# Does Music Evoke Emotional Responses?

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# Abstract

This study approaches the difficult task of determining if music does in fact evoke emotional responses in listeners. Initially the broad terms music and listeners were delimited. Music was delimited to western classical instrumental music with a homophonic texture, but without percussion, and listeners to listeners from the western culture. The approach of the study was to conduct an experiment to provide empirical evidence for the determination. The experiment relied on the understanding of emotions as consisting of components, and that a synchronisation of the two components – subjective feeling and physiological arousal – would indicate the occurrence of an emotional response. A two dimensional description of emotional states was adapted with the dimensions of valence and arousal. A developed application for continual self-reports was used to obtain continual valence levels in listeners. The arousal levels of listeners were obtained through ECG (heart activity) measurements. For a comparison with the state of musical features, an application for the detection of loudness, pitch level, pitch range, mode, harmony and timbre was developed. The experiment results indicated that an average of $30.8\%$ of listeners responded emotional to the listening experience. No correlations of emotional responses were found across a majority of listeners, and thus a correlation with musical features was determined premature.

# PREFACE

The report details the investigation carried out during the 10th semester of Medialogy at Aalborg University Copenhagen, in spring 2010. The investigation constitutes the master thesis of the author. In this preface an overview of the report contents will be provided.

The **introduction** presents the investigated topic music and emotion, through a discussion of novel research within the research area. The methods of fellow scholars are outline and discussed, to obtain knowledge on the research state heretofore. This leads to a discussion of influences on the relation between music and emotions. Based on the discussions the problem of interest is defined, and approached by introducing three hypotheses.

In the light of the introduction the two main areas of interest are analysis in the chapters **emotions** and **music**. Both chapters serves to provided a knowledge base for the task of answering the stated problem.

The provided knowledge is then subsequently used for the development of two applications, and the conductance of an experiment. The chapter **application developments** describes the two developed applications. First an application which was developed for the measurement of emotions, and last an application for the detection of the characteristics in music. The following chapter **experiment** then takes over and describes the details of a conducted experiment and the obtained results. The results are then interpreted in the chapter **discussion**, and concluded on in the **conclusion**. The final chapter **future perspectives** then round the report up with suggestions of directions to take.

The **appendix** placed in the back of the report, contains information related to the study, which was not considered suitable for the main body of the report.

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# CHAPTER 1

## Introduction

The introduction chapter serves to bring the reader an overview of the topic ´´Music and Emotions”, with a primary focus on the hypothesis ´´Music evokes emotional responses in listeners”. Research in the field heretofore is present with a discussion of the studies. Later in the chapter certain aspects of “emotional response evoked by music”, which are considered in this investigation, are delimitated, in order to derive a structured problem area of interest.

## 1.1 Music and Emotions

Since the times of Plato and Aristotle, emotions have been considered in the discussion of music [17]. For the layman of our times, it is not unnatural to consider music as a language of emotions, or to describe music with emotions adjective, like joyful or calming. In general musicologist, philosophers and psychologists agree on the existence of a relationship between music and emotions. Though the agreement does not go much further, leading to the following discussion of the relationship between music and emotions.

In regard to music, emotions can be considered in two different manners – *the recognition of emotions expressed in music*[1] and *the emotional response*[2] *evoked by music*[3]. Recognition of emotions expressed in music is the ability of listeners to recognise / perceive common emotions that a musical piece is expressing. The evoked emotional response is the change of the listeners internal emotional state, as a reaction to a music piece. It is crucial to distinguish between these two considerations of emotions in relation to music, since a recognition of an emotion expressed in music does not entail that the listener actually get emotional affected by the recognised emotion. To exemplify the distinction one can listen to a musical piece and recognise its expression of sadness, but still be left emotionally unaffected by the listening experience [18]. Prior to the discussion of how listeners can recognise emotions expressed in music, and how they might experience emotional responses evoked by music, the hypotheses that listeners actually can recognise emotions and experience emotional responses should be verified.

