. . .] As a result of these complex interactions, cardiovascular (CV) variability (V), rather than being "undesirable noise", reflects the activity of cardiovascular control mechanisms, representing a rich source of information on their performance in health and disease. The methods used to analyze this phenomenon include several approaches, respectively aimed at estimating BP or HR variance, their spectral powers [. . .] and coherence, HR turbulence [. . .], entropy, self-similarity and symbolic logic [. . .], or BP-HR interactions to quantify the baroreflex sensitivity on HR (BRS).

Teng, Wong, and Zhang (2007) investigated the effect of music on hypertensive patients in a study with thirty participants. After two participants dropped out for health and two others for personal reasons, and the data of another had been excluded since her systolic blood pressure (SBP) showed huge variations, the SBP values of the remaining subjects were found to have decreased significantly over a period of four weeks. However, some questions remain open regarding the overall sample size, and the controls, who were seated in a quiet room while the subjects receiving the treatment were listening to the music examples.

Blood pressure measurements are relatively easy to obtain, and are often used as an additional pre-post parameter in studies involving stress tasks or long-term relaxation treatment.[67] However, they may be easily susceptible to inter-individual and other variations. Therefore, when investigating blood pressure, large numbers of participants and a rigorous control of mediating variables are advisable.

[65](Akselrod, Gordon, Ubel, Shannon, Berger, and Cohen, 1981)

[66](Mancia, Ferrari, Gregorini, Parati, Pomidossi, Bertinieri, Grassi, di Rienzo, Pedotti, and Zanchetti, 1983)

[67]Cf., for example, Knight and Rickard (2001); Skille and Wigram (1995)

1.4 Effects on the respiration cycle

When investigating the effects of music, *respiration must be taken into account (or at least measured and factored in) if sense is to be made of short-term human cardiovasculuar rhythms.*[68]

In contrast to heart beat, without innervation by the autonomous nervous system (autorhythmicity) there is no spontaneous breathing oscillation. The normal respiratory cycles are caused by the rhythmical activity of specific inspiratory and expiratory active neurons in the hindbrain (*Medulla oblongata*), and adapted to the actual physiological needs. However, breathing activity can also be deliberately modulated, be it while singing or playing a wind instrument, which makes respiration regulation and its coordination with the cardiac regulatory cycle a function that is rather complex to model.

A number of studies have investigated the effect of music (mostly, relaxing music) on anxiety levels, analysing heart rate and respiratory rate.[69] A study by White (1992), a typical example, proves all of these parameters to be significantly reduced in the group that listened to relaxing music. Iwanaga, Ikeda, and Iwaki (1996) found significant music-by-phase interactions for respiration rate, but not for heart rate. However, this study lacks stringency with regard to sample size (only 12 participants took part in it), and the explanation of the effect does not stand up to a detailed discussion of the cause-and-effect chain.

Regarding study designs, Cooke et al. (1998, p. *H*709) suggest that *for short-term recordings, breathing protocols incorporating stepwise changes in frequency without stringent control of inspired volume may allow for the most efficient assessment of respiratory-mediated autonomic oscillations.*[70]

1.5 Effects on skin temperature and electro-dermal activity

The term *electrodermal activity* (EDA) was introduced by Johnson and Lubin (1966), and is applied to all electrical phenomena in skin, includ-

[68] (Cooke, Cox, Diedrich, Taylor, Beightol, Ames, Hoag, Seidel, and Eckberg, 1998, p. *H*715)

[69] (Lovell and Morgan, 1942; Haas, Distenfeld, and Axen, 1986)

[70] Compare the discussion of general limitations of the cardio-respiratory recording apparatus on p. 152.

ing active and passive electrical properties that can be traced to the skin and its appendages. In 1967, the *Society of Psychophysiological Research* published standardised measures, which soon became generally accepted.[71] Regarding the term *galvanic skin reflex* (GSR), which has often been used among therapists, Boucsein stated:

> An older notation persisting in the literature is "galvanic skin reaction" or "galvanic skin reflex" (GSR). It is recommended this term not be used for several reasons. Firstly, it suggests that skin can be regarded as a galvanic element, which does not correspond to the multiplicity and complexity of electrodermal phenomena [...] Secondly, it points to EDRs as being elicited as a kind of reflex, which is the case neither in spontaneous EDRs nor in psychologically elicited electrodermal changes.

The author mentions the earliest experiments on electrodermal activity, and its relation to psychological factors:

> He [DuBois-Reymond] had his subjects put either both hands or both feet into a zinc sulphate solution, and observed an electrical current going from the limb at rest to the one that was voluntarily contracted [...] However, in accordance with the opinion shared by most workers at that time, DuBois-Reymond considered the observed phenomenon as being due to muscle action potentials [...] The observation which first related psychological factors to electrodermal activity is attributed to Vigouroux (1879), an electrotherapist working in France. He measured skin response (SR) changes that paralleled changes in the amounts of anesthesia in hysterical patients, and supposed that both phenomena were dependent upon central processes.

Studies that investigate a direct effect of different types of music on skin temperature are relatively rare. McFarland (1985) investigated it, concluding that music *initially* affects skin temperature in ways that can be predicted from affective rating scales. However, the effect seemed to depend on other variables also, and the regulatory mechanism could also be attributed to measures of physiological arousal only, depending, among other factors, on preference.

[71] cf. Boucsein (1992, pp. 2 ff.)

1.6 Effects on the endocrine system

Listening to music may induce a variety of significant endocrine effects, as shown, for example, by McCraty et al. (1996) and Bartlett (1996). The effect appears to be mediated by emotional states; consequently, secretory Immunoglobuline A or S-IgA, a protein that is considered to be specifically responsive to an individual's emotional state, is often used as a marker for these effects.[72] Other factors indicating immune system changes include cortisol,[73] norepinephrine,[74] opioids such as β-endorphin,[75] the opiate antagonist naloxone,[76] corticotropin (ACTH),[77] prolactin, atrial natriuretic peptide (ANP) and tissue plasminogen activator (t-PA).[78]

McKinney, however, having found that *spontaneous imaging to selected music following a relaxation induction significantly decreased plasma B-endorphin*, admitted that *the relationship between central and peripheral levels is not clearly understood. We do not know whether the effects of music are central, peripheral, or both.*[79]

1.7 Effects on motor skills

Husain, Thompson, and Schellenberg (2002) have stated that the effect of music on different motor skills can be explained by its effect on arousal and mood. Today, most researchers believe that there is no direct "Mozart effect" in the sense that Francis Rauscher meant when she coined the term in 1993.[80] However, as music elicits changes in mood and arousal, a secondary or transfer effect of music on (often rhythmi-

[72] (Charnetski, Brennan, and Harrison, 1998; Hucklebridge, Lambert, Clow, Warburton, Evans, and Sherwood, 2000; Beck, Cesario, Yousefi, and Enamoto, 2000; Kreutz, Bongard, Rohrmann, Hodapp, and Grebe, 2004)

[73] (Beck, Cesario, Yousefi, and Enamoto, 2000)

[74] (VanderArk and Ely, 1993)

[75] (McKinney, Tims, Kumar, and Kumar, 1997)

[76] (Goldstein, 1980)

[77] Halpaap, 1985, cited by Spintge and Droh (1987)

[78] (Möckel, Röcker, Störk, Vollert, Danne, Eichstädt, Müller, and Hochrein, 1994)

[79] (McKinney et al., 1997, p. 97)

[80] Cf. Rauscher, Shaw, and Kye (1993); Newman, Rosenbach, Burns, Latimer, Matocha, and Vogt (1995); Carstens, Huskins, and Hounshell (1995); Fudin and Lembessis (2004); McCutcheon (2000); Hallam, Price, and Katsarou (2002). For a well-informed review of the "Mozart effect" and a brief chronological outline of the arguments before the effect received its *fatal blow* ("Todesstoß"), see Kopiez (2008).

cal) motor skills[81] and on cognitive abilities, as described in Schellenberg (2005) and Schellenberg and Hallam (2005), has been convincingly demonstrated.

The increasingly heated discussion about the Mozart Effect may therefore be explained from a socio-psychological standpoint (Kopiez mainly holds a psychological *weir effect* responsible). But this is easily resolved by accepting that it is probably based on transfer effects rather than neuro-physiologically, as Rauscher, Shaw, and Ky (1995) tried to establish and as even recent studies support.[82]

1.8 Effects on motor responses and work performance

The investigations into rhythmic auditory stimuli as internalized timekeepers for rhythmically patterned movements contributed to the formulation of basic questions raised by the work described in the second part of the present study. However, even if of some results overlap with those presented in the previous chapter, they should not generally be subsumed with those investigating mood-related effects.

For obvious reasons, the effect of music on work performance and productivity was investigated relatively early on.[83] The results of Anshel and Marisi (1978) suggested that physical endurance may be enhanced if movement is rhythmically coordinated with a musical stimulus. Lesiuk (2005), measuring the effect of music listening on state positive affect, work quality and time-on-task of computer information systems developers, notes that beneficial effects of music on task performance may be explained by increases in state positive affect: *When music evokes a pleasant mood and an increased arousal state, participants perform better on non-musical tasks.*[84]

Kwak (2007) used rhythmic auditory stimulation (RAS) in gait training sessions for children with spastic cerebral palsy (CP) to deter-

[81] See also p. 24 for a more detailed description of the effects of rhythmic stimulation on motor responses.

[82] A recent example is Jausovec, Jausovec, and Gerlic (2006) which *investigated the influence music has on brain activity of individuals in different stages of learning – priming and consolidation*, analysing different frequency bands of the EEG.

[83] cf. Kirkpatrick (1943)

[84] (Lesiuk, 2005, p. 173)

mine functional outcome effectiveness in gait training for ambulation.[85] Music – or rather rhythm[86] – was used as an external time cue to regulate body movements. However, no significant difference between a therapist-guided group, a self-guided group, and a control group were found,[87] and it was noted by the authors that *the exact mechanism and the neural basis of the synchronization of rhythmic physical movement such as finger-tapping or walking to an external auditory cue is not fully understood at present.*[88]

1.9 Effects on muscular tension

Skille and Wigram (1995) give account of a study by Wigram and Weekes (1989) that investigated the effect of low frequency sound on muscle tone in a relatively small trial group, and they found systolic blood pressure significantly reduced when low frequency sound with music was used as a stimulus in contrast to music alone. However, the authors also name a number of problems that might have influenced these results; for example, verbal encouragement by some of the evaluators, and inconsistencies in handling and evaluation. Necessary battery changes in the machines used produced blood pressure results that were not conclusive. In their general conclusion on studies investigating vibroacoustic therapy, they say that there could be a broader summary of many of the works they considered (several of which are referred to in the previous chapters of the present study): namely, that

> there is no doubt much in the anecdotal and the research material that is open to analysis and criticism [...] More sustained and extensive research needs to be undertaken to support the evidence that already exists that there is some significant effect.[89]

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[85] For more detailed investigations into periodic rhythms as key function of temporal ordering processes, see pp. 28ff.

[86] Three music examples were used that had *a basic steady beat pattern with* 4/4 *meter*, a metronome to *assist in synchronizing participants during the warm-up activity* and a djembe, *to emphasize the fundamental beat in the prescribed music [...] Clapping was also used for the same purpose* (Kwak, 2007, p. 202).

[87] (Kwak, 2007, p. 208)

[88] (Kwak, 2007, p. 215)

[89] (Skille and Wigram, 1995, p. 56)

2 Coordination of periodic rhythms

> *Rhythm as temporal ordering process – especially in its narrower sense as cyclical, periodic phenomenon – creates anticipation and predictability. Prediction and anticipation are key terms in certain theories of emotion and meaning [...] that have been extrapolated to the theories of emotion and meaning in music.*[90]

When investigating the nonlinear behaviour of biological systems, rhythm – in its broadest sense as *structure of temporal distribution and organisation*[91] – would be one of the obvious parameters to focus on.[92] In that respect, Thaut's observation that *since about 1985 or 1990, a new cognitive neuroscience of music has begun to develop, in basic research as well as in biomedically oriented research*,[93] is in some ways also true for some aspects of rhythm coordination and synchronisation in biological systems, where new and more accurate analysing methods and computational capability have led to a new understanding of how external rhythms can influence endogenous bodily rhythms, and how different regulatory physiological systems function and interact.[94]

New models of neural timekeepers are being developed,[95] as conceptions of how movements become rhythmically coordinated are revised.[96]. The following short overview of various perceptions of how periodic rhythms in biological systems interact, must therefore, as Thaut himself puts it, *remain in many ways only a sketch of a future building.*[97]

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[90](Thaut, 2007, p. 5)

[91](Thaut, 2007, p. viii)

[92]For a description of the basic principles of rhythm perception, inner *zeitgeber*, and timing, see Auhagen (2008).

[93](Thaut, 2007, p. 20)

[94](Babloyantz and Destexhe, 1988; Novak, Novak, de Champlain, Blanc, Martin, and Nadeau, 1993; Schuessler, Boineau, and Bromberg, 1996; Hoyer, Hader, and Zwiener, 1997; Rosenblum, Kurths, Pikovsky, Schäfer, Tass, and Abel, 1998; Eckberg, 2000; Fallen, 2000; Montano, Cogliati, da Silva, Gnecchi-Ruscone, and Malliani, 2001; Iellamo, 2001)

[95]Most are based on the findings of Constantinidis, Williams, and Goldman-Rakic (2002). For reviews of recent studies on neural timekeepers and the mechanisms that underlie musical experience, see Harrington and Haaland (1999); Janata and Grafton (2003)

[96](Beek, Peper, and Daffertshofer, 2002)

[97](Thaut, 2007, p. 20)

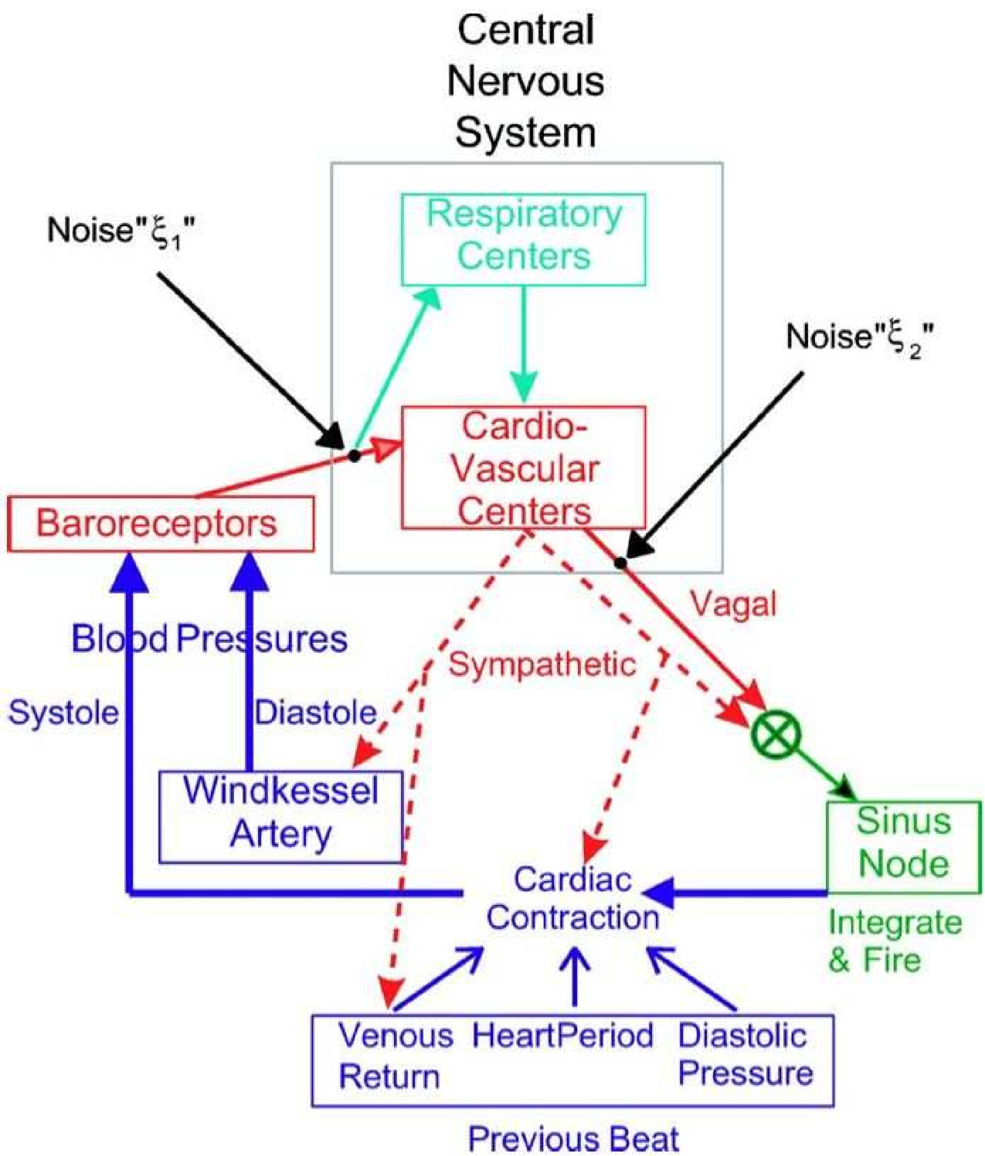

Figure 2: Modelling complex cardiovascular dynamics
Some attempts have been made to model the cardiovascular control system. This model of cardiovascular autonomic regulation by Kotani, Struzik, Takamasu, Stanley, and Yamamoto (2005) is physiologically motivated.

2.1 Rhythmic timing networks

Lewis (2002) named a network of cortical areas, including the dorsolateral prefrontal cortex and the right hemispheric perietal cortex which had previously been associated with time measurement, and suggested that they provided a 'central clock' whose frequency is controlled by dopamine levels.[98] However, she conceded that

> because the data showing involvement of these areas does not provide much information about the kind of activity occurring in them, their precise roles in time measurement, and how they work together to make up a putative 'clock' system, are not yet understood. Consequently we can only conjecture about the kind of neural activity and interaction involved and must therefore fall back upon models outlining possible scenarios.[99]

A paper cited by her describes inhibitory relationships between cell pairs that might result in another model of how time could be measured internally.[100] Grahn and Brett (2007) investigated perception of rhythm in musicians and non-musicians, and concluded that, in addition to their role in movement production, the basal ganglia and supplementary motor areas (SMAs) may mediate beat perception.[101]

Investigating motor synchronisation to auditory rhythm more generally, Thaut (2003) found that activated brain regions included primary sensorimotor and cingulate areas, bilateral opercular premotor areas, bilateral SII, ventral prefrontal cortex, and, subcortically, anterior insula, putamen, and thalamus. He therefore suggested benefits of rhythmic stimuli in rehabilitation training of people with motor disorders.

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[98] As, for example, in Meck (1983).

[99] (Lewis, 2002, p. 195)

[100] (Constantinidis et al., 2002)

[101] The authors hypothesised that the basal ganglia and SMA are the most likely candidate areas for the detection or generation of an internal beat, given that they are not only involved in attention to time, temporal sequencing, and predictable, internally generated movements (Grahn and Brett, 2007, p. 894). However, they also state that *further research is needed to clarify whether increased activity in basal ganglia and pre-SMA/SMA underlies the spontaneous movement that often spontaneously occurs to the beat.* (Grahn and Brett, 2007, p. 903)

2.2 Tempo preference

When investigating the coordination of endogenous periodic rhythms, the question was raised as to whether an "inner clock" exists that governs all timing processes. Fraisse (1982) called heart rate and respiration the pacemakers of a *preferred* or *personal tempo* that apparently influenced subjects' tapping rates and musical preference. Based on these findings, Iwanaga (1995) conducted a study in which subjects were asked to set a metronome to a tempo they preferred. It turned out that simple ratios of heart rate and chosen tempo were slightly favoured by the subjects. Although respiration was measured, the author did not provide results concerning preferred tempi in regard to respiration. Could the subjects – consciously or subconsciously – have favoured tempi that simply correlated with their respiration rhythm, and therefore, due to assumed phase locking of respiratory and cardiac rhythms,[102] correlated with their heart rates? The fact that *individuals are capable of detecting [their own] cardiac activity*,[103] and how that might have influenced the results of his study, was not discussed.

Taking the immense number of studies on spontaneous and preferred tempi into account, Madison (2001) provides a sound overview of the topic, and proposes a general model of the human timing mechanism. He also outlines the difficulties with the widespread conception of the "internal clock". Recent studies investigating stochastic and dynamic timing models,[104] timing variabilities of different time scales,[105] and rhythmic neuronal activity,[106] contribute further to the discussion.

2.3 Chronobiological aspects

Quite a number of parameters mediating the effects of music on listeners are mediated themselves by circadian variation, among them heart activity,[107] blood pressure,[108] hormonal levels,[109] and others.[110] Assuming

[102] (Schäfer, Rosenblum, Kurths, and Abel, 1998)
[103] (Brener and Kluvitse, 1988, p. 560)
[104] (Schöner, 2002)
[105] (Chen, Repp, and Patel, 2002)
[106] (Bevan, Magill, Terman, Bolam, and Wilson, 2002)
[107] (Young, 2006)
[108] (Degaute, Cauter, van de Borne, and Linkowski, 1994)
[109] (Linsell, Lightman, Mullen, Brown, and Causon, 1985)
[110] For a discussion of how circadian variations affect musicians, see the case study by Mulcahy, Keegan, Fingret, Wright, Park, Sparrow, Curcher, and Fox (1990). A

more generally that *homeostatic mechanisms would function more efficiently if the organism possessed a means for anticipation of daily routine changes in the environment*,[111] Young (2006, p.H1) explains that

> Diurnal variations in the responsiveness of the cardiovascular system to environmental stimuli are mediated by a complex interplay between extracellular (i.e., neurohumoral factors) and intracellular (i.e., circadian clock) influences [...] Evidence strongly supports the hypothesis that the circadian clock within the heart modulates myocardial metabolism, which in turn facilitates anticipation of diurnal variations in workload, substrate availability, and/or the energy supply-to-demand ratio.

The author also notes further on that

> Whether environmental modulation of synchronization between peripheral and central clocks contributes to cardiovascular disease development remains unknown; such a loss of synchronization is possible through changes in feeding and sleep patterns, as occurs during diabetes mellitus, obesity, sleep apnea, and shift work, all of which are associated with elevated risk for cardiovascular disease.[112]

Thus, when investigating the effects of external rhythmical stimuli on cardiovascular activity in the line of therapeutic intervention, chronobiological aspects should certainly be taken into account.

2.4 Cardio-respiratory coordination

First described by Ludwig (1847), the influence of respiration on heart activity, and particularly respiratory sinus arrhythmia (RSA) has long been a focus of study.[113] More thorough research on the mechanisms of cardio-respiratory coordination was made in 1956, when a study on this subject was done on rabbits.[114] Thereafter, and most notably, the work

general introduction of biological rhythms as a basis for perception and action can be found in Colquhoun (1971). For an introduction to cardiovascular chronobiology, see Lemmer (1994).

[111] (Young, 2006, p.H1)

[112] (Young, 2006, p.H5)

[113] See Yasuma and Hayano (2004) for a general introduction to the biological phenomenon of respiratory-circulatory interaction.

[114] (Bucher and Bättig, 1956)

group around Hildebrandt addressed and investigated the coordination of breathing and heart rate in people.[115] They detected coordinations of different intensity during different phases of sleep; however, if only a light physical strain was applied, a coordination could no longer be determined.[116] Some time later, Frank (1982, p. 139f.) said of her efforts to investigate synchonisation between biological spontaneous rhythmicity and the frequency characteristics of music:

> Die Korrelation zwischen den mittleren Puls- und Atmungsfrequenzwerten der einzelnen Versuchspersonen, zwischen den Variabilitätskoeffizienten von Puls und Atmung und zwischen den Ausgangswerten von Puls und Atmung vor Versuchsbeginn sind durchweg nicht signifikant.[117] Die Koppelung zwischen den beiden Parametern Pulsfrequenz und Atmungsfrequenz muß also als eher gering betrachtet werden, wobei es in diesem Fall um die Frage der überindividuellen Korrelation geht. Auf individueller Ebene ergibt sich ein außerordentlich differenziertes Bild. Korreliert man bei den einzelnen Versuchspersonen *fortlaufend* die Puls- und Atemfrequenzwerte der einzelnen Beobachtungsintervalle, so ergeben sich völlig widersprüchliche Werte, die von weitgehender Koppelung ($r = .52$) bis zu deutlich gegensinnigen Verläufen ($r = -.38$) reichen [...][118] Demgemäß liegt auch die mittlere Korrelation zwischen Puls- und Atmungsfrequenz in den einzelnen Beobachtungsintervallen nahe Null ($\overline{r} = .06$).

To investigate cardio-respiratory coordination further, Frank also measured the pulse-respiration ratio that had already been thoroughly described by Hildebrandt, and she discussed its volatility.[119]

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[115] This work is summarised in Hildebrandt (1991).

[116] as summed up in Raschke (1981)

[117] Frank (1982) investigated the correlation of average frequencies. A time series analysis might have come to different conclusions.

[118] An investigation that would have compared highly correlative and barely correlated phases with regard to musical characteristics such as loudness, rhythmicity, timbre, etc., might have come to different conclusions.

[119] *Einige Beobachtungen sind schließlich noch im Hinblick auf den sogenannten Puls-Atmungs-Quotienten (PAQ) mitzuteilen. Diese von Hildebrandt ausführlich beschriebene und von ihm als "rhythmische Funktionsordnung von Puls und Atmung" bezeichnete Maß mit einem Normwert von 4:1 bzw. 4,0 (als Verhältnis von Pulsfrequenz zur Atmungsfrequenz bzw. als Quotient der beiden Maßzahlen angegeben), das bestimmten tagesrhythmischen Schwankungen unterworfen ist, stellt nach Ansicht des Autors eine Art psychosomatisches Stabilitätsmaß dar, wobei Abweichungen nach oben zunehmende Labilität und Beeinflußbarkeit und Abweichungen nach untern zunehmende Stabilität und Starre bedeuten.* (Frank, 1982, p. 139f.)

Other studies showed that long-term physiological exercise affects cardio-respiratory regulatory mechanisms, especially in trained athletes. Faced with physiological stress, trained regulatory mechanisms adjust to the new oxygen demands rather by adjusting stroke volume than heart frequency.[120]

Apart from in certain pathological conditions, which are accompanied with a tight coupling between the circulatory and the respiratory system,[121] lacking or loose physiological interpretations detracted researchers from embarking on future cardio-respiratory investigations. In the following years, the attention of some work groups turned to another complex physiological phenomenon which was soon acknowledged to have a high prognostic relevance: heart rate variability, a measure of the neuro-vegetative activity and autonomous heart function. Although synchronisation effects could be convincingly shown with the arrival of newly developed mathematical algorithms,[122] the publication of Schäfer, Rosenblum, Kurths, and Abel (1998) put the coordination of heart rate and respiration rate on the agenda of clinical researchers once more.

Today, some attempts have been made to model cardio-respiratory synchronisation;[123] however, as Mrowka et al. (2000, p. 2485) puts it, *The exact physiological mechanisms responsible for cardiorespiratory synchronization are so far poorly understood.* It is, for example, noted that *published literature is divided sharply on the question of whether voluntary control of breathing affects the cardiovascular rhythms being measured.*[124] Nevertheless, a number of studies encourage the view that *the influence of voluntary control of breathing on human autonomic activity is probably small,* and *breathing at frequencies substantially* $> 0.1\ Hz$ *does not influence low-frequency* $(0.02 - 0.12\ Hz)$ *R-R interval or arterial pressure rhythms.*[125]

[120] Shlomo1982,Zauner1989,Fedel1995

[121] cf. Crowell, Guyton, and Moore (1956)

[122] cf. Kenner, Pessenhofer, and Schwaberger (1976)

[123] Cf. Chon, Mukkamala, Toska, Mullen, Armoundas, and Cohen (1997); Kotani, Takamasu, Ashkenazy, Stanley, and Yamamoto (2002); Rzeczinski, Janson, Balanov, and McClintock (2002); Kotani, Struzik, Takamasu, Stanley, and Yamamoto (2005); Luchinsky, Millonas, Smelyanskiy, Pershakova, Stefanovska, and McClintock (2005); Pokrovskii (2005); also see Figure 2 for a recent model of cardiovascular dynamics.

[124] (Cooke, Cox, Diedrich, Taylor, Beightol, Ames, Hoag, Seidel, and Eckberg, 1998, p. $H716$)

[125] (Cooke, Cox, Diedrich, Taylor, Beightol, Ames, Hoag, Seidel, and Eckberg, 1998, p. $H716$) Their findings were taken into account when designing the present study's experiments.

The majority of these studies try to prove coordinations by time series analyses.[126] Assuming that the interdependence of oscillatory activity of respiratory and cardiovascular systems might be physiologically relevant, it is now generally accepted that *the joint analysis of the two rhythms may provide additional physiological information and may be useful for early detection of malfunctioning* (Mrowka, Patzak, and Rosenblum, 2000, p. 2480).

According to Bernardi, Porta, and Sleight (2006), it is, in this respect, still an open question whether observed alterations of the cardiorespiratory regulatory system are due to direct sympathetic stimulation or secondary to respiratory entrainment to the music, or both. In their study,[127] the authors suggest *[...] that perhaps both respiratory entrainment by music and direct arousal [are] coexistent and interrelated – in fact, the increase in breathing rate in itself might [contribute] to the increase in sympathetic activity.* Again, Cooke et al. (1998) ask the question

> When breathing frequency approaches the frequency of slower R-R interval, arterial pressure, and muscle sympathetic nerve rhythms, does breathing entrain those rhythms or pull their frequencies toward that of respiration? If it does, does this mean that naturally occurring, lower-frequency rhythms arise from rhythm generators located in the medulla?[128]

Lorenzi-Filho, Dajani, Leung, Floras, and Bradley (1999) showed that deliberate periodic breathing affects HRV spectrum, heart rate, and blood pressure.[129] However, regarding performing musicians such as singers or wind instrumentalists, the circumstances of this coordinating effect have not been studied extensively. Generally, different breathing

[126] Cf. Prokhorov, Ponomarenko, Gridnev, Bodrov, and Bespyatov (2003). Compare also a substantial literature review by Cysarz (2003), and see Cysarz, Bettermann, Lange, Geue, and van Leeuwen (2004) for a comparison of different methods of detecting cardiorespiratory coordination.

[127] Bernardi, Porta, and Sleight (2006, pp.450-1.)

[128] Cooke, Cox, Diedrich, Taylor, Beightol, Ames, Hoag, Seidel, and Eckberg (1998, p. *H*718)

[129] Various authors have noted very high frequency peaks (VHF) in the spectra of blood pressure and heart rate variability at frequencies higher than the respiratory rate (Toledo et al., 2002). Toledo, Pinhas, Aravot, and Akselrod (2003) deduced *that this phenomenon originates from the mechanical coupling in the cardiorespiratory system.* However, they also state that *a deeper understanding of the physiological basis of this phenomenon has not been attempted* (Toledo, Pinhas, Aravot, and Akselrod, 2003, p. 433).

techniques, as they are, for example, taught in the Pranayama,[130] are not yet widely adopted in the field of music therapy. A thorough systematic review of treatments for music performance anxiety by Kenny (2005) cites only one study that indicates pre- to post-treatment improvements of self-report measures of performance anxiety using breathing techniques,[131] and concludes that

> the field is in urgent need of larger scale, methodologically rigorous studies to assist the large minority of musicians who suffer from performance impairing music performance anxiety.[132]

Further approaches considering bodily rhythms would therefore be needed, and may lead to further insight into cardio-respiratory coordination mechanisms. The most efficient assessment of short-term respiratory-mediated autonomic oscillations may be achieved with stepwise protocols, even without stringent control of inspired volume, as Cooke et al. (1998) noted.

2.5 Entrainment and interaction effects of heart rate with exogenous stimuli

It was noted earlier that Bason and Celler (1972, p. 279) had found *entrainment of the sinus rhythm with external auditory stimuli* under specific circumstances, and attributed it to *neural coupling into the cardiac centres of the brain.* Despite the fact that these results have not been directly replicated since, music therapists' opinion that *meeting the tempo of the patient is the initial key to therapeutic change*[133] has been incorporated in the general notion that a therapeutic intervention has to be aware of, and even can make use of, the correlation of external rhythmical stimuli with endogenous bodily rhythms.[134]

A direct cardiac interaction of maternal and fetal heart rhythms had been postulated by Hildebrandt and Klein (1979), and later confirmed by Cerutti, Baselli, Civardi, Ferrazzi, Marconi, Pagani, and Pardi (1986). However, when Leeuwen, Geue, Lange, Cysarz, Bettermann,

[130] cf. Bhargava, Gogate, and Mascarenhas (1988)
[131] cf. Deen (1999)
[132] Kenny (2005, p. 183)
[133] cf. Aldridge (1993)
[134] as, for example, expressed in Kerr (2004)

and Grönemeyer (2003) investigated potential fetal-maternal heart rate synchronisations using constructed surrogate data sets, they found no differences between real and surrogate data with respect to the number of synchronisation epochs found or to $n : m$ coupling ratios.

Thus, from the findings so far, entrainment and interaction effects between external stimuli and endogenous periodic rhythms should be expected to occur under certain conditions.[135] Most of the correlation or entrainment models applied to interpret the recorded data appear to still be inchoate, and therefore not adequate to explain the complex interaction of all the regulatory systems involved.

2.6 Synchronisation of heart rate with periodic exogenous stimuli

In recent years, only a small amount of studies has been dedicated to a potential synchronisation of heart frequency and musical rhythm. Their results are often not considered satisfactory by the researchers. Reinhardt (1999) investigated synchronisation effects during a relaxation therapy in cancer patients, and found a synchronisation of heart rhythm that was trainable within certain tempo limits, and was correlated with the formation and intensity of relaxation reactions.

Reinhardt (1999) found increasing synchronisation and coordination of heart frequency and musical beat in patients with chronic tumour pain, resulting in decreased agrypnia and analgesics consumption. However, the effects were not significant and have not been replicated since. [136] Similar studies alluded to the potential *neural couplings*; a coupling of heart rate – within biophysiologically reasonable limits – with an auditory stimulus (Bason and Celler, 1972). However, the question remains as to which biological mechanisms are the basis for such an entrainment, and to what extent these results, where the auditory stimuli had been highly discriminable metronome clicks, can be conferred upon studies investigating potential synchronisations of heart frequency with the complex rhythmical structures of musical works. Regrettably, Bason and Celler (1972) did not control for subconscious or even conscious alterations of heart activity by the subjects themselves; a fundamental question in syn-

[135] cf. Saperston (1993)

[136] In a clinical surrounding, music therapy in general has so far been proved to affect patients' general well-being, e.g. by raising their self-esteem, but whether it affects physiological regulation mechanisms is still open to question (Aldridge et al., 2005).

chronisation and coordination experiments that many researchers still disregard in more recent studies.[137] Frank (1982, S. 95) sums up the results of her study as follows:

> Das Ausmaß der Synchronisation im Sinne einer Koordination in ganzzahligen Verhältnissen (1 : 1, 1 : 2, 2 : 3) war im Vergleich zu Änderungen ohne prägnante Frequenzbeziehungen bescheiden [. . .] Betrachten wir unsere Resultate lediglich unter dem Aspekt, wie oft der Puls [. . .] während der Musikdarbietung "aus dem Takt" bzw. gar nicht in den Takt kam, weil sein Beharrungsvermögen in der Eigenrhythmik zu groß war, um sich in die Frequenz des Musikrhythmus zwingen zu lassen, mögen die seltenen Synchronisationsbeziehungen enttäuschend anmuten. Dies gilt besonders auch für die Atmung. Ihre Frequenzvariation ist sehr begrenzt.

It can be assumed that potential synchronisation effects decrease or even disappear with the increasing complexity of the stimulus, and decreasing rhythmical discriminability. On the other hand, it was observed that familiarity and identification with the music that is used as a stimulus has a positive influence on the quality of the subject's reaction;[138] a steady auditory signal, such as a metronome beat, cannot therefore be regarded an optimal stimulus. Frank (1982, S. 103) writes:

> Reine Metren führten höchst selten zu prägnanten Synchronisationsbeziehungen. Durch ihre Gleichförmigkeit und Ereignislosigkeit enthielten sie sehr viele störende Erlebnisfaktoren. Somit ist die reine Frequenzvariable eines Metrums als Synchronisator mindestens ebensowenig kontrollierbar wie vielgestaltige, von melodischen und harmonischen Elementen überformte rhythmisch-metrische Abläufe.

Allesch (1981) tested earlier assumptions regarding the influence of music on pulse and respiration frequency, and stated that large interindividual differences made a concise interpretation generally difficult.[139] Even today, many facets of the complex interaction mechanism of exogenous stimuli and the endogenous regulatory systems are discussed rather controversially.[140]

[137] as, for example, Saperston (1993) in his investigation of two music-based models for altering physiological responses

[138] cf. Grewe et al. (2007, p. 26)

[139] cf. Allesch (1982)

[140] cf. Yanagihashi, Ohira, Kimura, and Fujiwara (1997); Accurso, Shamsuzzaman, and Somers (2001); Blood and Zatorre (2001); Kodama, Honjo, and Boyett (2002);

2.7 Rhythm and motor coordination

The notion that *the spectral and temporal organization of music – its rhythm and pitch – derives from our biology*[141] is self-evident and gives support to theories that place the origins of musical rhythm in the motor rhythms controllling locomotion, breathing, and heart rate.[142] It was Todd (1999) who readopted earlier ideas of rhythm and motor coordination from a neurobiological perspective. Investigations into the nonlinear dynamics of inter-individual coordination effects might also contribute to a better understanding of the general mechanisms that govern individual timing and the coordination of regulatory cycles.[143]

Schmidt, Trainor, and Santesso (2003); Baumgartner, Lutz, Schmidt, and Jäncke (2006)

[141] For a short essay on the neural roots of music, see Trainor (2008)

[142] cf. Trainor (2008, p. 598). For reports on several findings regarding the role of body movement in musical rhythm perception and processing, see, for example, Phillips-Silver and Trainor (2005, 2007, 2008).

[143] cf. Schmidt, Carello, and Turvey (1990)

3 Summary

Since the beginning of the 20th century, the musicological literature has contained a number of physiological points of interest, among which can be singled out the effect of music on the cardiovascular system. The earliest scientific studies on the effect of music on pulse can be dated to around 1880.[144] In the years that followed, music-physiological research quickly developed, spurred by the invention of the Einthoven apparatus in 1905.[145] Generally, however, the investigators of the physiological effects of music were seldom musicologists. Psychologists, for example, were more often occupied with that topic.[146]

In fact, until today, the same questions of how music affects us, and, for example, whether and how it could be used as a means in therapeutical interventions, are dealt with by authors with diverse backgrounds. Be it medical practitioners, sports and rehabilitation therapists who contribute to an on-going discussion in their respective field or department by reporting results of their daily practice; biomedical staff who develop strategies and devices to investigate certain physiological parameters ever more thoroughly; biologists, biophysists, or psychoacousticians who may, for example, model the signal processing of certain auditory events; or music psychologists who investigate potential effects of certain musical phrases or parameters on emotional states. This diversity has entailed certain limitations regarding the studies' methodologies. These limitations still prevent seamless cooperation between the different scientific communities. Additionally, at least among musicologists, language barriers present further obstacles. Whereas it is perhaps not surprising that over 92 per cent of the sources listed in the bibliography of "The Art and Science of Music Therapy: A Handbook"[147] are English, many musicologists in Germany, France, Russia or the Orient tend to base their research mainly on literature in their respective first language. We are therefore dealing with a diffuse range of *"states-of-the-art"* even *within* some of the mentioned scientific communities. Another challenge in investigating the physiological effects of music arises from the focus of the

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[144] (Dogiel, 1880)

[145] (Soffer and Master, 2005)

[146] cf. Schoen (1927, p. 1): *The method of the laboratory and the tools of statistical procedure have been employed, yet not with the guiding insight of musician and aesthetician to furnish clues and to help in evaluating results. The contributors are not scientists only; they have also a competent acquaintance and a deep interest in the field of music whose secrets they are exploring.*

[147] Wigram, Saperston, and West (1995)

respective study. What is the best way to understand causes and effects of the complex interplay between certain kinds of music and the many accompanying stressors affecting – as described above – the central nervous system, the cardiovascular system, the endocrine system, and other regulatory cycles? How can one single out particular physiological influences on certain parameters while controlling others, and still be able to appreciate the overall effects of *music*?

There have been attempts at a broader hermeneutic approach to the topic.[148] Some of them have neglected detailed investigation into the correlations and interrelations that are the basis for a thourough understanding of the complex interplay of psychological and physiological parameters. Others have tackled the issue by analysing large numbers of physiological parameters simultaneously,[149] and also in complex experimental settings. It may generally be agreed that when studying the psycho-physiological effects of music, investigations have to focus on the complex interplay of parameters in everyday surroundings, as well as on the basic causalities and effects of laboratory conditions. What is decisive about a study's quality is often how both situations are taken into account in the process of understanding what is measured, and how well the results from other scientific fields and communities have been incorporated. However rapidly the interest in the respective fields has grown;[150] a thorough analysis of the literature of recent years reveals that as yet there is no overall concept of how music affects bodily regulatory mechanisms. Instead, there is a growing number of studies focusing on particular aspects, and their results sometimes contradict each other. Efforts to standardise the experimental setup in order to obtain unambiguous results often lead to unacceptable simplifications of the complex interrelation of different regulatory mechanisms. On the other hand, studies that draw a general picture of how music affects people often cannot produce comprehensible chains of causes and effects, and sometimes fail to interpret the interrelated results. Many researchers still tend to approach the problem more or less strictly from their discipline's point of view, and questions outside their special subject area are covered rather stereotypically. As a consequence, medical or therapeutical

[148] Cf. Kumler (2006)

[149] Knight and Rickard (2001), for example, measured subjective anxiety, heart rate, blood pressure, cortisol, and salivary IgA before and after a cognitive stressor task, in order to prove the robustness of the effect in the presence of a range of potentially mediating variables, but also in order to discuss inconsistencies in previous studies.

[150] Koelsch and Siebel (2005, p. 578), for example, noted that in cognitive sciences, *during the past few years, research activities on different aspects of music processing and their neural correlates have rapidly progressed.*

studies on the effects of music often disregard music-analytical, music-historical or social aspects, whereas musicologists sometimes lack insight into physiology.

A thourough analysis of the prevailing literature(s) eventually revealed two main challenges. Firstly, that we are dealing with a broad field of topics, approaches, and standards, that are not easily brought together when designing new studies; and secondly, that over the course of time, some assumptions seem to already have, by implication or by citing certain factoidal evidence, found their way into practical applications or therapy, although the complexity of the underlying regulatory mechanisms is still not fully understood, nor are certain transfer effects resulting from a complex experimental situation attributed to music itself. Statistical misinterpretations occur relatively often in this regard, for example, when test results on distress, self-esteem, and the mood of subjects participating in music therapy sessions are compared with those of controls on a waiting list, the differences are attributed to the intervention alone.[151] As Kreutz, Bongard, Rohrmann, Hodapp, and Grebe (2004, p. 625) puts it in regard to singing,

> the emotional effect of singing on the organism of the singer is yet poorly understood, although singing is probably the most common everyday musical activity observable in all cultures [...] More recent studies tend to corroborate subjective positive mood effects and health benefits of singing in groups [...] However, it is yet not clear whether and to what extent the observed effects could be attributed to mere passive exposure to musical sound, rather than active physical engagement in singing.

Bernardi et al. (2006), for example, cites a well-known article in *Berliner und Münchner Tierärztliche Wochenschrift* that described some (statistically not significant) effects of sound on milk production in cattle. Although effects like these have never been replicated, underlying notions that *cows give more milk if classical music is played to them* or – another well-known statement – *classical music tends to cause comfort and rock music and noise tend to cause discomfort* (Umemura and Honda, 1998) do seem to influence the discourse of scientists and therapists to a certain degree. If, for example, the discussion of the “Mozart effect” has showed us anything, it is that musicological research sometimes seems to confirm what might be assumed from everyday experience and observation,

[151](Hanser and Thompson, 1994)

and such assumptions are then all too easily taken up in therapeutical contexts before they are properly tested and investigated.[152]

In recent years, however, a paradigm shift seems to take place, which Thaut (2007), among others, regards as historic:

> By shifting one's notion of music in therapy from functioning as a carrier of sociocultural values in the therapeutic process to a stimulus that influences the neurophysiological basis of cognition and sensorimotor functions, a historical paradigm shift has emerged, driven by scientific data and insight to music and brain function. We can now postulate that music can access control processes in the brain related to control of movement, attention, speech production, learning, and memory, which can help retrain and recover functions in the injured or deseased brain.[153]

It is within the context of this paradigm that the study described in the following chapters investigates adaptation processes within the complex psycho-physiological regulatory mechanisms, because it has not only been the study of musical emotions that has suffered from a neglect of the mechanisms underlying these processes, as Juslin and Västfjäll (2008) argued, but also a more general understanding of the effects of listening to and performing music. It was therefore decided to test and review some fundamental mechanisms that may form the physiological basis for our understanding of how music affects us, and investigate them further in different conditions of complexity. Based on some open questions arising from the existing literature, a set of hypotheses was developed that aims to shed light on heart rate behaviour under fixed pulse-respiration ratios as well as during voluntary breathing phases; secondly, the effects of rhythmical acoustic stimuli on the respective regulatory mechanisms, and thirdly, the influence of bio-feedback on the ability to actively adapt and deflect heart rate to and from a steady periodic auditory stimulus.