### Can listeners recognise emotions expressed in music?

One way of verifying that listeners can recognise emotions in music is to investigate a causality between the musical structure and recognition of expressed emotions. This is exactly what Gabrielsson and Lindström have investigated in 2001 [11]. In the study several connections are outlined between the musical structure and the expression of emotion, but they conclude that despite all these connections, there still exist "*gasp, uncertainties, and ambiguities regarding the influence of various structural factors on emotional expression.*" [11, p. 242]Regardless of the partial paradigm linking the musical structure with the recognised expression of emotions, the study achieve, with the outlined connections, to show that listeners actually can recognise expressed emotions in music.

To maintain the conclusion Scherer et al. [30] state that solid empirical evidence from psychological studies have shown that listeners agree to a great extend of the emotions expressed in a musical piece – thus the listeners recognise emotions in music. The statement of Scherer et al. is amongst others based on the discussed research by Gabrielsson et al. [11]. Vladimir J. Konečni [19] evaluates the empirical results of different studies on listeners recognition of the emotions expressed in music. Konečni argues that studies such as [14, 20, 36] neglect to sufficiently inform the participants of the experiments to only report the recognised expressed emotions, and not their emotional response. Subsequently Konečni discusses the

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[1] Other scholars might use phrasing, as "*music representing or expressing emotion*" [19], "*perception of emotion*" [30], "*perception of emotional expression*" [11].

[2] *Response* is here used as "*A reaction, as that of an organism or a mechanism, to a specific stimulus.*" http://tfd.com/response (Accessed: 2010-05-08)

[3] Other scholars might use phrases, as "*The induction of emotions in the listener*" [19,28], "*production of emotions in the listener*" [30].

research by Gabrielson et al. [11] , and determines – as Scherer et al. – that based on the validity of this study, there "*seems to be little doubt – even, to some extent, cross-culturally – that music can depict, allude to, and represent (a) the auditory patterns commonly associated with emotions such as anger, joy, and sadness; and (b) the specific vocal and physical behavior of an organism experiencing and displaying such emotions.*" [19, pp. 119 – 120].

### Can music evoke emotional responses in listeners?

If music is to evoke emotional responses in the listeners, the occurrence of an emotional response should be common in time across listeners, and a causality between the occurrence of emotional responses and the musical structure should exist. If the emotional responses are actually evoked by music, and if different musical pieces can evoke different emotional responses, then what differentiates musical pieces – the musical structure – should be causally connected with the occurrence of emotional responses. A possible way of verifying that music actually can evoke emotional responses, is to determine the causality between the musical structure and the change of emotions in listeners over time.

The study of emotional responses evoke by music have gained less attention than that of recognition of emotions. Throughout the research, it is still argued whether or not music actually can evoke emotional responses in the listeners. Scherer and Zentner state that "*Whereas 'emotivists' hold that music elicits real emotional responses in listeners, 'cognitivists' argue that music simply expresses or represents emotions.*" [30, p. 361]. Scherer et al. considered it in 2001 to be premature to determine the validity of the two opposing views of the 'emotivists' and the 'cognitivists'. Konečni on the other hand sides mainly with the cognitivists, and concludes that music leads to responses in listeners, but that most of these responses are either not emotional responses or pseudo-emotional [19]. Furthermore he concludes that in the possible cases of emotions being induced by music, is most likely due to personal associations with emotional events.

Gomez and Danuser [12] investigated in 2007, based on the assumption that music evoked emotional responses, the causality between musical structure and psycho-physiological responses in listeners. The validity of their study is questionable. Gomez et al. neglect to determine when the combination of self-reported felt emotion, and physiological responses, are an expression of an emotional response, and when they are merely, what Konečni denotes non-emotional or pseudo-emotional responses. I question the validity of their experiment based on an analysing of their methodology of the experiment. Gomez et al. use overall values for both the state of the musical features[4]– which are determined by experts – and the self-reported felt emotions. Hereupon I ask: Is it not possible for the musical features to change state over time? Is it not possible for emotional states to change over time? Is it not a possibility that the assumed evoked emotional responses to music, are reactions to the continuous change in state of the musical features? Issues that have previously been acknowledge [33].