[152] Regarding, for example, the "Baby Einstein" controversy, cf. (Christakis and Zimmerman, 2009)

[153] (Thaut, 2007, p. 116)

Part II

Investigating psycho-physiological responses to music

4 Purpose of the study

The purpose of the study described below was to determine how auditory stimuli affect human cardio-respiratory rhythms, and to what extent subjects can actively influence their respective regulatory mechanisms. Via complementary questionnaires, subjects were asked to give evidence of their musical backgrounds and abilities, the relaxation techniques they might be using or have learned to apply, and their overall expressivity. The experiments were designed in a way that would enable their results to contribute in some measure to the broader understanding of cardio-respiratory coordination and entrainment principles.[154]

The study design and some of the problems that are investigated are based on earlier findings of Morgenstern (2002). A MATLAB-based software, adapted to the experiment's needs by Rivera (2006) and Reuter (2007), and a number of bio-medical recording devices, which are described later on, are used to record heart, respiration and electrodermal activity in subjects listening to acoustical stimuli, and provide them with feedback about their heart activity.

In a number of experiments that preceded the study described in this study, potential topics and questions were considered. A pilot study, in which the overall design was tested for potential flaws and shortcomings, took place in 2006 in a laboratory of the Technische Universität Dresden, which was later used for parts of the experiments of the full study. It is described in the following chapter.

[154] Compare Raschke (1981); Kotani, Takamasu, Ashkenazy, Stanley, and Yamamoto (2002); Cysarz (2003); Renner (2001).

5 A pilot study

To develop and reliably test experimental setups for signal recording and processing, to find an optimal lineup of experiments for gathering as much useful data as possible while not fatiguing the subjects, and to find a suitable music example that would ensure an attentive listening process among professional musicians and controls alike, a preliminary pilot study was conducted. During that study, different modes and actions of data acquisition were tested for reliability, applicability, convenience and usefulness. A complete data acquisition and analysis setup was developed, tested, revised, and completed (see Figure 3). Rivera (2006) revised a MATLAB program that processed the acquired physiological data. The program called "Kardio.m" was later revised and extended to imbed signal processing of a respiration belt and a chest wall ECG unit by Reuter (2007).[155] Originally, respiration rates had been extracted from the ECG by evaluating respiratory sinus arrhythmiae (RSA). It was then decided to opt for a supplementary respiration measuring device (a respiration belt), and to additionally measure electrodermal activity in order to control for stress and involvement.

Different musical samples were tested with regard to their usability and explanatory significance. The choice of musical sample was based on the findings of Bernardi et al. (2006), who rated a variety of different samples in terms of their tempi, rhythms, melodic structures, and in relation to individual preferences, habituation, order effect of presentation, and previous musical training. For the pilot study, two samples directly opposed in tempo, rhythm, melodic and harmonic structure, and habituation were chosen according to Bernardi's findings: (1) A slow Indian Raga played by Ravi Shankar, a piece with modal rhythm and with hardly any rhythmical structure, and (2) a fast (♩= 150) classical piece with baroque melodic and harmonic structures: Antonio Vivaldi's *Presto* from "L'Estate", Concerto for Violin, Orchestra, and Continuo no. 2, Op 8 (1725).

[155] Reuter's publication *Einbindung einer 16-Bit-Wandlerkarte und einer EKG-Erfassungseinheit in ein musikphysiologisches Experiment und Bewertung der Datenqualität* describes the technical challenges of the experiment in detail, and discusses health and safety issues.

Figure 3: Experimental Setup of the Pilot Study
In this setup, subjects were attached to an ECG measuring device (Hellige 250 SMK) with extremity electrodes. Visual and acoustic feedback of their ECG characteristics (real-time electrocardiogram, and averaged heart rate over 4 beats) were provided.

5.1 Choice of musical samples

In the pilot study, the potential effects of different musical preferences and different musical education levels were investigated. Therefore, two contrasting musical samples were tested for psycho-physiological involvement and arousal. The samples had been chosen from a set of musical samples collected, graded and tested by Bernardi, Porta, and Sleight (2006).[156]

Bernardi et al. noted the different characteristics of the musical tracks used in their study, which ranged from an Indian raga (tempo: 55 bpm, modal harmonic structure, modal melodic structure, minimal rhythmic structure), to a Presto from Vivaldi's *Four Seasons*, a piece rated as exemplary for a *classical fast* style, with a so-called *conventional* harmonic and melodic structure, and a strong, non-syncopated rhythmical structure, for which they noted a tempo of 150 bpm (see Figure 4).[157] Two musical pieces with similarly contrasting characteristics were used in the pilot study.

Information about the recordings and interpretations used is usually not provided in investigations by researchers with medical backgrounds, and that of Bernardi et al. is not an exception. However, from the verbal feedback of musicians taking part in the pilot study, it can be noted that interpretation (and therefore, musical style and performance aesthetics) do play an important role when taking musical preferences and familiarity into account, and when physiological involvement of the listener is investigated.[158] The musical example for the main study was selected from a variety of recordings, taking these findings into account. Also of concern was the length, complexity, and style of the musical sample presented or performed.[159]

Verbal feedback from professional musicians and subjects in the control group revealed that pieces like Vivaldi's "Four Seasons" are often regarded as stereotypically *classical*. In many studies that have a medical concern, musical stimuli tend to be chosen from a small pool

[156] For a thorough discussion of the effect of music with regard to preference, involvement, arousal, etc., see pp. 5 f.

[157] cf. Bernardi et al. (2006, p. 446)

[158] For a list of subjects' remarks regarding the respective interpretation, see pp. 216.

[159] Petsche et al. (1996) showed that there are different mental processes involved when imagining playing tonal scales or a musical piece. Grewe, Nagel, Kopiez, and Altenmüller (2005) found that ecstatic experiences aroused by music do not occur in a reflex-like manner, but strongly depend on the actual level of attention, musical experience, and the state of conscious musical enjoyment.

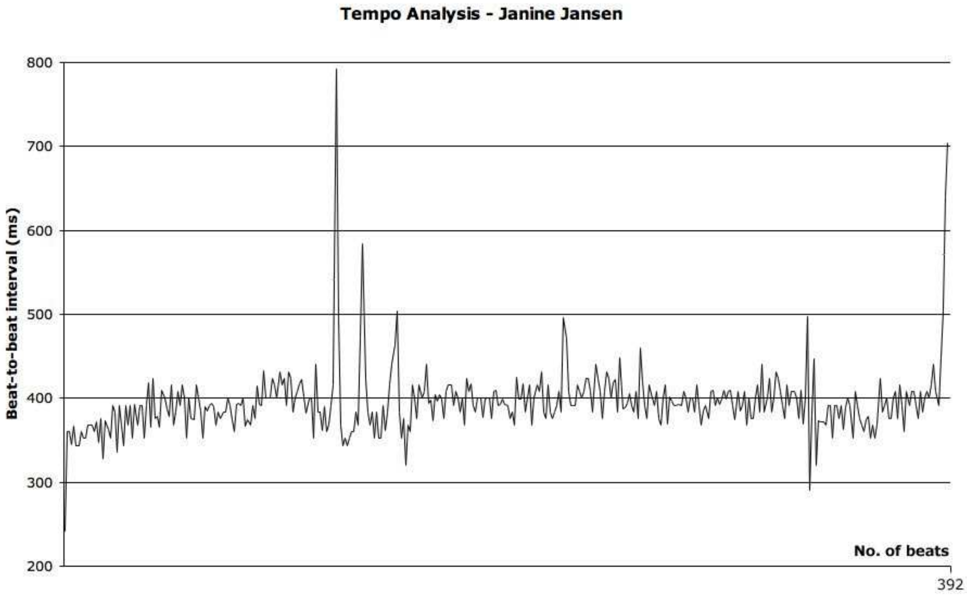

Figure 4: Qualitative beat-to-beat tempo analysis of a movement from Antonio Vivaldi's "Four Seasons" (soloist: Janine Jansen)

For an ideal state of alertness and arousal, it was decided to use a recent and relatively fast interpretation of Vivaldi's "Four Seasons": a recording made by Janine Jansen.[160]*. A tempo analysis made with a simple tapping apparatus (mean values of downbeat taps recorded in five consecutive sessions on a computer keyboard; length of the sample:* $2:35$ *min) documented this vivid interpretation, which has a base tempo of 150 bpm, with major temporary decelerations and accelerations. (The mean beat frequency is* $2.53\ Hz$*, which equals a mean beat-to-beat-interval of* $395\ ms$*.)*

of well-known classical pieces that have been scrutinised by generations of researchers due to their immense popularity: Johann Sebastian Bach's "Air on the G-String" (BWV 1068, 2nd movement),[161] Ludwig van Beethoven's short piano piece "Für Elise" (WoO 59),[162] Barber's "Adagio for Strings" op. 11 [163] or movements from Antonio Vivaldi's "Four Seasons" (op. 8).[164] Assuming that these pieces are well liked by their subjects, researchers use them to ensure high levels of attention and musical enjoyment, invoking the results of earlier studies that have used those musical samples before. (The concept of what *classical music* actually embraces varies in its scope – another fact many researchers do not take into account.) However, attention and enjoyment levels with these pieces tend to be quite low among professional musicians, since listening to them or even playing them does not provide them with much mental or technical challenge. If the score of the musical sample is well-known to them, experienced listeners tend to concentrate rather on technique and interpretation (for example, tempo, bowing, articulation, dynamics, and intonation) than on its musical structure, as answers to Questionnaire 2 showed.[165]

Therefore, if the effects of musical stimuli are investigated in professional musicians, researchers have to ensure high attention levels by challenging the subjects' musical interest. This can be done by choosing work by unknown composers, pieces that are seldom played or not in the usual concert repertoire, or interpreters whose technical abilities meet the demands of the experienced listener. Furthermore, if struc-

[161] cf. Mitchell and Zanker (1948); Mitchell (1950); Williams (1974); Rosling and Kitchen (1993); Kain, Wang, Mayes, Krivutza, and Teague (2001); Kain, Caldwell-Andrews, and Wang (2002); Halstead and Roscoe (2002); Awe (2004); Rickard (2004).

[162] cf. Turner (2004); Wristen (2006); Suda, Morimoto, Obata, Koizumi, and Maki (2008); Chang, Chen, and Huang (2008).

[163] cf. (Halberstadt, Niedenthal, and Kushner, 1995; Trask and Sigmon, 1999; Blood and Zatorre, 2001; Gomez and Danuser, 2004; Broderick, 2005; Hunt and Forand, 2005; Zelevansky, 2006; Heene, Raedt, Buysse, and Oost, 2007).

[164] cf. Peretz, Kolinsky, Tramo, Labrecque, Hublet, Demeurisse, and Belleville (1994); Hermans, Houwer, and Eelen (1996); Thulin (1997); Pfister, Berrol, and Caplan (1998); Gilboa-Schechtman, Revelle, and Gotlib (2000); Faith and Thayer (2001); Davey, Startup, Zara, MacDonald, and Field (2003); Emery, Hsiao, Hill, and Frid (2003); Wright, Startup, and Mathews (2005); Campo, Gil, and Davila (2005); Graham (2006); Granath, Ingvarsson, von Thiele, and Lundberg (2006); Irish, Cunningham, Walsh, Coakley, Lawlor, Robertson, and Coen (2006); Wilson, Harpur, and McConnell (2007); Luck, Toiviainen, Erkkilä, Lartillot, Riikkilä, Mäkelä, Pyhäluoto, Raine, Varkila, and Värri (2008).

[165] See p. 216 for details, and p. 147 for a discussion of how familiarity and involvement are correlated.

tural hearing processes are being considered, a musical piece would need to have a framework in which certain themes or strophes are occuring repeatedly.[166]

Taking these considerations into account, it was decided to use a single music example repeatedly in the final experiment, which would match most of the requirements mentioned above, and, at the same time, fit into the overall time of experiment, the attention span of the subject, and other required specifications. The musical example that was therefore chosen was a five minute excerpt from Ludwig van Beethoven's Piano Concerto No. 5.[167] The musical excerpt consists of 150 seconds of slow, soothing music from the second movement (including a cadenza at the end), followed *attaca* by a vivid, strongly rhythmical excerpt from the third movement (150 seconds long). The two parts of the musical example differ in tempo, pulse salience,[168] volume, and meter, as described in detail later on. That way, the regulatory mechanisms of how external rhythmical stimuli influence endogenous bodily rhythms could be studied comprehensibly, assuming that there was probably no easy stimulus-response pattern but a more complex interplay of different processes of psycho-physiological stress, habituation, rhythmical coordination and synchronisation. Information about musical preferences would be retrieved via a questionnaire.

5.2 Ensuring musical awareness during the tests

Heart rate represents first and foremost a measure of a general level of sympathetic arousal, and is prone to be mis-interpreted when the experimental setup does not control for habituation and learning effects, or when unwanted stress factors in the study design affect the outcome of the measuring process. The final setup had to be refined, regarding these considerations. It included a randomisation of certain trials, to control for any famimliarisation / habituation effects.

Some earlier investigations into the effect of auditory stimuli on subjects' heart rate had not found any significant influence. Zimny and Weidenfeller (1963, pp. 312-13), for example, stated that their *analysis of the results using heart-rate for each of the three musical pieces yielded*

[166] For a discussion of musical priming, compare Tillmann (2005).
[167] For a detailed discussion of interpretations and questions of tempo, pulse, and rhythmicity, see pp. 212 f.
[168] a term coined by Parncutt (1994)

no significant differences, and suggested to use *GSR rather than heart-rate in studies of the emotional effects of music*. A device measuring electrodermal activity was therefore included in the final experimental setup, to be able to control and compare stress levels, involvement, and arousal.

6 Hypotheses

Based on questions derived from the literature on the heart rate behaviour of subjects presented with auditory stimuli, a set of hypotheses was developed. These hypotheses are:

1. The ratings of the *Affective Communication Test*[169] show no significant group differences (musician vs. control group).
2. When breathing rate is voluntary, average heart frequency, average respiration frequency and skin conductance significantly increase when activating music is played, in comparison to phases without music and phases where sedating music is played.
3. When respiration is locked in entrainment to heart rate via a pulse-respiration ratio, average heart frequency and skin conductance significantly increase when activating music is played, in comparison to phases without music and phases where sedating music is played.
4. Subjects are able to increase their heart rate significantly (compared to their heart rate at rest) via the help of bio-feedback.
5. Subjects belonging to the “musicians” group perform the test in Experiment 2 more accurately than subjects in the control group, i.e. they are better able to actively aim at certain pre-defined heart rates.
6. In Experiment 2, due to the induced stress, skin conductance values are significantly higher in phase 3 and 4 in comparison with phase 1, 2, 5, and 6.[170]
7. In an inter-individual comparison, the acquired heart rate at rest is significantly higher in subjects who suffer from stage anxiety.

[169] (Traue, 1998)
[170] For a description of the different phases in the experimental schedule, see p. 85.

7 Experimental setup

7.1 Presentation of the stimulus

Previous researchers investigating the psychological and physiological effects of music listening or playing have described the challenges of how to present the stimulus in a way that fatigue, learning, habituation or transfer effects could be distinguished from the effect the stimulus might cause. In a majority of studies,[171] repetition and habituation effects were avoided by presenting a relatively short musical stimulus (or performance task) only once to each subject.[172] In these cases, inter-individual reagibility, long-term base-line shifts in stress or anxiety levels, or musical preferences could not be taken into account for statistical analyses. Other studies investigate learning and habituation effects with a smaller number of subjects repeatedly performing a musical task, or listening to the same sample of music again and again over a longer period of time,[173] but in these cases, the discussion of learning and habituation is often marginalised.

As a consequence, in the present study, the same short musical stimulus (5 minutes long) is presented three times to the subjects, separated by phases of rest, and randomised regarding certain breathing conditions the subject has to maintain. By accompanying the experiment with questionnaires, the subject is encouraged to listen attentively, to ensure a high involvement when investigating psycho-physiological effects of the stimulus while keeping habituation effects small.

Each of the participants took part in a continuous sequence of experiments. These were carried out according to a pre-fixed time schedule,[174] which allowed for short breaks for saving data and rebooting the

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[171] Hyde (1927), Ellis and Brighouse (1952), Zimny and Weidenfeller (1963), Mulcahy et al. (1990), Hunsaker (1994), LeBlanc, Young, Obert, and Siivola (1997), Escher and Evequoz (1999)

[172] LeBlanc et al. (1997, p. 484) reported that the study designers *had earlier considered standardizing the music to be performed by requiring a single selection to be played by all participants in the study, but we rejected this idea because we thought it would be unattractive to our participants, and it would require the peer-group audience to the same selection many times.*

[173] cf. Petsche, von Stein, and Filz (1996); Bernardi, Porta, and Sleight (2006)

[174] See p. 85 for the experimental schedule.

computer,[175] but primarily to ensure that stress and relaxation were experienced by the different subjects over roughly the same periods of time.

7.2 The musical sample

A musical sample was determined for the experiment after a trial and selection process during the pilot study. The sample consists of clips from Beethoven's 5th piano concerto.[176] The clips have a duration of five minutes, and cover parts of the second movement (including a slow cadenza), and the final movement (see Figure 5).

The musical sample comprises two parts that last 150 seconds each. The first part, an extract from the slow second movement of the concerto, is set at a tempo of ♩ = 40; the second part, the beginning of the fast third movement of the concerto, is set at ♪ = 360. The two parts differ in mood, loudness, and dynamic range (see Figure 6).

7.3 Design of the questionnaires

All subjects were asked to fill out questionnaires which complemented the bio-data gathered in the experiments. Questionnaire details are given in the Appendix (pp. 195 ff.).

7.3.1 Acquisition of musical and medical backgrounds

The Questionnaire *Fragebogen zum musikalischen und medizinischen Hintergrund* (see p. 197) gathered information about age, gender, education, relaxation techniques, musical preferences, potential experience in bio-feedback tasks, and self-experienced severity of stage anxiety. Furthermore, the date and location were noted, which allowed for the investigationg of potential laboratory effects.[177]

[175]To ensure that the digital metronome was as exact as possible, the computer had to be restarted before Experiment 2.

[176]Claudio Arrau's 1984 recording of the concerto, with the Staatskapelle Dresden conducted by Sir Colin Davis, was used. For a discussion of different interpretation and the tempo relations of the second and the third movement, see page 212.

[177]The experimental apparatus had to be moved because building work, which had not been announced when the experiment started, was being carried out near the laboratory.

Figure 5: The Musical Sample used in Experiment 1

This musical sample is an extract from Beethoven's 5th piano concerto, from bar 60 (2nd movt.) to bar 109 (3rd movt.). In the experiment, the sample was acoustically faded in and out to ensure that arousal would be due to the sample's musical context rather than aural "surprise".

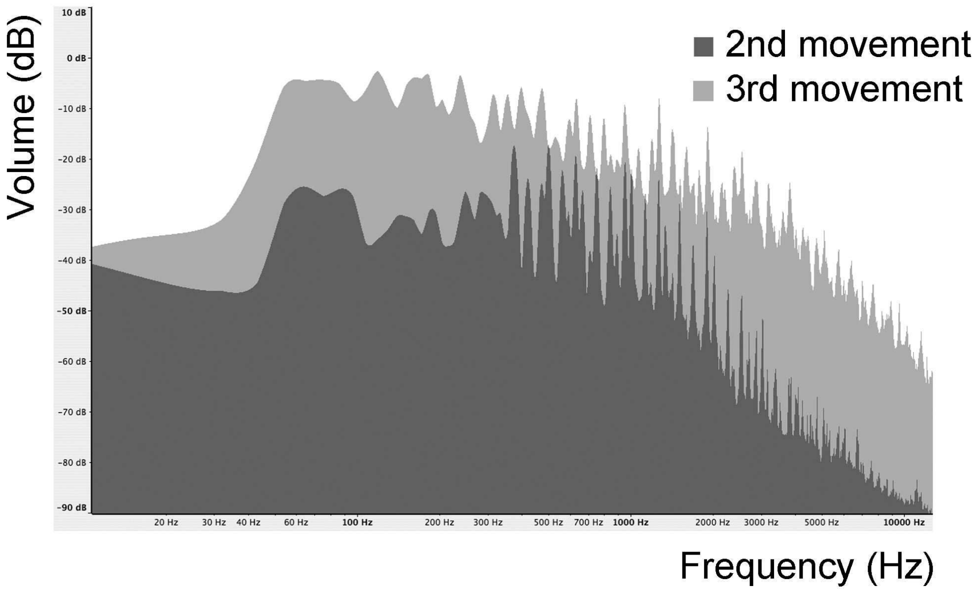

Figure 6: Comparison of loudness between the two parts of the musical sample

A spectral analysis of a clipping of 23 seconds around the loudness peak of the two parts of the musical sample (Hanning) reveals the loudness differences. Whereas part 1 shows a peak amplitude of $-15.27\ dB$ *at an average root mean square power of* $-36,22\ dB$*, part 2 shows a peak amplitude of* $-2.7\ dB$ *at an average RMS power of* $-24.06\ dB$*.*

7.3.2 The Affective Communication Test

For testing non-verbal expressiveness of the subjects, the *Affective Communication Test* (ACT) was used.[178] The test is a 13-item self-report and measures individual differences in expressiveness or "charisma" (Friedman, Prince, Riggio, and DiMatteo (1980)).

The Active Communication Test has been used to rate non-verbal expressiveness in depressed patients,[179] to investigate creative productivity in performing artists,[180] to predict physician workload,[181] psychosocial problems,[182] and even humor appreciation.[183] Sometimes, parts of the ACT were used in combination with other tests of emotional intelligence to acquire new measures of expressiveness.[184] The test itself has been analysed and discussed in various studies on *emotional intelligence* and experience.[185].

It was decided to include the test in the final setup, to use it as an additional measure to compare expressiveness levels in the musician and the control group, and to further investigate correlations with stage anxiety and other factors.

7.4 Qualification of subjects

Potential subjects for the study were approached in various ways. Invitations were placed on the notice-boards of the local Academy of Music, the local music conservatoire, and at venues where professional and semi-professional musicians could be approached, for example, concert halls and the opera. A popular internet platform was also used to invite music students whose user profile stated that they were or had been members of local choirs or other ensembles. Positive responses were less than anticipated, probably because it had been decided not to offer payments

[178] The German version, translated by Traue (1998), was used (see p. 196); compare also the original test in: Friedman, Prince, Riggio, and DiMatteo (1980)

[179] cf. Busch (2005)

[180] Cf. Kogan (2002). Regarding professional musicians, opinions vary on their expressiveness levels and the effects on group mood in an orchestra (Boerner and von Streit, 2007).

[181] cf. DiMatteo, Hays, and Prince (1986)

[182] cf. Segrin and Flora (2000)

[183] cf. Mobbs, Hagan, Azim, Menon, and Reiss (2005)

[184] cf. Petrides, Frederickson, and Furnham (2004); Leising, Müller, and Hahn (2007)

[185] cf. Craik (1986); Gross and John (1997); Law, Wong, and Song (2004); Deighton and Traue (2006)

for participating, and professional musicians and music students at the Academy tended to eschew the effort. Others were invited to participate regardless of their field of activity, who matched the musical participants in age, but these were controlled for effects of professional educations and practise.

To qualify as a member of the "musician" group, subjects had to have had at least eight years of music education, and be currently performing in public concerts at least twice a year. Depending on whether subjects fulfilled these requirements or not, they were sorted into either the *musicians*' group or the *control* group when they had successfully completed the experiment. The subjects did not know about the qualification process, nor that a control group existed; this way, potential motivating or demotivating effects were minimised.

Statistical analysis later confirmed that group differences were significant. Compared to controls, musicians had had a longer music education ($T(1/33) = -5.164, p < 0.001$), had spent significantly more time rehearsing ($T(1/33) = -3.505, p < 0.001$), and were giving more public performances ($T(1/33) = -2.909, p < 0.01$).

Potential participants who reported to be on constant medication, or who had a background of cardiovascular or respiratory disease, did not qualify for the experiments. In one case, a previously undiagnosed age-related pathological cardiac arrhythmia led to the disqualification of the subject after she had completed the experiment. Her acquired physiological data were not taken into statistical account; neither was the information she provided via the questionnaires. Another subject who stated in the questionnaire that she had been treated for epilepsy but was mainly symptom-free, was nevertheless excluded after a medical supervisor had been consulted. Since the experiment contained various forms of exposure to rhythmical acoustical stimuli, there was an increased risk of a possible seizure.

It was, however, decided to include the data of a subject who showed an increased amount of non-pathological cardiac arrhythmiae during the experiment, which seemed to impede her from satisfactorily performing the synchronisation task in Experiment 2. When asked, she stated that she knew about the arrhythmiae (which usually occurred in stressful situations), and she had been informed, after a long-term ECG had been recorded, that no further medical attention was required.

After subjects had given information about their qualifications in a questionnaire and had been successfully registered, they gave their written consent to their participation in the experiments. An experimental schedule was handed to them before the experiments.

7.5 Data acquisition – Recording design and apparatus

The experiments took place in Germany over three months in summer 2007, firstly at the Technical University Dresden, Department of Electrical Engineering and Information Technology, Institute of Biomedical Technology, and then at a Musical Summer Academy of the Friedrich Ebert Stiftung in Rheinsberg / Mark. The experimental conditions in Rheinsberg matched those in Dresden as closely as possible (see Figure 18 on page 18). Both groups (musicians and control group) were equally distributed at the two locations; correlation analyses did not reveal any significant lab effects among the over 80 parameters and variables.

The study design was discussed and revised in cooperation with the providers of the signal processing apparatus. Experiences gathered from an earlier experiment by this author[186] were taken into account when designing the overall setup.

7.5.1 Electrocardiogram monitoring devices

For measuring cardiac activity, a medical ECG monitoring system, Hellige SMK-250, was used together with three ECG clamp electrodes that were attached to both wrists and the left ankle of the subject (see Figure 7). The voltage drop on the body surface, which occurs with every heart beat, can be measured with this system.

According to its data sheet, the monitoring device is to be used with chest wall electrodes. Since the ECG data was only recorded to determine RR intervals and not for to diagnose potentially pathological conditions of the heart, a derivation via electrodes placed at the extremities after Einthoven's standard method was regarded as valid. Among the three possible derivations, the second was chosen, because it provided the biggest R waves in normal, healthy subjects.

The monitor gave live optical feedback of the entire heart curve and the actual heart frequency, averaged over three beats, as a numerical

[186] (Morgenstern, 2002)

Output voltage	$\pm 1\ V$
Impedance against signal ground	$> 10\ M\Omega / < 1,2\ pF$
Working range for differential signals	$6\ mV$[187], $600\ mV$[188]
Input direct current against N	$< 1\ nA$
Leakage current	$< 1\ \mu A$
Heart rate measurement range	20 to 350 pulses per minute
Smallest QRS width	7 ms
Frequency transmission range	0.3 Hz to 35 Hz (-3 dB)

Table 1: Technical specifications of the Hellige 250-SMK, as cited in (Reuter, 2007)

value. This feedback was visible to the subject during the entire course of events; however, during the warming-up experiment, subjects were not able to look at it since they had to complete a reaction test with a computer mouse, and had to watch a computer screen.

Before the electrodes were attached, they were moistened with water to minimize the impedance between the electrodes and the subject's skin.

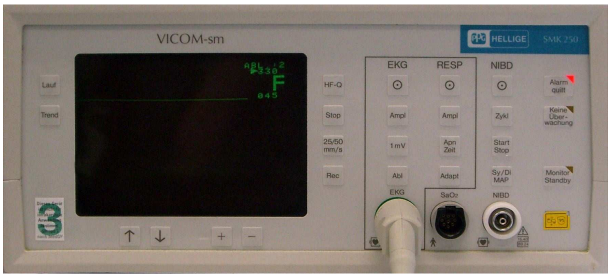

Figure 7: Hellige 250-SMK
As used to record subjects' cardiac activity.

The *Kardio.m* Software (see Figure 19) was used to indentify QRS complexes, and a cardiologist was consulted whenever apparently misleading identifications of QRS complexes (for example, arrhythmias or artifacts) needed to be clarified.

7.5.2 Respiration belt

Where there is a low level of artifacts (i.e. induced by bodily movements), respiration rates can be obtained solely from the ECG data. Due to RSA (Respiratory Sinus Arrhythmiae), heart rates vary periodically with the respiration frequency. However, respiration frequency and respiration depth influence the parameter values of RSA.[189]

When investigating RSA, respiration frequency can be calculated, but the inspiration point in time cannot be determined accurately, since we can only deal with a beat-to-beat resolution. Therefore, if synchronisation and coordination effects are investigated, a respiration belt has to be used for a more accurate measurement (resolution of up to 1000 Hz). Because of the high rate of artifacts, 16-bit resolution of the A/D-converter processing the measured data is necessary.[190] After having completed the pilot study, it was decided to use a respiration belt in all follow-up experiments, since with decreasing pulse respiration ratio, RSA shows up less pronounced (compare Figure 8, Figure 9, and Figure 10).

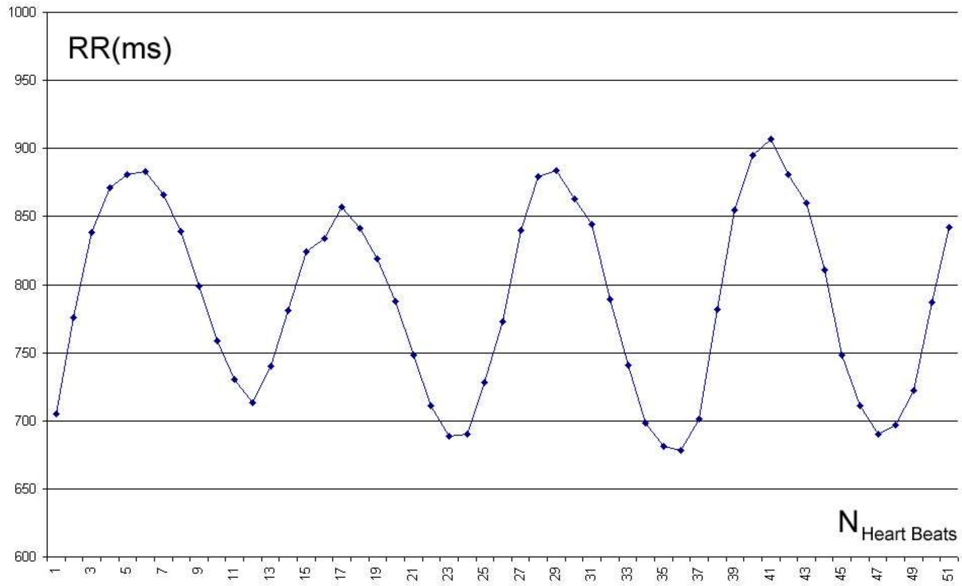

Figure 8: Respiratory Sinus Arrhythmia during controlled deep breathing
The subject was asked to breath deeply, with a controlled cardio-respiratory phase synchronisation via bio-feedback of $12:1$

The respiration belt was used to measure the variation in the inductive reactance of an external oscillator whose oscillation frequency is altered when the copper wire that is sewn into the flexible belt is bent.

[189] cf. Patzak, Ebner, Johl, Berndt, Orlow, and Camman (1992, p. 121)

[190] cf. Angelone and Coulter (1964) and also the findings of Rivera (2006, p. 34), which were completed after the pilot study was completed, but which helped in the development of the final experimental setup.

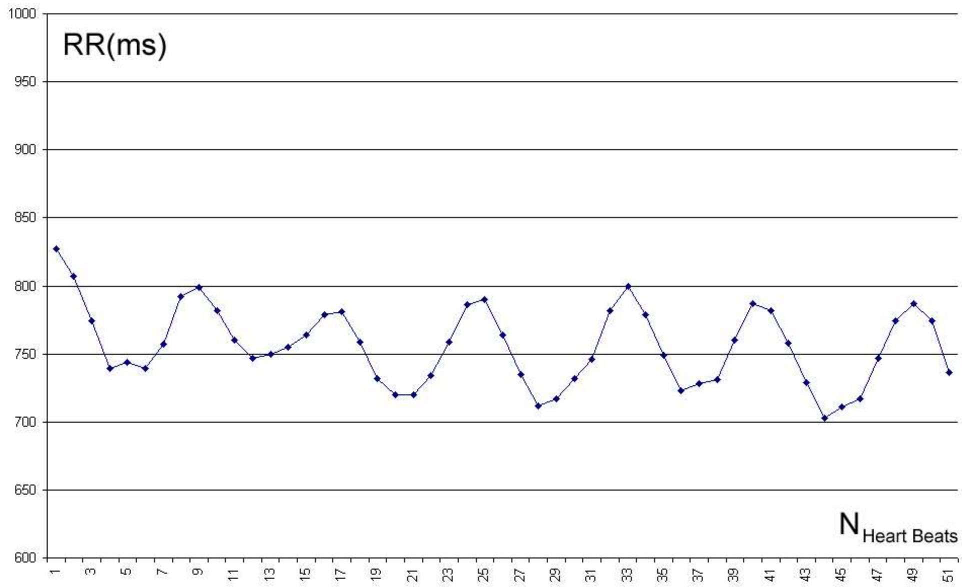

Figure 9: Respiratory Sinus Arrhythmia during controlled normal breathing

The subject was asked to breath normally, with a controlled cardio-respiratory phase synchronisation via bio-feedback of 8 : 1

Voltage supply	5 V
Wattage	approx. 2 mA
Fundamental output voltage	1.5 V[191]

Table 2: Technical specifications of the respiration belt

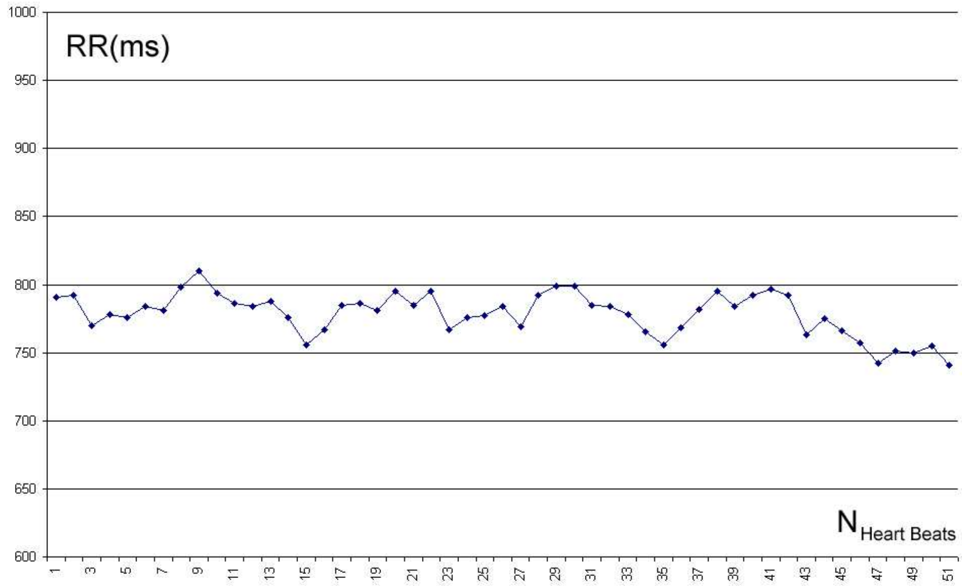

Figure 10: Respiratory Sinus Arrhythmia during controlled fast breathing

The subject was asked to breathe quickly, with a controlled cardio-respiratory phase synchronisation via bio-feedback of $4:1$*. RSA is hardly pronounced; a computational extraction of breathing rate would be deficient.*

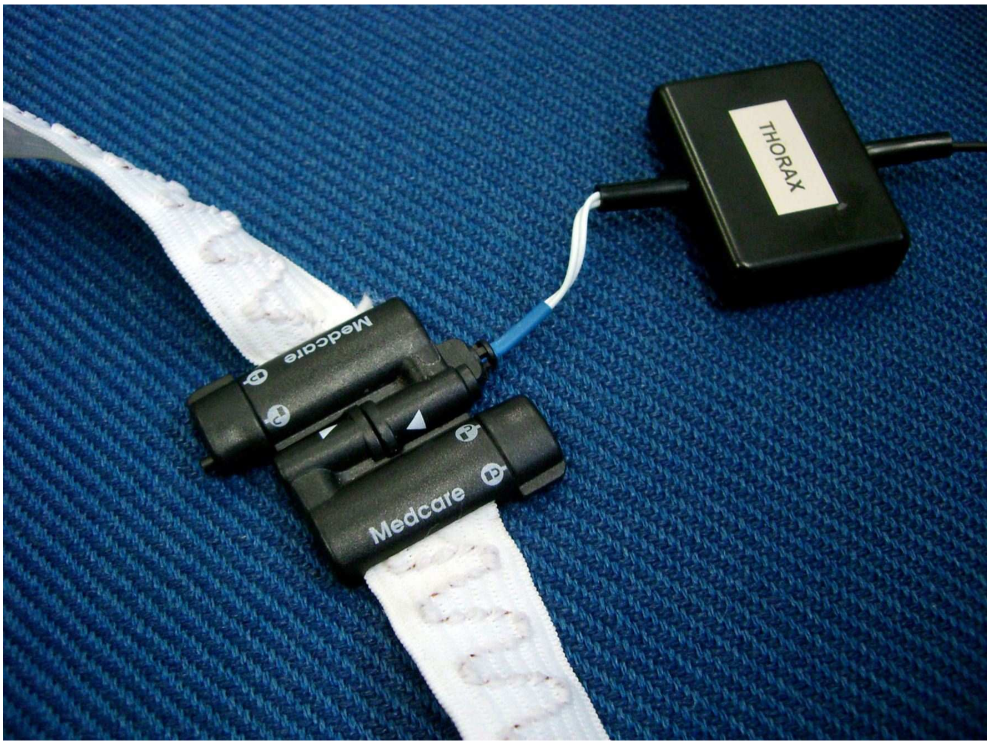

Figure 11: Adjusting the respiration belt

The band and the copper wire inlay had to be cut to a suitable length, the wire then had to be inserted into the two metal clamps that were then connected together. A recording test showed that the operating point of the belt was reached only 83 seconds after the clamps had been connected.

Figure 12: Becker Meditec Respiration Belt
For measuring chest respiration, as used in the experiment.

The belt is designed to measure abdominal or chest breathing and detects small thorax excursions (see Figure 11). It can be adjusted to the subject's girth by cutting the fabric band (see Figure 12). After clipping the wires with the two black clamps and closing the belt, the contacts were tested with an ohmmeter to avoid invalid recordings.[192] The belt was used only after its data measurement unit had reached its operating point, and this took 83 seconds after the belt was closed.

Before being used, the respiration belt was tested for reliablility, durability, and practise, because there was no prior exerience with the data measurement unit. During the tests, it turned out that the fundamental output voltage specified by the manufacturer was inaccurate. Instead of 1.5 $V \pm 300\ mV$, the belt showed an output voltage of 1.37 $V \pm 1.3\ V$. The dynamic range of all sensors was then determined, and specified in the "Kardio.m" analysis program with the software tool "Instacal" that comes with the A/D converter.[193]

7.5.3 Monitoring electrodermal activity

Boucsein (1992, p. 89) demonstrated the challenges of electrodermal activity recordings with an example:

> Problems for the amplification of the EDA signal mainly result from its wide range, since the many possible inter- and intra-individual differences in EDLs result in a large recording range. In comparison, the fluctuations appearing as EDRs are relatively small. When, for example, an SC-recording device covers a range from 0 to 100 myS, and fluctuations with amplitudes of .05 myS should be scored as SCRs [...], the resolution in the analysis must be better than .0005 [...] With a computer analysis [...] using A/D conversion with 12-bit accuracy, such resolution would only just be achieved; thereby, possible 4,096 digital scores would lead to a resolution of .025 myS/bit, and the minimal amplitude of .05 myS would be converted into 2 bits.

For measuring electrodermal activity (EDA), a *Becker Meditec* sensor was used (see Figure 13).

[192]The ohmic resistance of the belt should be in the range of 300 $k\Omega$ and 400 $k\Omega$, depending on the length of the belt.

[193]For further details of the dynamic range setting process, see Reuter (2007), p. 18.

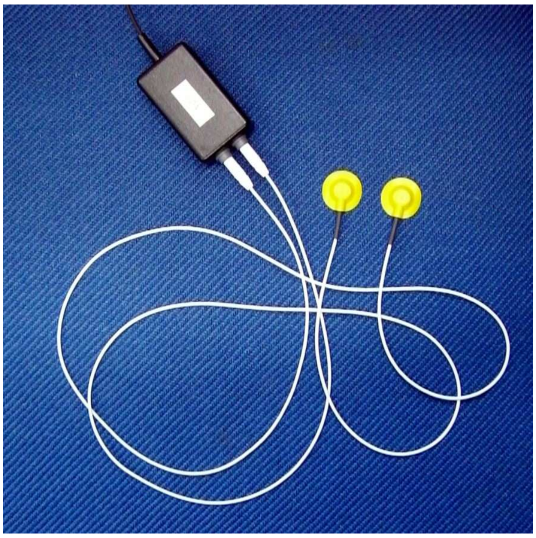

Figure 13: Becker Meditec skin conductance monitoring system
The system consists of two wired reversible electrodes and an EDA module that measures the electric conductance of the skin by applying a DC voltage (U) of $0.5\ V$ *and determining the resulting current* I*, where* $G = \frac{I}{U}$.

This DC sensor analyses exosomatic conductance with the most frequently used method for electrodermal recording: applying a constant voltage U of $0.5\ V$ between two sintered silver/silver chloride (Ag/AgCl) reversible electrodes that are located at the medial phalanges of two fingers, in this case, the middle and ring finger of the non-dominant hand (see Figure 14). The electrodes were always placed on the left hand, beacuse all the subjects had decided to use the computer mouse in the Stimulus Reaction Test[194] with their right hand.

To minimise transition impedance between the electrode and the skin, the electrode paste TD-246 was used. Since the interaction between skin and electrolytes can have a marked effect on variations in EDA, the whole electrolyte-skin system should be disturbed as little as possible.[195] Before the pilot study took place, the ideal position for placing the electrodes was investigated, as described in more detail by Reuter (2007, p. 32) (compare Figure 15). Velcro® strips were used to secure the electrodes on the fingers.

For a more detailed discussion of the influence of temperature changes under the Velcro® strips, the ideal position of EDA electrodes,

[194] For a description of the Stimulus Reaction Test, see p. 84.
[195] cf. Boucsein (1992, p. 107) for choice of electrolytes and electrolyte media

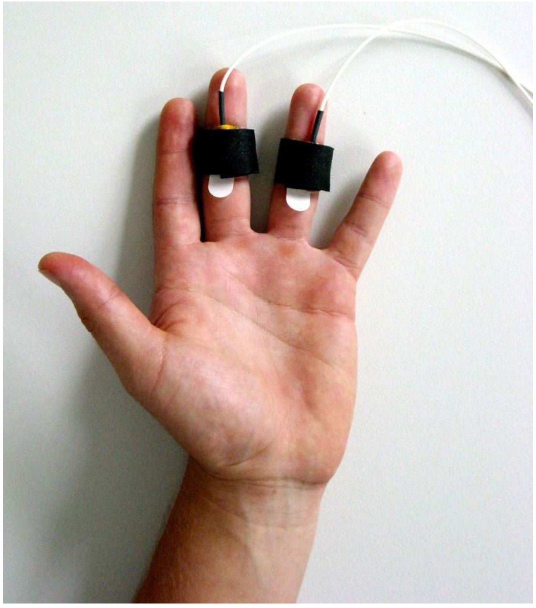

Figure 14: Application of DC electrodes to measure skin conductance
DC electrodes were applied at the medial phalanges of the middle and ring fingers.