Furthermore the validity of the experiment weakens when Gomez et al. chose to expect the participants to "*suppress the influence of personal and situational factors*" [12, p. 382]. In the case that a experiment conductor have expectations

[4] "*Musical feature*" is here used to denote, the distinct and characteristic parts of music structure, according to the definition of feature – http://dictionary.reference.com/browse/feature (Accessed: 2010-03-15)

of his or hers participants – without reliable reassurance of the occurrence – it cannot be ensured whether or not the intended have been measured, and consequently the measurements cannot lead to reliable results. In the case of the experiment by Gomez et al. it means that the measurements of emotional states might not be connected with the music. Additionally their set expectation is questionable doable: Is it even possible for an individual to be so subconsciously aware, that he or she can differentiate the cause of their felt emotional response? Fox states: "*It is commonly assumed (...) that we are usually not aware of the processes in our mind that trigger them [emotions].*" [9, p. 24].

Concurrently Gomez et al. state that the personal and situational factors might have even more influence on the emotional response than the music itself, but still they conclude that the results suggest that "*the internal structure of the music played a primary role in the induction of the emotions in comparison with extramusical factors.*" [12, pp. 382 – 383].

Positively Gomez et al. question whether or not the self-reported emotional response despite the wording in the experiment instructions, does in fact represent actually emotional responses, recognised expressed emotion or a combination of the two. Consequently this study does not verify the hypothesis that music evokes emotional responses in listeners.

The question: "*Can music evoke emotional response in listeners?*" remains unanswered and well debated. Hereby it becomes the interest of this investigation. In agreement with Scherer et al. I find it in 2010 to be premature to state the conclusion of Konečni, or to assume the opposite, that music actually can evoke real emotional responses in listeners. To answer the question it should be empirically investigated with a non-questionable valid experiment methodology. As mentioned in the beginning of this section a possible way is to investigate the causality between the musical structure and the possibly evoke emotional responses. If emotional responses are evoked, and the occurrence of these are common in time amongst numerous listeners, it can be exclude that the evoked emotional responses are caused by personal associations to events. To conduct a valid experiment it is necessary to consider the mistakes of others – e.g. the before mentioned mistakes of Gomez et al. [12] and those pinpointed by Konečni [19]. The most crucial is to make the distinction between recognition of expressed emotions and the evoked emotional responses. The great problem in other studies have been a vague and inconsequent division of these two considerations of emotions in regards to music. When experiment conductors ask the participants, either vocally or through a questionnaire, to self-report their emotional response evoked by music, the participants have a tendency to consider the expressive qualities of the musical pieces [19]. Thus in the design of the experiment it should be considered that people in general are more likely to monitor their own external stimulus continuously, than the actually changes in their own internal emotional state.

Working with emotions also require clear and differentiated definitions of the various aspects of emotions. Konečni stated that the responses to music are primarily non-emotional or pseudo-emotional. His critique of the measurement of emotions by others, should be considered, as a physiological change might not elicit an emotional response. To obtain solid empirical results, it should therefore not be discussable whether or not the measured are actually emotional - or merely non-emotional responses. Consequently the term emotion should also be defined, according to the field of affective science, and it should be determined how emotions are both described and measured. In this process the term emotions will be distinguished from other affective terms, like feelings, moods and attitudes. Distinguishing between affective states allows for a discussion of what affective states – if not emotions – can be evoked by music, and also how current affective states can influence a listeners emotional response to music.

The causality between music and the possibly evoked emotional responses is in the view of Kronečni, in the minimal cases where emotional responses are evoked, merely personal association with emotional events. Investigating the causality between the musical structure and the possible evoke emotional response, can enlighten if it is the music that evokes emotional responses, or if it is external influential factors – extra-musical factors.

## 1.2 Influences on evoked Emotional Response

For music to evoke emotional responses in the listeners, a causality must exist between the internal structure of music and the evoked emotional response. For an investigation on the causality between musical structure and the possible evoked emotional responses, it is essential to consider both the internal and external – extra-musical – factors, which might influence the listeners emotional response.

The considered influences on the evoked emotional responses, are divided into 4 categories: *the musical structure*, *the performance features*, *the listeners features* and *the contextual features*, in accordance with Scherer et al. [30]. Where the musical structure and the performance features are considered internal influences, and the listeners features and the contextual features as external influences.