Voltage supply	$5\ V$
Wattage	$< 1\ mA$
Measurement range	$0...100\ \mu Siemens$
Output voltage	$25 mV per\ \mu Siemens$

Table 3: Technical specifications of the EDA sensor, as provided by Becker (2006)

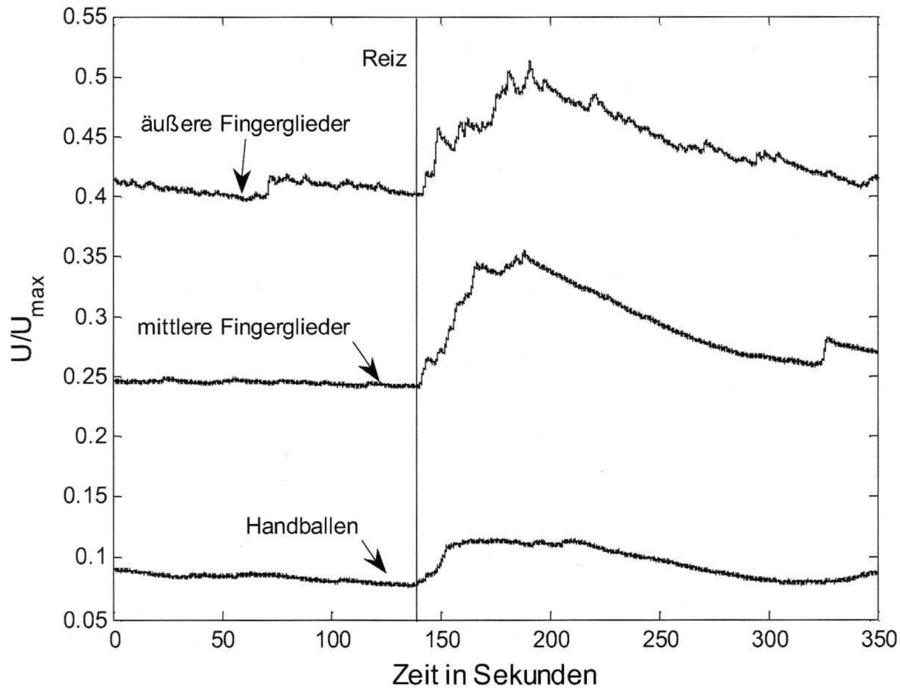

Figure 15: Effect of a stimulus on EDA at different measurement positions

Temporal stimulus-reaction pattern, measured at different measurement positions: at the distal phalanges (above), the medial phalanges (middle) and the palm (below). (Reuter, 2007); used by permission of the author.

maximum measuring times, movement artefacts, and other restricting parameters of a reliable EDA measurement, as well as a short historical outline of the measurement of galvanic skin response (GSR), see Reuter (2007).

7.5.4 Acoustic equipment

Three different devices were used to provide acoustical stimuli. The musical samples in Experiment 1 (see page 86 for detailed information about the schedule of the musical samples) were played to the subject from a portable CD player via headphones (see Figure 16).[196] The headphones were removed immediately after the experiment. In Experiment 2, two other acoustic stimuli were introduced: the real-time acoustic biofeedback of the subject's heart beat via an in-built speaker in the ECG monitoring system (a 'beep' sound); and a short metronome click generated by the *Kardio.m* software and applied via a stereo desktop speaker system calibrated to a conventional sound level.

Figure 16: Headphones used for Experiment 1
A pair of full open-air type dynamic headphones was used that also allowed the subject to listen to the supervisor's briefings before the experiment.

7.5.5 Analog-digital data conversion

To convert the recorded signals into digital format, the 16-bit A/D converter "USB-1608 FS" from the *RedLab* series by Meilhaus was used (see

[196]Technical specifications of the SONY®MDR-F1 headphones: Impedance 12 Ω at 1 kHz; Sensitivity 100 dB/mW; Frequency response $10 - 30,000$ Hz

Figure 17).[197] With its 16-bit resolution, it is able to extract the small amplitude of wanted signal from the raw EDA data. The converter was connected to the computer hardware via USB cable. For the input of the raw data, three of its eight single-ended analogue input canals were connected to heart, respiration, and skin conductance sensors. The "Kardio.m" software had to be adapted to the converter. As Reuter (2007) describes, various implementation problems had to be overcome; for example, an older version of the MATLAB Data Aquisition Toolbox was identified to be faulty and had to be updated. But eventually it was possible to record whole data sets of all three signals simultaneously up to a recording sample length of 1800 seconds, as stipulated in the experimental schedule.

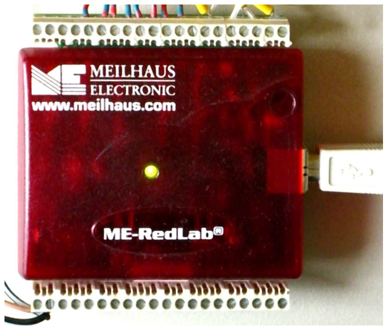

Figure 17: A/D converter
The A/D converter converts raw data from heart monitoring, respiration monitoring and skin conductance monitoring systems into a digital format that can then be analysed with the Kardio.m *software.*

7.5.6 Computer hardware and analysing and processing software

For processing and analysing the recorded bio-signals and generating acoustical and optical stimuli, a personal computer and a laptop, both with Windows XP operating systems, were used. To provide another visual stimulus in the pilot study (see page 46 for details), a laptop with a Mac OS X operating system was used. A computer with Mac OS X 10.4.11 running Windows XP programmes, such as SPSS ver. 10 on a virtual machine was used for data analysis.

[197] A different A/D converter, with a 12 bit resolution, was used during the pilot study.

Figure 18: Experimental setup
The setup showing the personal computer that records the data, the laptop that displays the initial stimulation-reaction test, and the bio-sensors.

The MATLAB-based software program *Kardio.m* was written by Gätjens (2002) to process physiological data. It was later revised and adapted to the needs of this study by Rivera (2006), Reuter (2007) and the author (see Figure 19). It uses the MATLAB Data Aquisition Toolbox (version 2007a) to process data input, and peripheral devices (computer screen, sound card and desktop speakers) for signal processing and production. The *Kardio.m* software that records the data from the ECG, the respiration sensor, and the EDA sensor in parallel, is described in detail in Rivera (2006).

In addition, a short MATLAB program named "Tastatur.m" was used to guide the subject through the initial Stimulus Reaction Test (see Figure 20 for a screenshot of the test interface).[198] A computer mouse was used as an input device during the test.

For the analysis of all the recorded data, a MATLAB-based software called "HRV.m" was used (see Figure 21). It was written by Rivera (2006) and later revised by Reuter (2007) and the author to adapt it to the requirements of the study. Its features are explained in detail on page 224.

The analysis of the ECG data recorded during the course of the experiments revealed a number of different arrhythmias that sometimes led to mis-detections of R waves by the "HRV.m" software, including false positive and false negative detections. The most common mis-detection occured when a subject's ECG showed knots in the left bundle branch

[198]The full program code is included on page 229.

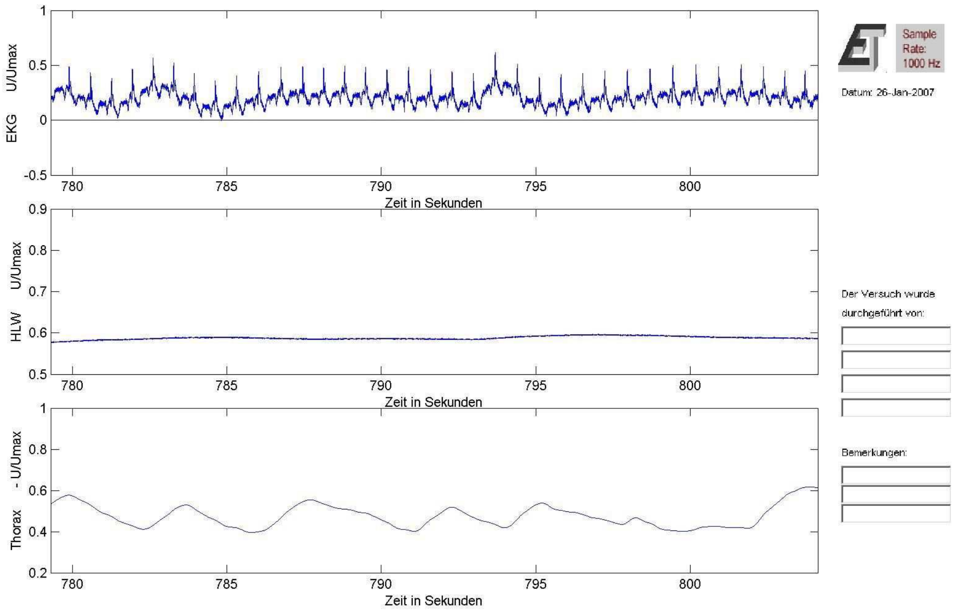

Figure 19: The "Kardio.m" program
A screenshot of the "Kardio.m" data acquisition and processing software program. Three data streams (cardiac, respiration and electrodermal data) can be processed in parallel.

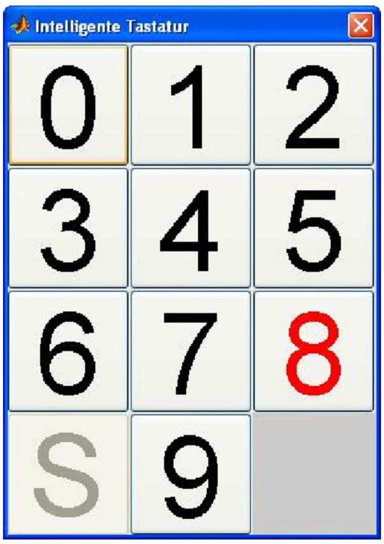

Figure 20: The "Tastatur.m" program
A screenshot of the "Tastatur.m" program. The data are put in via a computer mouse and saved in a log file.

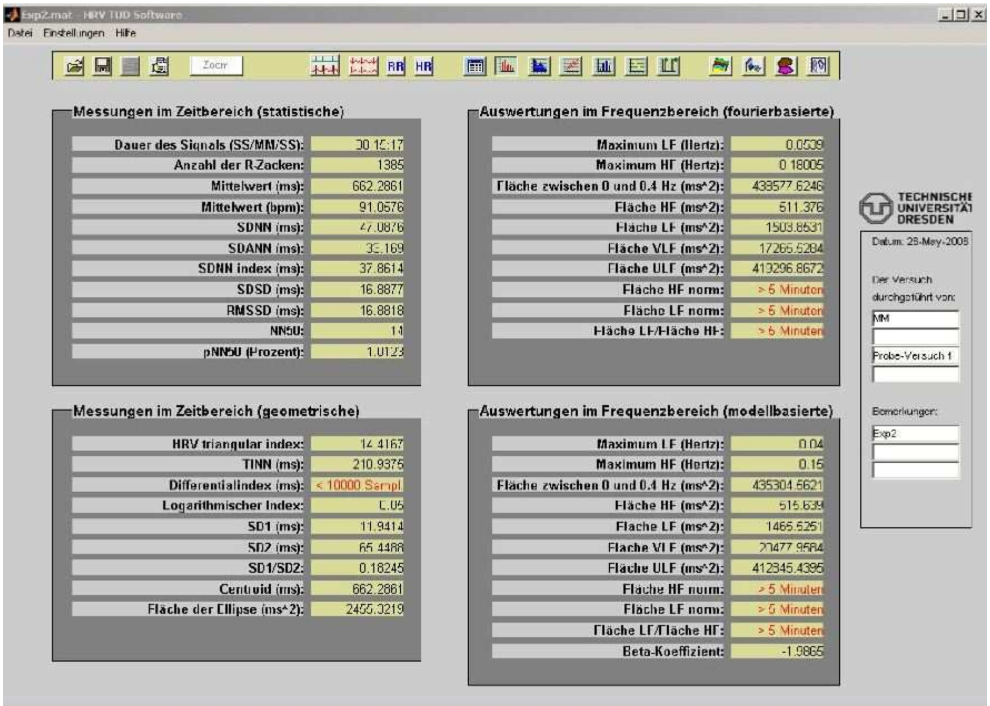

Figure 21: The "HRV.m" program

A screenshot of the statistical analysis tool in the "HRV.m" program. The data are processed and analysed according to the guidelines of the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996).

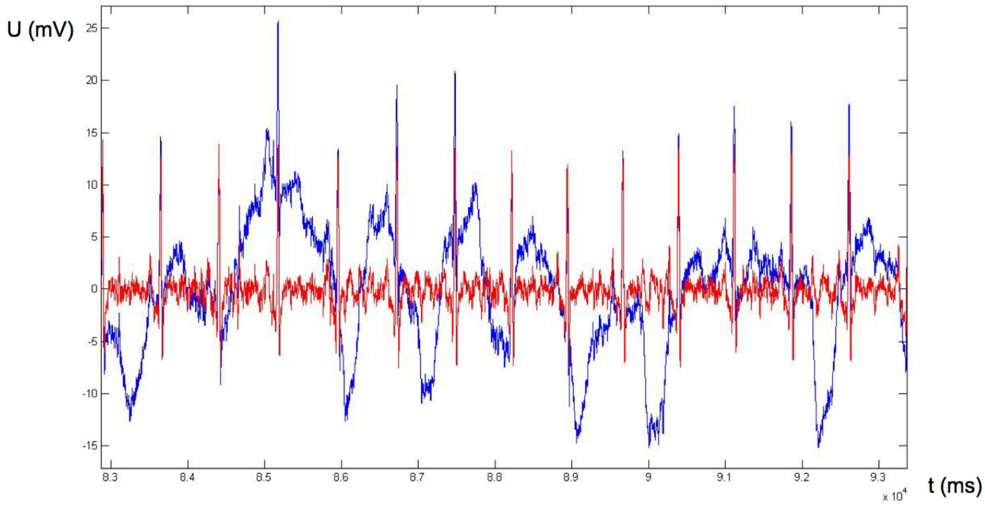

Figure 22: ECG filter included in the "HRV.m" software
The "HRV.m" software contains a number of detachable data processing tools, among them is a band-pass filter to prepare electrocardiographic raw data for analysis. (blue: raw ECG data; red: ECG data filtered with a [5 45 Hz] *band-pass filter.*

– a sign of unspecific intra-ventricular excitation propagation.[199] It was decided not to correct these mis-detections of the R wave since they produced an error shorter than 20 ms. All other mis-detections were corrected during the analysis using the correction tool in the "HRV.m" software. The analysis of the processed respiration data also revealed that some breaths were not detected because they did not reach the calculated average breathing volume threshold. These also had to be manually corrected (see Figure 24 and Figure 25).

With the subject moving the right hand to operate the computer mouse, the electrocardiac raw data was prone to show irregularities since muscular movements result in an offset of the ECG base line (see Figure 26). However, by applying a bandpass filter (see, for example, Figure 22 on page 22 for the band pass filter implemented in "HRV.m"), the ECG could still be analysed satisfactorily, and the RR intervals could be detected automatically.

[199] See Schuster and Trappe (2005, p. 44) for details.

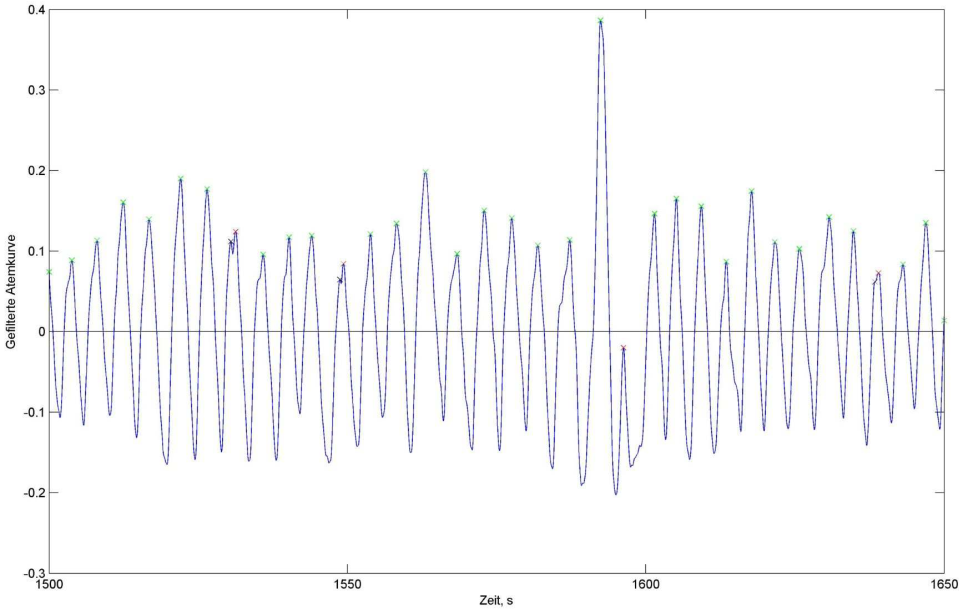

Figure 23: Failed respiration detection has to be manually corrected
All processed respiration data sets had to be manually corrected in case single breaths had not been detected automatically, or had falsely been detected.

During the Stimulus Reaction Test, subjects showed a variety of breathing characteristics. The quality of the computer-generated analysis with HRV.m varied accordingly.

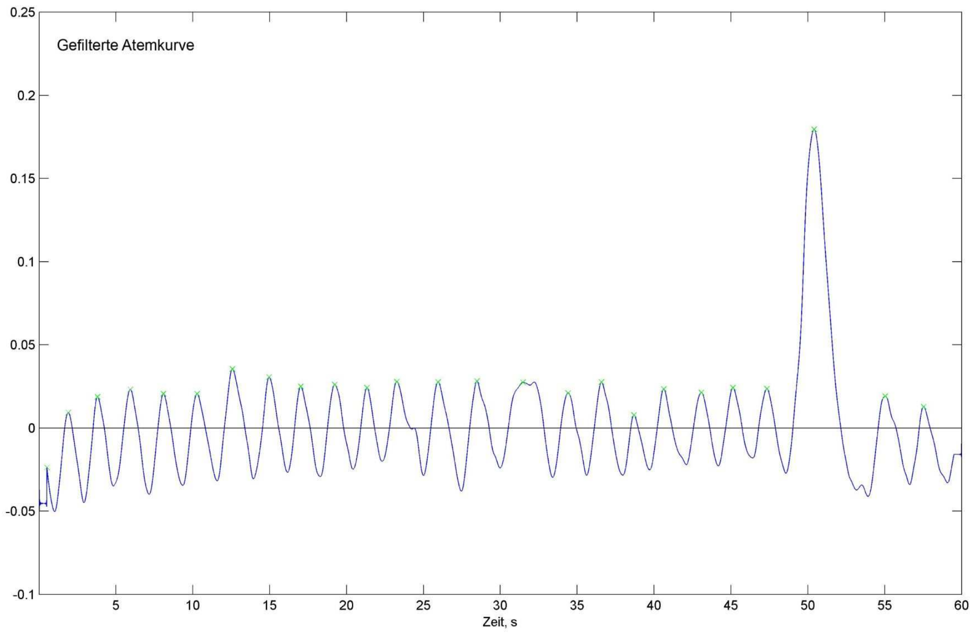

Figure 24: Regular breathing pattern during the Stimulus Reaction Test
This example (from subject No. 132) shows a breathing pattern that can be easily analysed; its breaths can be singled out and counted, and the breathing rate calculated.

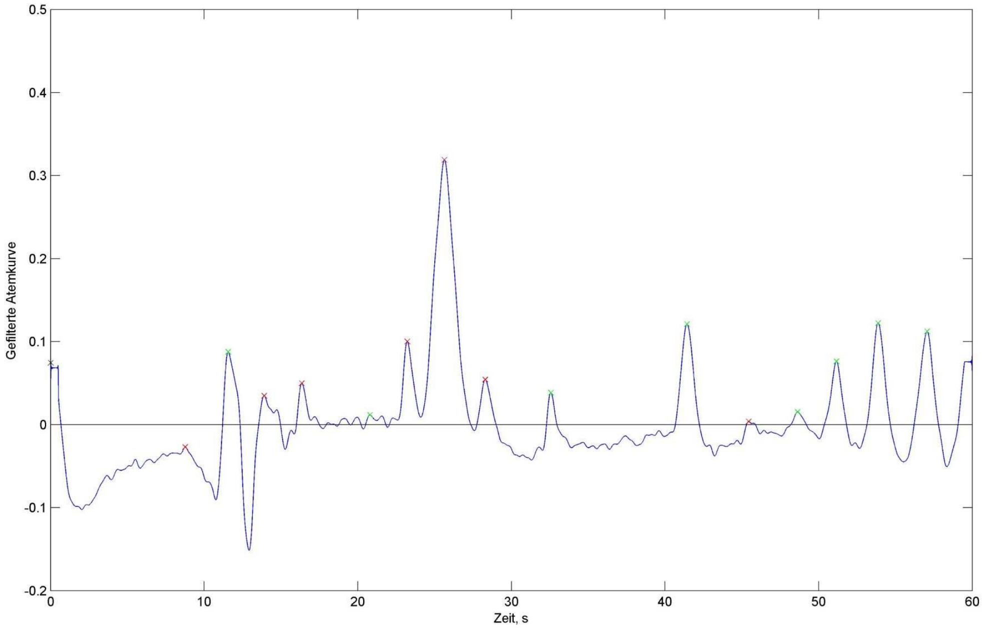

Figure 25: Irregular breathing during the Stimulus Reaction Test
This example (from subject No. 125) shows a chaotic breathing behaviour that cannot be easily analysed. To calculate the average breathing rate, breaths need to be re-counted and re-determined manually (red) after the computer had carried out its analysis (green).

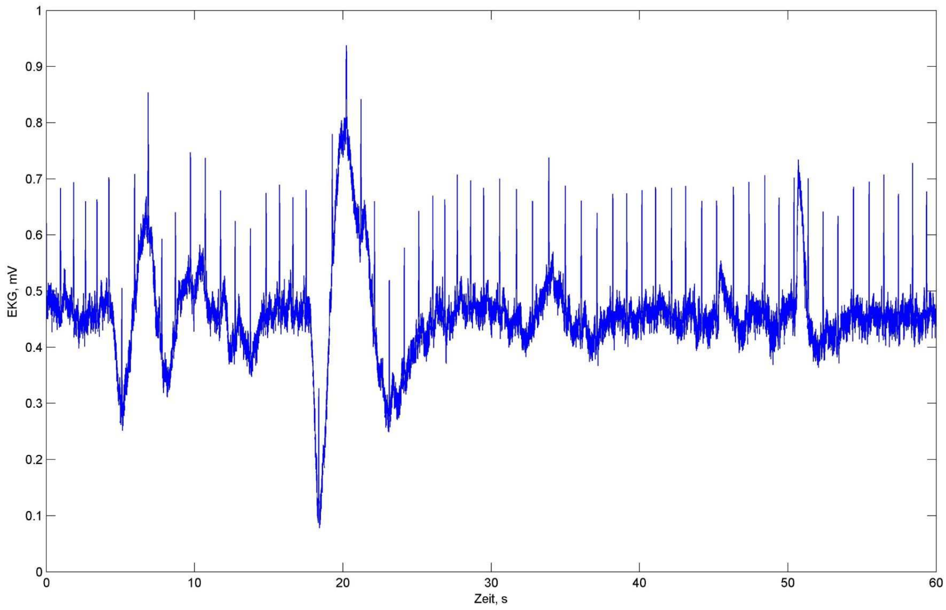

Figure 26: ECG raw data corrupted by muscular movement of the subject
This example (from subject No. 117) shows an offset of the ECG baseline that makes automatic RR detection difficult.

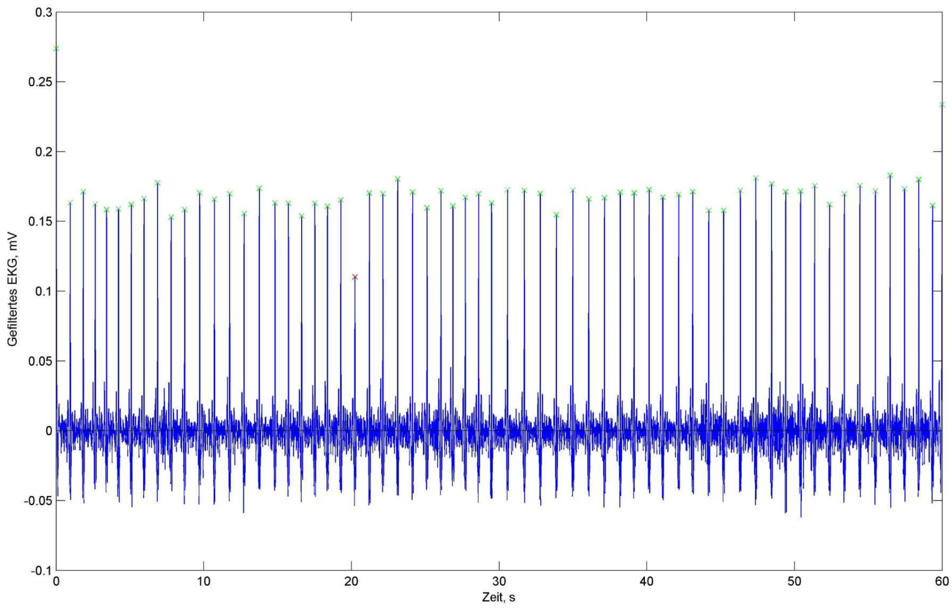

Figure 27: Bandpass filter helps to correctly detect QRS complexes and RR intervals
With the application of a bandpass filter, ECG raw data can be analysed more easily for RR waves (green: positive detection).

8 Methods

Altogether, thirty-five subjects (aged 17-60 years) ran through the whole chain of experiments and questionnaires. During the study, they were not addressed as belonging to a particular group to avoid discouragement and hence any influence on the outcome of the study. It was only after they had successfully completed the full experiment that subjects were classified in the musician or control group, as described. For age and gender of the participants, see the table on page 82.

	Musicians	Control group	Total
No. of subjects	17	18	35
Mean Age (a)	29.1(±7.7)	27.8(±9.6)	28.4(±8.6)
Gender	12f / 5m	8f / 10m	20f / 15m
Av. rehearsal time (min/d)	80.29(±79.3)	13.11(±18.0)	45.74(±65.4)
Public performances (p.a.)	16.91(±23.5)	0.75(±1.5)	8.6(±18.1)
Musical education[200](a)	12.71(±5.1)	4.22(±4.5)	8.34(±6.4)

Table 4: Specifications of Subjects

8.1 Statistical analysis

Generally, significance was tested via ANOVA involving repeated or univariate measures, with F accounting for the degrees of freedom, with the respective requirements being met.[201] Levels of significance were $p < 0.001$, $p < 0.01$, and $p < 0.05$. Ordinal data niveaus (for example, in the Likert scales used in the questionnaires) were tested using Spearman's rank correlation coefficient; for all other correlation analyses, the Pearson product-moment correlation coefficient was calculated.[202] Information on mean values (for example, of subjects' age) were complemented with standard deviations (for example, as "29.1(±7.7)"), and in the figures, they were illustrated with standard errors (see, for example, Figure 29 on page 29).

Heart rate and heart rate variability characteristics were deter-

[200]musical education on subject's main instrument
[201]cf. Bortz (1993)
[202]The test statistic verifying the significance of that coefficient is t-distributed with $n-2$ degrees of freedom; cf. Kreyszig (1973).

mined and analysed according to the standards set by the HRV Task Force.[203]

The following values were implemented in the Kardio.m analysis software:

- Time Domain (statistical): Length of signal, Number of RR waves, Mean RR interval (ms), Mean heart frequency (bpm), SDNN (ms), NN50, and pNN50 (%)
- Time Domain (geometrical): SD1 (ms), SD2 (ms), SD1/SD2
- Frequency Domain (fourier-based): Maximum LF (Hz), Maximum HF (Hz), HF (ms^2), LF (ms^2), VLF (ms^2), HF norm, LF/HF
- Frequency Domain (model-based): Maximum LF (Hz), Maximum HF (Hz), HF (ms^2), LF (ms^2), VLF (ms^2), HF norm, LF/HF

When the sample length recommended by the Task Force was not met by the raw data set, the analysis software would not calculate the respective value.

For organisational reasons, the experiments were carried out in two different laboratories. The experimental conditions were kept identical; the laboratory situation, including size of the lab, temperature, and technical devices, was the same to exclude laboratory-specific confounding factors.

8.2 Education and musical career

Three subjects (aged 17, 18, and 22) still attended secondary school; two of them were classified as controls. Three subjects (aged 21, 22, and 23) attended a university of applied sciences; two of them were classified as controls, the third, who studies ergo-therapy, was classified as a 'musician'. 23 subjects, 14 of whom classified as controls, were studying or had studied at a university. Their main areas of study ranged from German, English, and French literature, psychology, medicine, philosophy and arts, to architecture, physics, electrical engineering, and biochemistry. 7 subjects were studying or had studied at a music academy; all seven met the criteria as musicians for the experiment (see chapter 7.4 for further details). The musicians' main instruments (i.e. most used

[203] (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996)

in performance) were: recorder (1), violin (4), viola (1), violoncello (1), voice (2), piano (4), oboe (1), flute (1), and saxophone (2).

Regarding musical careers, the subjects' experiences differed quantitatively (for mean rehearsal time per day, the number of public performances and the musical education time on their main instrument, see the table on page 82) and, as the analysis of the questionnaires shows (see chapter 9.2), qualitatively.

8.3 Experimental schedule

After subjects had been informed about the general Experimental schedule,[204] they had to complete two questionnaires that covered age, gender, musical education and practise, daily rehearsal duration, musical preferences, and overall expressivity. In Questionnaire 1, subjects had to sign a consent that they *would take part voluntarily* and *did according to their prior knowledge not suffer from any diseases that influence the functionality of the cardiovascular system.*[205] They could decide whether any medical information arising from the analysis of their raw data should or should not be brought to their attention.

8.3.1 The Stimulus Reaction Test

The initial Stimulus Reaction Test was included to ensure that the biomedical recording devices were applied and working correctly, and to get the subjects acquainted with the experimental situation, and to identify their physiological parameters at rest. During the test, a computer screen showed a panel of numbers in the range of $0 - 9$ and highlighted

[204] See p. 85 for the experimental schedule.

[205] In the course of this study, all experiments were carried out non-invasively. Although they did not pose any risk to the subjects' health, the subjects were informed that they could cancel their participation at any given moment. In the preparation phase of the experiments, it was made sure that the apparatus met the necessary safety criteria, and all measuring devices and procedures did not pose a risk to subjects' health.

[206] For every phase in Experiment 1, the subject received different breathing instructions. After two phases of voluntary breathing, different pulse-respiration ratios had to be maintained with the help of visual ECG feedback. For every phase in Experiment 2, the subjects received different instructions on how to adapt or detach their heart rate (which is fed back visually and acoustically) to or from the metronome beat.

Duration		Phase
	FEX Questionnaire	
	Questionnaire 1	
	Application of respiration belt. Application of ECG and skin conductance electrodes. ECG monitored until steady state is reached	
1 min.	**Stimulus Reaction Test**	
	Application of headphones; Instruction to Experiment 1	
30 min.	**Experiment 1:** Cardiovascular changes induced by music	1[206]
		2
		3
		4
		5
		6
	Removal of headphones	
	Questionnaire 2	
	Instruction to Experiment 2	
15 min.	**Experiment 2:** Entrainment and detachment from auditory stimulus	1
		2
		3
		4
		5
		6
	Removal of electrodes and respiration belt	

Table 5: Experimental schedule

them one at a time in random order. The subject was instructed to click on the highlighted numbers as quickly as possible.[207]

The test lasted 60 seconds. During the test, the subjects' biosignals (cardiac activity, respiration activity, electrodermal activity) and their reaction times were recorded, and written into a log file.

8.3.2 Experiment 1: Cardiovascular changes induced by music

Experiment 1 was a thirty-minute listening experiment to investigate cardiovascular behaviour during phases of controlled and uncontrolled breathing. The subject was instructed to listen to a musical sample three times, alternated with phases of silence. With every phase, different breathing instructions, which were explained before the experiment and were also available as a written schedule throughout the experiment, had to be carried out. After two phases of voluntary breathing, different pulse-respiration ratios had to be maintained with the help of visual ECG feedback. The subjects were instructed to listen attentively, since a questionnaire about the musical and interpretational features of the musical sample had to be completed afterwards.

The subject was placed on a slightly padded chair whose backrest had been lowered so as not to disturb the respiration belt measurements. The ECG electrodes, the respiration belt, and the skin conductance electrodes were applied. Then there was a pause of about five minutes to normalise the subject's cardiovascular and respiratory functions and their skin conductance levels. The ECG was supervised until a stationary status had been reached.[208] Meanwhile, the experiments were explained to the subjects. They were instructed not to speak during the experiments and to move around as little as possible to minimize artefacts in the recorded data.[209]

Experiment 1 consisted of three parts: phases 1 and 2, phases 3 and

[207] If a wrong number was clicked on, no new number was highlighted.

[208] Stationarity was assumed when the average heart rate displayed by the Hellige ECG did not fluctuate over a course of three minutes.

[209] While the experiments took place, the supervisor of the study and usually one technical assistant were present to manage the recording devices, help the subject with the headphones, play the musical sample CD, switch on acoustic feedback from the ECG monitoring device, and provide the instructions necessary to perform all the experiments. While the experiments were running, no instructions were given, and the amount of potential disturbances from noises, movement in the room etc. were minimised.

Phase No.	Musical sample	Pulse-Respiration Ratio
1	-	voluntary breathing
2	X	voluntary breathing
3	-	10:1
4	X	10:1
5	-	6:1
6	X	6:1

Table 6: Experimental Schedule of Experiment 1 (Example)

4, and phases 5 and 6; each phase lasted 5 minutes. Every part consisted of a phase without music, followed by a phase with music. In phases 1 and 2, breathing was voluntary. In the following four phases, respiration frequency was defined by heart rate, set in a fixed pulse-respiration ratio of 6:1 or 10:1.[210] Whether the pulse-respiration ratio in phases 3 and 4 was 6:1 or 10:1, was randomly determined before the experiment began; the other pulse-respiration ratio had then to be applied in phases 5 and 6. In that way, there could be two different schedules in Experiment 1.

The subject was asked to breathe regularly during phases with voluntary breathing. When a certain pulse-respiration ratio had to be employed, the subject had to control his or her respiration rate by adapting it to the given pulse rate: to achieve a 6:1 ratio, a full respirational cycle has to last six heart beats, and for a 10:1 ratio, a full respirational cycle has to last ten heart beats. For simplification, inhalation and exhalation duration had to be the same. The subjects therefore had to breathe in and out for three or five heart beats respectively. When the inhalation finished before the three or five heart beats were over, the subject was advised to hold his or her breath before exhaling.

The partly randomised schedule for the different phases of the experiment is described by the table on page 87.

To guarantee that the subject was highly involved, concentrated on the music and tried to avert distraction, the supervisor announced that a questionnaire inquiring the musical sample in detail would have to be filled out directly after the experiment. The subject was advised to listen

[210] These ratios were chosen to make the subject breathe slightly slower or faster than the mean ratio needed to maintain the oxygen saturation of the blood; cf. Bucher and Bättig (1956)

carefully to be able to answer this questionnaire. Thus involvement and the ability to concentrate was partly controlled via the questionnaire.[211]

During the experiment, heart activity, respiration activity, and electrodermal activity were recorded. Heart activity was fed back to the subjects via a running ECG signal and actual average heart rate (bpm) visible on the ECG monitor screen.

8.3.3 Experiment 2: Entrainment and detachment from auditory stimulus

In Experiment 2, several effects of cardiac and respiratory interaction with external periodic stimuli were investigated. The subject was instructed in detail on how to actively govern his or her heart rate by visualising moments of stress and relaxation. By means of optical and acoustical bio-feedback, subjects were asked to approximate their heart beats as accurately as possible to certain frequencies pre-defined by their physiological baselines.[212] The whole schedule was explained before the experiment started, so that there was little or no need to intervene verbally during the experimental task.

After the second questionnaire – containing questions about the state of arousal, involvement, and preference – was completed, the subjects' average heart rates at rest were determined via the ECG monitoring device. The subjects were then given a written schedule, informing them about the second experiment. This experiment lasted fifteen minutes, during which the subject listening to a 150-second periodic metronome beat whose frequency was adjusted to the subject's average heart rate at rest;[213] this alternated with 150 second periods of silence.

[211] see page 200 for the questionnaire.

[212] Entrainment effects between heart rate and a simple external auditory stimulus have been investigated by various researchers (Bason and Celler, 1972; Frank, 1982; Reinhardt, 1999). The fact that any form of acoustic feedback that might trigger entrainment effects should take into account inter-individual differences among subjects, has been outlined but not thoroughly investigated (Fraisse, 1982; Brener and Kluvitse, 1988; Acosta and Pegalajar, 2003). Thus, for the second experiment, an extended setting was designed so that entrainment to a periodic acoustic stimulus could be adapted to the physiological baseline of the subject, and still produce statistically reliable data.

[213] Before the experiment, the integral average heart rate of the subject at rest was estimated. The data from the first phase of Experiment 1 (when the subject's cardiac activity at rest was recorded) and the overall prevailing heart performance were taken into account in the estimation. The numeric value was written down in a copy of the experiment's explanatory schedule, and the copy was given to the subject.

The metronome click, fixed to stimulus frequency *SF*, was audible during phases 1, 3, and 5. Subjects were asked to keep their heart rate as close as possible to the stimulus frequency in phases 1, 2, 5, and 6, while their heart activity was being fed back throughout the entire experiment, as a visible signal on the ECG monitoring device, and a numerical heart rate (in beats per minute) also on the ECG monitoring device. For phases 3 and 4, subjects were asked to accelerate their heart rate by 10 bpm compared to the original stimulus frequency by imaginating stress-full situations, such as a public solo performance, an oral exam, etc., and then keep their heart rate as close as possible to that accelerated frequency. During phases 1 and 5, the audible metronome frequency could be used by subjects to keep their heart rate stabilised at the required frequency; however, during phase 3, the metronome (still set at the original stimulus frequency) could not be used to adjust or maintain the faster heart frequency; it might, in fact, have a de-stabilising effect.

The experiment itself, containing six consecutive phases lasting 150 seconds each, ran as follows:

Phase	Metronome stimulus	Target heart rate
1	X	SF
2	–	SF
3	X	SF+10 *bpm*
4	–	SF+10 *bpm*
5	X	SF
6	–	SF

9 Results

9.1 Relaxation techniques, stage anxiety and experience in bio-feedback tasks

Subjects were asked to rate their general level of stage anxiety on a four-point scale; the results show a higher level on average in musicians (1.82 ± 1.38) than in the control group (1.17 ± 1.65). However, the difference was not significant ($T(1/33) = -1.272, p = .212$). Of the 9 subjects who stated that they would "often" or "occasionally" experience stage anxiety, only two subjects (22.2%) used any form of relaxation technique to ease that anxiety. See p. 204 in the Appendix for a detailed list of subjects' remarks regarding their performance anxiety.

Of the 17 subject in the musician group, 7 (41.2 %) did not use any relaxation technique to reduce stage anxiety. Among the 18 controls, 12 did not use any of the four relaxation techniques described in the questionnaire (Autogenic training, Eutony,[214] Muscle relaxation, and Yoga). However, two of them stated "bicycling" under "another" relaxation technique. Alternative relaxation techniques described under "another" were: *stretching* and *TENS*[215] (1 subject), *jogging* (1 subject), *Alexander Technique* (2 subjects), *Reiki* (1 subject), *Tai Chi* (1 subject), and *bicycling* (2 subjects, one of whom also entered *swimming*). In total, twenty per cent of subjects said they had previous experience with bio-feedback

9.2 Musical preference and listening profile

In the questionnaire that accompanied the experiment,[216] the subjects were asked to specify their musical preferences on a four-point scale ("In my spare time, I listen to this music (3) *often*, (2) *occasionally*, (1) *rarely*, (0) *never*"). Results show that most musicians preferred to listen to

[214]The concept of Eutony was developed by Gerda Alexander, and is not to be confused with the 'Alexander Technique' (after Frederick Matthias Alexander); see Jain et al. (2004) for further details.

[215]TENS: *transcutaneous electrical nerve stimulation*. Simkin and Bolding (2004) undertook a literature search of articles relating to the effectiveness of non-pharmacologic methods used to relieve pain. All the methods studied "had evidence of widespread satisfaction among a majority of users". They rate the effects of a TENS intervention as "promising" and state that it requires further study.

[216]See (Renner, 2001, pp. 38 f.) for a similar questionnaire, some of was used here.

classical music in their spare time, whereas the control group overall preferred to listen to *rock/pop* music (see Figure 29). Otherwise, musical preferences were similar in both groups, and covered a spectrum of musical styles.

Of the 17 musicians, 11 often, 5 occasionally, and 1 rarely listened to classical music, whereas of the 18 control group members, 4 listened to it often, 8 occasionally, 4 rarely and 2 never. That means that almost all tested musicians (94.1 %) "often" or "occasionally" listen to classical music in their spare time, while only two thirds of the control group listen to it (see Figure 28).

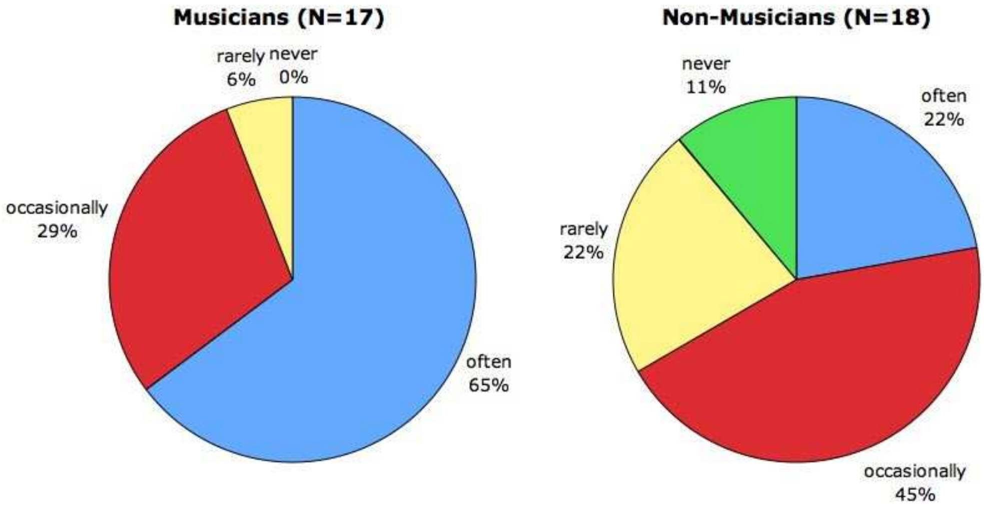

Figure 28: Listening to classical music.
Subjects in the two groups differ in their listening preference. Classical music is "often" or "occasionally" listened to by 94.1 % of the musicians, whereas it is listened to by only two thirds of the control group.

Compared with the controls, the self-estimated familiarity with the musical style ("Sind Sie mit dieser Musikrichtung vertraut?") was significantly higher in the musician group (5.00 versus 3.28 on average on a scale from 0 to 6; $T(1/33) = -3.506, p < 0.01$). 9 out of 17 musicians identified the piece as written by Ludwig van Beethoven ("Eine Vermutung, welcher Komponist das Stück geschrieben hat?"), whereas 4 out of 18 subjects in the control group did. Other attributions were: Wolfgang Amadeus Mozart (2), Frederyk Chopin or Franz Schubert (by the musicians); Wolfgang Amadeus Mozart (3), Johann Sebastian Bach (2), Joseph Haydn (2), Peter Tschaikowsky, Edward Grieg, Leonard Bernstein or Robert Schumann (by the controls).

Relaxation technique	Musicians	Control group	Total
Autogenic training	6	5	11
Eutony	0	0	0
Muscle relaxation	5	0	5
Yoga	5	3	8
other	3	4	7

Table 7: Relaxation techniques applied by subjects

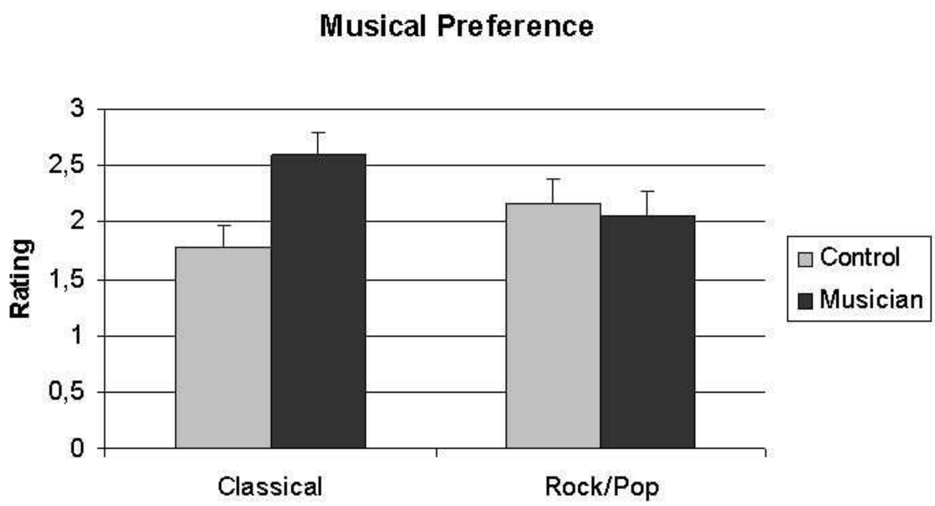

Figure 29: Music preferences.
According to questionnaire 1, musicians and controls differ significantly in how much classical music they hear ($F(1/33) = 8.927, p < 0.01$). Musicians listen to classical music more than to rock/pop; however, the controls listen to rock/pop more than to classical music; the interaction effect (group$*$musical style) is significant ($F(1/33) = 5.231, p < 0.05$).