### Internal influences

The musical structure consists of distinct and characteristics musical features, such as tempo, rhythm and timbre. When investigating the causality between the structure of music and evoke emotional responses, different measurements bare interest. The state of each musical feature, the change of these states and the composition of musical features.

Apart from the musical structure, another internal factor, that might have a great influence on a listeners emotional response to music, is what Scherer et al. denote as*the performance features* [30]. Hereby is meant the individuality in the way a musical piece is executed by a performer.

### External influences

Scherer et al. [30] also discuss the two categories of external or extra-musical factors that might influence the response of the listener – *the listener features* and *the contextual features*. The listener features consist of a variety of individualities in the listeners. For example the listeners familiarity with the music, both with the tonal system and the genre of a musical piece, but also with a specific musical piece. The familiarity of cultures with the tonal system is further discussed in the section cultural differences (see section 1.2). In this category the key parameters of influence are familiarity, preferences, personality, prior experiences, musical talent, learned associations[5], motivational state, concentration and mood. In this study I would like to additional introduce another listener feature that might influence the evoked emotional

[5] "*Learned associations*" is the learned associations between musical features and emotional content, like the association of the mode minor with melancholic or sadness.

response: the auditory ability. The auditory sensitivity of different frequencies varies amongst listeners, and this might influence their experience of listening to music.

The category *contextual features* includes the key parameters: the location of the listening experience, the material properties of the surroundings, the surrounding event, the manners of emitting the sound and the possible interference with the listening experience, like a cough from another listener.

#### Cultural differences

In the category *listeners features* of external / extra-musical influences, the influence of familiarity in coherence with culture is mentioned. Across cultures music is composed on different tonal systems, and as of now it has not been clarified to which degree peoples familiarity with the tonal system used in their culture effect their response to music [30, 17, 28, 32]. In the context of this study the possible cultural influence bares no primary interest. Thus as the majority of studies on music and emotions, this study is delimited to investigate merely music based on the tonal system used in the western world – the chromatic scale – in combination with listeners from the local western culture. This delimitation allows for the differences in responses, due to different tonal systems across cultures, to be avoided.

## 1.3 Type of Music

The possible influences of culture on the emotional responses evoked by music, have delimitated the type of music to music from the western culture, which are composed based on the chromatic scale (see section 1.2). The type of music investigated is further delimitated to western classical instrumental homophonic music without percussion:

**Classical:** Other studies on music and emotions have delimited the type of music to western classical music [30]. Here these footsteps are followed, since it is considered important to obtain a paradigm for musical features and possibly evoked emotional responses, within this narrowed field, before adding additionally influential factors.

**Instrumental:** Western classical music include vocal music, such as opera. To avoid the influence of a possible induction of emotions caused by the lyrics of the vocals, the type of music is delimited to instrumental.

**Homophonic:** With the current technology within digital signal processing, several difficulties exist in the detection of musical features dependent on the texture of the music. The use of percussion might for instance make pitch level detection difficult, so does the use of polyphonic music[6]. Monophonic music[7]on the other hand, exclude harmony, which might have a great influence on the evoke emotional responses. A compromised is therefore taken, inform of a delimitation to Homophonic music[8]. A

[6] Polyphonic music is defined as "*music with two or more independent melodic parts sounded together.*" http://www.tfd.com/polyphony (Accessed: 2010-05-08)

[7] Monophonic music is defined as music "*having a single melodic line*" http://www.tfd.com/monophonic (Accessed: 2010-05-08)

[8] Homophonic music is defined as music "*having or characterized by a single melodic line with accompaniment*" http://www.tfd.com/homophonic (Accessed: 2010-05-08)

minor delimitation as the music of the classical period is actually characterised by homophonic music.

**No percussions:** The accompaniment of Homophony Music can though consist of percussion, which complicates the digital signal procession.

## 1.4 Problem Outline

Based on the discussion the problem of interest for investigation can now be stated, as follows

> Does western classical instrumental homophonic music evoke emotional responses in listeners from the western culture? If so how are the evoked emotional responses causally connect to the musical structure?