Group effect in question...	Level of significance
“Kannten Sie das Stück?”	$p < 0.05$
“Sind Sie mit dieser Musik vertraut?”	$p < 0.01$
“Haben Sie das Stück intensiv erlebt?”	$p < 0.05$

Table 8: Ratings with significant group differences

To test the consistency of the answers over different questionnaires, a set of correlation analyses (Spearman-Rho) was applied. The answers proved to reliably map the subjects preferences.[217] The stated listening preference of “classical music” (Questionnaire 1) and the “familiarity with the listening sample” (Questionnaire 2) were significantly correlated ($r = .664, p < 0.01$), as were the stated listening preference of “classical music” and the knowledge of the (classical) musical sample used in the experiment (“Kannten Sie das Stück?”, $r = .507, p < 0.01$), and the two answers regarding familiarity and knowledge of the musical sample ($r = .668, p < 0.01$).

Perhaps not surprisingly, according to the subjects’ self-ratings, musicians were significantly more familiar with the musical sample than the controls. On a 7-point Likert scale (0-6),[218] musicians rated their familiarity with the piece at 2.88 on average, whereas controls rated it at 1.33 ($T(1/33) = -2.242, p < 0.05$).

There was no significant correlation between the subjects’ self-ratings in Questionnaire 2 regarding intense experience (“Haben Sie das Stück intensiv erlebt?”) and familiarity (“Kannten Sie das Stück?”); because, inter alia, many controls rated their listening experience as “intense” although they did not know the musical piece. However, there were a number of significant differences in ratings between the two groups, as shown on p. 93.

9.3 Results of the Affective Communication Test

To further investigate non-verbal expressiveness in the study and the control group, the German version of the *Affective Communication Test*,

[217]For an analysis of musical preferences, see p. 205 in the Appendix.
[218]All questionnaires are listed in the Appendix on pp. 195ff.

"FEX" (Traue (1998)) was used.[219] Regarding the results of the FEX,[220] there were no differences between musicians and controls.[221]

There was, however, a significant correlation ($r = .513, p < 0.01$) between the FEX results and the self-rating in Questionnaire 2 on how intensely the music example had been experienced ("Haben Sie das Stück intensiv erlebt?"). The higher the subject scored in the FEX, the more intensely the music had been experienced (see Figure 30).

Self-ratings of how much stage anxiety or psychological stress with exams ("Prüfungsangst") the subject suffered were not significantly correlated with the FEX ratings ($r = -.124, p = 0.479$). The subjects who scored highest in the FEX suffered only "sometimes" from these anxieties.

9.4 Results of the Stimulus Reaction Test

The Stimulus Reaction Test insured that the experimental apparatus would measure data accordingly. It also gave the subject the opportunity to get acquainted with the physiological measurement procedures before the actual experiments took place. Although this test was incorporated partly for calibration reasons, the data were analysed for potential heart rate, breathing rate, and skin conductance behaviour, and also abnormalities and arrhythmias. In the end, however, the test revealed no abnormally high or low state of arousal in any of the subjects. A comparison with the heart rates at rest (recorded at the beginning of Experiment 1, and before Experiment 2) showed that average heart rates were higher during the Stimulus Reaction Test, alluding to the (small) psycho-physiological strain or work-load of the test. During the course of experiments, controls showed almost no further deceleration of heart rates, where musicians' heart rates slightly decelerated (see the table on p. 96).

The Stimulus Reaction Test did not inflict a physiological stress on the subject (which would show as a highly negative gradient of RR intervals, as the subject's heart rate would increase over time). However, there are some subjects whose heart rate shows a decrease over the course

[219] The FEX is listed in the Appendix on pp. 196f. It proved to reliably measure the subjects' expressiveness or *charisma* in a longitudinal test; see p. 132.

[220] Subjects scored a minimum 44, a maximum 101, and 71.06 ± 13.75 on average.

[221] For a detailed discussion of socio-cultural issues and the overall reliability of the FEX, see p. 132.

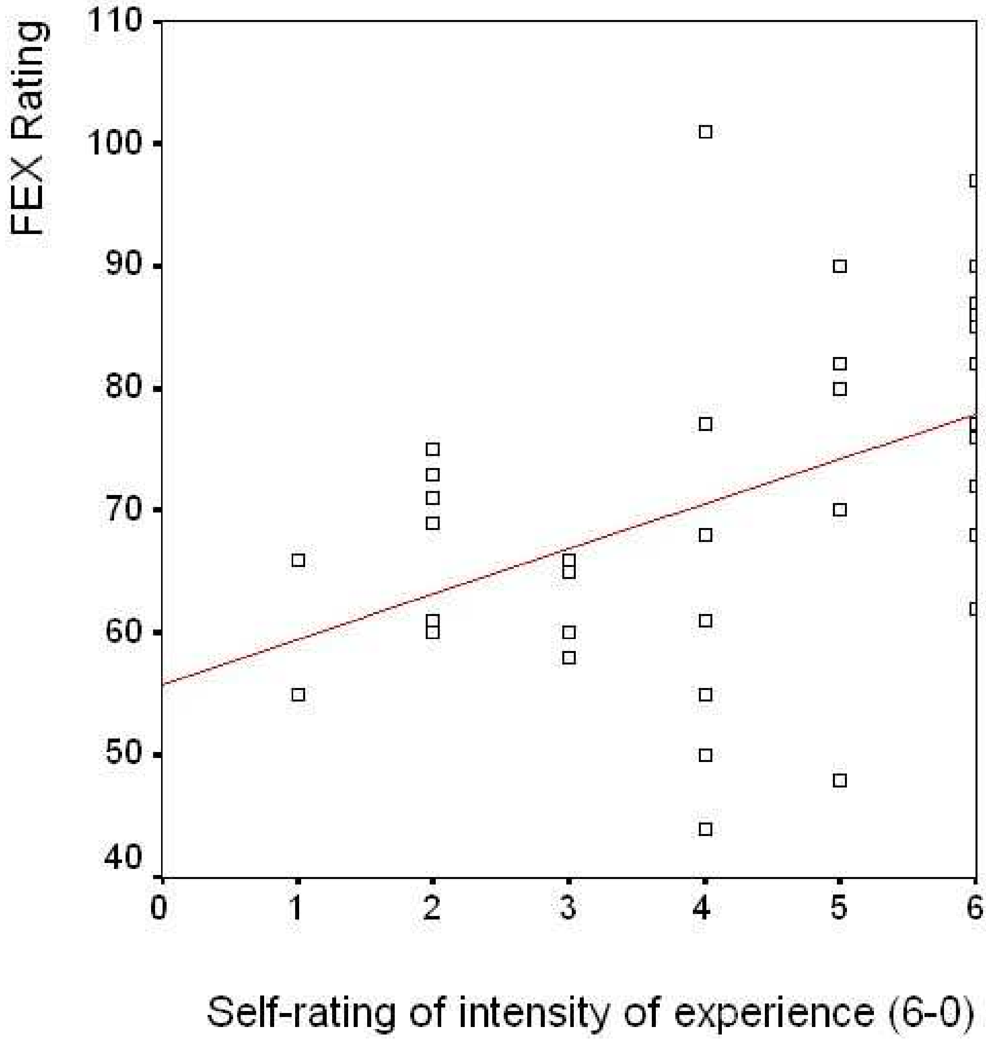

Figure 30: Self-rating of intense experience correlated with the FEX
There was a significant correlation ($p < 0.01$) between the FEX results and the self-rating of how intensely the music example had been experienced ("Haben Sie das Stück intensiv erlebt?"). The higher the subject scored in the FEX, the more intensely the music had been experienced.

	SR Test	Exp. 1, Phase 1	Target frequency for Exp. 2
musician	85.32	75.60	73.47
control	80.53	70.58	69.33
total	82.86	73.02	71.34

Table 9: Heart rates of subjects (bpm) throughout the experiment

of the experiment, alluding to a high arousal state at the beginning of the experiment (see Figure 31 and Figure 32). For a list of the recorded values, see page 105.

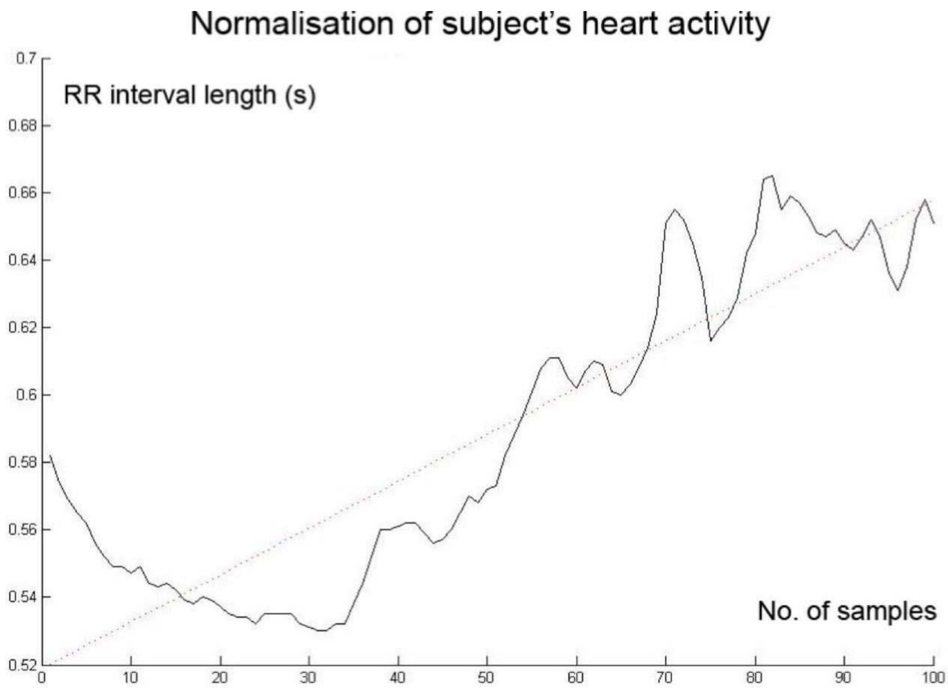

Figure 31: Normalisation of heart activity during the Stimulus Reaction Test, Subject No. 113

Some subjects showed a decrease of heart rate after a short initial increase (Example: Subject No. 113).

Average heart rates at the beginning of Experiment 1 (phase 1, heart rate at rest) and the target frequency chosen for Experiment 2, which was determined from the heart rate at rest between the two experiments, did not vary greatly ($F(1/33) = 3.496, p = 0.07$). After the initial normalisation phase, there was no long-term heart rate trend found that might have influenced the test results to a noticeable extent.

Regarding electrodermal activity, the subjects showed heteroge-

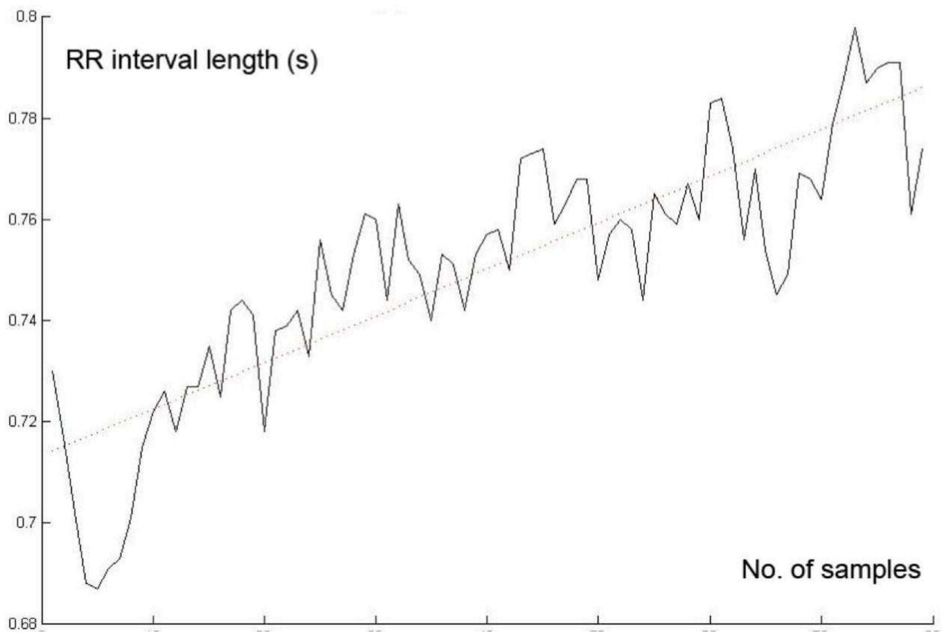

Figure 32: Normalisation of heart activity during the Stimulus Reaction Test, Subject No. 110

Some subjects showed a decrease of heart rate almost immediately after the start of the test (Example: Subject No. 110).

neous behavioral patterns over the course of time (compare Figure 33 and Figure 34). The assumption that subjects' skin conductance would show a reproducible pattern of an 'activation phase' (with their skin conductance ascending) and a 'habituation phase' (with their skin conductance descending again) could not be confirmed. Instead, different subjects showed different skin conductance characteristics depending on their state and development of arousal. There was no distinguishable difference in potential activation or habituation patterns between the groups. However, the Stimulus Reaction Test did serve its purpose of calibrating and testing the measurement apparatus in all cases.

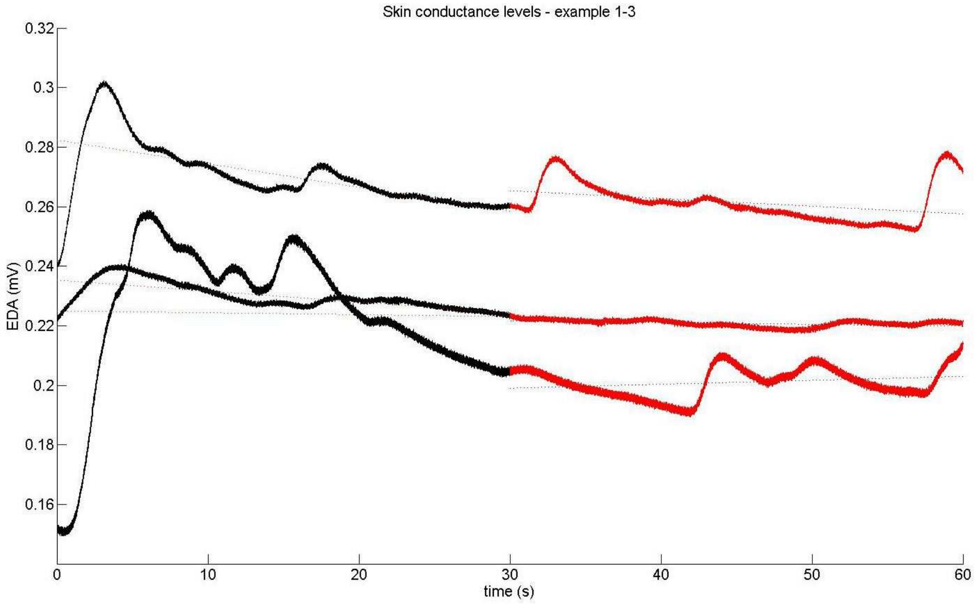

Figure 33: Heterogeneous skin conductance characteristics - Example 1-3
The subjects showed heterogeneous behavioral patterns that were only analysed typologically, and not processed statistically. The graph shows three examples of descending skin conductance over the course of the experiment, with a short activation phase at the beginning. The assumed 'activation phase' (the first 30 seconds) and the assumed 'habituation phase' are depicted in black and grey colour. However, a reproducible pattern could not be confirmed.

Regarding reaction times and learning, the analysis showed that 77.14 % of the subjects showed a performance that improved over time, resulting in a negative gradient of reaction times. There were no interrelations between average heart rate and overall learning effect in the Stimulus Reaction Test. Subjects with both very slow and very fast

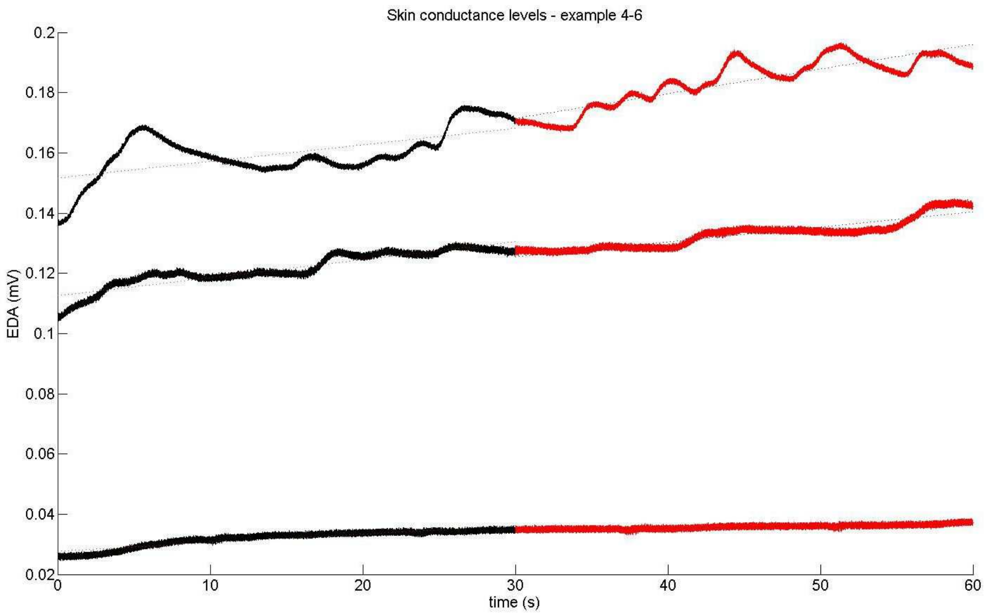

Figure 34: Heterogeneous skin conductance characteristics - Example 4-6
The subjects showed heterogeneous behavioral patterns that were only analysed typologically, and not processed statistically. The graph shows three examples of ascending skin conductance over the course of the experiment.

average heart rates showed improvements of reaction times during the test.[222]

9.4.1 Age

Age and reaction time were significantly correlated ($r = .463, p < 0.01$, Pearson); the older the subjects were, the slower they performed the Stimulus Reaction Test (see Figure 35). Average reaction times were similar in both groups (0.76 *s* musicians; 0.74 *s* controls). Subjects with a very high average heart rate showed no significant deceleration; and subjects with a very slow average heart rate did not show an acceleration. These results were not as expected with regard to arousal and attentiveness.

[222] Analysis of the data of the pilot study showed that reaction times were delayed after a number had to be hit twice in the Stimulus Reaction Test. To maximise the subjects' attentiveness, it was decided not to simplify the test by eliminating consecutive doubles. Instead, the subjects were told to be aware that numbers might show up twice.

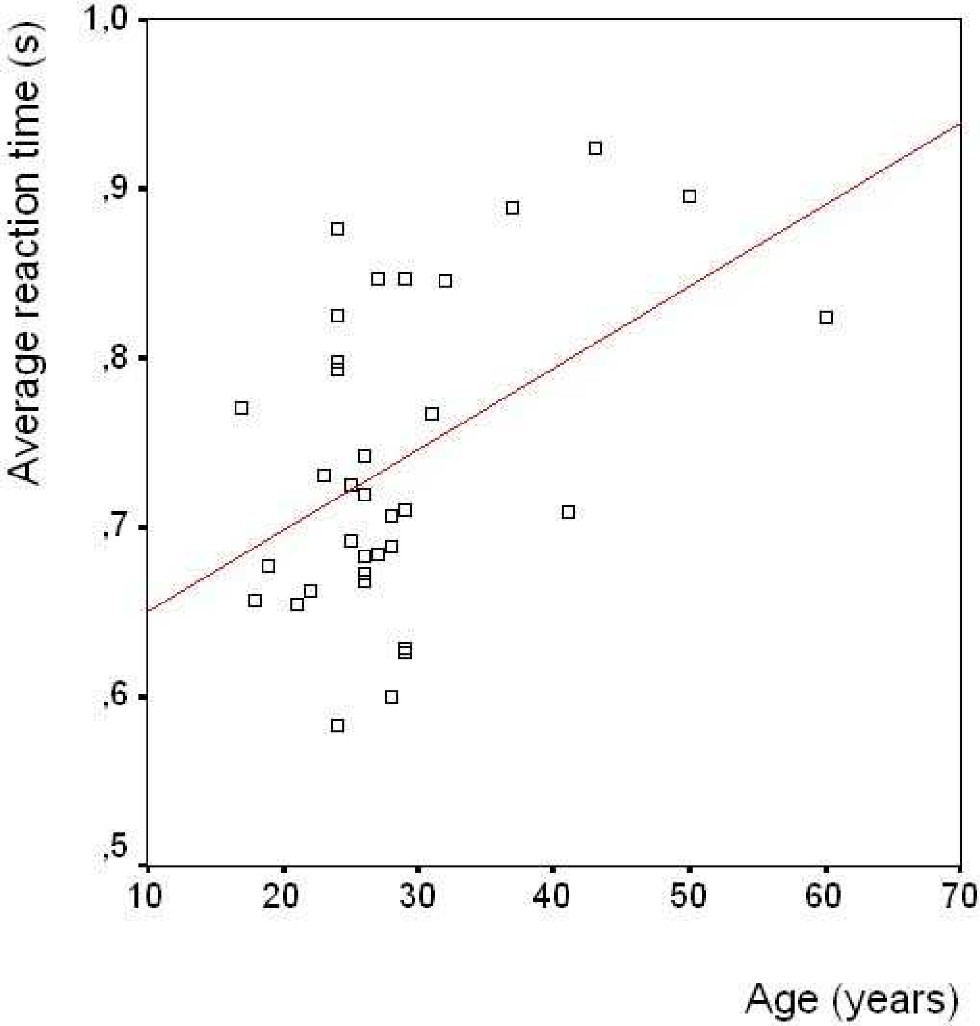

Figure 35: Age correlated with reaction time
Age and reaction time were significantly correlated ($r = .463, p < 0.01$, Pearson); the older the subjects were, the slower they performed the Stimulus Reaction Test.

There was a significant non-parametrical correlation of age and familiarity. The older the subjects were, the more likely it was that they knew the musical sample ($r = .396, p < 0.05$).[223]

9.4.2 Heart activity and pulse-respiration ratios

The pulse-respiration ratios of the subjects varied mainly between 3:1 and 5:1. With 3.93:1 and 3.97:1, respectively, the average frequency ratios of pulse and respiration were almost identical for both groups. There was no significant correlation between average heart rate and reaction time, as one might have expected. The average breathing rates did not correlate with the average heart rates of the subjects in the 1-minute Stimulus Reaction Test.[224]

9.4.3 Stage anxiety correlated with average heart rate

The subjects' self-rated severeness of stage anxiety ("Leiden Sie unter Lampenfieber?", to be rated on a scale from 0-5) was significantly correlated with average heart rate ($r = .5, p < 0.01$) and average respiration rate ($r = .482, p < 0.01$) during the Stimulus Reaction Test (see Figure 36 and Figure 37). The higher the subjects had self-rated the effect of stage anxiety, the higher were their average heart and respiration rates.

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[223] According to their answer in Questionnaire 2, "Kannten Sie das Stück?".

[224] The variety of respiration characteristics during this short test, from almost chaotic to very regular, is indicated by two examples on page 78. It was decided not to pursue the quantitative analysis of respiration further.

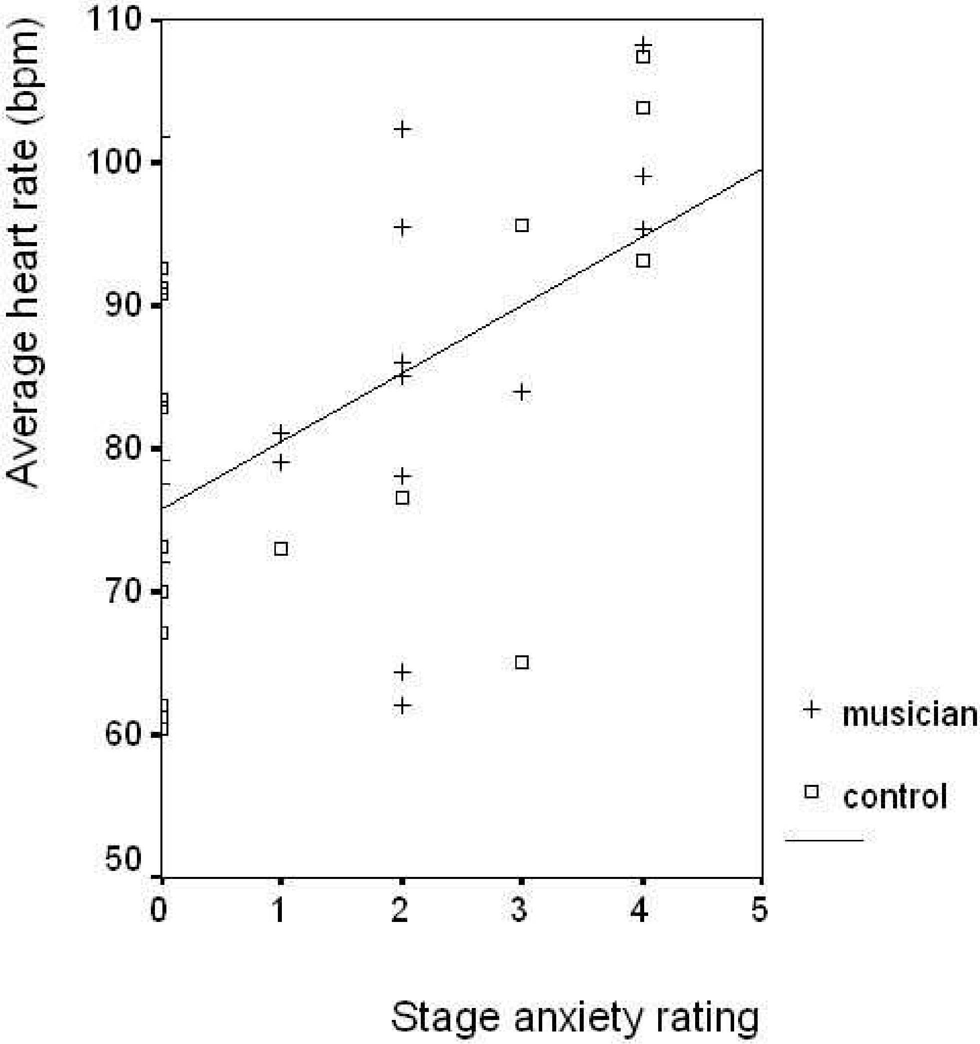

Figure 36: Stage anxiety score correlating with average heart rate
The subjects' self-rated severeness of stage anxiety correlated significantly ($r = .5, p < 0.01$) with the average heart rate during the Stimulus Reaction Test.

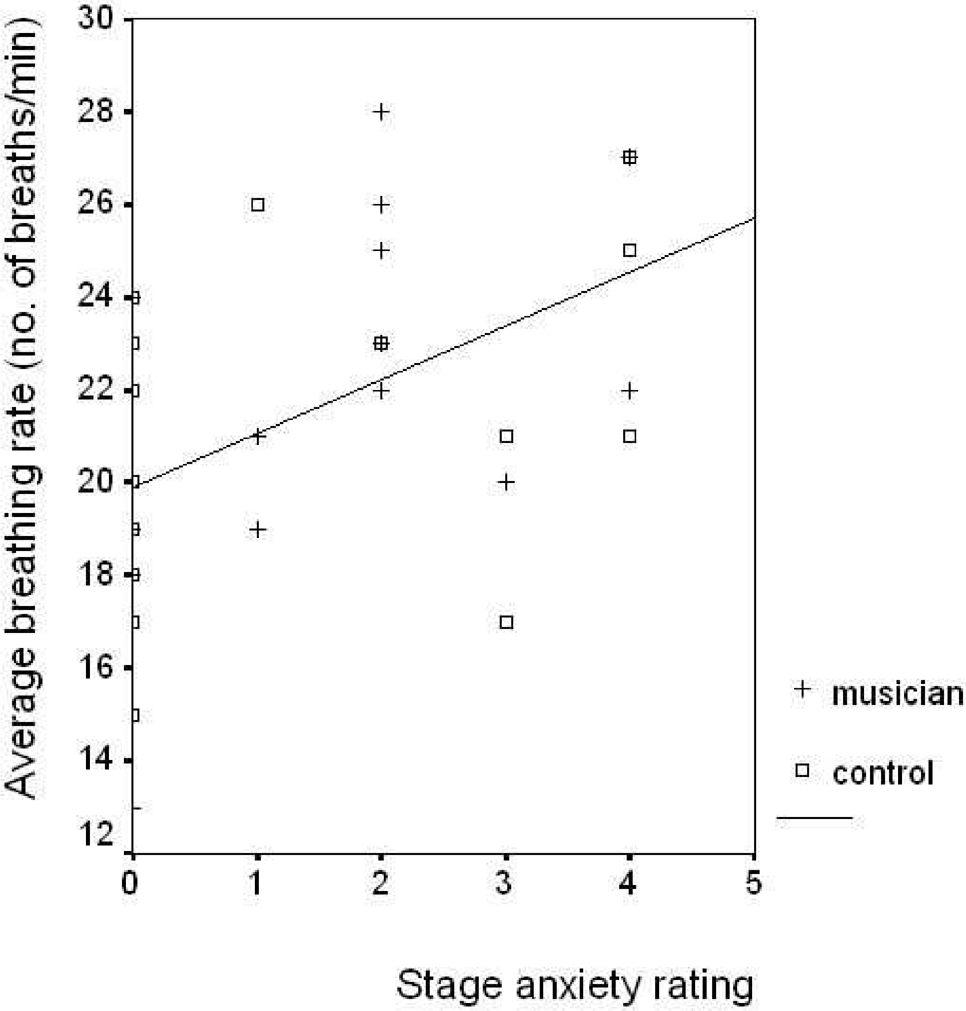

Figure 37: Stage anxiety score correlating with average respiration rate
The subjects' self-rated severeness of stage anxiety correlated significantly ($r = .482, p < 0.01$) with the average respiration rate during the Stimulus Reaction Test.

9.5 Results of Experiment 1

[225]'X' = music, sample length: 300 s ; '–' = no music, sample length: 300 s ; 's' = slow music, sample length: 150 s ; 'f' = fast music, sample length: 150 s

	Music[225]	PRR	N	min	max	mean	sd
No. of breaths	–	–	35	30.00	101.00	63.40	18.73
No. of breaths	s	–	35	18.00	59.00	38.43	9.91
No. of breaths	f	–	35	18.00	59.00	42.49	9.62
average RR (brpm)	–	–	35	6.00	20.20	12.68	3.75
average RR (brpm)	s	–	35	7.20	23.60	15.37	3.96
average RR (brpm)	f	–	35	7.20	23.60	16.99	3.85
average RR (brpm)	X	–	35	36.00	118.00	80.91	18.91
No. of breaths	–	6:1	35	43.00	80.00	62.66	9.68
No. of breaths	s	6:1	35	21.00	45.00	32.00	5.39
No. of breaths	f	6:1	35	22.00	46.00	32.86	5.24
No. of breaths	X	6:1	35	43.00	85.00	64.86	10.17
No. of breaths	–	10:1	35	25.00	52.00	37.74	6.29
No. of breaths	s	10:1	35	12.00	31.00	18.94	4.00
No. of breaths	f	10:1	35	13.00	27.00	19.40	2.95
No. of breaths	X	10:1	35	25.00	54.00	38.34	6.43
average HR (bpm)	–	–	35	47.80	93.81	73.02	11.99
average HR (bpm)	s	–	35	48.05	94.81	74.13	12.28
average HR (bpm)	f	–	35	47.28	102.01	74.73	12.87
average HR (bpm)	X	–	35	47.66	98.01	74.43	12.49
average HR (bpm)	–	6:1	35	52.00	108.67	77.28	12.77
average HR (bpm)	s	6:1	35	53.61	112.56	79.33	13.63
average HR (bpm)	f	6:1	35	53.46	117.10	78.86	13.36
average HR (bpm)	X	6:1	35	53.53	114.83	79.10	13.40
average HR (bpm)	–	10:1	35	51.17	96.66	74.67	11.27
average HR (bpm)	s	10:1	35	51.36	97.49	75.69	11.37
average HR (bpm)	f	10:1	35	52.01	104.62	76.47	11.59
average HR (bpm)	X	10:1	35	51.68	101.06	76.08	11.42

Table 10: Analysed parameters in Experiment 1 (table a - all subjects)

	Music[226]	PRR	N	min	max	mean	sd
No. of breaths	–	–	17	30.00	101.00	60.94	19.09
No. of breaths	s	–	17	28.00	59.00	41.06	8.66
No. of breaths	f	–	17	36.00	59.00	47.06	6.81
average RR (brpm)	–	–	17	6.00	20.20	12.19	3.82
average RR (brpm)	s	–	17	11.20	23.60	16.42	3.47
average RR (brpm)	f	–	17	14.40	23.60	18.82	2.73
average RR (brpm)	X	–	17	64.00	118.00	88.12	14.50
No. of breaths	–	6:1	17	48.00	80.00	64.00	8.99
No. of breaths	s	6:1	17	25.00	45.00	32.47	5.55
No. of breaths	f	6:1	17	26.00	46.00	32.76	4.72
No. of breaths	X	6:1	17	51.00	85.00	65.24	9.65
No. of breaths	–	10:1	17	30.00	50.00	38.82	5.07
No. of breaths	s	10:1	17	12.00	31.00	19.94	4.45
No. of breaths	f	10:1	17	17.00	24.00	19.88	2.26
No. of breaths	X	10:1	17	29.00	54.00	39.82	5.98
average HR (bpm)	–	–	17	52.60	93.81	75.60	10.67
average HR (bpm)	s	–	17	53.61	94.81	76.93	11.09
average HR (bpm)	f	–	17	53.21	102.01	78.10	11.98
average HR (bpm)	X	–	17	53.41	98.01	77.51	11.42
average HR (bpm)	–	6:1	17	55.92	108.67	79.07	12.52
average HR (bpm)	s	6:1	17	62.02	112.56	82.50	14.33
average HR (bpm)	f	6:1	17	60.43	117.10	82.17	13.48
average HR (bpm)	X	6:1	17	61.22	114.83	82.34	13.77
average HR (bpm)	–	10:1	17	63.06	96.66	77.69	9.31
average HR (bpm)	s	10:1	17	64.30	97.49	78.63	10.14
average HR (bpm)	f	10:1	17	63.35	104.62	79.45	10.09
average HR (bpm)	X	10:1	17	64.88	101.06	79.04	10.01

Table 11: Analysed parameters in Experiment 1 (table a - musicians)

	Music[227]	PRR	N	min	max	mean	sd
No. of breaths	–	–	18	36.00	100.00	65.72	18.62
No. of breaths	s	–	18	18.00	53.00	35.94	10.60
No. of breaths	f	–	18	18.00	50.00	38.17	10.04
average RR (brpm)	–	–	18	7.20	20.00	13.14	3.72
average RR (brpm)	s	–	18	7.20	21.20	14.38	4.24
average RR (brpm)	f	–	18	7.20	20.00	15.27	4.02
average RR (brpm)	X	–	18	36.00	103.00	74.11	20.40
No. of breaths	–	6:1	18	43.00	76.00	61.39	10.39
No. of breaths	s	6:1	18	21.00	39.00	31.56	5.35
No. of breaths	f	6:1	18	22.00	41.00	32.94	5.82
No. of breaths	X	6:1	18	43.00	80.00	64.50	10.90
No. of breaths	–	10:1	18	25.00	52.00	36.72	7.26
No. of breaths	s	10:1	18	12.00	25.00	18.00	3.38
No. of breaths	f	10:1	18	13.00	27.00	18.94	3.49
No. of breaths	X	10:1	18	25.00	52.00	36.94	6.70
average HR (bpm)	–	–	18	47.80	91.07	70.58	12.93
average HR (bpm)	s	–	18	48.05	90.53	71.49	13.06
average HR (bpm)	f	–	18	47.28	90.32	71.56	13.20
average HR (bpm)	X	–	18	47.66	90.18	71.52	13.08
average HR (bpm)	–	6:1	18	52.00	94.34	75.58	13.12
average HR (bpm)	s	6:1	18	53.61	94.72	76.33	12.59
average HR (bpm)	f	6:1	18	53.46	97.77	75.74	12.84
average HR (bpm)	X	6:1	18	53.53	96.25	76.03	12.67
average HR (bpm)	–	10:1	18	51.17	93.58	71.83	12.43
average HR (bpm)	s	10:1	18	51.36	95.73	72.92	12.04
average HR (bpm)	f	10:1	18	52.01	96.97	73.65	12.46
average HR (bpm)	X	10:1	18	51.68	96.35	73.28	12.22

Table 12: Analysed parameters in Experiment 1 (table a - controls)

	Music	PRR	N	min	max	mean	sd
No. of R waves	–	–	35	240.00	470.00	365.60	60.02
No. of R waves	s	–	35	121.00	238.00	185.69	30.73
No. of R waves	f	–	35	119.00	256.00	187.14	32.21
No. of R waves	X	–	35	240.00	492.00	372.83	62.54
No. of R waves	–	6:1	35	261.00	543.00	386.26	63.75
No. of R waves	s	6:1	35	135.00	281.00	198.31	33.78
No. of R waves	f	6:1	35	134.00	292.00	197.14	33.33
No. of R waves	X	6:1	35	269.00	573.00	395.46	66.66
No. of R waves	–	10:1	35	256.00	484.00	373.31	56.43
No. of R waves	s	10:1	35	129.00	244.00	189.46	28.43
No. of R waves	f	10:1	35	131.00	260.00	191.00	28.81
No. of R waves	X	10:1	35	260.00	504.00	380.46	56.98
No. of heartbeats / breath	–	–	35	3.39	15.67	6.31	2.44
No. of heartbeats / breath	s	–	35	3.14	10.33	5.20	1.78
No. of heartbeats / breath	f	–	35	3.02	10.06	4.67	1.57
No. of heartbeats / breath	X	–	35	3.13	10.19	4.90	1.61
No. of heartbeats / breath	–	6:1	35	4.89	7.40	6.17	0.40
No. of heartbeats / breath	s	6:1	35	5.44	8.52	6.22	0.55
No. of heartbeats / breath	f	6:1	35	4.14	7.30	6.02	0.59
No. of heartbeats / breath	X	6:1	35	4.71	7.65	6.11	0.51
No. of heartbeats / breath	–	10:1	35	5.42	11.57	9.99	1.09
No. of heartbeats / breath	s	10:1	35	6.00	15.08	10.21	1.46
No. of heartbeats / breath	f	10:1	35	7.76	11.82	9.90	1.00
No. of heartbeats / breath	X	10:1	35	6.94	12.66	10.01	1.07
Skin conductance (mV)	s	–	35	0.03	0.68	0.21	0.15
Skin conductance (mV)	f	–	35	0.03	0.69	0.22	0.16

Table 13: Analysed parameters in Experiment 1 (table b - all subjects)

	Music	PRR	N	min	max	mean	sd
No. of R waves	–	–	17	264.00	470.00	378.65	53.34
No. of R waves	s	–	17	135.00	238.00	192.71	27.85
No. of R waves	f	–	17	134.00	256.00	195.71	29.97
No. of R waves	X	–	17	269.00	492.00	388.41	57.26
No. of R waves	–	6:1	17	280.00	543.00	395.53	62.50
No. of R waves	s	6:1	17	156.00	281.00	206.35	35.38
No. of R waves	f	6:1	17	151.00	292.00	205.41	33.50
No. of R waves	X	6:1	17	307.00	573.00	411.76	68.24
No. of R waves	–	10:1	17	315.00	484.00	388.53	46.77
No. of R waves	s	10:1	17	161.00	244.00	196.76	25.30
No. of R waves	f	10:1	17	159.00	260.00	198.47	25.04
No. of R waves	X	10:1	17	325.00	504.00	395.24	49.87
No. of heartbeats / breath	–	–	17	3.50	15.67	6.94	2.97
No. of heartbeats / breath	s	–	17	3.14	8.07	4.95	1.50
No. of heartbeats / breath	f	–	17	3.14	5.76	4.23	0.83
No. of heartbeats / breath	X	–	17	3.16	6.70	4.54	1.08
No. of heartbeats / breath	–	6:1	17	4.89	7.40	6.19	0.56
No. of heartbeats / breath	s	6:1	17	5.87	8.52	6.39	0.67
No. of heartbeats / breath	f	6:1	17	5.48	7.30	6.27	0.52
No. of heartbeats / breath	X	6:1	17	5.67	7.65	6.32	0.51
No. of heartbeats / breath	–	10:1	17	7.26	11.57	10.07	1.02
No. of heartbeats / breath	s	10:1	17	6.00	15.08	10.22	2.02
No. of heartbeats / breath	f	10:1	17	8.22	11.82	10.03	1.08
No. of heartbeats / breath	X	10:1	17	6.94	12.66	10.05	1.36
Skin conductance (mV)	s	–	17	0.06	0.53	0.21	0.12
Skin conductance (mV)	f	–	17	0.05	0.69	0.23	0.15

Table 14: Analysed parameters in Experiment 1 (table b - musicians)

	Music	PRR	N	min	max	mean	sd
No. of R waves	–	–	18	240.00	455.00	353.28	64.77
No. of R waves	s	–	18	121.00	227.00	179.06	32.60
No. of R waves	f	–	18	119.00	256.00	187.14	32.21
No. of R waves	X	–	18	240.00	452.00	358.11	65.31
No. of R waves	–	6:1	18	261.00	472.00	377.50	65.45
No. of R waves	s	6:1	18	135.00	237.00	190.72	31.29
No. of R waves	f	6:1	18	134.00	245.00	189.33	32.12
No. of R waves	X	6:1	18	269.00	482.00	380.06	63.16
No. of R waves	–	10:1	18	256.00	467.00	358.94	62.12
No. of R waves	s	10:1	18	129.00	240.00	182.56	30.16
No. of R waves	f	10:1	18	131.00	242.00	183.94	31.01
No. of R waves	X	10:1	18	260.00	482.00	366.50	61.06
No. of heartbeats / breath	–	–	18	3.39	9.79	5.72	1.67
No. of heartbeats / breath	s	–	18	3.24	10.33	5.43	2.03
No. of heartbeats / breath	f	–	18	3.02	10.06	5.09	1.98
No. of heartbeats / breath	X	–	18	3.13	10.19	5.24	1.97
No. of heartbeats / breath	–	6:1	18	5.97	6.47	6.15	0.14
No. of heartbeats / breath	s	6:1	18	5.44	6.89	6.06	0.36
No. of heartbeats / breath	f	6:1	18	4.14	6.45	5.79	0.57
No. of heartbeats / breath	X	6:1	18	4.71	6.66	5.91	0.44
No. of heartbeats / breath	–	10:1	18	5.42	10.94	9.91	1.17
No. of heartbeats / breath	s	10:1	18	8.88	11.38	10.20	0.66
No. of heartbeats / breath	f	10:1	18	7.76	11.46	9.78	0.94
No. of heartbeats / breath	X	10:1	18	8.58	11.42	9.97	0.73
Skin conductance (mV)	s	–	18	0.03	0.68	0.20	0.17
Skin conductance (mV)	f	–	18	0.03	0.69	0.20	0.17

Table 15: Analysed parameters in Experiment 1 (table b - controls)

9.5.1 Music does not alter heart rate when breathing rate is voluntary

When breathing rate was voluntary, listening to the musical sample generally had neither soothing nor stimulating effects on the subjects' heart rates in both groups. The two musical samples had been chosen to maximise potential differences of psycho-physiological arousal, to investigate and compare the effects of these different kinds of music on the heart activity of the subjects. The slow part of the musical sample, the last part of the 2nd movement of Beethoven's Fifth Piano Concerto, was assumed to have a rather soothing or sedating effect on the subjects.[228] The findings of earlier studies[229] could only partly be confirmed: listening to soothing music under three conditions of voluntary breathing and maintaining a pulse-respiration ratio of 6:1 and 10:1, respectively, had no significant effect on subjects' heart rates.[230]

The second, faster part of the musical sample, the beginning of the 3rd movement of Beethoven's Fifth Piano Concerto, was assumed to have a rather stimulating effect on the subjects. The findings of earlier studies[231] [232] [233] could only partly be confirmed: listening to activating music under three conditions of voluntary breathing and maintaining a pulse-respiration ratio of 6:1 and 10:1, respectively, had no significant effect on subjects' heart rates.