Onwards listeners from the western culture is merely denoted listeners, and western classical instrumental homophonic music as western classical music.

## 1.5 Hypotheses

To investigate the stated problem, it is divided into minor problems areas, that are approached by stating hypotheses.

### Hypothesis I

> Western classical music can evoke emotional responses in listeners.

Due to the debate of this hypothesis, it must be verified or falsified empirically. It should though be mentioned that a missing verification might not entail a falsification. Since a missing verification could be a result of lack of evidence that the measured are in fact emotions and not pseudo-emotions.

### Hypothesis II

> The musical features of western classical music are causally connected to the evoked emotional responses in the listeners.

The second hypothesis should also be verified or falsified empirically. If hypothesis I is verified, meaning emotional responses are measured, the investigation of hypothesis II can determine if the responses are causally connected to the music features. If the empirical findings coherent with hypothesis I failed to verify that the measured responses are emotions, the causality between the responses and the musical features can still be investigated.

### Hypothesis III

To the extent of my knowledge, the majority of researchers, who have attempted to determine the causality between the musical structure and the evoked emotional responses, have looked upon the emotional responses, as being absolute emotional states, which are not relative to the current affective state. In these manners a certain musical structure would evoke a certain emotional response. The results from these attempts have been relatively weak [19]. It is my hypothesis that this could partly be a result of a narrow perception of the evoked emotional responses being absolute. Thus does this investigation intent to open up for this narrowed perception, by stating the following two hypotheses.

**Hypothesis IIIa**

> The emotional responses evoked in listeners by western classical music are absolute emotional responses, which are relative to the current affective state of the listener. (See figure 1.1 A)

**Hypothesis IIIb**

> The emotional responses evoked in listeners by western classical music are relative emotional responses, which are relative to the current affective state of the listener. (See figure 1.1 B)

With this investigation it is the intention to verify one of the the two stated hypotheses, or falsify both. Figure 1.1 serves to provide a better comprehension of the two stated hypotheses.

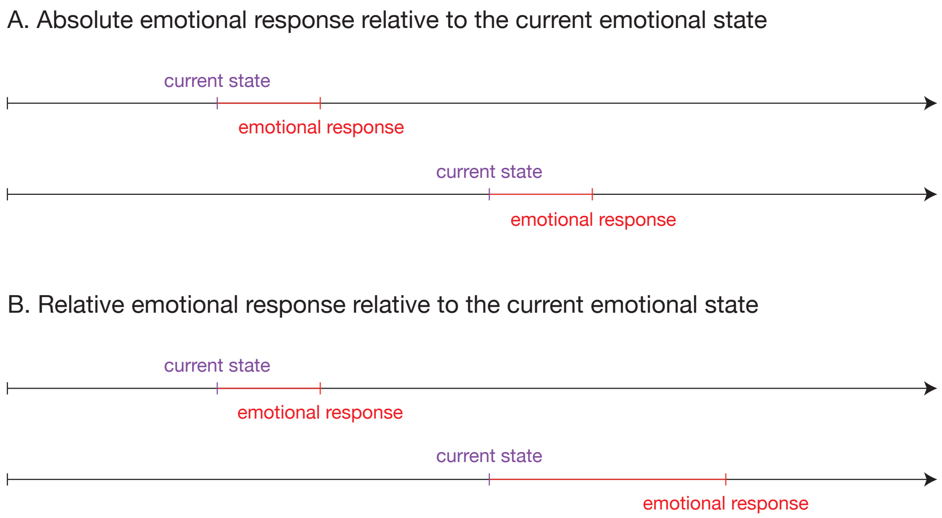


Figure 1.1: The figure illustrates the emotional response to music as two different response types. A shows the emotional response as an absolute response, which is relative to the current affective state. B shows the emotional response as a relative response, which is relative to the current affective state.

# Chapter 2

# Emotions

The following chapter provides the reader with basic knowledge on emotions. Initially it is investigate how emotions are defined and what differentiates emotions from other affective states. Subsequently different approaches to the description of emotional states are discusses, and the measurement of emotional states.