Average heart rates at rest,[234] and while listening to slow[235] and fast[236] music were significantly correlated with the self-rated intensity of experience (see Figure 38). The higher the subjects had rated their intensity of experience in questionnaire 2, the higher their average heart rates proved to be in the respective phases of the experiment.

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[228] cf. Bernardi, Porta, and Sleight (2006)
[229] Ellis and Brighouse (1952); Taylor (1973); Davis and Thaut (1989); Bernardi, Porta, and Sleight (2006)
[230] For the recorded values, see pp. 105ff.
[231] Zimny and Weidenfeller (1963)
[232] Landreth and Landreth (1974)
[233] White (2000)
[234] $r = .374, p < 0.05$
[235] $r = .38, p < 0.05$
[236] $r = .41, p < 0.05$

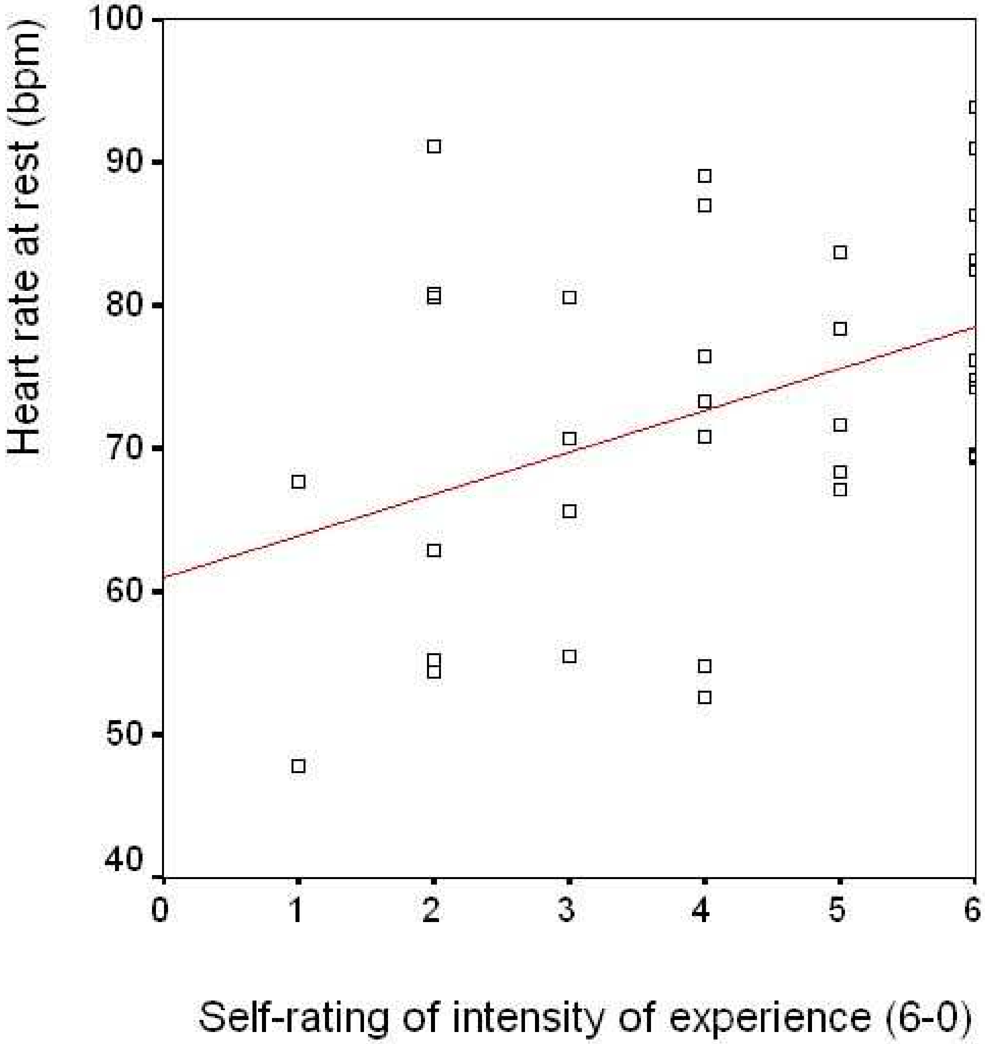

Figure 38: Average heart rate at rest correlated with self-rating of intensity of experience

The higher the subjects had rated their intensity of experience in questionnaire 2, the higher their average heart rate at rest proved to be in phase 1 of Experiment 1.

9.5.2 Music alters respiration rate

The analysis of the respiratory patterns in the first phase of Experiment 1, when no music was played and breathing was voluntary, usually showed a small respiration rate variability with some irregularly deep breaths (see, for example, Figure 39 and Figure 40).

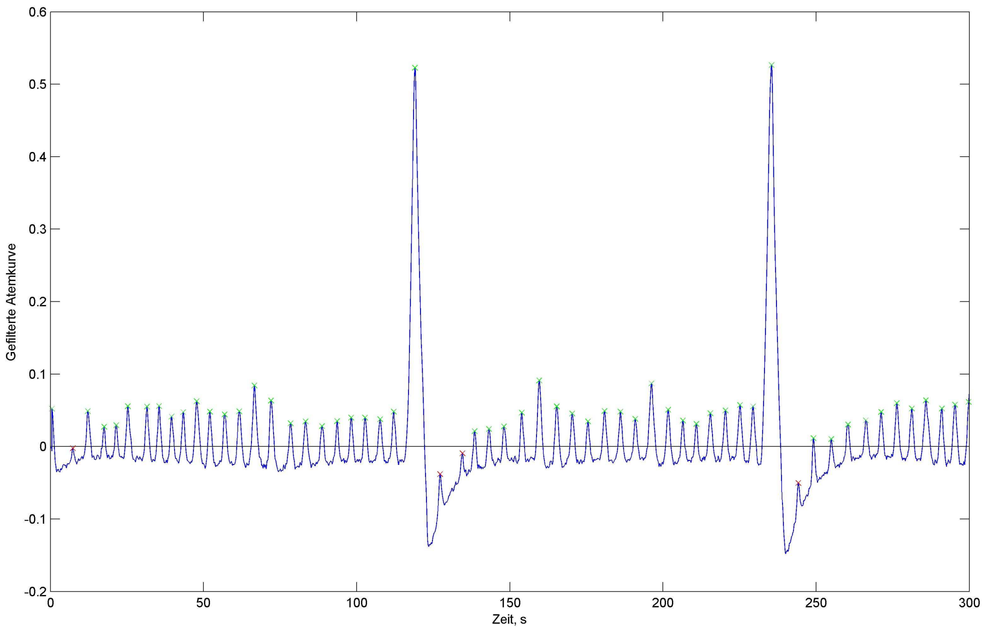

Figure 39: Regular respiration pattern during phase 1 of Experiment 1; Subject No. 121

The analysis of the respiratory patterns in the first phase of Experiment 1, when no music was played and breathing was voluntary, usually showed a small respiration rate variability with some irregularly deep breaths.

When breathing rate was voluntary, listening to music generally had a stimulating effects on the subjects' average respiration rates. In comparison with the no music condition, breathing accelerated when the sample from the slow movement was played, and accelerated even more when the sample from the fast movement was played (see Figure 41). ANOVAs showed significant changes, comparing phases with no music and slow music ($F(1/33) = 47.502, p < 0.001$), phases with no music and fast music ($F(1/33) = 80.748, p < 0.001$), and phases with slow and fast music ($F(1/33) = 28.141, p < 0.001$). In both music conditions, there were also significant differences between groups. Both differences in average respiration rate were higher in musicians, compared to controls

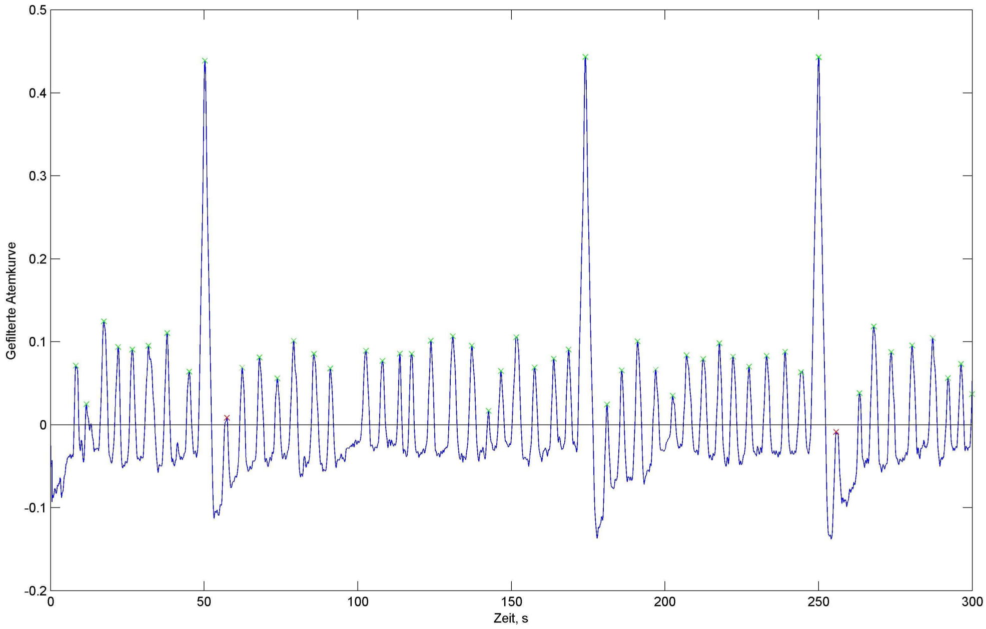

Figure 40: Changes in respiration volume complicate threshold analysis
The irregular breaths complicated the automatic breathing rate analysis, since the threshold was moved, and smaller breaths not detected. They then had to be manually marked.

(comparing respiration rates at rest and during fast music, an ANOVA revealed $F(1/33) = 21.444, p < 0.001$, see Figure 42).

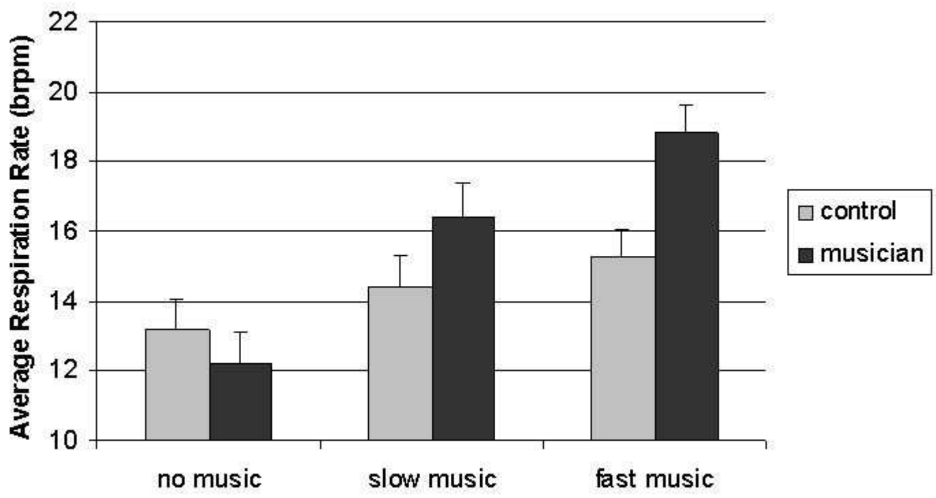

Figure 41: Effect of music on respiration rate
There were significant differences in average respiration rate during phases without music, and phases in which soothing and stimulating music was played.

The fact that subjects breathed faster when they listened to the "fast music" sample compared to the "slow music" sample, suggests that they experienced the faster tempo of the music. Indeed, the average increase in breathing rate (from the "slow music" to the "fast music" phase) was higher if subjects had rated the tempo to be "firstly slow, than fast" in questionnaire 2,[237] compared to subjects who had not experienced any change in tempo (13.8% ± 3.1 vs. 9.3% ± 2.5).[238]

[237] Question 1: "Das Musikbeispiel gliederte sich in zwei größere Abschnitte. Wie würden Sie den Tempoverlauf der Musik beschreiben?"
[238] Just four subjects stated that they did not notice any change of tempo (one of them a musician, three of them belonging to the control group).

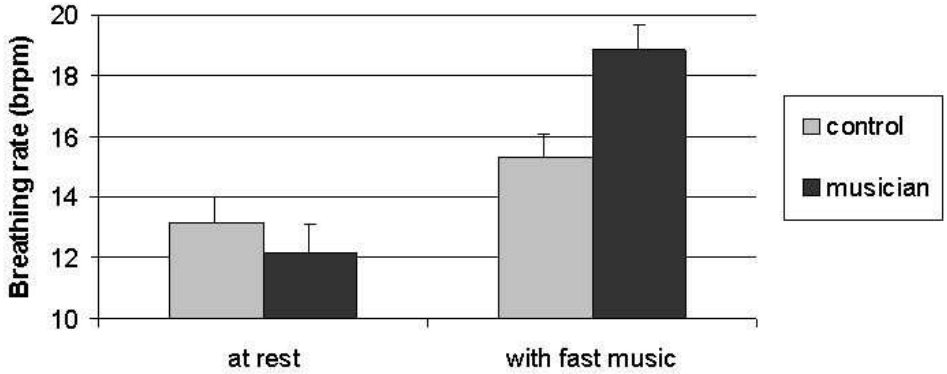

Figure 42: Significant group differences of increase of average breathing rates

There were significant group differences of increase of average respiration rate during phases without music and the phase in which stimulating music was played.

9.5.3 Music does alter electrodermal activity in musicians

Regarding the level of relaxation while listening to the musical sample in Questionnaire 2, musicians rated their own relaxation levels significantly lower than controls on a 7-point Likert scale ($F(1/33) = 11.443, p < 0.01$). According to their answers,[239] both groups appeared to be significantly more relaxed when the slow piece of music was played ($F(1/33) = 34.1, p < 0.001$, see Figure 43). An analysis of the recorded data revealed no significant increases of EDA between different phases.

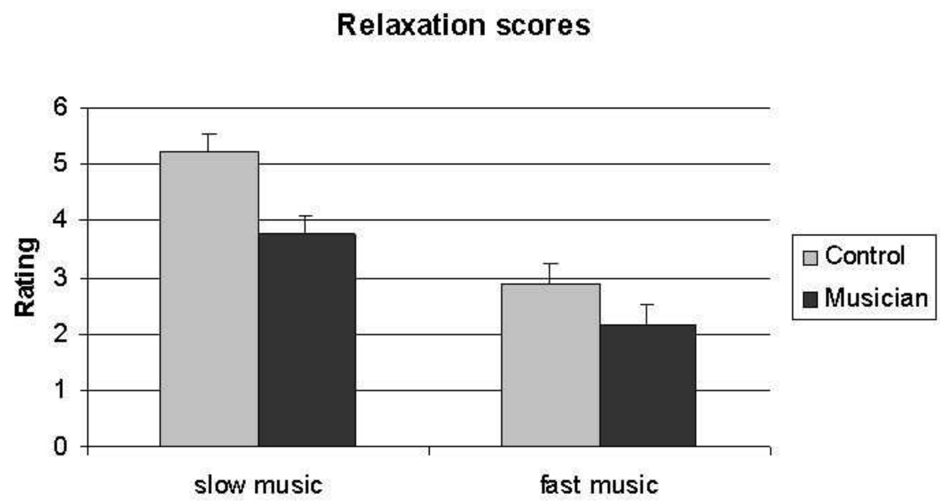

Figure 43: Self-rating: “Relaxation”
In Questionnaire 2, musicians rated their relaxation levels lower than controls on a 7-point Likert scale. However, both groups rated their relaxation level higher when the slow part of the musical sample was being played.

[239] “Konnten Sie sich während des ersten Teils der Musik entspannen?” / “Konnten Sie sich während des zweiten Teils der Musik entspannen?”

9.5.4 Heart rate correlated with intense experience of the music

Average heart rates in phase 1 (voluntary breathing, no music) and phase 2 (voluntary breathing, music) both correlated significantly (phase 1: $r = .374, p < 0.05$; phase 2: $r = .404, p < 0.05$) with the self-rating of the subject in the questionnaire, whether he or she had "intensely experienced the music" (7 point Likert scale). The faster their average heart rate during these phases, the more intense the subjects rated their experience of the music. Average respiration rates were not significantly correlated with these ratings.

9.5.5 Increase of heart rate and electrodermal activity correlated with intensity of experience

For each score from the self-rated level of experience intensity ("Haben Sie das Stück intensiv erlebt?"), the increase of heart rate, breathing rate and skin conductance values during slow music and fast music were analysed. There are significant correlations between intensity scores and increase of heart rate ($r = .343, p < 0.05$) and electrodermal activity ($r = .451, p < 0.01$) values; subjects who rated their level of experience intensity higher, showed a higher increase of heart rate and EDA (see Figure 44). With $r = .177, p = .31$, increase of breathing rate did not correlate significantly with self-rated level of experience.

9.5.6 Cardio-respiratory regulatory patterns and mechanisms

The analyses of average heart rates in the different phases of Experiment 1, with or without musical stimuli and with different pulse-respiration ratios to be maintained, reveal a complex interaction of stresses and demands. Significant correlations and effects are described in the following.

Significantly higher heart rate were observed in phases during which a PRR had to be maintained and music was played, compared with the respective phases without music ($F(1/33) = 7.162, p < 0.01$ for PRRs of $6:1$, $F(1/33) = 14.145, p < 0.01$ for PRRs of $10:1$). With *no* differences in heart rate between phases when subjects were asked to breathe voluntarily, it is assumed that maintaining a PRR while a musical stimulus was playing caused the subjects to experience physiological

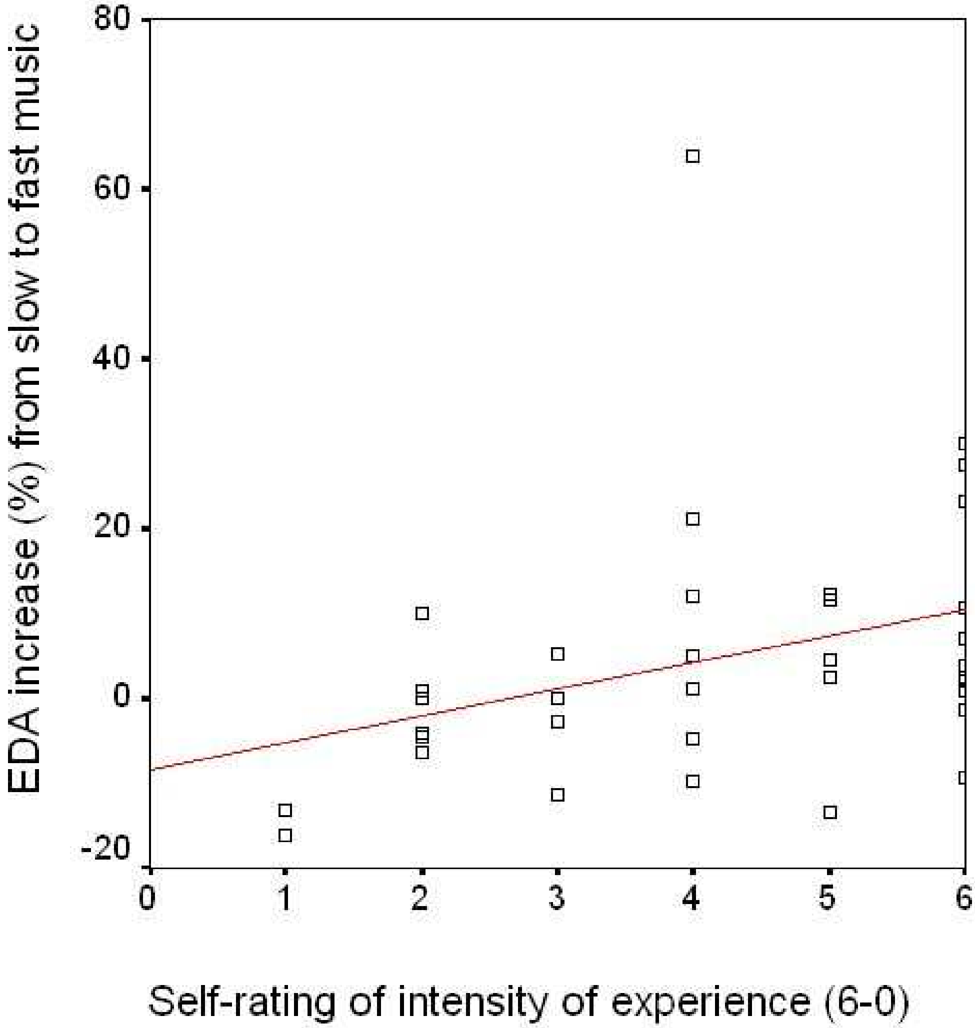

Figure 44: Increase in EDA correlated with intensity of experience
The more intense the subjects rated their experience of the piece, the higher was the increase in electrodermal activity (from slow to fast movement).

stress.[240] This stress was significantly higher at a PRR of 6 : 1, compared to 10 : 1 ($F(1/33) = 13.843, p < 0.01$ in phases without music, $F(1/33) = 18.787, p < 0.001$ in phases with music). Furthermore, with PRRs of 6 : 1, there is a difference between musician and control groups. Musicians' average heart rates increased significantly more than those of controls ($F(1/33) = 6.929, p < 0.05$). No group differences were observed in phases where a PRR of 10 : 1 had to be maintained.

9.5.7 Heart rate variability

Heart rate variability was analysed in phases with voluntary breathing, with and without listening to music, since the average heart rate turned out to be not significantly altered over the course of these phases. For the comparison, the pNN50 value was used.[241]

Generally, a change of pulse-respiration ratio alters RR interval spectral power.[242] However, analyses of spectral power were not pursued.

In both groups, heart beats became more regular when the subjects listened to music. The pNN50 values differ significantly between phases with no music and slow music ($F(1/33) = 6.661, p < 0.05$), and between phases with no music and fast music ($F(1/33) = 13.65, p < 0.01$).[243] Bearing in mind that the two "music conditions" always followed the "no music condition" in the course of the experiment, it cannot be ruled out that the decrease of heart rate variability is simply time-dependent, namely, that subjects' heart rate became more regular over the course of the experiment, regardless of whether or what music was played to them (see Figure 45). Hence, only a group effect would account for an influence of heart rate variability by music. However, the analysis showed

[240] This stress is not due to arousal activated by music, since there is no significant difference between average heart rates in phases with slow and fast music (both with PRRs to be maintained).

[241] It was decided to stick to the standard thresholds recommended by the HRV Task Force. For a discussion of the pNNx threshold, see Mietus, Peng, Henry, Goldsmith, and Goldberger (2002).

[242] Angelone and Coulter (1964) and Brown, Beightol, Koh, and Eckberg (1993) have studied this effect. Furthermore, Bernardi, Wdowczyk-Szulc, Valenti, Castoldi, Passino, Spadacini, and Sleight (2000, p. 1468) concluded that *the slowing of breathing observed with mental stress had the invariable effect of generating an increase in LF components in the RR power spectrum, regardless of the amount of stress involved in the mental task performed.*

[243] A more thorough analysis was not possible because of the shortness of the individual phases. For the same reason, an analysis of the respiration rate variability (RRV) was omitted.

that there were no group effects: $F(1/33) = .309, p = .582$ (no music, slow music); $F(1/33) = 1.958, p = .171$ (slow music, fast music).

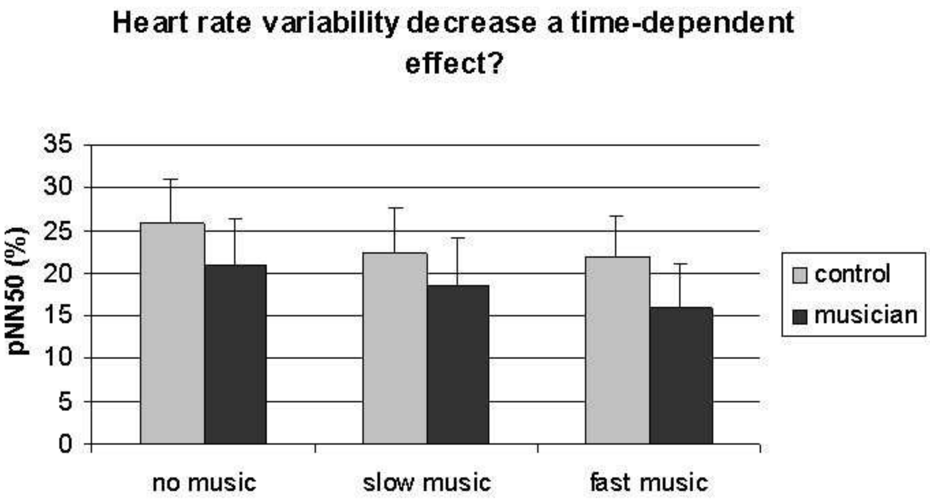

Figure 45: pNN50 decrease a time-dependent effect?

In both groups, heart beats became more regular when the subjects listened to soothing music, and even more regular when they listened to stimulating (and more rhythmical) music. However, it cannot be ruled out that the decrease in HRV is a time-dependent effect.

9.6 Results of Experiment 2

	phase No.	N	min	max	mean	sd
overall target HR		35	46	93	71.34	11.10
average RR (brpm)	2	35	14	68	31.97	11.15
average RR (brpm)	4	35	23	81	44.66	13.40
average RR (brpm)	6	35	10	53	33.14	9.83
average HR (bpm)	1	35	48.20	99.32	72.97	11.83
average HR (bpm)	2	35	48.29	99.32	73.67	11.94
average HR (bpm)	3	35	48.48	105.71	77.47	12.55
average HR (bpm)	4	35	51.25	104.87	77.87	13.26
average HR (bpm)	5	35	50.17	102.52	74.29	12.81
average HR(bpm)	6	35	49.54	99.34	74.03	12.42
difference from target HR	1	35	-4.44	7.92	1.63	3.01
difference from target HR	2	35	-3.91	9.32	2.33	3.00
difference from target HR	3	35	-2.78	12.71	6.12	3.65
difference from target HR	4	35	-5.06	13.41	6.52	4.66
difference from target HR	5	35	-6.41	12.52	2.95	3.97
difference from target HR	6	35	-6.26	9.27	2.69	3.78
Skin conductance (mV)	1	35	0.04	0.72	0.27	0.15
Skin conductance (mV)	2	35	0.04	0.68	0.25	0.15
Skin conductance (mV)	3	35	0.04	0.68	0.27	0.16
Skin conductance (mV)	4	35	0.04	0.68	0.26	0.16
Skin conductance (mV)	5	35	0.04	0.68	0.24	0.16
Skin conductance (mV)	6	35	0.04	0.68	0.23	0.15

Table 16: Analysed parameters in Experiment 2

Subjects were able to increase their heart rate significantly (compared to their heart rate at rest) with the help of bio-feedback; simultaneously, electrodermal activity increased significantly ($F(1/33) = 19.911, p < 0.001$; factor: average EDA (mV) of phase 2 vs. 3). An external acoustic stimulus (a regular metronome click) did not significantly facilitate nor counteract this ability. Since the single phases in Experiment 2 lasted only 150 seconds each, effects of the periodic stimulus on HRV were not considered valid. Other regulatory mechanisms are analysed and discussed in the following.[244]

[244]For a list of the recorded values, see page 122.

	phase No.	N	min	max	mean	sd
overall target HR		17	55	93	73.47	10.05
average RR (brpm)	2	17	14	50	32.29	11.11
average RR (brpm)	4	17	23	80	45.76	12.77
average RR (brpm)	6	17	10	53	34.12	11.98
average HR (bpm)	1	17	54.91	99.32	75.61	10.86
average HR (bpm)	2	17	54.26	98.46	75.92	10.97
average HR (bpm)	3	17	57.14	105.71	79.72	11.77
average HR (bpm)	4	17	56.80	104.87	80.53	12.47
average HR (bpm)	5	17	52.39	100.45	76.07	12.12
average HR(bpm)	6	17	52.83	99.34	75.88	11.89
difference from target HR	1	17	-4.44	6.82	2.14	2.90
difference from target HR	2	17	-3.30	6.39	2.45	2.89
difference from target HR	3	17	-2.78	12.71	6.25	4.21
difference from target HR	4	17	-5.06	13.41	7.06	5.41
difference from target HR	5	17	-6.41	8.95	2.60	4.40
difference from target HR	6	17	-6.26	8.59	2.41	4.11
Skin conductance (mV)	1	17	0.04	0.72	0.24	0.17
Skin conductance (mV)	2	17	0.04	0.68	0.23	0.17
Skin conductance (mV)	3	17	0.04	0.67	0.24	0.17
Skin conductance (mV)	4	17	0.04	0.66	0.24	0.16
Skin conductance (mV)	5	17	0.04	0.65	0.23	0.16
Skin conductance (mV)	6	17	0.04	0.63	0.21	0.15

Table 17: Analysed parameters in Experiment 2 - musicians

	phase No.	N	min	max	mean	sd
overall target HR		18	46	90	69.33	11.93
average RR (brpm)	2	18	17	68	31.67	11.49
average RR (brpm)	4	18	30	81	43.61	14.26
average RR (brpm)	6	18	19	48	32.22	7.50
average HR (bpm)	1	18	48.20	97.92	70.47	12.47
average HR (bpm)	2	18	48.29	99.32	71.55	12.72
average HR (bpm)	3	18	48.48	101.24	75.34	13.22
average HR (bpm)	4	18	51.25	101.93	75.35	13.83
average HR (bpm)	5	18	50.17	102.52	72.61	13.55
average HR(bpm)	6	18	49.54	99.27	72.29	13.00
difference from target HR	1	18	-3.13	7.92	1.14	3.10
difference from target HR	2	18	-3.91	9.32	2.22	3.18
difference from target HR	3	18	1.14	11.55	6.01	3.15
difference from target HR	4	18	-1.47	12.92	6.02	3.91
difference from target HR	5	18	-2.11	12.52	3.28	3.61
difference from target HR	6	18	-3.55	9.27	2.96	3.55
Skin conductance (mV)	1	18	0.07	0.66	0.29	0.14
Skin conductance (mV)	2	18	0.06	0.66	0.27	0.14
Skin conductance (mV)	3	18	0.06	0.68	0.29	0.16
Skin conductance (mV)	4	18	0.05	0.68	0.27	0.16
Skin conductance (mV)	5	18	0.05	0.68	0.26	0.16
Skin conductance (mV)	6	18	0.04	0.68	0.25	0.16

Table 18: Analysed parameters in Experiment 2 - controls

9.6.1 Influencing heart rate with the help of bio-feedback

When subjects were asked whether they *believed* that music (as a general stimulus, regardless of tempo etc.) had any influence on their stress sensation,[245] their answers were significantly correlated with their differences in heart rate, be they positive or negative ($r = .349, p < 0.05$), and also with the absolute values of heart rate differences ($r = .461, p < 0.01$) between phase 1 (with metronome stimulus) and phase 2 of Experiment 2 (without the stimulus). Despite the subjects being asked by the investigator to use only their imagination to increase their heart rate (for example, by imagining a stressful situation, a live performance of a difficult musical piece, or sitting a difficult exam), and *not* to breathe faster to achieve the heart rate increase, almost all subjects showed a significantly increased respiration rate in the respective phases (see Figure 49 on p. 129).[246] A qualitative analysis of the breathing patterns revealed irregularities of frequency and respiration volume that could be explained by a volitional influence, rather than any general increase of sympathetic arousal (see Figure 50).

9.6.2 Influence of a metronome stimulus

Further analyses suggested that the metronome stimulus probably did not alter the subjects' ability to adjust to (comparing phase 1 and 2) or detach from (comparing phase 3 and 4) a certain defined frequency. However, phases with a metronome stimulus always preceded phases without one; therefore, time-dependent effects cannot be ruled out. There were no significant group effects; musicians and controls were both able to actively influence their heart rates with the help of visual and acoustical bio-feedback.

[245] "Glauben Sie, dass die Musik auf Ihre Stressempfinden Einfluss hatte? (egal, ob positiv oder negativ)"

[246] $F(1/33) = 46.646, p < 0.001$.

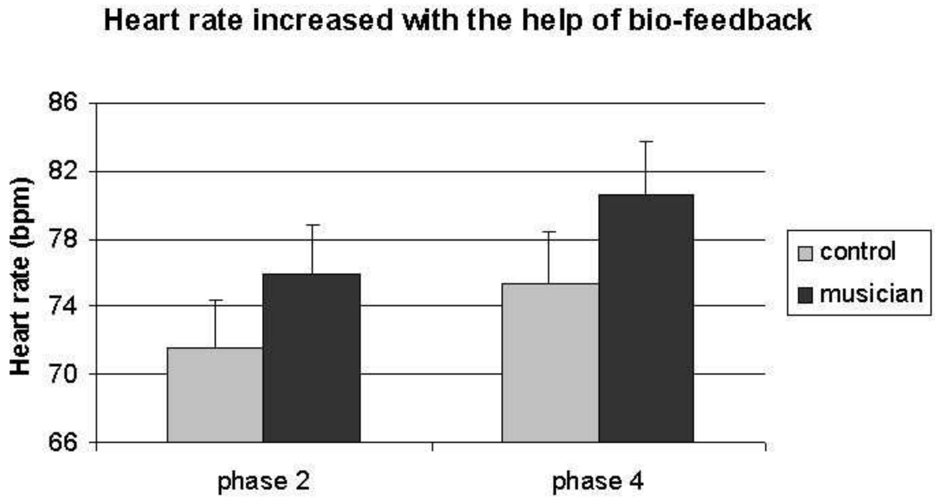

Figure 46: Heart rate actively increased
With the help of bio-feedback, subjects were able to actively increase their heart rate. A comparison of phase 2 and 4 of Experiment 2 shows a significant difference of average heart rates ($F(1/33) = 43.012, p < 0.001$).

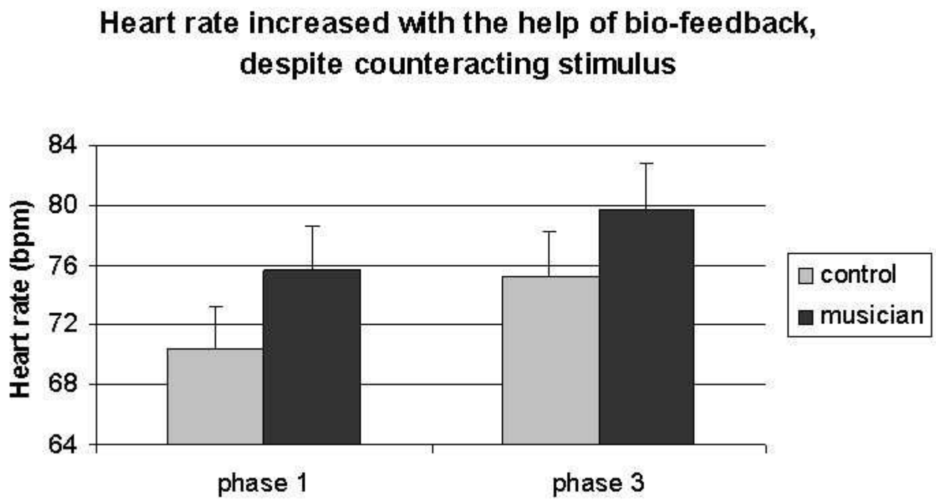

Figure 47: Heart rate actively increased despite a counteracting stimulus
With the help of bio-feedback, subjects were able to actively increase their heart rate despite a counteracting metronome stimulus that was set to the frequency of heart beat at rest. A comparison of phase 1 and 3 of Experiment 2 shows a significant difference of average heart rates ($F(1/33) = 63.616, p < 0.001$).

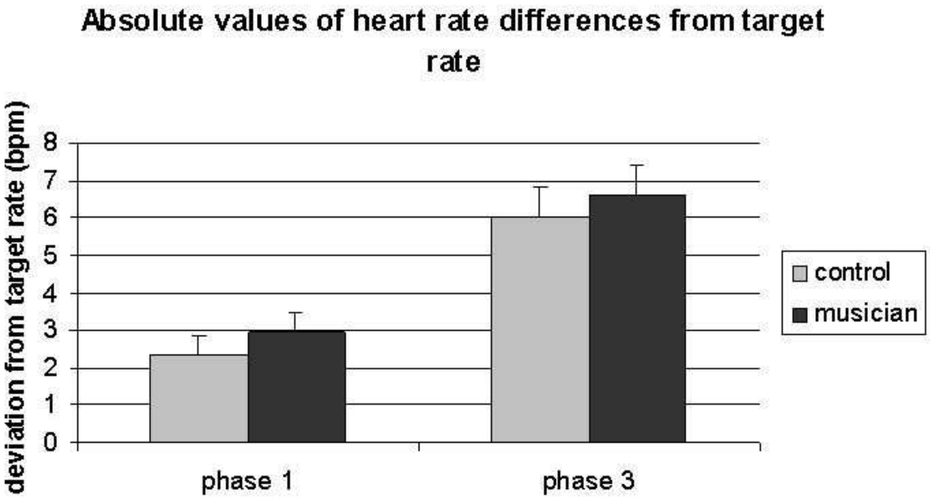

Figure 48: Heart rate differences to target rate
Although the majority of subjects did not manage to increase the rate to the stipulated 10 beats per minute, the increase was still significant. There were no significant group effects.

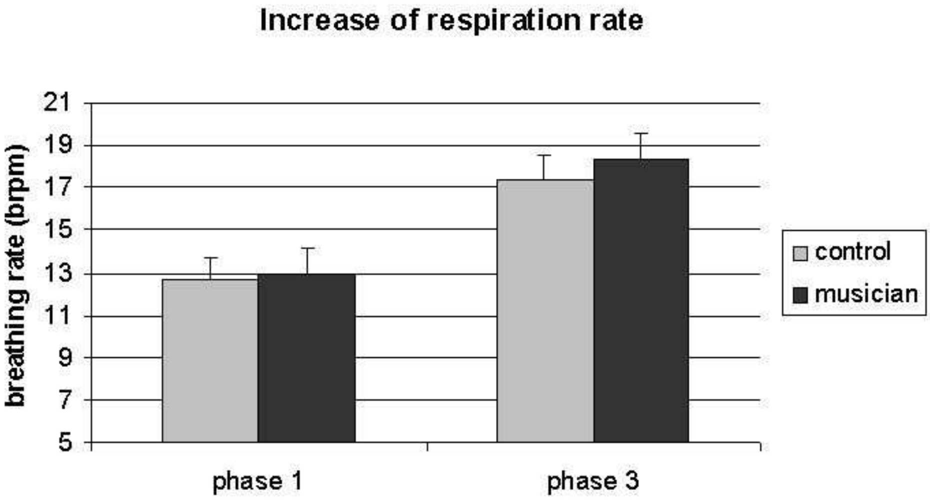

Figure 49: Increase of respiration rate
The subjects were asked to use only their imagination to increase their heart rate; however, almost all subjects showed a significantly increased respiration rate ($F(1/33) = 46.646, p < 0.001$) in the respective phases.

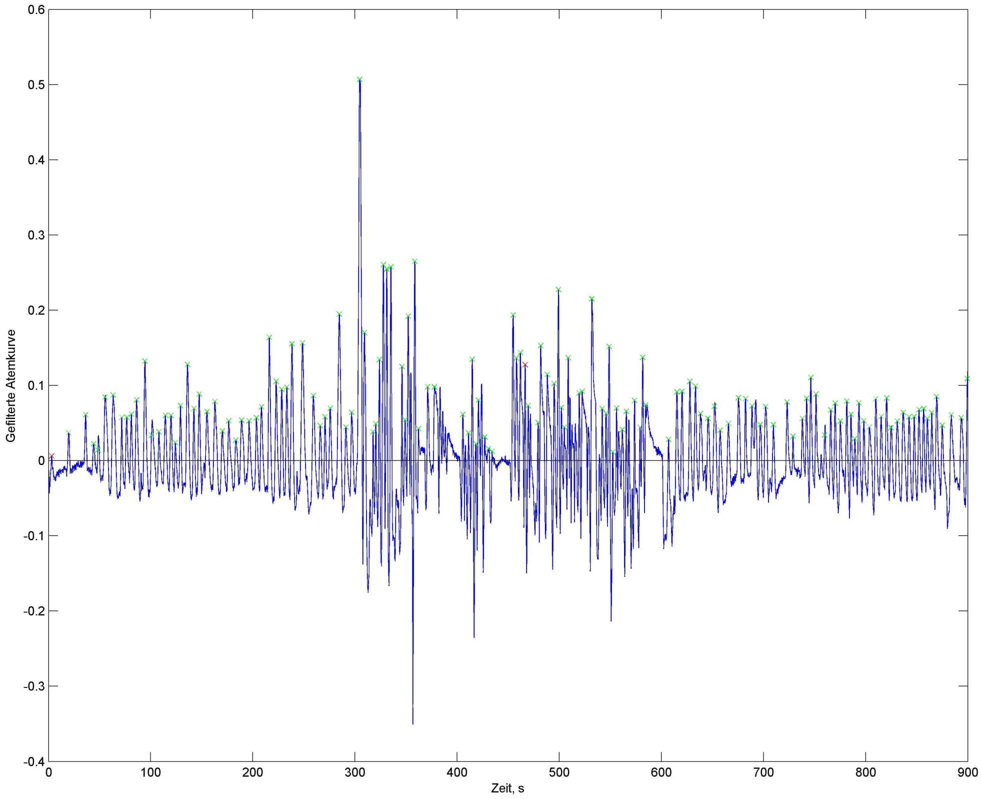

Figure 50: Chaotic respiration behaviour as a strategy of increasing heart rate

The graph shows how the subject's respiration volume and variability changed with the subject's effort to actively increase heart rate during phases 3 and 4 (the graph shows all six consecutive phases, each 150 seconds long).
Example: Subject No. 110

10 Discussion

In the following chapters, different aspects of statistical reliability and other challenges to the present study are discussed. The arguments of earlier studies on the effects of music on cardiac and respiratory function are compared, and it is shown where a re-evaluation of the results they obtained might be necessary.

10.1 Reliability of the FEX

A close examination of the Affective Communication Test – or rather, its German translation "FEX" by Traue (1998) – raised questions that would have to be investigated further if the German test version was to be used in future studies. Is the existing translation valid? Does the formulation of certain questions in the FEX restrict its application in studies on socio-cultural groups other than the one it was designed for (namely, American students of acting)? How reliably would the test measure "charisma" over a certain time span? And, last not least, could it also be used as a pre-post-test of expressiveness for a music therapy intervention?

10.1.1 Half split reliability

A half split reliability test (with the first seven against the last six questions) revealed a comparably low overall reliability with a correlation coefficient of $r = .538, p < 0.01$. Furthermore, correlation analyses of the results of single questions against the overall test results revealed which questions appeared to be of lower reliability. With correlation coefficients of $r = .205$ (question 1, "Wenn ich gute Tanzmusik höre, kann ich kaum noch stillsitzen"), $r = .204$ (question 5, "Es ist mir meistens unangenehm, wenn mich viele Leute anschauen"), $r = .333$ (question 12, "Ich kann andere Leute gut nachahmen und tue das gerne"), and $r = .266$ ("Wenn ich jemanden mag, zeige ich das zum Beispiel durch Umarmen"), the results of four out of thirteen questions did not significantly correlate with the overall test results. However, even when these four questions are excluded from the test, there are no significant group differences regarding the revised test results.

10.1.2 Socio-cultural issues

When group differences of the FEX ratings are analysed, socio-cultural issues should also be considered. Musical preference obviously influences the test results, as is clearly the case with question 1 ("Wenn ich gute Tanzmusik höre, kann ich kaum noch stillsitzen"). Controls, even if they do not listen to Rock/Pop or Techno music significantly more often than musicians,[247] rate this question significantly higher than musicians ($F(1/33) = 7.384, p = 0.010$). The slightly higher ratings of musicians in question 8 ("Auf kleinen Festen ziehe ich stets die Aufmerksamkeit auf mich"; $F(1/33) = 3.559, p = .068$) and question 9 ("Ich falle gern auf, wenn ich in Gesellschaft bin"; $F(1/33) = 3.408, p = .074$) also seem allegeable. Thus, even with a valid analysis of musicians' personality traits involving more subjects than in the present study, group differences in FEX ratings should not be interpreted without a discussion of the respective socio-cultural implications.

10.1.3 Cronbach's alpha

Although the analysis of Cronbach's alpha[248] produced a reliable $\alpha = 0.7006$ (35 cases, 13 items), the question should be raised as to whether it is advisable to use the test in a socio-cultural environment other than the one it was designed for, and with subjects who are not students of acting.

10.1.4 Longitudinal validity

To further test the validity of the results of the Affective Communication Test in its FEX version, two months after the experiments took place, all subjects who had agreed to be contacted were asked to complete the FEX questionnaire for a second time. 23 subjects responded. A correlation analysis of both test results was performed. With $r = .832, p < 0.01$, the test can be regarded reliable over time (see Figure 51), and would be able to validate the effects of a medical or music therapy intervention which tries to modify the client's expressiveness, as described by Busch (2005), but with all the limitations mentioned above.

[247] For the different musical tastes and preferences of the two groups, see p. 90.

[248] For a description of this measure, see Cronbach (1951).

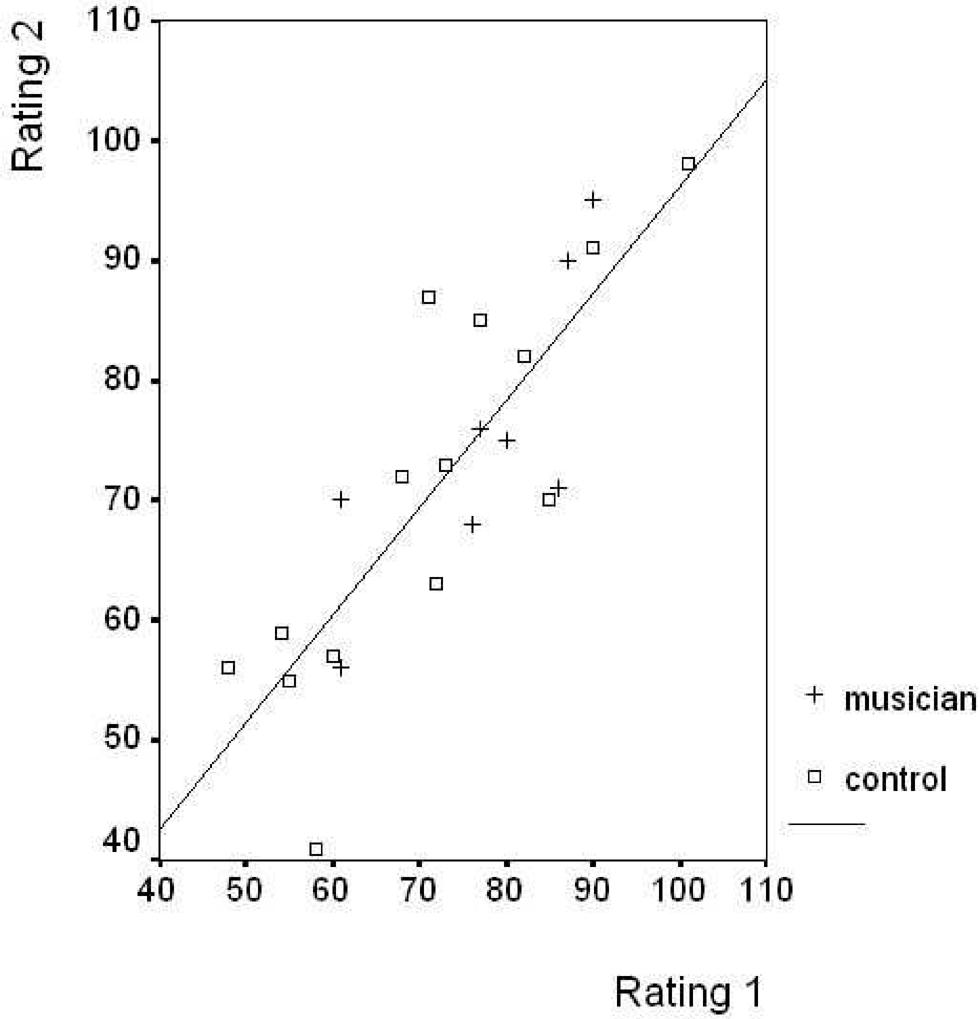

Figure 51: FEX longitudinal validity
The FEX reliably depicts expressiveness ($r = .832, p < 0.01$).

10.2 Age and gender issues

The analyses of the various parameters and their interactions in Experiment 1 and 2 revealed a number of age and gender effects, some of them expected, for example, a higher heart rate at rest for female subjects,[249] some of them not, for example, the ability to actively influence heart rate and attach or detach it from a target frequency, or the self-rated intensity with which the music had been experienced. Thus, even if an analysis with Fisher's exact test showed that gender was not an influencing factor (2-tailed, $p = 0.176$), differences such as the ones mentioned above have to be considered when examining and interpreting any study. When developing tests and questionnaires, age and gender issues should therefore be taken into account.

10.3 The influence of stage anxiety

The examination of the questionnaires showed that of the 9 subjects who stated that they would "often" or "occasionally" experience stage anxiety, only two used any form of relaxation technique to ease that anxiety. Although the study's focus was not on stage anxiety, results such as these described require further and more detailed research on how often and how many musicians suffering from stage anxiety use relaxation techniques, and on why the help of therapists or the use of such techniques might be not as common as expected.

Do teachers at the music academies tell their students enough about this issue? Have professional musicians easy access to potential therapies, and can they call on help without fear that their reputation might be compromised?[250] The influence of stage anxiety, which should be regarded as an important stressor within cardiorespiratory regulatory

[249] See the general results of Umetani, Singer, McCraty, and Atkinson (1998) and the discussion of LeBlanc, Young, Obert, and Siivola (1997) regarding gender and audience anxiety.

[250] There is a vast range of literature on stage anxiety, relaxation techniques and drug abuse among professional musicians. However, therapeutic recommendations and alerts seldom make their way into the music academies, nor into the professional music sphere. Meta-studies and systematic reviews which pursue the discussion of bodily regulatory mechanisms and potential therapies were provided by Middlestadt and Fishbein (1988); Salmon (1990); Sataloff, Rosen, and Levy (1999); Kenny (2005). A critique of current research practises and findings is provided by Brodsky (1996). Comments on respiration and hyperventilation are by Widmer, Conway, Cohen, and Davies (1997).

mechanisms, while investigating the effects of listening to and performing music must not be under-estimated, and would have to be taken into account in similar studies in the future.

10.4 Reliability of the Stimulus Reaction Test

Analyses of the recorded data from the short Stimulus Reaction Test show that the test did not inflict a high psycho-physiological stress onto the subjects; there were no significant increases in heart rate or respiratory rate or electrodermal activity. However, there were two significant effects: the older the subjects were, the slower were their reaction times; and male subjects reacted significantly faster than females. Since age and gender were equally distributed in both groups, there were no significant interactions; nevertheless, tests in future experiments should be designed so that results are completely independent of age and gender to avoid any possibility of interaction effects from these factors.

10.5 Reliability of the ECG recording device

The Hellige ECG monitoring device was not originally intended to be used with extremity electrodes. To test the reliability of the device, a second set of ECG electrodes for chest wall derivations was additionally implemented, but they were not used during the course of the experiments. It was shown by Reuter (2007) that the quality of the data obtained from extremity electrodes and recorded by the Hellige device was sufficient for the intended purpose (RR wave extraction); see Figure 52 for a comparison of the respective data.

10.5.1 Maintenance of pulse-respiration ratio

Generally, subjects managed to maintain a steady pulse-respiration ratio (PRR) according to the experimental guidelines very well. There were no significant group differences in how exactly the target ratio was maintained, except that musicians' ability to maintain the faster 6:1 pulse-respiration ratio while music was played was significantly worse than in controls (see Figure 60 and the respective table on page 137): while the average PRR in controls was 5.913 ± 0.112, it was 6.316 ± 0.115 in musicians ($F(1/33) = 6.318, p < 0.05$).

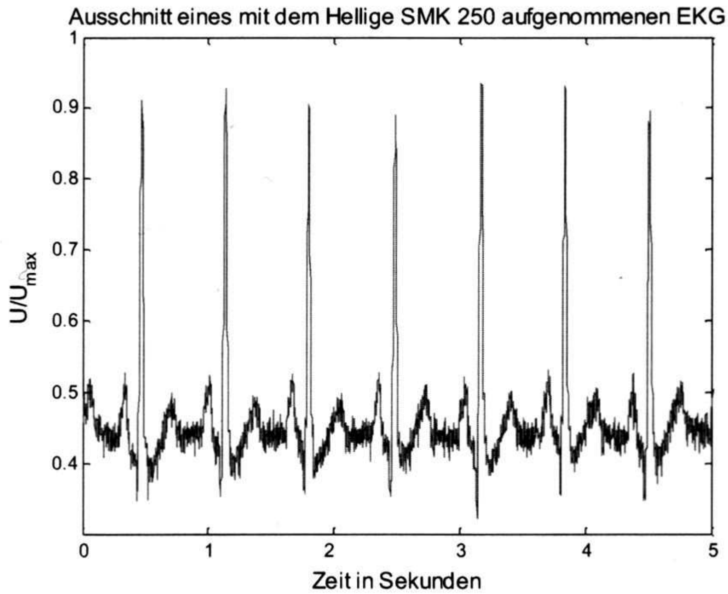

Abbildung 7: Ausschnitt eines mit dem Hellige SMK 250 aufgenommenen EKG

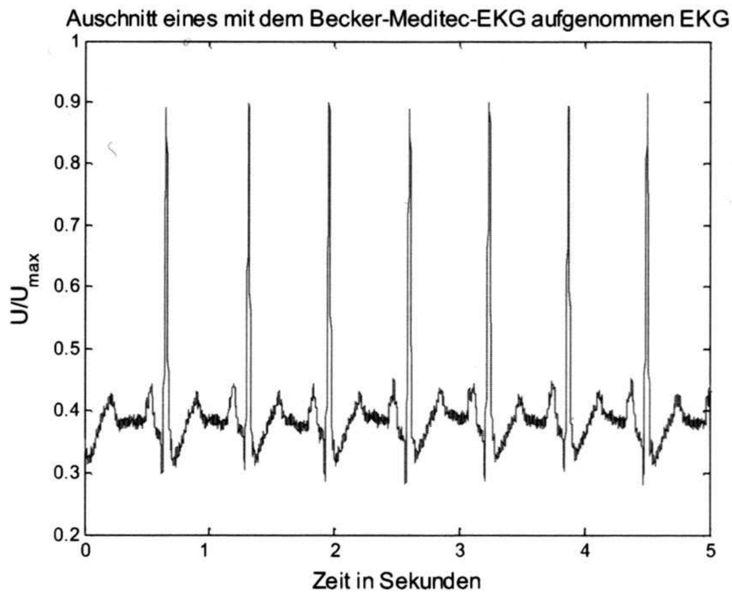

Abbildung 8: Ausschnitt eines mit dem Becker-Meditec-EKG aufgenommenen EKG

Figure 52: Reliability of the ECG monitoring device
Reuter (2007, p. 10) showed that the quality of the data recorded by the Hellige ECG with extremity electrodes was sufficient to reliably extract RR waves.

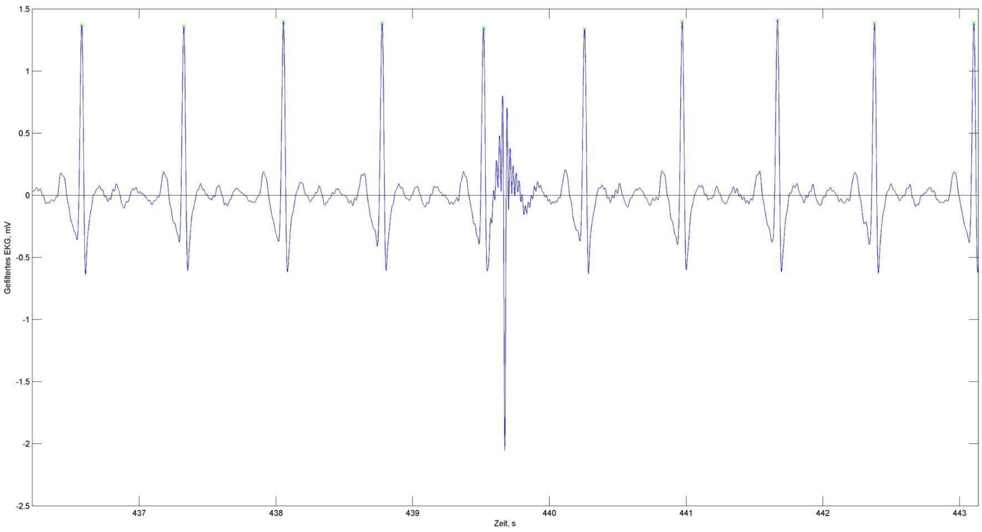

Figure 53: Arrhythmias and artefacts in the electrocardiac data set
The HRV.m software showed limitations in the automatic detection of R waves, especially with irregular beats. The depicted irregularity occured during a listening phase with voluntary breathing in Experiment 1. It was not marked as a beat by the software due to its reduced threshold.

PRR deviation	external stimulus	musician	control
6:1	-	0.19	0.15
6:1	X	0.32	-0.09
10:1	-	0.07	-0.09
10:1	X	0.05	-0.03

Table 19: PRR deviation in phases with or without music

Regardless of group, in phases with an additional external stimulus (in this case, music), subjects performed slightly better in maintaining the required PRR. However, the setup did not include randomisation for potential order effects regarding the sequence of phases with and without a stimulus. Thus, subjects might have improved their ability to maintain a PRR closely in phases without the external stimulus, which always preceded the respective PRR phases with the stimulus. Musicians' propensity to stick to a given musical rhythm might have contributed to their lower scores, particularly in maintaining the faster 6:1 PRR.

When subjects were asked to breathe voluntary in the first two phases of Experiment 1, their pulse-respiration ratios varied. They were significantly lower when subjects were listening to a musical sample, compared to the phase where no music was played ($F(1/33) = 19.748, p <$

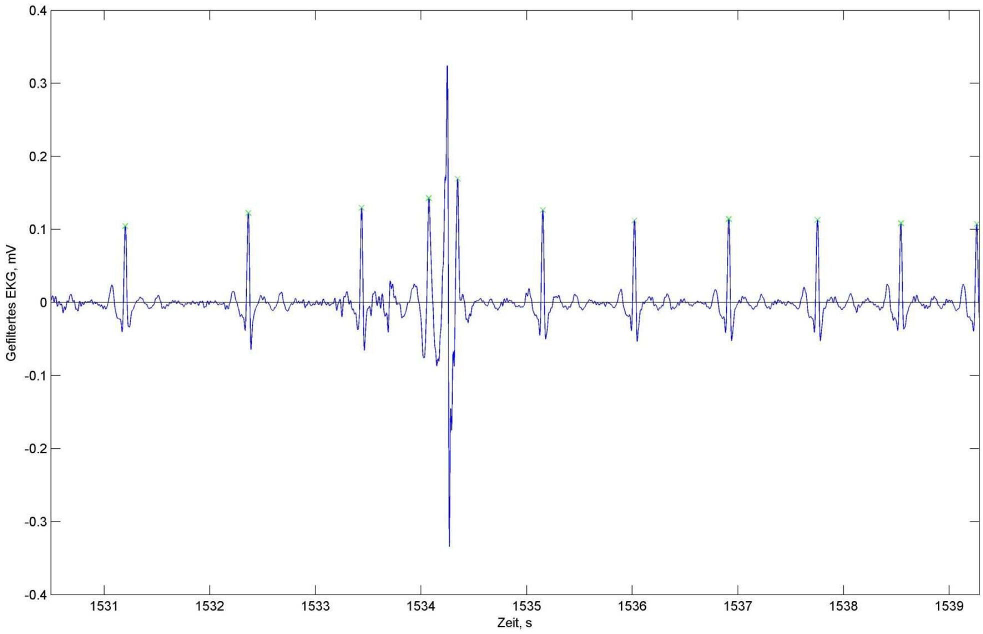

Figure 54: Arrhythmias and artefacts in the electrocardiac data set II
The HRV.m software showed limitations in the automatic detection of R waves, especially with irregular beats. The depicted irregularity occured during a listening phase with a pulse respiration ratio of 10:1 in Experiment 1. It might have been the result of an abrupt baseline shift, and was not marked as a beat by the software due to its missing QRS complex.

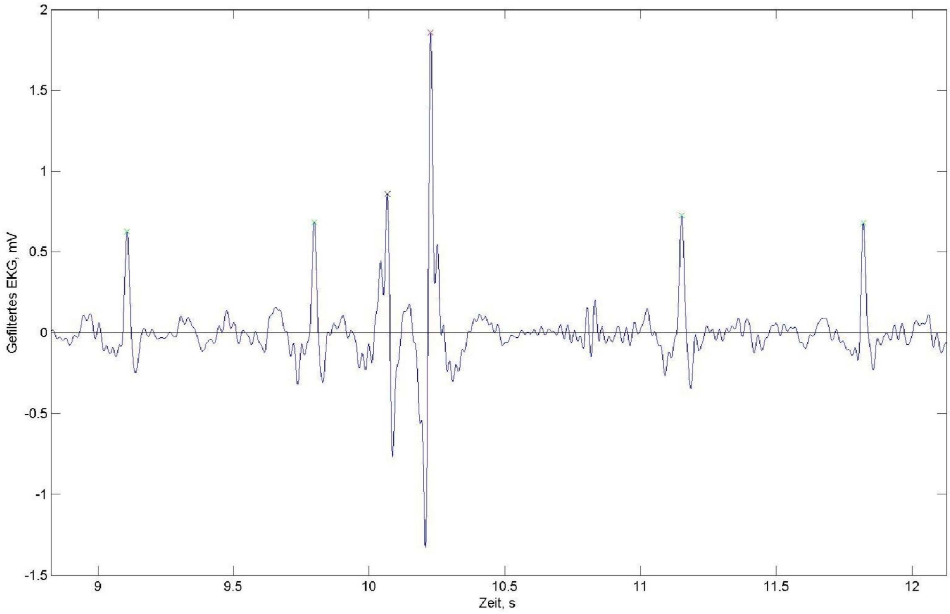

Figure 55: Limitation of RR wave detection - irregular beat

The depicted irregularity, most likely a coupled ventricle extra-systole with compensatory pause (advisory information by head cardiologist Dr. C. Siegert, Bad Nauheim) occured during the Stimulus Reaction Test. The second R wave had to be manually marked, since the R wave detection program excluded it because of the unexpectedly small interval preceding it.

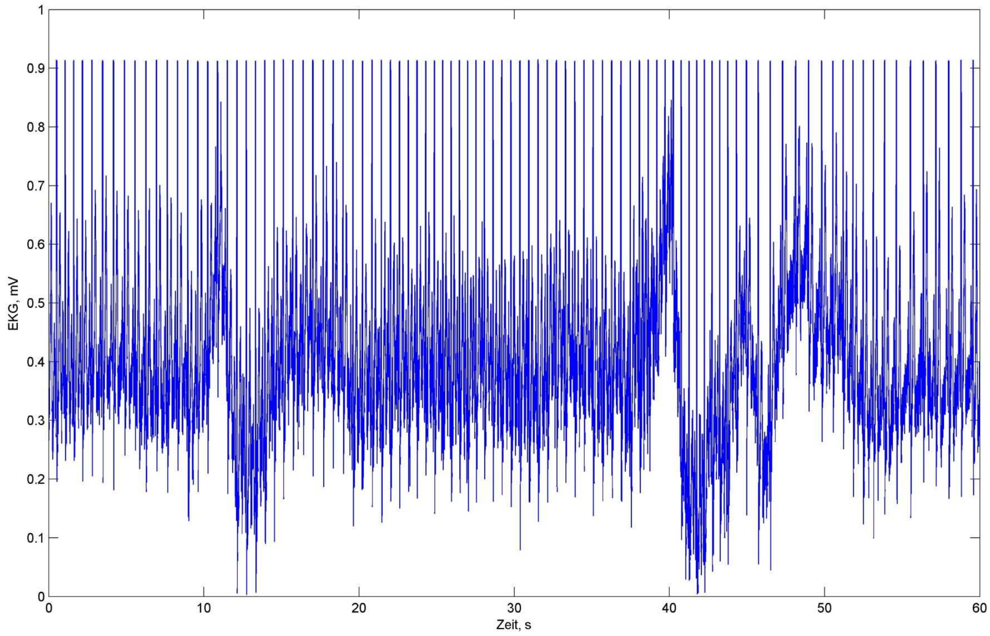

Figure 56: Movement of the extremities leads to baseline shifts in the ECG

The Stimulus Reaction Test required the subject to operate a computer mouse with his or her preferred hand. Muscular currents influence the ECG and may lead to baseline shifts, even to the extent that the limits of the ECG's normal recording range are reached, resulting in a reduction of data quality.

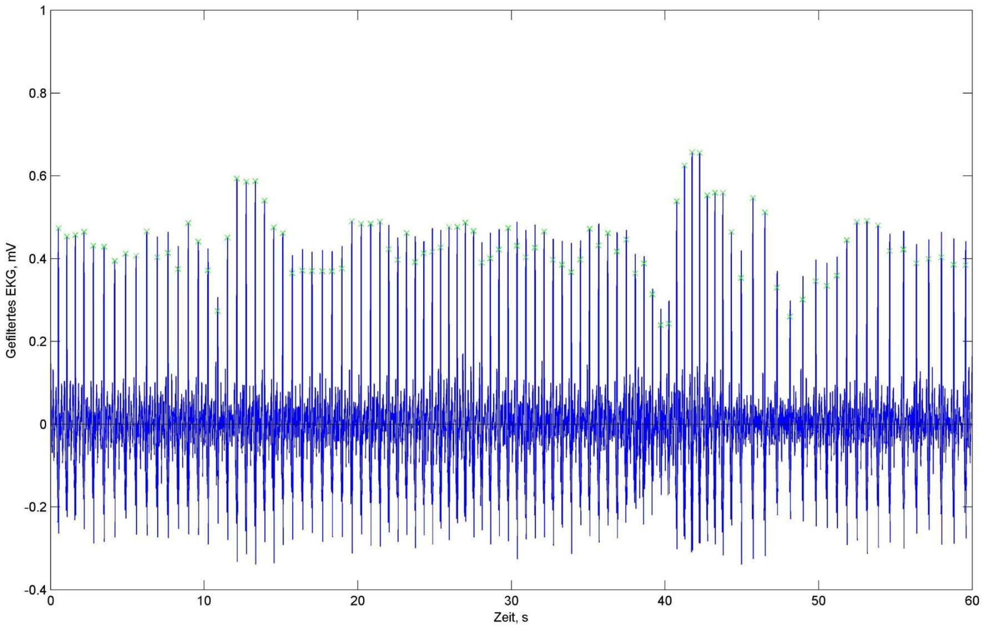

Figure 57: False positive detections of R waves
The depicted problem, false positive detections of irregular-shaped R waves, occured during the Stimulus Reaction Test. It had to be corrected manually with the manual R wave detection tool in the HRV.m software.

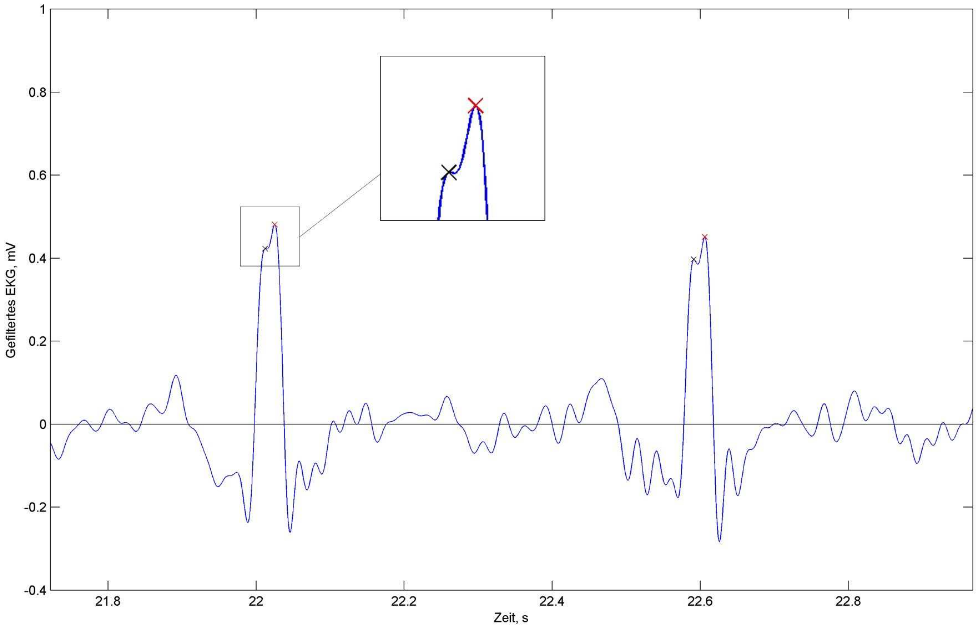

Figure 58: Manual correction of false positive detection of R wave
With the help of the manual R wave detection tool in the HRV.m software, false positive detections were corrected (red: manual detection of R wave point in time).

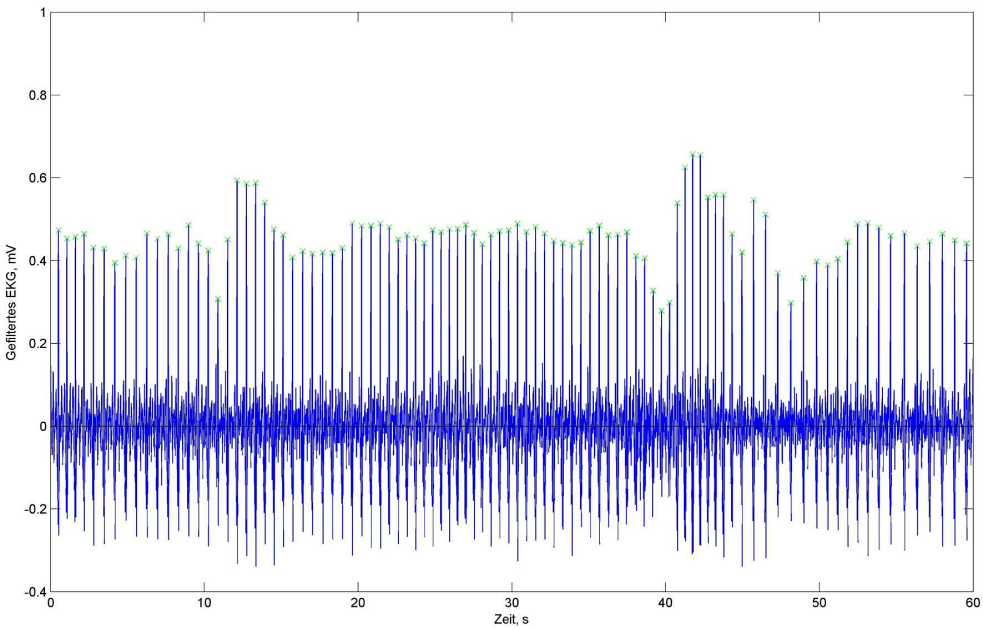

Figure 59: Corrected RR interval set
The manually corrected data set now contains the correct RR wave lengths.

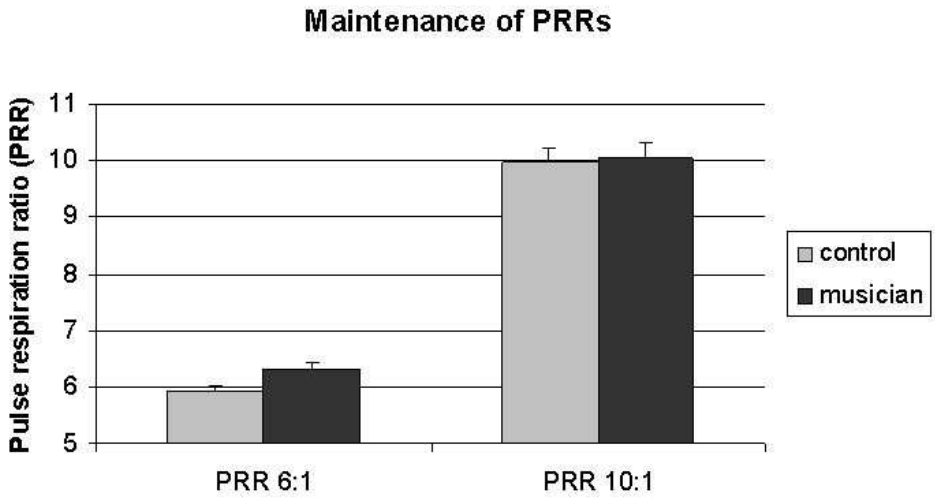

Figure 60: Musical stimulus prevents musicians from maintaining a steady pulse-respiration ratio

Generally, subjects managed to maintain a steady pulse-respiration ratio (PRR) very well. However, musicians' ability to maintain the faster 6 : 1 *pulse-respiration ratio while music was played was significantly worse than in controls.*

0.01). Since the subject's oxygen demand was regarded to be relatively equal throughout all phases, it is assumed, from a basic understanding of the physiological regulatory system, that the average respiration volume was higher during the phases without the stimulus, and then decreased in the listening phase. The respiration volumes could, however, not be determined due to limitations of the available bio-medical apparatus.[251]

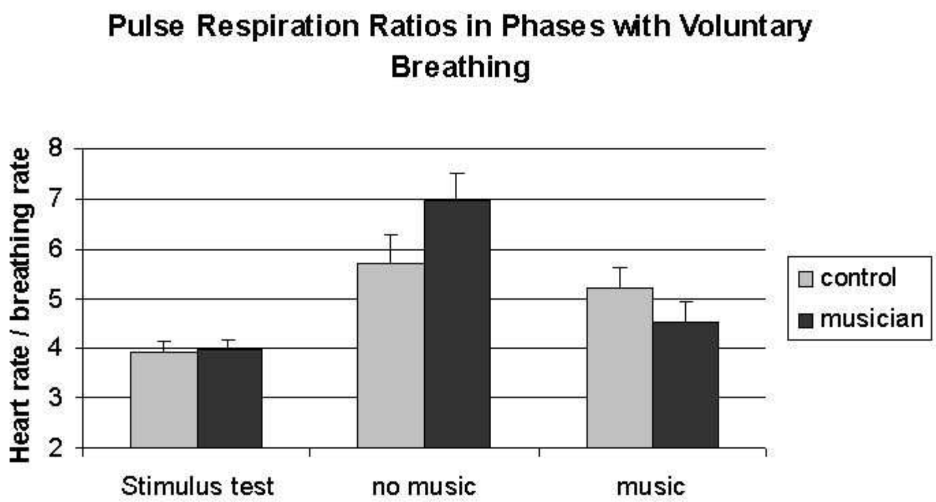

Figure 61: Pulse-respiration ratios in phases with voluntary breathing
Pulse-respiration ratios in phases with voluntary breathing: during the Stimulus Reaction Test, and during phase 1 (no music) and 2 (music) of Experiment 1.

10.6 Biological variation

The non-linear dynamics of the investigated biological regulatory systems are a challenge to the experimenter who aims to understand more than a singular cause-and-effect chain, which in any case is too crude a reading of the complex interplay of all the different parameters involved. In

[251]For a discussion of this issue, refer to Cooke, Cox, Diedrich, Taylor, Beightol, Ames, Hoag, Seidel, and Eckberg (1998).

the present study, the whole experimental environment – room temperature, time of day, technical apparatus, experimental schedule, subjects' anamnesis, etc. – was well-documented, and all the procedures, with the limitations described above, were kept unaltered, in order to monitor varation that might affect the results.

However, the analysis of the data obtained during the pilot study revealed that some results, which yielded little information about the underlying functioning system, needed further interpretation. When a single deep breath would noticeably influence heart rate and electrodermal activity,[252] it was clear that the reproducibility of the measurement would be compromised.

As a consequence, all experiments were adjusted with regard to the optimisation of experimental penetration, stimulus sample length, insights and benefits, always keeping in mind habituation and other 'negative' effects.[253] Nevertheless, a lot of fluctuating co-factors, such as general psychological involvement, temporary distraction caused by fatigue, or gradual learning in continuous bio-feedback tasks, influenced the outcome of the results to an extent that if, for example, the whole set of experiments was repeated with the same subjects on another day,[254] some findings varied. This observation resulted in further adjustments, with regards to the overall number of subjects and the depth of psychophysiological investigation. These adjustments also maximised potential conclusions, and at the same time ensured statistical reliability, taking into account the recommendations of the HRV "Task Force",[255] and others.

10.6.1 Influencing heart rate by adapting respiration behaviour

Regarding the coordination of heart and respiration, the analysis of the results in Experiment 1 revealed that although the subject's respiration rates increased significantly during the phase when stimulating music

[252]as shown on page 147

[253]In a way, the final test design still embraced compromises. For example, some subjects expressed initial difficulties in concentrating on the bio-feedback monitor when music was played to them via earphones. Even if the phases of the experiment were randomised, involvement and concentration remained somehow compromised by the fact that subjects had to maintain pulse respiration ratios while listening to music.

[254]as was done in the course of the pilot study

[255]cf. Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (1996)

was played, subjects' heart rate did not. Thus, in the complex cardio-respiratory regulatory system, the parameters of heart frequency and respiration frequency seem to function relatively independently in this setup, although coordination and synchronisation effects might occur. Respiration frequency did obviously not function as a trigger for an entrainment as speculated in Bernardi et al. (2006),[256] nor as a trigger of an overall sympathetic arousal, as skin conductance levels of this phase would have revealed.

However, some results from Experiment 2 where subjects were able to increase their heart rate significantly, and at the same time showed a significantly increased respiration rate, might lead to a more complex interpretation of the data. Despite the subjects being asked by the investigator to use only their imagination to increase their heart rate (for example, by imagining a stressful situation, a live performance of a difficult musical piece, or sitting a difficult exam), and *not* to breathe faster to achieve the heart rate increase, almost all subjects showed a significantly increased respiration rate in the respective phases (see Figure 49 on page 49). A qualitative analysis of the breathing patterns revealed irregularities of frequency and respiration volume that could be explained by a volitional influence, rather than any general increase of sympathetic arousal (see Figure 50).

Thus, the experiment demonstrates that even when subjects are asked not to change their respiration behaviour during an investigation of heart activity, they might - consciously or unconsciously - do just that, thereby altering their heart rates (see Figure 46, Figure 47 and Figure 48 in chapter 8 for different aspects of the phenomenon).[257] It is in this context that earlier experiments investigating heart rate entrainment and synchronisation[258] would have to be re-interpreted. Future experiments should therefore discuss the potential influence of a conscious or unconscious change of respiration behaviour when investigating heart rate entrainment or synchronisation to an external rhythmical stimulus. To obtain a control for respiration behaviour, a measuring belt or even an apparatus that is able to record respiration volume and blood gas saturations would be recommended.

[256] "Whether the effects observed in our study were secondary to respiratory entrainment or to a direct sympathetic stimulation by arousal remains speculative. [...] Perhaps both respiratory entrainment by music and direct arousal were coexistent and interrelated - in fact, the increase in breathing rate in itself might have contributed to the increase in sympathetic activity." (pp. 450f.)

[257] For more examples, see the Appendix on page 79 f.

[258] cf. Bason and Celler (1972); Frank (1982); Reinhardt (1999); Iwanaga (1995)

10.7 Habituation and learning effects

The required pulse-respiration ratios were maintained by the subjects in a prescribed randomised order. An analysis of the average PRR deviation values, sorted according to which PRR was presented first, revealed no significant relaxation, habituation or learning effects that might have resulted in a respective order effect (see Figure 62 and Figure 63).

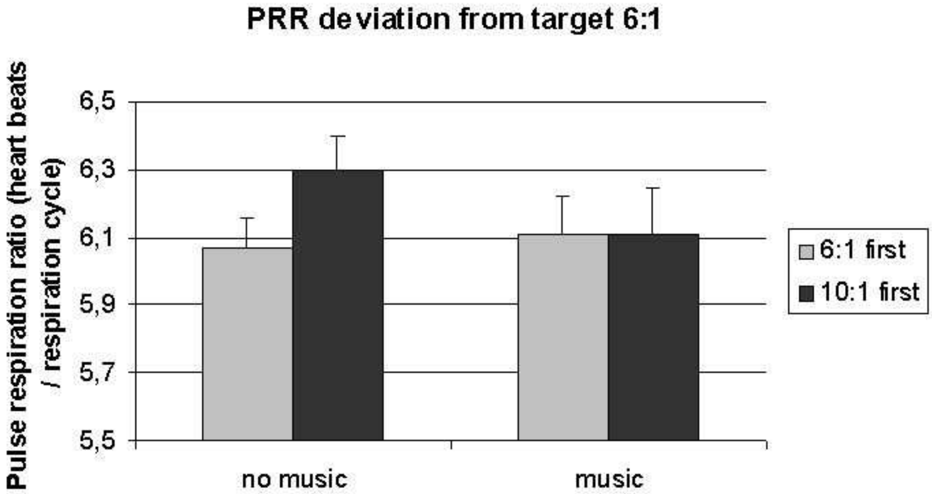

Figure 62: Investigating potential order effects of PRR deviation, PRR 6:1

The analysis of subjects' deviations from the 6:1 pulse respiration ratio, analysed according to which PRR was presented first, revealed no significant order effect.

10.8 Familiarity influences involvement

An analysis of how high subjects rated their familiarity with the musical sample ("Kannten Sie das Stück?") and the increase of electrodermal activity between the slow and the fast parts of the musical sample revealed a significant correlation ($r = .380, p < 0.05$, see Figure 67). Acknowledging that the correlation was not significant when the subject showing

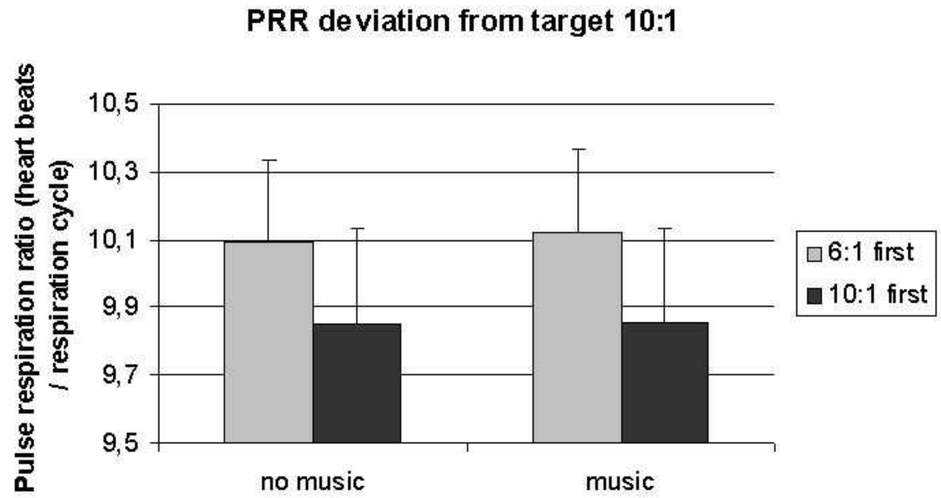

Figure 63: Investigating potential order effects of PRR deviation, PRR 10:1

The analysis of subjects' deviations from the 10:1 pulse respiration ratio, analysed according to which PRR was presented first, revealed no significant order effect.

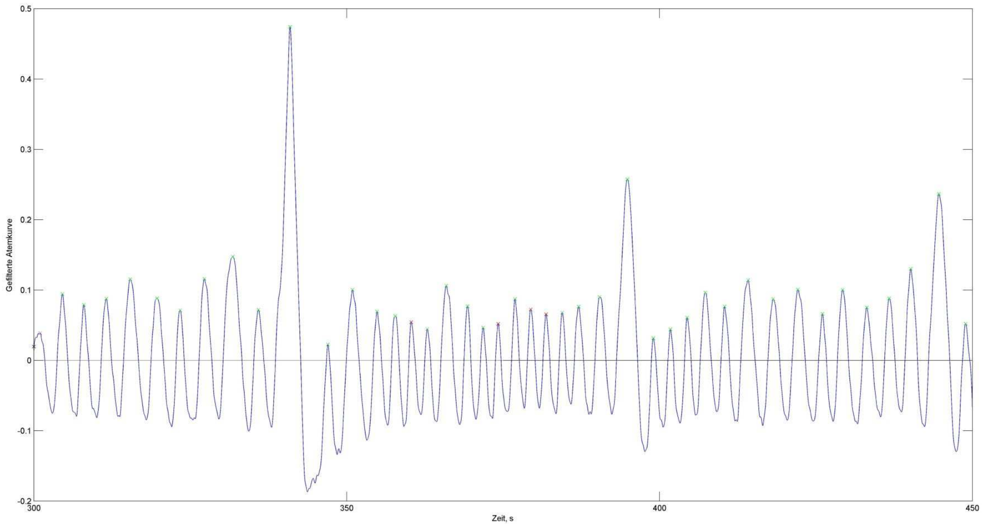

Figure 64: Limitations of reproducibility
Physiological irregularities were marked by occasional deep breaths, which could not be directly ascribed to musical events (Example: subject No. 108, phase 3 of Experiment 1).

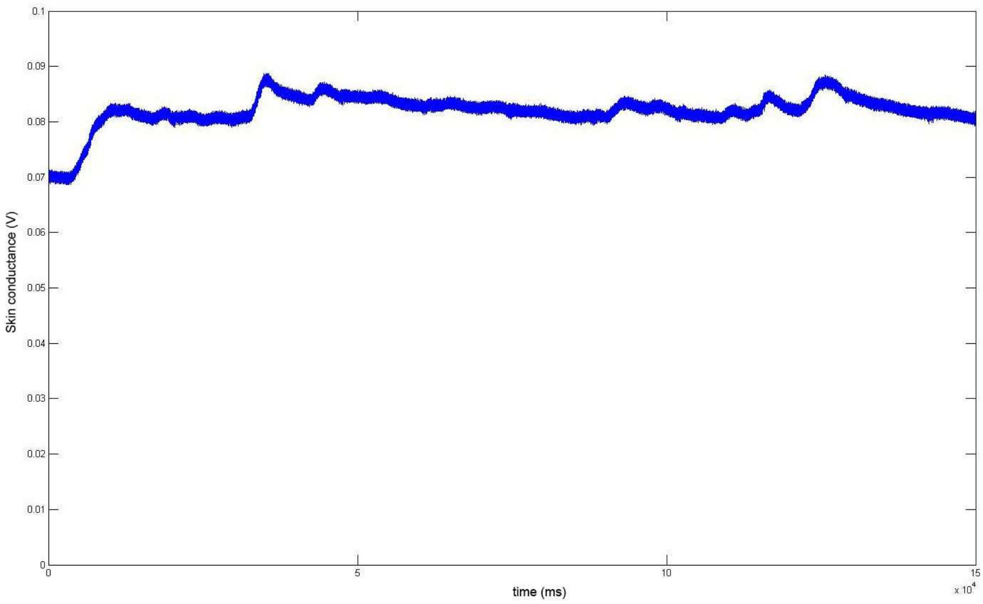

Figure 65: Influence of breathing irregularities on skin conductance
Respiration behaviour directly influences skin conductance. Deep breaths result in a marked increase of skin conductance (Example: subject No. 108, phase 3 of Experiment 1).

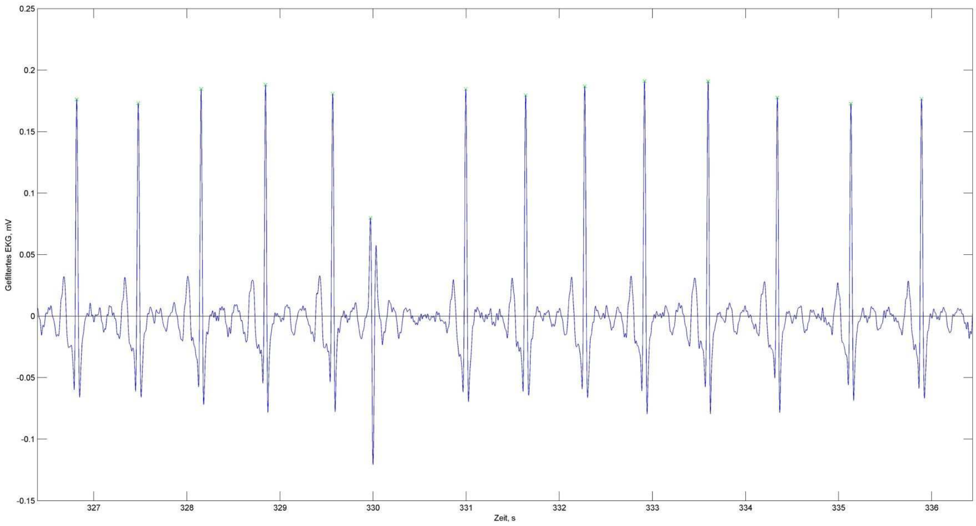

Figure 66: Influence of breathing irregularity on heart activity
Deep breaths might even trigger cardiac arrhythmias, as this example (subject No. 108, clipping from phase 3 of Experiment 1) shows.

the highest increase ($r = .324, p = 0.062$) was excluded from the correlation analysis, the issue of how preference and familiarity influence involvement should nevertheless be discussed in every investigation into the effect of music on psycho-physiological regulatory systems. Even if the assumption that popular pieces guarantee a high involvement holds true, researchers should still discuss subjects' musical preferences when, for example, designing a study about relaxation, or evaluating different concepts of music therapy.