## 2.1 Definition of Emotions

Within studies of music and emotions, music researchers have had a tendency not to define which aspects of affect they are dealing with, and they have used the terms, like affect, mood, emotion and feeling, interchangeable [18]. Thus to avoid confusion, the consensus of affective science is use to define emotions conceptually.

### Affective states

In the "Handbook of Affective Sciences" [4] Davidson et. al. define and distinct between six phenomena of affect – *emotions*, *feelings*, *mood*, *attitudes*, *affective style* and *temperament* (see table 2.1). Others like Fox [9] base their work on these definitions and distinctions of affect. Scherer and Zentner [30] have based their research on a similar distinction of affective states, which in the view of Konečni is an essential distinction [19]. Juslin and Västfjäll [17] considers only three of the phenomena, namely emotions, feelings and moods, defined accordingly to Davidson et al.. Consequently this affective paradigm is used as a foundation for the work with emotions throughout this investigation.

| **Affective Phenomena** | **Description** |
|---|---|
| Emotions | "*a relatively brief episode of coordinated brain, autonomic, and behavioral changes that facilitate a response to an external or internal event of significance for the organism.*" |
| Feelings | "*the subjective representation of emotions.*" |
| Mood | "*a diffuse affective state that is often of lower intensity than emotion, but considerably longer in duration.*" |
| Attitudes | "*relatively enduring, affective colored belief, preferences, and predispositions towards objects or persons.*" |
| Affective Style | "*Relatively stable dispositions that bias an individual toward perceiving and responding to people and objects with a particular emotional quality, emotional dimenstion, or mood.*" |
| Temperament | "*particular affective style that are apparent early in life, and thus may be determined by generic factors.*" |

Table 2.1: The definition of six affective phenomena according to [4]

The distinction is also use, as it is considered essential to distinguish between the different affective states, in order to verify whether or not the possible evoked responses are actually emotional responses. Heretofore it is a possibility that music evoke moods as well as feelings, in addition to emotions, or perhaps rather than emotions. Thus in the attempt to establish if any or one of the affective states are evoked by music, it is necessary to gain a broad understanding of the phenomena.

The remaining affective states – *attitudes*, *affective style* and *temperament* – are all related to the extra-musical influences in the category *listener features*, and will be discuss in coherence with the extra-musical influence (see section 3.3).

### Emotions

In affective science an emotion is defined as "*a relative brief episode of coordinated brain, autonomic, and behavioral changes that facilitate a response to an external or internal event of significance for the organism*" [4]. It is though fare from all researchers that agree on this definition of emotion. This lack of a consensus have been acknowledge by many, Lundqvist [22], Fox [9] and Juslin et. al [17] to name a few. To conprehend the disagreements on the exact definition of emotions, it servers to discuss what the majority of researchers agree on, which is the manifestation of emotional responses in components. Researchers strive to define emotions from the involved components and the composition of these components, on which great disagreements exists.

According to Juslin et al. [17] emotions involve six components:

- Cognitive appraisal (evaluation of the situation, e.g. dangerous)
- Subjective Feeling (e.g. feeling afraid)
- Physiological arousal (e.g. increasing heart rate)
- Expression (e.g. screaming)
- Action tendency (e.g. running away)
- Regulation (e.g. calming down)

Scherer considered five of these six components of emotions, leaving *regulation* a side [28]. These five components are also discussed by Fox [9]. A wide consensus though merely exist on four of these components, namely subject feeling[1], physiological arousal[2], expression[3]and action tendency[4], as components of emotions [17, 29, 9]. The discussion is now, if cognitive appraisal should be considered a component of emotion, or as a separate individual system. Fox [9] considers both these perspectives on the manifestation of emotions into components – the appraisal-based models and the component process. In the appraisal-based models, the cognitive appraisals are considered as causes of emotions, and not as a component of emotion. Whereas with the component process, the cognitive appraisals are considered as a component of emotion. The component process is the definition proposed by Scherer in 1982 [29].