10.9 Musical preference influences stress behaviour

An observation sometimes neglected in similar studies is that musical preference and stress behaviour are significantly correlated. According to their answers in the questionnaires, the more often the subjects listened to music of the respective style in their daily life, the less likely were they able to relax while listening to it in the experiment ($r = .-412, p < 0.05$). This effect always has to be taken into account when designing and reinterpreting studies investigating stress behaviour, therapeutic interventions using music of a particular style, or therapies targeted at groups with a certain listening profile (e.g. classical musicians).[259]

[259]cf. Kenny, Davis, and Oates (2004); Usry (2006)

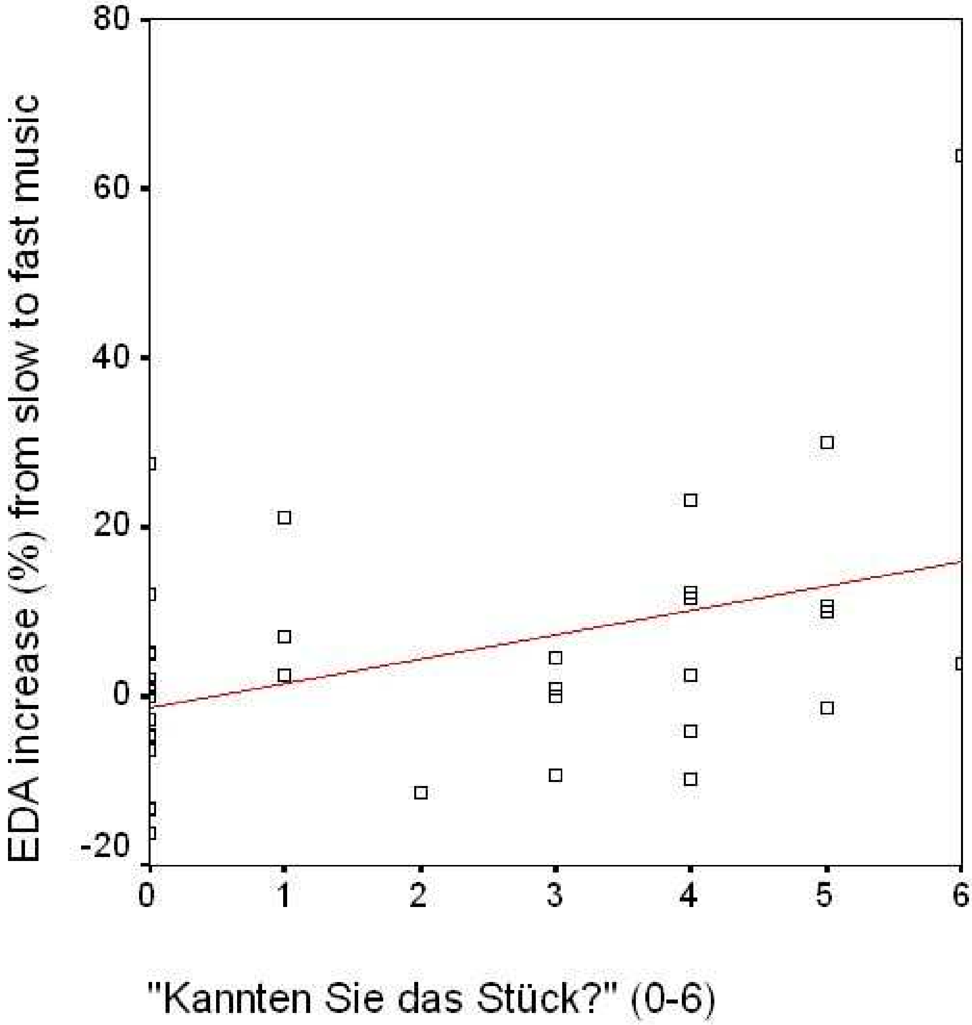

Figure 67: Increase in EDA correlated with familiarity of the musical piece

The more familiar the subjects rated their own familiarity with the piece, the higher was the increase in electrodermal activity (from slow to fast movement).

10.10 Experience with bio-feedback influences breathing behaviour

In total, twenty per cent of subjects stated they had previous experience with bio-feedback (four musicians and three subjects from the control group). Statistical analysis suggests that this experience might influence a subject's behaviour during the experiments and/or their psycho-physiological results, since there were significant differences in breathing behaviour, depending on the subject's experience with biofeedback (see Figure 68). Subjects with biofeedback experience showed a higher increase of average breathing rates when breathing voluntarily while listening to the slow and fast music in Experiment 1. Regarding pulse-respiration ratios in phase 1 of Experiment 1 (no music, voluntary breathing), all subjects with experience in biofeedback showed a $PRR > 6$,[260] whereas the majority of subjects without that experience (60.7%) showed a $PRR < 6$. Generally, PRRs differed significantly, depending on biofeedback experience ($F(1/33) = 4.438, p < 0.05$).

These effects of biofeedback experience therefore have to be taken into account when interpreting the results of breathing behaviour and psycho-physiological regulatory mechanism investigations, for example, in terms of breathing strategies.

10.11 General limitations of the cardio-respiratory recording apparatus

The complex cardio-respiratory regulatory system, when influenced by psychological and physiological stress, meets metabolic demands with little time delay. In the present study, the actual cardiac and respiratory output could only be mapped by measuring frequencies, because the recording device used recorded heart and breathing rates but not stroke or tidal volumes. The actual *minute output*, and how it was adjusted according to stress, could not be determined. With the given apparatus, it is therefore not possible to thoroughly model the regulatory mechanisms of how exogenous stimuli influence endogenous rhythms.

Whereas it might have been possible to measure tidal volumes, it is still not possible to measure cardiac stroke volume non-invasively

[260] For a discussion of deviations from target pulse-respiration ratios (PRR), see p. 147.

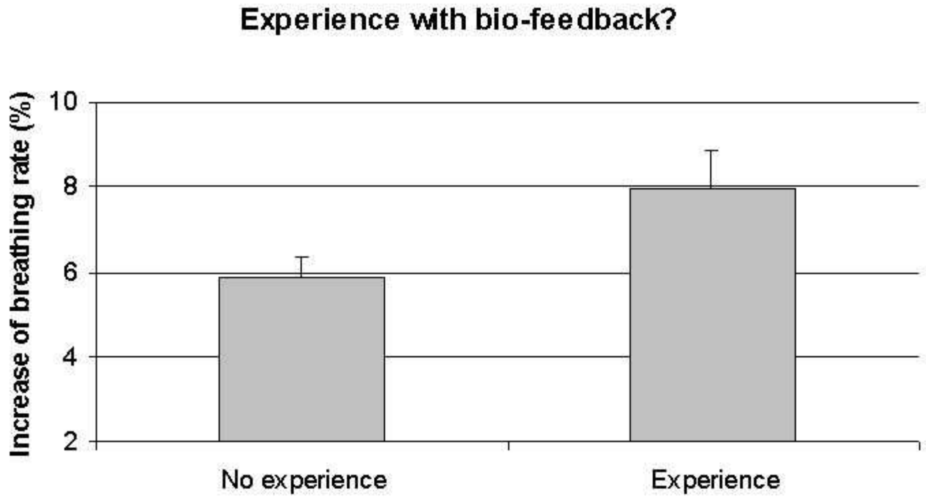

Figure 68: Experience in biofeedback tasks influences breathing behaviour

There was a significant difference in breathing behaviour, depending on the experience the subjects had with biofeedback ($F(1/33) = 6.306, p < 0.05$)*. Subjects with experience with biofeedback tasks showed a higher increase of average breathing rates from the slow music to the fast music parts in phase 2 of Experiment 1.*

during routine monitoring. The question as to whether and how athletes (or professional musicians) differ from healthy controls who do not carry out daily exercise routines would therefore have to be investigated more thoroughly in future experiments, which might take advantage of prospective developments in advanced three-dimensional imaging methods that reliably depict cardiac stroke volumes and tidal volumes. It is also in these respects that investigations of how certain relaxation or meditation strategies often involving deep, rhythmical breathing should be criticly revisited,[261] and new experiments should be designed.

10.12 Limitations in modelling psycho-physiological responses

As the present study showed, the autonomous auto-rhythm of the heart can be actively influenced by conscious or unconscious breathing patterns, apparently even to the point where subjects are able to produce a complete cessation of heartbeat.[262] As a result, any model of cardio-respiratory regulatory function might exemplify coherences of effects and causes, but might not be able to display coordination mechanisms and psycho-physiological input parameters as a whole. An active psychological influence on the results, be it conscious or unconscious, cannot be ruled out when investigating cardio-respiratory function. Consequentially, any future research in this field should include additional information on the monitored and also the self-perceived behaviour of the subjects.

In summary, any experiment on the effects of music and rhythm on cardiac function should not only carefully control for respiratory regulation (respiration frequency, and, if possible, stroke volume), but also for any symptoms of stress or altered state of mood for potential changes in subject reagibility and involvement (musical preference, chronobiological aspects, fatigue etc.), and other concomitant factors (room temperature etc.) that might influence cardiac regulation. A re-evaluation of earlier studies on the effects of different kinds of music on heart rate, often proposing direct stimulus-response patterns, might lead to different and certainly more complex ideas of how external stimuli exert influence on bodily parameters.

[261] cf. Bettermann, von Bonin, Frühwirth, Cysarz, and Moser (2002); Chang, Midlarsky, and Lin (2003); Cysarz and Büssing (2005); Khalsa and Cope (2006)

[262] See, for example, McClure (1959) for a unique case report.

10.13 The relationship between musical tempo and body pulse

When investigating musical tempo, the question that often springs to mind is whether it might be linked to the body pulse of the performer or listener. There is still much debate regarding music theoreticians' efforts to investigate temporal musical measures and link them to periodic bodily rhythms, and how early musicians and composers thought about such a connection. Kümmel (1970) stated that the *tempo of the mensural music is still an unsolved problem, mostly because [. . .] there is only one source available to us that can be used to obtain a steady measure.*[263] The idea of musical measures being identified with the body's pulse persists until today; primarily because body pulse, although *quite variable [. . .] does have the advantage of being instantly available.*[264] Whereas Vetulus, as quoted by Segerman (1996), wrote that the breve in *tempus perfectum medium* lasted for the time of an *unica*, which he said was $^1/_{480}$th of an *hora*, which in turn was $^1/_{24}$th of a day,[265] later theoreticians referred to bodily rhythms for practical reasons such as that described, even if the

[263] *Das Tempo in der Mensuralmusik ist noch immer ein unzureichend geklärtes Problem, vor allem deshalb, weil die Musiktheoretiker zwar manchen Aufschluß über relative Tempounterschiede und deren zahlenmäßige Abstufungen geben, uns aber bisher nur eine einzige Quelle zur Verfügung steht, aus der sich ein festes Zeitmaß gewinnen läßt. Diese Tempoberechnung des Johannes Verulus de Anagnia (um 1350) war vor Michael Praetorius der einzige bisher bekannte Versuch, für das musikalische Tempo einen absoluten Zeitwert zu bestimmen.* (Kümmel, 1970, p. 150)

[264] Cf. Houle (1987, p. 3)

[265] Segerman (1996, p. 227)

Latin term *pulsus* and the French *temps* sometimes led to misinterpretations.[266]

In the words of Thaut (2007, p. 5), *Marin Mersenne [already] equat[ed] the* tactus *with a second in time, one-sixtieth of a minute, therefore with MM* 60. *He [Mersenne] also explains that the* tactus *is related to the body's pulse.* The alluringly simple idea that any *brevis* lasted a heart beat, and the *longa* was sung in one breath[267] was not, however, able to adequately represent the complexity of time measures and the proportions of mensural notation. Therefore, when suitable mechanical devices became available, composers and performers came to rely on them to allocate particular tempi to music. An entry in Grassineau's 1740 translation of de Brossard's *Dictionaire de musique* reads:

> But then what that slow, brisk, and quick is, is very uncertain, and only to be learned by practice; the nearest measure we know of it, is to make a quaver the length of a pulse of a good watch.[268]

With the recent development of bio-medical apparatus which are able to make combined analyses of heart and respiration activity, investigators are provided with a new and more precise means of examining

[266] As Segerman (1996, p.227), for example, tries to elucidate,

> Howard Mayer Brown (1980) states that Gaffurius (1496) wrote that 'one tactus equalled the pulse of a man breathing normally, suggesting that there was an invariable tempo then of $MM = c.\ 60 - 70$ for a semibreve in integer valor'. This most probably is in error. Bonge (1982) has pointed out that Gaffurius was ambiguous in relating the pulse and tempo. In one passage Gaffurius discussed how physicians considered the pulse as the basic unit of time measurement in medicine, and that it was composed of two components of equal time each-dilatation and contraction. In a second passage, he mentioned that modern musicians considered the regular semibreve in a similar way, as the basic unit of time measurement in music, also composed of two components of equal time each (minims). In a third passage he stated that a dissonance in counterpoint cannot last as long as a regular semibreve, a full measure of time, namely 'in modem scilicet pulsus aeque respirantis'. Bonge translated the phrase left here in Latin as 'in the manner of the pulse of [someone] breathing evenly'. This is the most obvious and direct interpretation of the Latin.

[267] *Brevis, die kurze Note der ursprünglichen Gregorianik, dauert etwa einen Herzschlag lang, und Longa, die Länge dieser choralen Musik, wurde in einem Atemzug gesungen.* (Moser et al., 2004, p. 26f.)

[268] (de Brossard et al., 1740, p. 41)

the relationship between the body and music, even in smaller studies. And since an analysis of heart activity alone does not discriminate between the effects of different kinds of music on the psycho-physiological regulatory system, the present study measured not only respiration, but also electrodermal activity, and these two parameters showed musical samples provoking the most significant effects. Many of the results of earlier studies therefore should be re-examined, and in future investigations, additional parameters such as those mentioned, should be taken into account.

11 Resume

This study aims to shed light on basic regulatory functions within the complex psycho-physiological mechanisms of subjects under the influence of different auditory stimuli. A series of experiments were carried out to investigate heart rate behaviour under fixed pulse respiration ratios and during voluntary breathing phases, the effects of rhythmical acoustic stimuli on subjects' cardio-respiratory regulatory mechanisms, and the influence of bio-feedback on the ability to actively adapt and deflect their own heart rate to and from a steady periodic rhythmical stimulus.[269] A set of questionnaires accompanied the experiments, providing information about musical preferences, learning issues, stage anxiety biases, and similar parameters that might be of help in understanding how subjects react to psycho-physiological stress.

Subjects in both the musicians and the control groups increased breathing frequencies when listening to both slow or activating music compared to silence. Differences in average respiration rate were higher in musicians compared to controls. However, the alterations of heart frequency while listening to activating or sedating music were not significant, although the questionnaires account for high subject involvements.

The results of the second experiment showed that subjects were able to actively increase their heart rates (compared to their heart rates at rest) with the help of bio-feedback; while, at the same time, their electrodermal activity increased. An external acoustic stimulus (a regular metronome click) did not significantly facilitate or counteract this ability. Regarding the coordination of heart and respiration, the analysis revealed that although the subjects' respiration rates increased significantly during the phase when activating music was played, their heart rates did not. Thus, in the complex cardio-respiratory regulatory system, the parameters of heart frequency and respiration frequency seemed to function relatively independently, although coordination and synchronisation effects might have been occurring.

An investigation into heart rate variability suggested that heartbeats became more regular when the subjects listened to music. However, that the decrease of heart rate variability is time-dependent, namely that subjects' heart rates became more regular over the course of the experiment regardless of whether any music was played to them, cannot be ruled out since the experimental setup did not always allow a control for

[269]See p. 85 for the experimental schedule.

habituation effects. Additional analyses revealed that the more severely subjects rated their stage anxiety, the higher were their average heart rates and respiration rates.

An analysis of the results of an Affective Communication Test (ACT) revealed no significant differences between musicians and controls. However, the higher subjects scored in the test, the more intensely they rated their experience of the music.

12 Outlook

Even if the technical apparatus of empirical investigation into listeners' psycho-physiological states is quite advanced, and nearly every biological factor can be observed, retrieved and registered nowadays, the underlying regulatory mechanisms are still not fully understood. The interplay of various causes and effects among parameters with often non-linear dynamic behaviours makes it only rarely possible to arrive at certain predictions. Correlation models that are used, for example, as the basis for easy-to-follow therapeutic claims and interventions (*music of the character of the symphony [is] not to be recommended for individuals who are fatigued, depressed, or ill*, Hyde (1927, p. 190)) have – in all their simplicity – proven to be inadequate all too often.

Therefore, when designing listening experiments similar to the ones described in this study, the musicological researcher inevitably faces a problem. If, for the sake of investigating correlations and causalities in general, the number of shifting variables is minimised, thus simplifying the experimental setup, some of the effects that occur in more complex systems become unobservable. Any physiological correlation effects of music are based on the emotional involvement of the subject, as Frank (1982) convincingly described. If the whole emotional world of "listening to music" or "performing music" is reduced to an abstract situation in a laboratory, where subjects lack the stimulus of a concert hall environment, or the interaction of a soloist with an audience, any effects music might have on listeners or performers might be affected; and the more times any listening or performing task is repeated for experimental purposes, the more learning effects, fatigue, and habituation affect the outcome.

Despite the fact that various effects of music on different psychological and physiological parameters and regulatory mechanisms have probably been under constant consideration as long as music itself has been made, there are still many open questions; but researchers have recently begun to tackle them. The complex functioning of the cardio-respiratory regulatory cycle and how it can be influenced by external stimuli, or how music might affect certain cognitive processes in the light of learning or with regard to emotional influence – issues such as these still present challenges to investigators who seek a broader understanding of cause-and-effect principles. Although the therapeutic effects of music have been widely demonstrated, their application has still not found its way into the hospitals and healthcare institutions.[270]

Regarding the achievements and practicability of the diverse rhythm therapies offered today, the situation has not changed much since Frank's 1982 critical evaluation.[271] The large variety of new theories about cardiac and respiratory rhythmogenesis suggests that some fundamental bio-physical mechanisms have not yet been comprehensively clarified.[272] However, the on-going discussions are helping researchers dealing with open questions regarding the possibilities of music influencing the biological regulatory systems of the human body, and they pave the way to more effective stress prevention methods and therapies. Further work on potential synchronisation and coordination effects of endogenous and exogenous rhythms is needed, and – if they cannot be confirmed or verified – the focus of music-therapeutical rhythm research will have to move into new areas yet to be opened up. In this context, further investigations of inter-individual synchronisation and coordination effects in musicians while playing would be fruitful, and these should include analyses of different cardio-respiratory coordination processes and regulatory mechanisms in subjects who are able to breathe voluntarily during the experiment (for example, pianists), and subjects whose breathing rhythm is induced by their instruments (singers, wind instrument players).

One of the greatest challenges today is to understand the complex neuronal activity during active music performance. Recent devel-

[270] "Although there is now an extensive empirical base for the therapeutic usefulness of music therapy, particularly with the myocardial infarction population, few hospitals have adopted music therapy programs" (White, 2000).

[271] "Von einer gezielten therapeutischen Anwendung von Musikrhythmen bei gestörten biologisch-rhythmischen Funktionen kann noch keine Rede sein." (Frank, 1982, p. 103)

[272] cf. Richter, Ballanyi, and Schwarzacher (1992); Wiedemann and Luethi (2003); Dunin-Barkowski, Escobar, Lovering, and Orem (2003); Pokrovskii (2005); Purvis, Smith, Koizumi, and Butera (2007)

opments, especially in the field of emotion research, encourage multidisciplinary collaborations between physicians, musicologists, music therapists, and professional musicians. The results and findings of this study might contribute new insights into the effects of rhythmical stimuli on endogenous regulatory mechanisms. They could function as a basis for further experiments, including those using the latest image-guided examination methods in the area of cardio-respiratory control and neuronal signal processing, and thus help towards an understanding of the different desirable effects of music on people.

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Part III

Appendix

13 Questionnaires and handouts

13.1 The Affective Communication Test (German Version FEX)

Der vorliegende Fragebogen wurde an einer amerikanischen Universität entwickelt und sollte Selbsteinschätzungen unter anderem von Schauspielstudenten erfassen.[273] *Alle Angaben werden selbstverständlich anonym behandelt.*

Es geht in diesem Fragebogen darum, wie Sie sich selbst sehen und empfinden. Dabei gibt es keine richtigen oder falschen Antworten, da sich jeder Mensch in seinen Erfahrungen und Verhaltensweisen von anderen unterscheidet. Kreisen Sie bitte spontan diejenigen Antwortmöglichkeiten ein, die am ehesten für Sie stimmen, auch wenn nicht alle Fragen völlig auf Ihre eigene Situation zutreffen mögen. Dabei stehen Ihnen neun Antwortmöglichkeiten von "trifft sehr zu" bis "trifft gar nicht zu" zur Verfügung. Wenn Sie sich nicht entscheiden können, kreisen Sie einfach die Null in der Mitte ein.

[273] Traue (1998)

		Trifft sehr zu								*Trifft gar nicht zu*
1	Wenn ich gute Tanzmusik höre, kann ich kaum noch stillsitzen.	4	3	2	1	0	1	2	3	4
2	Ich lache nur selten laut und herzhaft.	4	3	2	1	0	1	2	3	4
3	Auch beim Telefonieren kann ich leicht meine Gefühle ausdrücken.	4	3	2	1	0	1	2	3	4
4	Ich habe die Angewohnheit, meine Freunde während der Unterhaltung zu berühren.	4	3	2	1	0	1	2	3	4
5	Es ist mir meistens unangenehm, wenn mich viele Leute anschauen.	4	3	2	1	0	1	2	3	4
6	An meinem Gesichtsausdruck können meine Gesprächspartner nicht ablesen, was ich gerade fühle.	4	3	2	1	0	1	2	3	4
7	Die Leute meinen, ich würde einen guten Schauspieler abgeben.	4	3	2	1	0	1	2	3	4
8	Auf kleinen Festen ziehe ich stets die Aufmerksamkeit auf mich.	4	3	2	1	0	1	2	3	4
9	Ich falle gerne auf, wenn ich in Gesellschaft bin.	4	3	2	1	0	1	2	3	4
10	In Gegenwart von Fremden bin ich schüchtern.	4	3	2	1	0	1	2	3	4
11	Wenn ich will, kann ich sehr charmant sein.	4	3	2	1	0	1	2	3	4
12	Ich kann andere Leute gut nachahmen und tue das gerne.	4	3	2	1	0	1	2	3	4
13	Wenn ich jemanden mag, zeige ich das zum Beispiel durch Umarmen.	4	3	2	1	0	1	2	3	4

Table 20: The Affective Communication Test (German Version FEX)

13.2 Questionnaire 1

Proband Nr. ____

Fragebogen zum musikalischen und medizinischen Hintergrund

Um die im Versuch aufgezeichneten Daten möglichst umfassend auswerten zu können, benötige ich noch einige ergänzende Informationen von Ihnen. Bitte beantworten Sie jede Frage so exakt wie möglich und kreuzen Sie jeweils das Kästchen an, das für Sie am ehesten zutrifft. Die Daten werden ausschließlich für die Auswertung des praktischen Experiments verwendet.

Alter: _______ Jahre □ männlich □ weiblich

Wenn Sie Schüler/in einer □ **Haupt- / Realschule** / □ **Berufsschule** / □ **am Gymnasium** sind:

□ Musisch vertiefte Ausbildung

□ keine musisch vertiefte Ausbildung

Wenn Sie an einer □ **Fachhochschule** / □ **Universität** / □ **Kunst- oder Musikhochschule** immatrikuliert waren oder sind, ist oder war Ihr Hauptfach:

□ **musisch orientiert**[274], nämlich: ________________

□ **nicht musisch orientiert**, nämlich: ________________

Instrumentalunterricht auf folgenden Musikinstrumenten:

[274] Diplom-Orchestermusiker, Schulmusiker, Musikwissenschaftler mit Instrumentalunterricht

_______ Jahre: ________________ (_______ Stunden Üben pro Tag)

_______ Jahre: ________________ (_______ Stunden Üben pro Tag)

_______ Jahre: ________________ (_______ Stunden Üben pro Tag)

Als Entspannungstechnik(en) nutze ich

☐ regelmäßig	☐ selten	☐ nie	**Autogenes Training**
☐ regelmäßig	☐ selten	☐ nie	**Eutonie**
☐ regelmäßig	☐ selten	☐ nie	**Progr. Muskelentspannung**
☐ regelmäßig	☐ selten	☐ nie	**Yoga**
☐ regelmäßig	☐ selten	☐ nie	***andere:*** ________________
☐ regelmäßig	☐ selten	☐ nie	***andere:*** ________________

In meiner Freizeit höre ich folgende Musik

☐ oft	☐ gelegentlich	☐ selten oder nie	**Entspannungsmusik**
☐ oft	☐ gelegentlich	☐ selten oder nie	**Hard Rock / Metal**
☐ oft	☐ gelegentlich	☐ selten oder nie	**Indische Musik**
☐ oft	☐ gelegentlich	☐ selten oder nie	**Jazz**
☐ oft	☐ gelegentlich	☐ selten oder nie	**Klassische Musik**
☐ oft	☐ gelegentlich	☐ selten oder nie	**Musical**
☐ oft	☐ gelegentlich	☐ selten oder nie	**Rock / Pop**
☐ oft	☐ gelegentlich	☐ selten oder nie	**Schlager**
☐ oft	☐ gelegentlich	☐ selten oder nie	**Techno**
☐ oft	☐ gelegentlich	☐ selten oder nie	**Volksmusik**
☐ oft	☐ gelegentlich	☐ selten oder nie	***andere:***_________

Haben Sie bereits aktive Erfahrungen / Übung mit mit Biofeedback-Messungen?

☐ nein ☐ ja, nämlich: ___________________________

Leiden Sie bei öffentlichen Auftritten unter Lampenfieber bzw. Bühnenangst? ☐ nein ☐ selten ☐ manchmal ☐ oft ☐ fast immer ☐ weiß nicht

Können Sie Ihre Symptome (und evtl. wie sie sich entwickelt haben) kurz beschreiben?

Hiermit willige ich ein, daß meine Angaben für die Auswertung eines musikwissenschaftlichen Experiments statistisch verarbeitet werden. An dem nun folgenden praktischen Experiment nehme ich freiwillig teil. Soweit mir bekannt ist, leide ich nicht an Krankheiten, die die Funktionalität des Herzkreislaufsystems beeinflussen. Aus der Analyse der Rohdaten resultierende medizinische Diagnosen möchte ich mitgeteilt / nicht mitgeteilt bekommen (bitte zutreffendes unterstreichen).

__________________ __________________

Ort, Datum Unterschrift

13.3 Questionnaire 2

Musiktheoretischer Fragebogen zum Musikbeispiel in Exp. 1[275]

Bitte kreuzen Sie auf den Skalen jeweils das Kästchen an, das für Sie am ehesten zutrifft.

1. Das Musikbeispiel gliederte sich in zwei größere Abschnitte. Wie würden Sie den Tempoverlauf der Musik beschreiben?

□ erst schnell, dann langsam
□ erst langsam, dann schnell
□ keine Änderung im Tempo
□ weiß nicht / keine Angabe

2. Kannten Sie das Stück?

Nie gehört □ □ □ □ □ □ □ auswendig

3. Sind Sie mit dieser Musikrichtung vertraut?

Überhaupt nicht □ □ □ □ □ □ □ sehr

4. Haben Sie das Stück intensiv erlebt?

Ja □ □ □ □ □ □ □ Nein

[275] nach Renner (2001)

5. Konnten Sie sich während des ersten Teils der Musik entspannen?

Ja □ □ □ □ □ □ □ Nein

6. Konnten Sie sich währen des zweiten Teils der Musik entspannen?

Ja □ □ □ □ □ □ □ Nein

7. Glauben Sie, dass die Musik auf Ihr Stressempfinden Einfluss hatte? (Egal, ob positiv oder negativ)

Starker Einfluss □ □ □ □ □ □ □ Kein Einfluss

8. Eine Vermutung, welcher Komponist das Werk geschrieben hat?

____

9. Sind Ihnen Besonderheiten der Interpretation aufgefallen? Was fanden Sie an der Aufnahme bemerkenswert?

____

____

13.4 The handout explaining the test procedures

1. Erwärmungsübung (1 min.)

Bitte klicken Sie mit der Maus so schnell wie möglich die Zahlen an, die rot aufleuchten.
Tip: Es kann sein, dass eine Zahl zwei mal nacheinander aufleuchtet.
Start: Klick auf "S".

2. Musikbeispiel/Atemexperiment (30 min.)

In den Phasen 2, 4 und 6 hören Sie jeweils dasselbe Musikbeispiel. Bitte lassen Sie sich möglichst auf die Musik ein, die Sie hören; im Anschluss an das Experiment wird ein musiktheoretischer Fragebogen, das Beispiel betreffend, auszufüllen sein.
In den Abschnitten 3-6 atmen Sie bitte im angegebenen Puls-/Atem-Verhältnis. Dafür gilt es, die numerische Anzeige des EKG-Gerätes zu beobachten und die Atemgeschwindigkeit darauf einzustellen.[276]

Abschnitt *(je 5 min.)*	Musik	Puls-/Atem-Quotient
1	–	–
2	X	–
3	–	:
4	X	:
5	–	:
6	X	:

[276] Die Atemquotienten werden vom Versuchsleiter eingetragen. "6:1" bedeutet: ein Atemzug soll sechs Herzschläge lang dauern, nämlich drei Herzschläge lang einatmen und drei Herzschläge lang ausatmen. "10:1" bedeutet: ein Atemzug soll zehn Herzschläge lang dauern, nämlich fünf Herzschläge lang einatmen und fünf Herzschläge lang ausatmen. *Achtung*: Bitte verändern Sie nicht Ihre Atem*tiefe*! Ein normales Atemvolumen soll über den gesamten Versuch beibehalten werden; nur die Geschwindigkeit der Atmung variiert. Es ist erlaubt, nach dem normalen Einatmen den Atem kurz anzuhalten, um das Puls-/Atemverhältnis einzustellen.

3. Metronom-/Feedback-Experiment (15 min.)

Bitte versuchen Sie, rein durch Imagination von Stress-Situationen oder entspannenden Szenarios (möglichst nicht durch Veränderung der Atmung, Körperbewegungen o.ä.) Ihre Herzfrequenz mittels des optischen und akustischen Feedbacks zu beeinflussen. *Achtung: Die Metronomfrequenz bleibt dabei immer gleich!* Die Metronomfrequenz wird vom Versuchsleiter in den Titel der mittleren Spalte eingetragen; die Zielfrequenzen der jeweiligen Abschnitte werden in die rechte Spalte der Tabelle eingetragen.

Abschnitt *(je 150 s.)*	Metronom (bpm)	Ziel der Herzfrequenz
1	X	bpm
2	–	bpm
3	X	bpm
4	–	bpm
5	X	bpm
6	–	bpm

14 Additional material

The following pages contain additional material, including the physiological data recorded during the Stimulus Reaction Test and the two experiments, and a number of diagrams that further illustrate the results described earlier on. To provide an overview of the analysed data, of the 139 parameters analysed in total, the most important are listed below, with the total number of valid cases, minimum, maximum, and mean values, and standard deviation indicated respectively.

14.1 Material from the questionnaires

14.1.1 Subjects' descriptions regarding their performance anxiety

Examples of how subjects in the musicians group described their performance anxiety in Questionnaire 1:

- have a lump in the throat, a "gut feeling", flat breathing, overall strain/tightness
- fear of forgetting the notes, fear of a big concert hall / a big audience
- shaky hands, dry mouth
- cold and sweaty hands, increased intestinal function
- restlessness, connected with sweating and other vegetative symptoms. Increased heart frequency, "heartthrob", deficiency in concentration
- jumpiness
- shivering, rarely cramps
- only when performing solo: heart throbbing, shaking of the violin bow, the feeling "I stand besides myself"
- over-tension in the arms (shivering), sweaty hands, tension in the belly / the legs when sitting, sometimes tachycardias. Whether the symptoms occur depends solely on overall preconditions, and my own expectation
- cold, sweaty hands; strong inner nervousness; concentration problems during the performance

- very nervous, occasional blackout. "During the concert, at an unexpected solo, I suddenly had forgotten how to play an 'f'. Of the 120 % that had been there before, there were only 80 % left"
- stage anxiety decreased by job routine. Started to be bothered by it during adolescence, at about 16. Suddenly, one gets aware of one's role, and the pressure starts to grow
- Strong stage anxiety. Subject underwent a 24-hour ECG. There are arrhythmias known, but they do not require therapy. Overall high stress levels at the moment

Descriptions of anxieties experienced by subjects in the control group were quite similar, and included

- sweating, cold hands, shaky, red face
- heart throbbing, sometimes intestinal disturbances, restlessness
- sweaty, wet hands, increased heart frequency
- nervousness; at times nausea; restlessness, and, as a consequence, the ambition to rehearse again, and more properly
- heart throbbing, tachycardia, wet hands, thoughts spinning round. All that is suddenly gone when the performance starts!
- fast heart beat

14.1.2 Musical preferences

Subjects were asked to name their music preferences in Questionnaire 2, and note how often they listened to the respective musical style. Their answers show that subjects belonging to the 'musicians' group generally prefer to listen to "Classical Music" in their spare time. Other musical styles named by the subjects were "Gothic/Middle Age", "Tango", "Ethno/Folk", and "Chanson". Controls generally prefer to listen to "Rock/Pop" in their spare time. Other musical styles named by the subjects were "Blues", "World Music", and "Contemporary Music".

14.2 Material from the Stimulus Reaction Test

A Stimulus Reaction Test had to be performed by the subjects before the experiments were conducted. For the test, a MATLAB program was

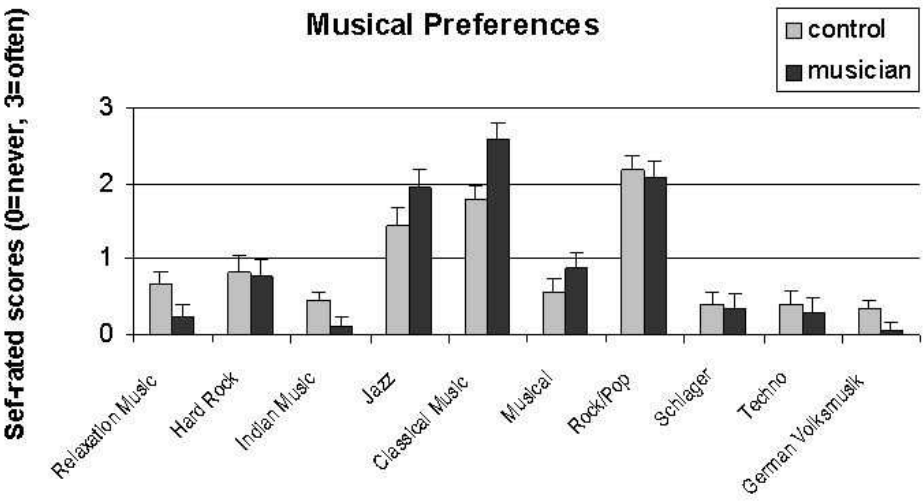

Figure 69: Music preferences, according to Questionnaire 2
Cumulated ratings show that subjects belonging to the 'musicians' group generally prefer to listen to Classical Music *in their spare time, whereas controls generally prefer to listen to* Rock/Pop.

	N	min	max	mean	sd
No. of breaths	35	13	28	21.6	3.6
No. of R-waves	35	61	109	83.4	14.1
PRR[277]	35	2.42	6.07	4.0	0.9
av. reaction time (s)	35	0.58	1.11	0.8	0.1

Table 21: Analysed parameters in the Stimulus Reaction Test

written by Araguzo Rivera, and revised by Reuter and Morgenstern. It displays a numerical keypad on the computer screen. The test lasts one minute, during which time numbers on this keypad light up consecutively in random order, and the subject has to click onto the highlighted number as quickly as possible. As soon as a number is hit correctly, the next number is highlighted. The same numbers can light up more than once. After the test is finished, "Tastatur.m" writes the reaction times into a log file named *Ergebnistastatur.mat*, which is overwritten with every new trial.

During the Stimulus Reaction Test, artefacts were recorded in a relatively high number of subjects. Most of these artifacts were due to muscular activity when using the computer mouse. The following three graphs show three different examples. Because of the relatively poor data quality resulting from high muscular activity during the test, the ECG was not analysed further, and only the RR intervals were analysed. For the program code, see 229.

[277]Pulse-respiration ratio

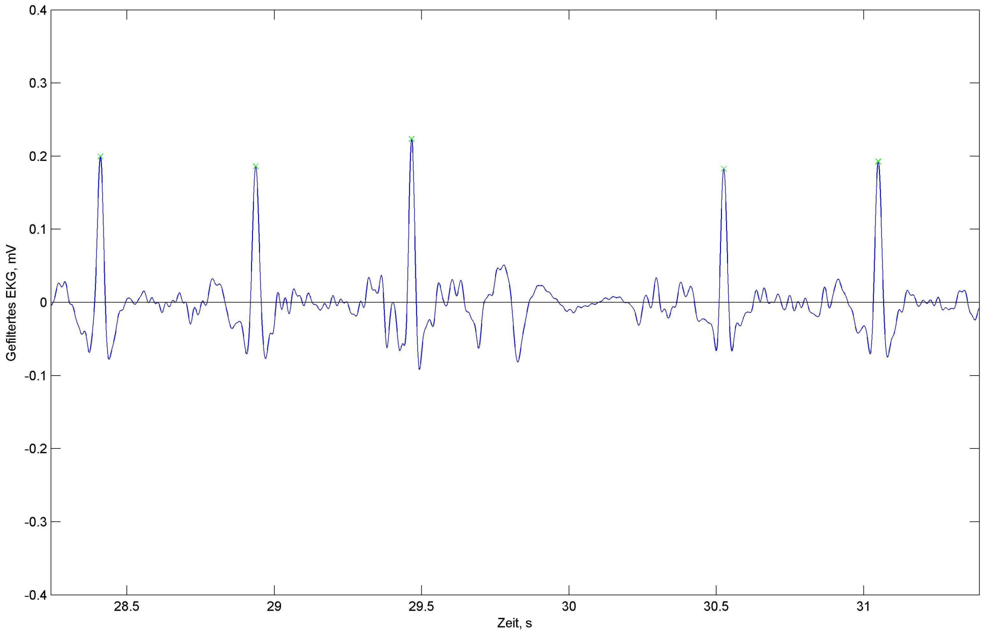

Figure 70: Recorded artefact during the Stimulus Reaction Test (I)
Example 1 (from subject No. 124): What could be a systolic pause, was rated as an artefact due to muscular activity during the Stimulus Reaction Test.

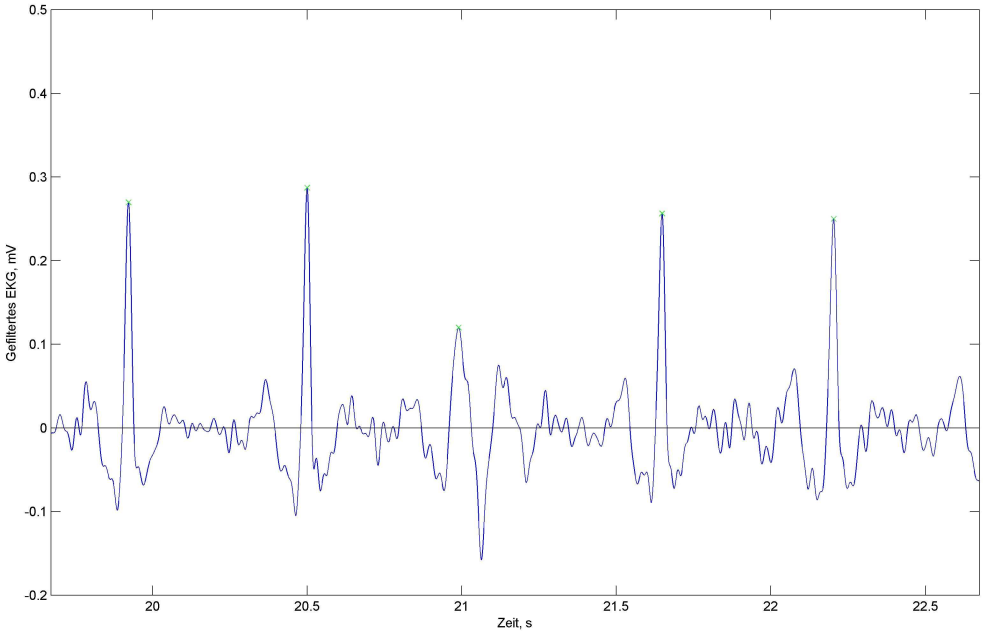

Figure 71: Recorded artefact during the Stimulus Reaction Test (II)
Example 2 (from subject No. 129): The irregular shape of a QRS complex was rated as an artefact due to muscular activity during the Stimulus Reaction Test

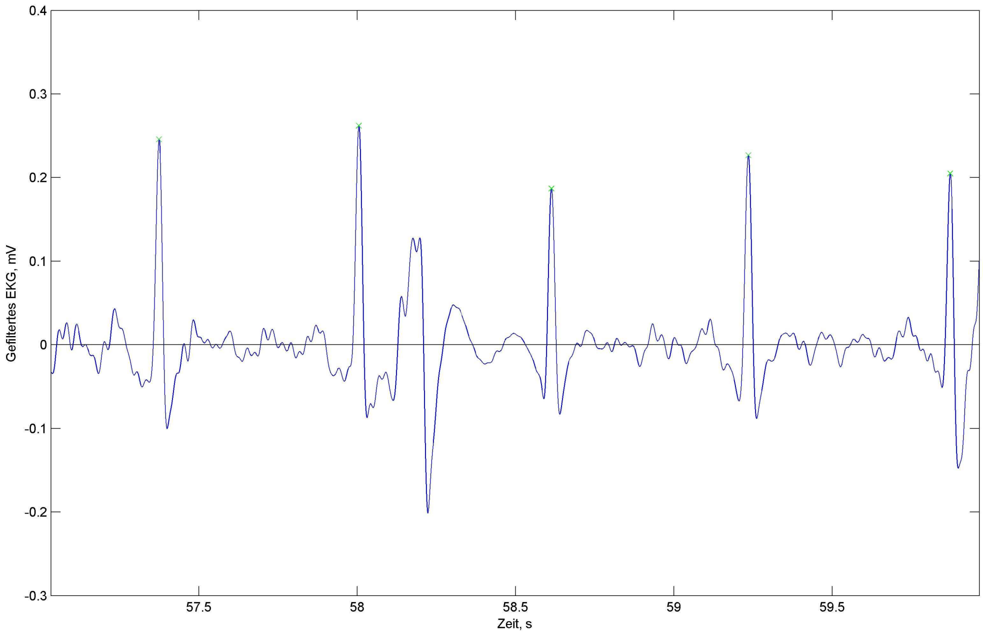

Figure 72: Recorded artefact during the Stimulus Reaction Test (III)
Example 3 (from subject No. 120): What could be a ventricular extra-systole (VES) was nevertheless rated as an artefact due to muscular activity during the Stimulus Reaction Test.

14.3 Material from Experiment 1

14.3.1 Tempo analysis

To determine beat-to-beat tempo changes in music recordings for further correlation analyses, a Java™ program was written by Wieland Morgenstern.[278] It is freeware, and so it can be freely distributed and used for further musicological and other experiments.

The beat-to-beat tempo is obtained by averaging data from a number of tapping trials. To predict and tap on musical beats as accurately as possible, the experimenter has to choose an appropriate tapping tempo. In this example, covering parts of two different movements and the adjoining cadenza, the experimenter tapped the slow movement in quavers, and the fast movement in half bars, which resulted in tapping interval lengths of around 1000 ms. High correlation coefficients between the trials ($\rho^{1/2} = 0.981$; $\rho^{2/3} = 0.978$; $\rho^{1/3} = 0.981$ for the overall tapping task, including both movements) suggest that the tempo assessment procedure is reliable.

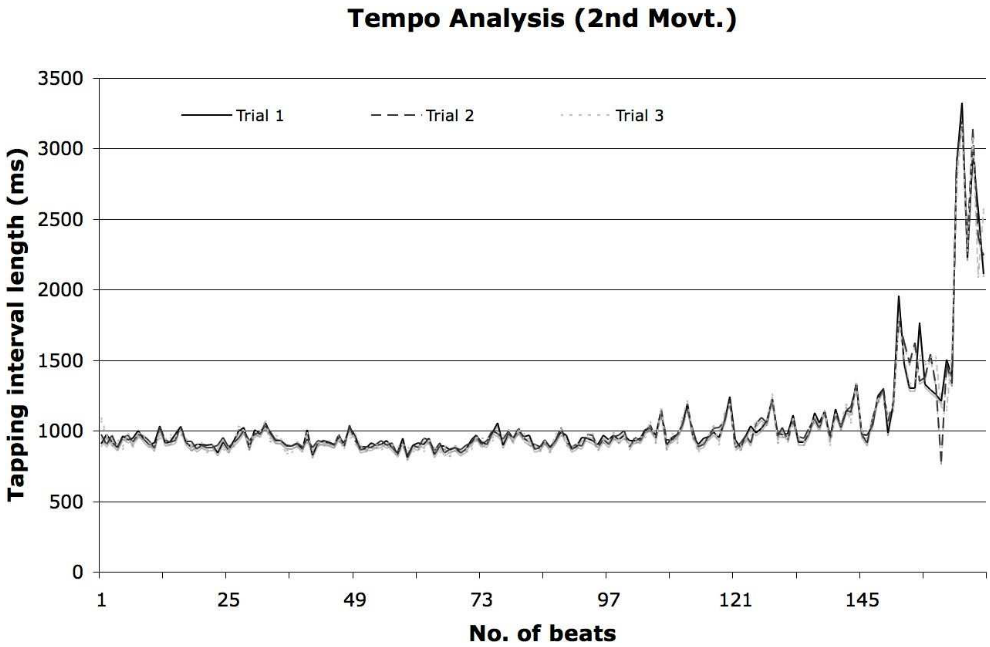

Figure 73: Tempo assessment (2^{nd} movt.)
The graph shows a clip from three trials of a tempo assessment of Glenn Gould's interpretation of Beethoven's Fifth Piano Concerto (2^{nd} movt.). See Figure 74 also.

[278]Java, and all Java-related trademarks are trademarks or registered trademarks of Sun Microsystems, Inc., USA. For further information, see Krüger (2006).

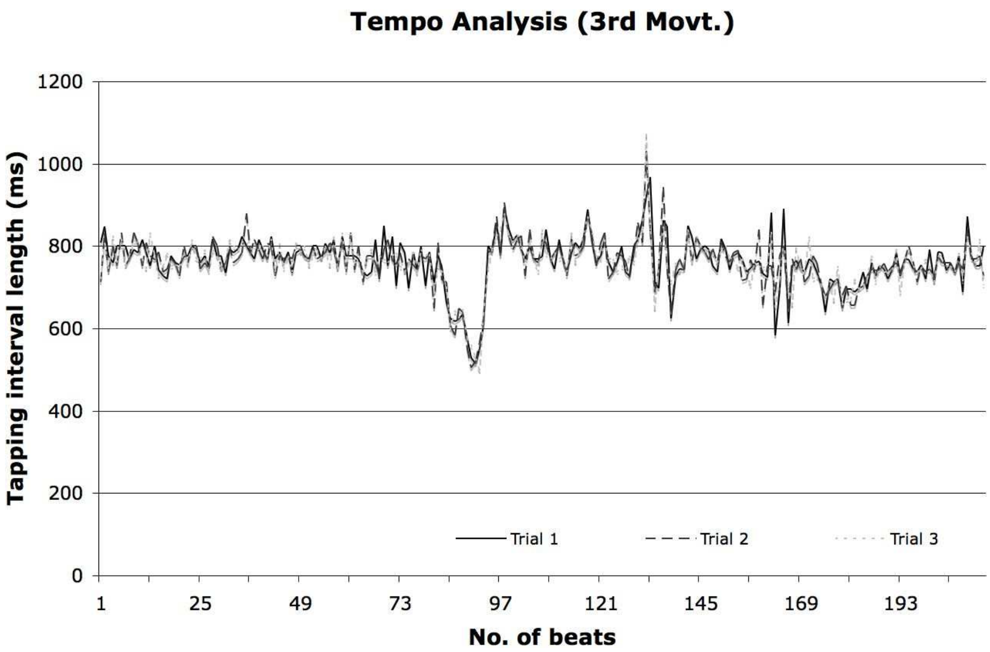

Figure 74: Tempo assessment (3^{rd} movt.)
The graph shows a clipping from three trials of a tempo assessment of Glenn Gould's interpretation of Beethoven's Fifth Piano Concerto (3^{rd} movt.).

For Experiment 1, an audio sample had to be chosen where potential coordination effects between musical beat and cardio-respiratory rhythms could be investigated. Therefore, different interpretations of the same music sequence from Beethoven's 5^{th} Piano Concerto in E-flat Major op. 73 ("Emperor") were compared in overall tempo, and tempo variability and stability. The interpretations were by:

1. Rudolf Serkin (Piano); Leonard Bernstein conducting the New York Philharmonic (recorded 1962) ©1991 Universe UN026
2. Alexis Weissenberg (Piano); Herbert von Karajan conducting the Berliner Philharmoniker (recorded 1988) ©1989 EMI CZS 25 2172 2
3. Walter Gieseking (Piano); Artur Rother conducting the Großes Berliner Rundfunkorchester (recorded 1944) ©1988 DANTE PRODUCTIONS HPC133
4. Claudio Arrau (Piano); Sir Colin Davis conducting the Staatskapelle Dresden (recorded 1984) ©1984 VEB ETERNA Deutsche Schallplatten Berlin 3 29 083
5. Glenn Gould (Piano); Leopold Stokowski conducting the American

Symphony Orchestra (recorded 1966) ©1992 SONY Classical SM3K 52632 ADD

The musical tempo was analysed in samples lasting approximately 5 minutes, starting in bar 60 of the 2^{nd} movement, and ending after bar 109 of the 3^{rd} movement. In that way, two different, relatively tempo-stable segments and the transition were included.

The analysis showed that the relative conformity of tempi among the five interpretations is high. All performers play a natural ritardando at the end of the 2^{nd} movement starting in bar 76 (although it is not marked in the ur-text version of the score), and decelerate the tempo further in the last bars of the 2^{nd} movement. Except for these ritardandi, soloists keep a more or less steady beat during the 2^{nd} and the 3^{rd} movement, only decelerating for the ritardandi noted in the score (3^{rd} movement, bar 59-60 and 61-62).

An evaluation of the analysed tempo decelerations and accelerations led to the decision to use Claudio Arrau's interpretation for Experiment 1. Arrau plays the 19 bars of the 2^{nd} movement before the cadenza (bars 60–78) in an average tempo of 80.15 *bpm* (counting quavers); the 3^{rd} movement is played with $77,24$ *bpm* (counting half 6/8 bars).

These findings support the notion that interpretors tend to match the musical pulse of the movements of a concerto;[279] a conductor (beating the slow movement in crotchets and the fast 3^{rd} movement in half bars), would try to perpetuate the underlying beat.

[279] For a discussion of *pulse salience*, see Parncutt (1994). For a discussion of the temporal organisation regarding perceived rhythms in musical sequences and the extraction of an underlying beat, see Peretz (2000, p. 531f.)

Figure 75: Ritardando at the end of 2^{nd} movement
All performers play a natural ritardando at the end of the 2^{nd} movement. This is not marked in the urtext version of the score.

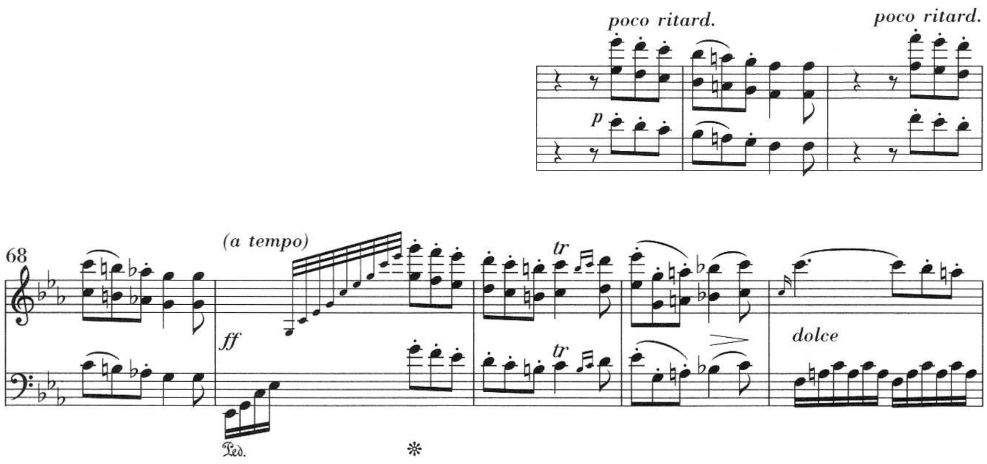

Figure 76: Two ritardandi in the solo piano
Tempo assessment of Beethoven's Fifth Piano Concerto. All the interpretations used in the analysis, except that from Glenn Gould, contain the two ritardandi. Gould, instead, accelerates the tempo only when the piano has its first solo of the 3^{rd} movement.

14.3.2 Subjects' remarks regarding the interpretation of the musical sample

Regarding the verbal and written feedback of subjects, it should be noted that the aesthetic aspects of a musical interpretation play a vital role in the involvement of listeners and therefore influence their psycho-physiological reaction. Although disregarded by almost all studies investigating the psycho-physiological effects of music in a clinical setting, parameters such as recording quality, intonation, ornamentation, instrumentation, technique, reverb, etc. do obviously influence the general reception of a musical piece. Therefore, there should be more attention paid to such parameters in future studies. The table on page 223 lists written feedback from Questionnaire 2 regarding interpretational issues of the recording played during Experiment 1.

14.4 Material from Experiment 2

Experiment 2 demonstrated that even when subjects are asked not to change their respiration behaviour during an investigation of heart activity, they might - consciously or unconsciously - do just that, thereby altering their heart rates (see, for example, Figure 79, Figure 80, Figure 81, and Figure 82).

Figure 77: Tempo acceleration of the solo voice
Tempo assessment of Beethoven's Fifth Piano Concerto. Glenn Gould noticeably accelerates the beginning of the solo, later decelerating to the general tempo again in bar 47 and 48, where all the other performers keep the tempo steady.

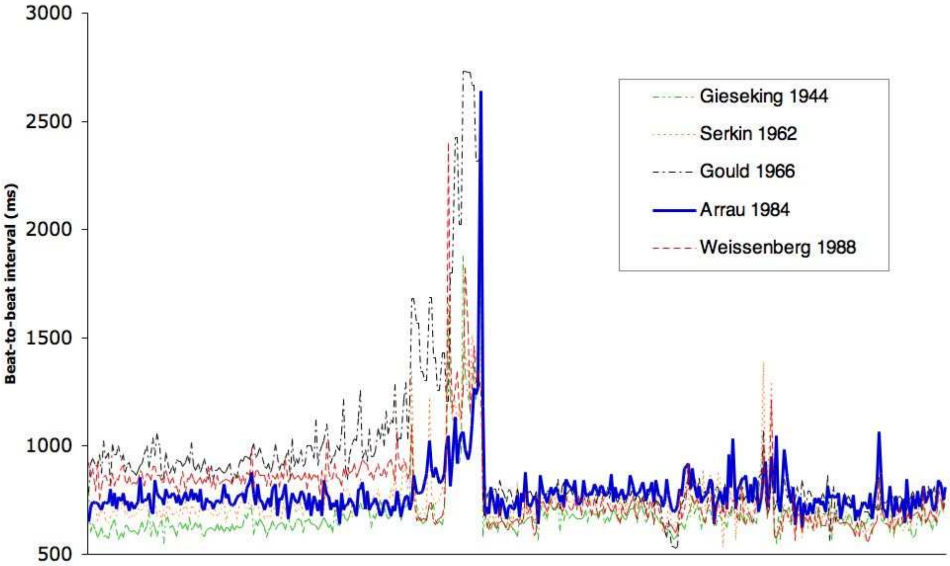

Figure 78: A tempo analysis of five performances

A tempo analysis of the musical samples reveals that in Arrau's performance of 1984, the 2^{nd} *and* 3^{rd} *movements are closely matched regarding overall tempo. The graph shows discrete tapping intervals over a standardised time scale, representing quavers (*2^{nd} *movement) and half bars (*3^{rd} *movement), with the shift after the cadenza.*

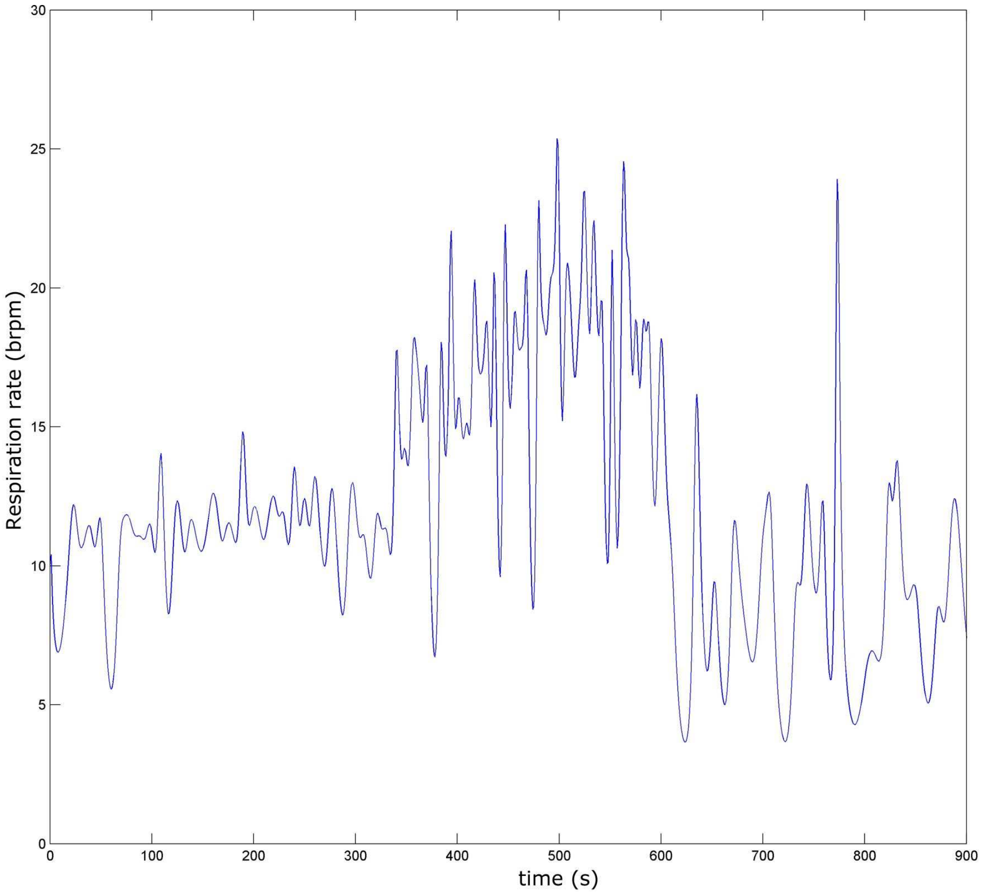

Figure 79: Increase and decrease of respiration rate as a strategy of influencing heart rate

The graph shows how the subject's respiration rate changed with the subject's effort to actively increase and decrease heart rate (the graph shows all six consecutive phases, each 150 seconds long). Example: Subject No. 109

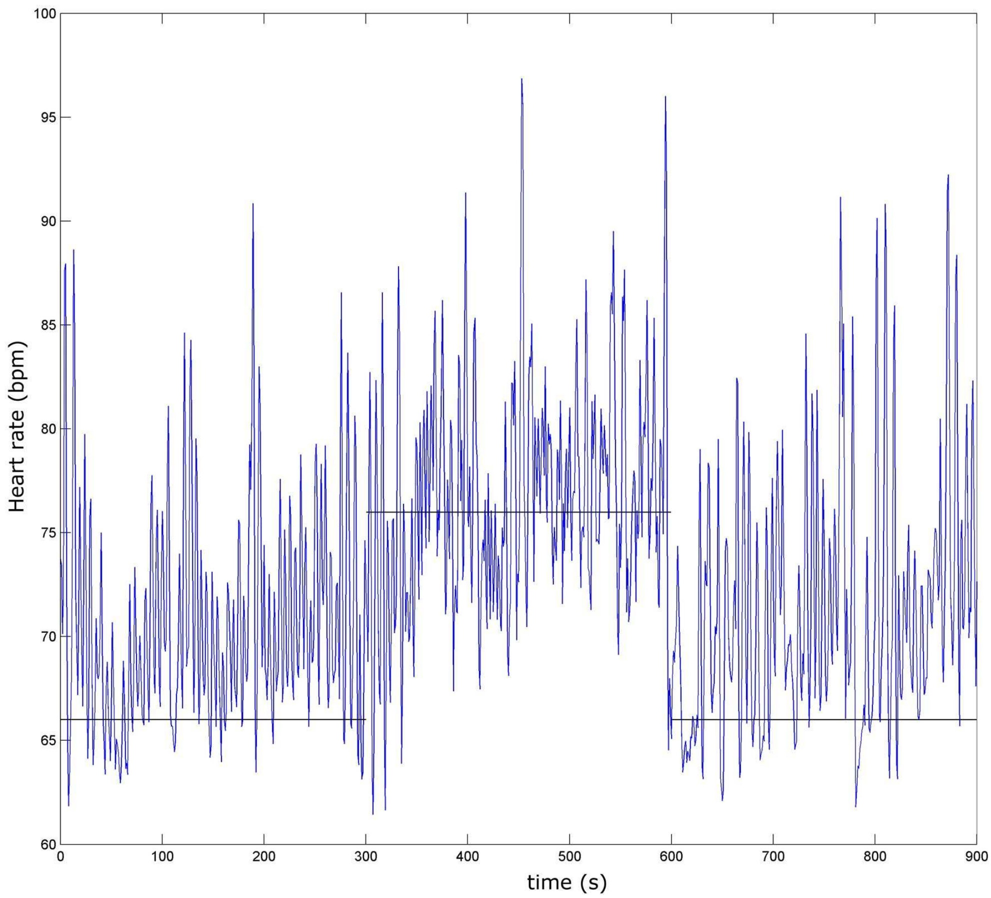

Figure 80: Changed heart rate as a result of increased and decreased respiration rate

The graph shows the successful result of the subject's effort to actively increase and decrease heart rate (the graph shows all six consecutive phases, each 150 seconds long). Example: Subject No. 109. Target heart rate is depicted as black line.

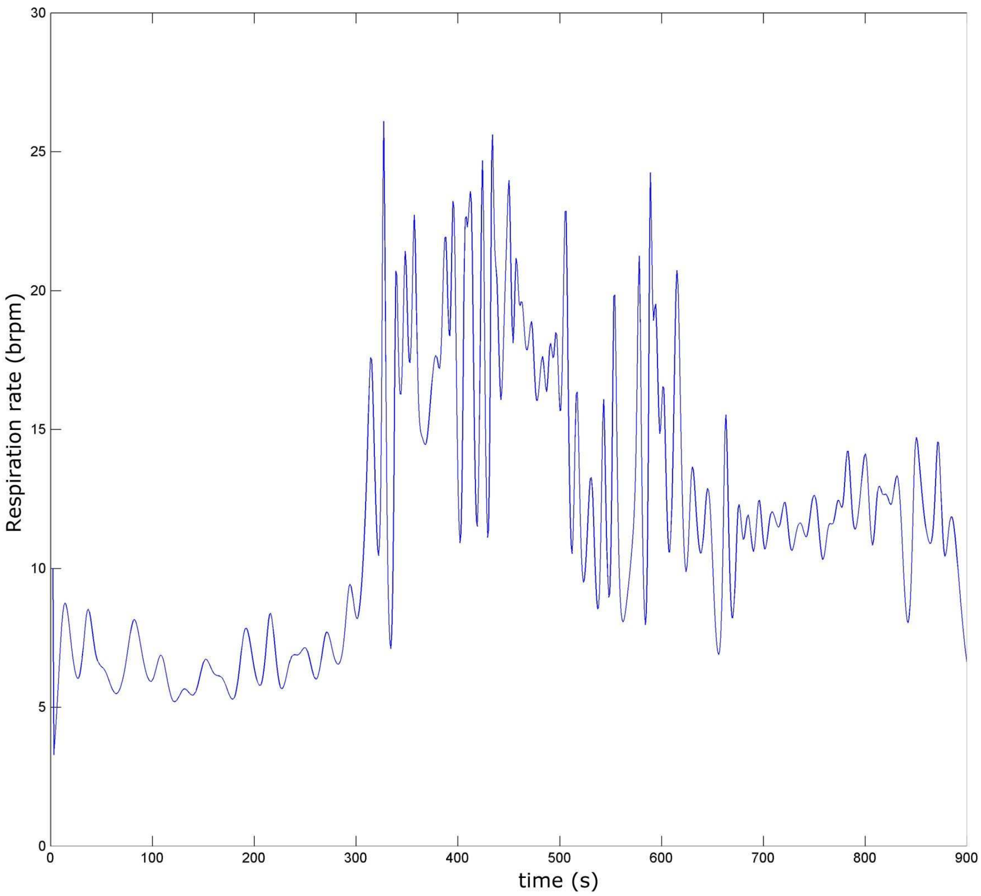

Figure 81: Increase of respiration volume as a strategy of increasing heart rate

The graph shows how the subject's respiration volume and variability changed with the subject's effort to actively increase heart rate during phases 3 and 4 (the graph shows all six consecutive phases, each 150 seconds long). Example: Subject No. 116

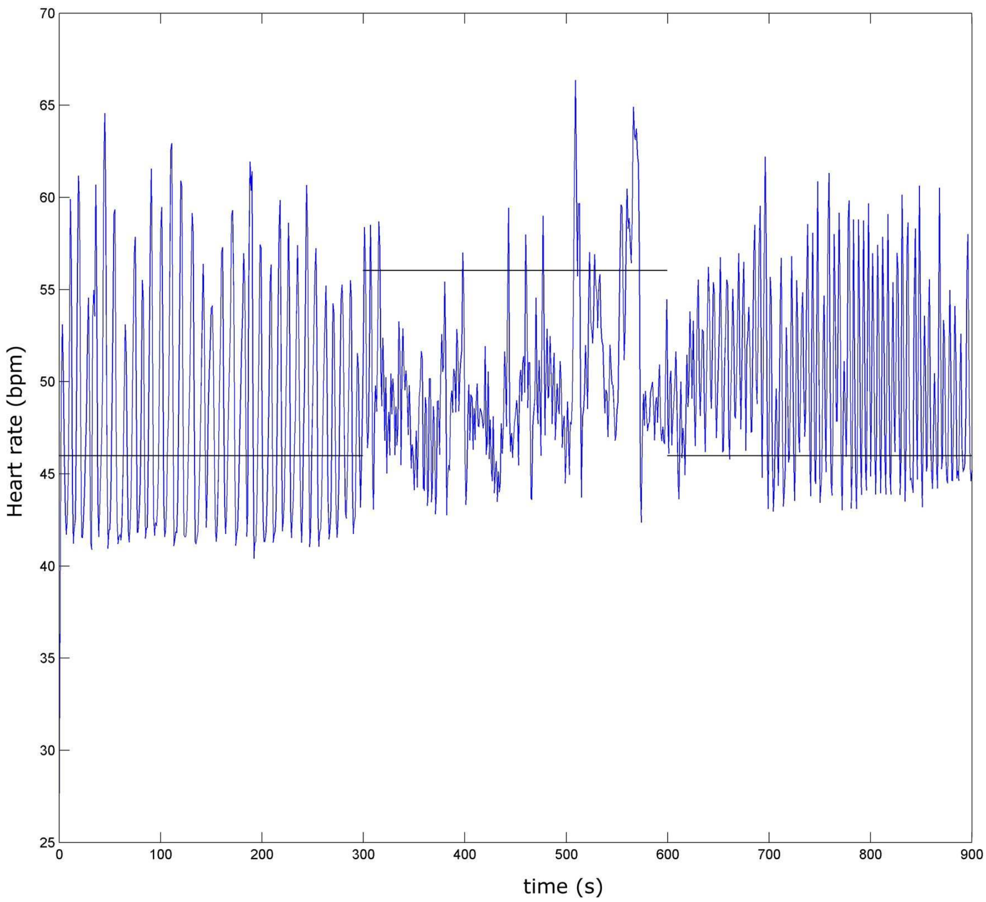

Figure 82: Changed heart rate behaviour as a result of chaotic respiration behaviour

The graph shows how the subject's heart rate variability increased with the subject's effort to actively increase heart rate during phases 3 and 4 (the graph shows all six consecutive phases, each 150 seconds long). Example: Subject No. 116. Target heart rate is depicted as black line.

Subject No.	
102	Der Pianist war nicht so gut.
107	Große dynamische Unterschiede.
109	Unsauber gespielte 16tel im Klavier.
110	Übergänge sehr musikalisch empfunden [...] ohne Brüche.
113	Etwas langsam, zu statisch.
114	Sehr langsam, auch der schnelle Teil. Schlechter Pianist.
117	Gute Ausgewogenheit Klavier/Orchester, aber hat mich klanglich & von der Spannung her weniger angesprochen (v.a. Klavier).
118	Violinen klangen fast nach Synthesizer.
124	Der Holzbläsersatz war sehr schön.
125	Etwas zu viel künstlicher Hall.
128	Schöne Holzbläser.
131	Klavier war mir zu "brutal". Mir geht es zu "nah".
135	Solist hat die Tempi schön gewählt. 2./3. Satz gut interpretiert. Flötensoli schön gespielt.

Table 22: Subjects' remarks regarding the musical sample

14.5 Software programs

In the course of preparing the experiments for this study, a number of software programs were developed. Since the documentation and publication of these programs might not only help to explain and reproduce the experiments conducted, but might also stimulate further research in this area, it was decided to include some of them in this Appendix.

14.5.1 Recording bio-data with "Kardio.m"

The Kardio.m program that was used in the present study is described in detail in Rivera (2006). It provides routines to record and store any bio-data that is streamed in via an A/D converter, and can be adapted to various resolutions and amplitudes.

14.5.2 Analysis of cardiovascular and respiratory parameters with "HRV.m"

The HRV.m program that was also used in the present study is described in detail in Reuter (2007). It provides routines to analyse pre-recorded cardiac and respiratory data, and to calculate various standard measures.

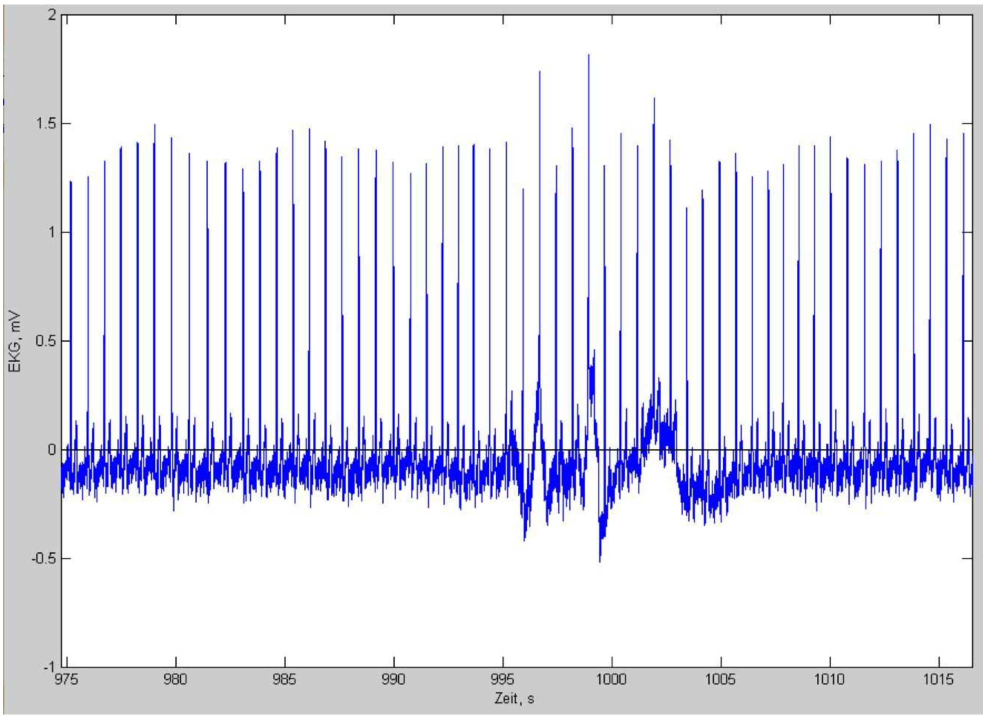

Figure 83: Baseline shift of the electrocardiac raw data
Baseline shifts occur due to physical movements of the subjects during the recording. They alter the electrophysical relations of the three extremity electrodes. With the help of a band-pass filter, they can be extracted from the raw data set.

14.5.3 The tapping analysis program "Tapping.m"

```
% --------------   TEMPO ANALYSIS PROGRAM    --------------------

import java.awt.BorderLayout;
import java.awt.FlowLayout;
import java.awt.GridLayout;
import java.awt.event.KeyEvent;
import java.awt.event.KeyListener;
import java.awt.event.WindowEvent;
import java.awt.event.WindowListener;
import java.io.BufferedWriter;
import java.io.FileWriter;
import java.util.Calendar;

import javax.swing.JFrame;
```

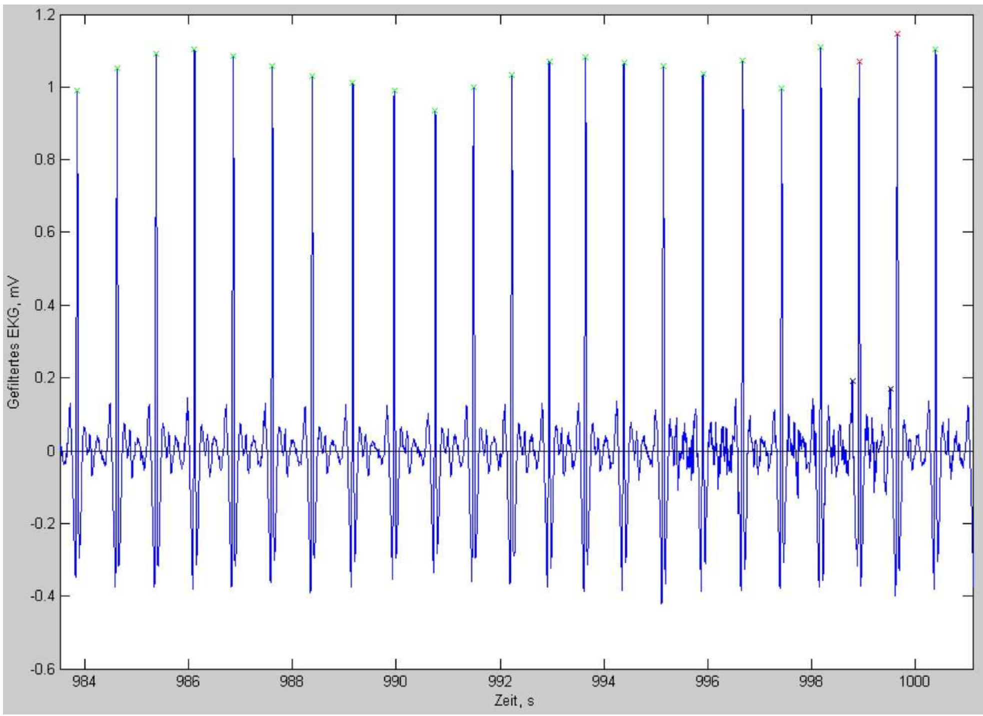

Figure 84: R wave detection via the "HRV.m" software program
To determine the RR intervals, the R waves had to be extracted from the raw data. The software also allows the operator to manually add or remove detected R waves later in case the threshold was not chosen accurately enough, or in case of irregular beats.

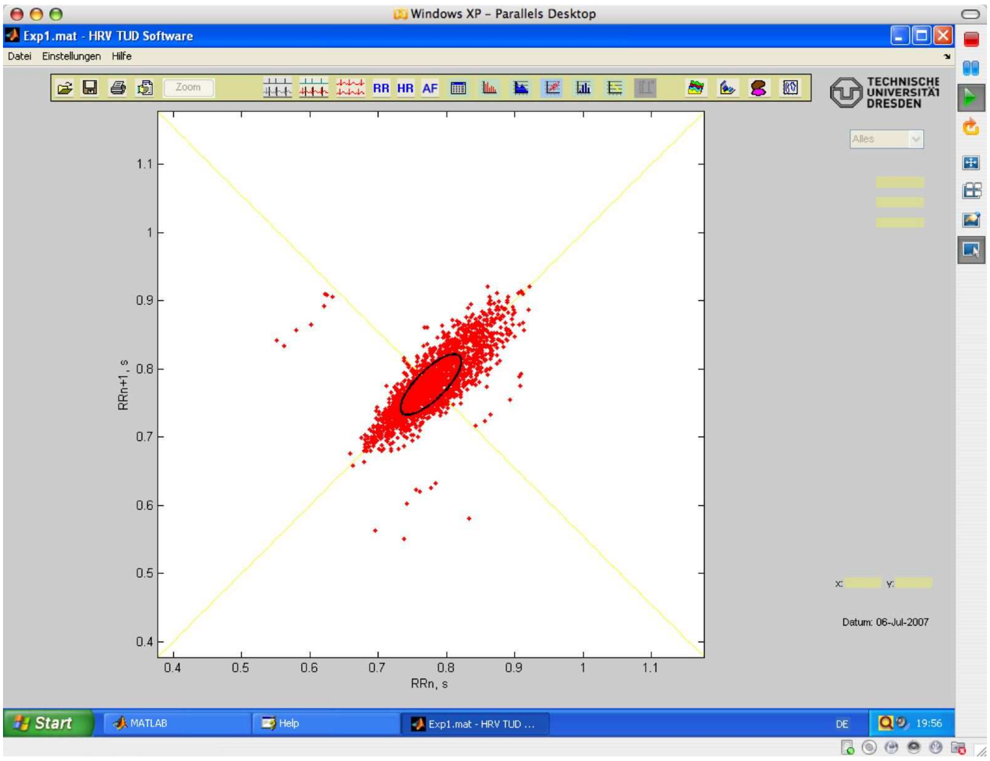

Figure 85: "HRV.m": Lorenz plot reveals irregular R wave detections
The Lorenz plot function – a geometric phase-space representation of RR interval data – displays heart rate variability, but can also reveal irregular R wave detections.

```
import javax.swing.JLabel;
import javax.swing.JOptionPane;
import javax.swing.JPanel;
import javax.swing.UIManager;

public class TempoAnalysis implements KeyListener, WindowListener {

        public static void main(String[] args) {
                new TempoAnalysis();
        }

        JLabel ltime;

        public TempoAnalysis() {
                try {
                        UIManager.setLookAndFeel(UIManager.getSystemLookAndFeelClassName());
                } catch (Exception e) {
                }
                JFrame fra = new JFrame();
                JPanel panel = new JPanel();
                JLabel l1 = new JLabel(''  This tool will record the time that elapses between keystrokes in milliseconds.'');
                JLabel l2 = new JLabel(''  To terminate the application and generate a log file press 'q' or close the window.'');
                JLabel l3 = new JLabel(''  Use the alphabetical keys (except 'q') to trigger the event of recording.'');
                JLabel l4 = new JLabel(''  Note: Using this tool on a Windows9x machine will lead to inaccuracy of 50-55ms.'');
                ltime = new JLabel(''  Last time span: n/a'');
                fra.setBounds(200, 200, l2.getPreferredSize().width+50, 200);
                panel.setLayout(new GridLayout(0,1));
                panel.add(l1);
                panel.add(l2);
                panel.add(l3);
                panel.add(ltime);
                panel.add(l4);
                fra.getContentPane().add(panel);
                fra.setTitle(''Tempo-analysis'');
                fra.addKeyListener(this);
                fra.addWindowListener(this);
                fra.setVisible(true);
        }

        public void close(){
                if(inputData.length > 0){
                        try {
                                Calendar cal = Calendar.getInstance();
                                FileWriter fw = new FileWriter(''log tempo-analysis ''
                                                + cal.get(Calendar.DAY_OF_MONTH) + ''-''
                                                + cal.get(Calendar.MONTH) + ''-''
                                                + cal.get(Calendar.YEAR) + '' ''
                                                + cal.get(Calendar.HOUR_OF_DAY) + ''h''
                                                + cal.get(Calendar.MINUTE) + ''m''
                                                + cal.get(Calendar.SECOND) + ''s.txt'');
                                BufferedWriter bw = new BufferedWriter(fw);
                                int sum = 0;
                                for (int i = 0; i < inputData.length; i++) {
                                        sum += inputData[i];
                                        bw.write('''' + inputData[i]);
                                        bw.newLine();
                                }
                                bw.write(''---------------------'');
                                bw.write('''' + ((double) sum / inputData.length));
                                bw.close();
                        } catch (Exception ex) {
                                JOptionPane.showMessageDialog(null, ''Error writing log file.'', ''Error'', JOptionPane.ERROR_MESSAGE);
                        }
                }
                System.exit(0);
        }

        public void keyPressed(KeyEvent e) {
        }

        public void keyReleased(KeyEvent e) {
        }

        int[] inputData = new int[0];

        long lastTime = -1;

        public void keyTyped(KeyEvent e) {
                String f = Character.toString(e.getKeyChar());

                if (f.equals(''q'') || f.equals(''Q'')) {
                        close();
                } else {
                        if(lastTime != -1){
                                int[] newData = new int[inputData.length + 1];
```

```
                        for (int i = 0; i < inputData.length; i++) {
                                newData[i] = inputData[i];
                        }
                        inputData = newData;
                        inputData[inputData.length - 1] = (int) (System.currentTimeMillis() - lastTime);
                        ltime.setText(''  Last time span: ''+ (System.currentTimeMillis() - lastTime)+''ms'');
                }
                lastTime = System.currentTimeMillis();
        }
}

public void windowActivated(WindowEvent e) {
}

public void windowClosed(WindowEvent e) {
}

public void windowClosing(WindowEvent e) {
        close();
}

public void windowDeactivated(WindowEvent e) {
}

public void windowDeiconified(WindowEvent e) {
}

public void windowIconified(WindowEvent e) {
}

public void windowOpened(WindowEvent e) {
}

}
```

14.5.4 The Stimulus Reaction Test program "Tastatur.m"

```
% --------------   PROGRAM TASTATUR.M   -------------------------

function Tastatur1(varargin);

if nargin == 0
    Tastatur1('Oberflaeche');
elseif ischar(varargin{1})
    try
        feval(varargin{:})
    catch
        disp('Das Programm muss geschlossen werden.')
    end
end

% --------------------------------------------------------------------------------
function Limpiar

global B0
global B1
global B2
global B3
global B4
global B5
global B6
global B7
global B8
global B9

set(B0,'ForegroundColor','k')
set(B1,'ForegroundColor','k')
set(B2,'ForegroundColor','k')
set(B3,'ForegroundColor','k')
set(B4,'ForegroundColor','k')
set(B5,'ForegroundColor','k')
set(B6,'ForegroundColor','k')
set(B7,'ForegroundColor','k')
set(B8,'ForegroundColor','k')
set(B9,'ForegroundColor','k')
return

% --------------------------------------------------------------------------------
function Introducenumero(numero)
%Es zeigt die neue Nummer an und erfasst die Eingaben

global B0
global B1
global B2
global B3
global B4
global B5
global B6
global B7
global B8
global B9
global Ergebnis
global numale
global Serie
global TANFANG
global Zeit
global Zeitabs
global Zanfang



if (numale == numero)
    Zeitabs=[Zeitabs etime(clock,TANFANG)];
    Serie=[Serie numero];
    Zeit=[Zeit etime(clock,Zanfang)];
    Ergebnis=[Serie', Zeitabs', Zeit'];
    uiresume;
end

return

% --------------------------------------------------------------------------------
function Oberflaeche
%Konfiguration der Bedienoberfläche

global BS
global B0
global B1
```

```
global B2
global B3
global B4
global B5
global B6
global B7
global B8
global B9

tamanoboton=100;

Fenster = figure('NumberTitle','off','Name','Intelligente Tastatur','MenuBar','none',...
    'Position',[10 40 10*tamanoboton 7*tamanoboton],'WindowStyle','modal','Closerequestfcn','Tastatur1(''Schliessen'')');

BS = uicontrol(Fenster,'Style','PushButton','String','S','Position',[3.5*tamanoboton 1.5*tamanoboton tamanoboton tamanoboton],...
    'Callback','Tastatur1(''Randomisierung'');','FontSize',70);

B0 = uicontrol(Fenster,'Style','PushButton','String','0','Position',[3.5*tamanoboton 4.5*tamanoboton tamanoboton tamanoboton],...
    'Callback','Tastatur1(''Introducenumero'',0)','FontSize',70);

B1 = uicontrol(Fenster,'Style','PushButton','String','1','Position',[4.5*tamanoboton 4.5*tamanoboton tamanoboton tamanoboton'],...
    'Callback','Tastatur1(''Introducenumero'',1)','FontSize',70);

B2 = uicontrol(Fenster,'Style','PushButton','String','2','Position',[5.5*tamanoboton 4.5*tamanoboton tamanoboton tamanoboton'],...
    'Callback','Tastatur1(''Introducenumero'',2)','FontSize',70);

B3 = uicontrol(Fenster,'Style','PushButton','String','3','Position',[3.5*tamanoboton 3.5*tamanoboton tamanoboton tamanoboton'],...
    'Callback','Tastatur1(''Introducenumero'',3)','FontSize',70);

B4 = uicontrol(Fenster,'Style','PushButton','String','4','Position',[4.5*tamanoboton 3.5*tamanoboton tamanoboton tamanoboton'],...
    'Callback','Tastatur1(''Introducenumero'',4)','FontSize',70);

B5 = uicontrol(Fenster,'Style','PushButton','String','5','Position',[5.5*tamanoboton 3.5*tamanoboton tamanoboton tamanoboton'],...
    'Callback','Tastatur1(''Introducenumero'',5)','FontSize',70);

B6 = uicontrol(Fenster,'Style','PushButton','String','6','Position',[3.5*tamanoboton 2.5*tamanoboton tamanoboton tamanoboton'],...
    'Callback','Tastatur1(''Introducenumero'',6)','FontSize',70);

B7 = uicontrol(Fenster,'Style','PushButton','String','7','Position',[4.5*tamanoboton 2.5*tamanoboton tamanoboton tamanoboton'],...
    'Callback','Tastatur1(''Introducenumero'',7)','FontSize',70);

B8 = uicontrol(Fenster,'Style','PushButton','String','8','Position',[5.5*tamanoboton 2.5*tamanoboton tamanoboton tamanoboton'],...
    'Callback','Tastatur1(''Introducenumero'',8)','FontSize',70);

B9 = uicontrol(Fenster,'Style','PushButton','String','9','Position',[4.5*tamanoboton 1.5*tamanoboton tamanoboton tamanoboton'],...
    'Callback','Tastatur1(''Introducenumero'',9)','FontSize',70);
return

% ------------------------------------------------------------------------------
function Randomisierung
% Es wählt eine neue Ziffer und legt die initiale Zeit fest

global BS
global B0
global B1
global B2
global B3
global B4
global B5
global B6
global B7
global B8
global B9
global numale
global Serie
global TANFANG
global Zanfang
global Zeit
global Zeitabs

set(BS,'Enable','off');

Serie=[];
Zeit=[];
Zeitn=[];
Zeitabs=[];


TANFANG = clock;
while etime(clock,TANFANG) < 60
    numale=fix(10*rand(1,1));
    switch numale
        case 0
            set(B0,'ForegroundColor','r')
        case 1
```

```
            set(B1,'ForegroundColor','r')
        case 2
            set(B2,'ForegroundColor','r')
        case 3
            set(B3,'ForegroundColor','r')
        case 4
            set(B4,'ForegroundColor','r')
        case 5
            set(B5,'ForegroundColor','r')
        case 6
            set(B6,'ForegroundColor','r')
        case 7
            set(B7,'ForegroundColor','r')
        case 8
            set(B8,'ForegroundColor','r')
        case 9
            set(B9,'ForegroundColor','r')
        otherwise
            disp('Error en switch')
    end
    Zanfang=clock;
    uiwait;
    Tastatur1('Limpiar');
end

set(BS,'Enable','on');

return

function Schliessen

global Ergebnis

closereq

save Ergebnistastatur.mat Ergebnis
return
```

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