The inclusion of cognitive appraisal is though controversial, which Scherer also acknowledged. His argument for the inclusion is that "*all subsystems underlying emotion components function independently much of the time and that the special nature of emotion as a hypothetical construct consists of the coordination and synchronization of all of these systems during an emotion episode, driven by appraisal*" [29]. For example imagine taking a taxa in a foreign place, it is dark outside, and you have no idea were you are going. Do you then wonder if the taxa driver have true intentions? Does the speculations (cognitive appraisals) make you sacred?

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[1] Subjective feeling component (emotional experience or subjective experience) by Scherer [29]
[2] Neurophysiological component (bodily symptoms) [29]
[3] Motor expression component (facial and vocal expression) [29]
[4] Motivational component (action tendencies) [29]

Another argument for the inclusion of cognitive appraisal is the order of events connected with the components progress – the event focus. One evaluates the significance of an occurrence for the organism, which might stimulate or trigger a response [29]. The occurrence could both be of external and internal nature. In this fashion cognitive appraisals lead to strong bodily reactions, which will generate a subjective experience of feeling. Finally the experience of feeling will lead to expressions and action tendencies [16]. Regarding the order of these events theorists and researchers also disagree amongst each others.

Konečni also considers cognitive appraisals as a component of emotions. According to the Prototypical Emotion-Episode Model – PEEM – proposed by Konečni [19], the order of events are similar to those of Scherer. It initiates with the occurrence of an event, which will lead to the perception and interpretation of this event. The interpretation of the event being the cognitive appraisals discussed by Scherer. The perception and interpretation will occur in a feedback loop. Eventually arousal and / or facial expression and / or postures occur, in an additional feedback loop with perception and interpretation. At this stage arousal, facial expression and posture also influence each other. The bodily interaction will then cause an emotion labeling, which will result in behaviour, followed by counter-behaviour.

On the opposing side theorist prefer to separate emotion and cognition, as two individual system, which interacts with each other. Izard [13] divide emotions into two subcategories – basic emotions and emotion schema. She defines basic emotions as emotions that are not characterised by cognitive content, but by having evolutionary neurobiological substrates. Emotion schema on the other hand are characterised by the interaction of emotion and cognitive appraisals. It is the view of Izard that researchers lack of distinction between basic emotion and emotion schema, have lead to much confusion in emotion science [9].

Juslin et al. [17] discuss the meaning of cognition appraisal in the context of emotional responses evoke by music. They state that many researchers have a tendency to assume that emotions reflect cognitive appraisals. In this case music does not induce emotional responses, since the act of listening to music does not involve cognitive appraisals. Juslin et al. agree with Izard that cognitive appraisals have relevance in regards to some emotions – denoted emotion schema by Izard [13]. Furthermore Juslin et al. emphasize that it is far more important to consider the underlying psychological mechanism involved in emotions, than merely cognitive appraisals.

Consequently the division into emotions and emotion schema are adapted, as it allows for an investigation of emotional responses evoked by music. The considered components of emotions are subjective feeling, physiological arousal, expression and action tendency. With this decision follows the possible consequence that future research determines that the measurements of this study is not actually emotions. The lack of consensus at current time does though not allow for such a risk to be diminished.

### Feelings

Feelings are in affective science defined as "*the subjective representation of emotions*" [4]. In the light of the manifestation of emotions into components, feelings are then the subjective experience of an emotion. Due to the disagreement on the extend to which the components of emotions are synchronised during an emotional response, there exist no direct connection between feelings and emotions. Heretofore emotions can occur without the activation of a subjective experience, and the presence of feelings do not entail the occurrence of emotions.

### Moods

By Davidson et al. moods are defined as "*a diffuse affective state that is often of lower intensity than emotion, but considerably longer in duration.*" [4]. Many researchers agree that moods are a subset of emotion, but dragged out in time and lowered in intensity [9]. A better comprehension of moods are therefore considered to be through a differentiation from emotions.

Juslin et al. [16], Scherer [29] and Fox [9] distinguish emotions and moods by several factors. Juslin et al. discuss the duration, the function, the cause and the presence of facial expressions. Fox include the intensity, the autonomic arousal and neural substrates (see table 2.2).

| **Distinctions** | **Emotions** | **Moods** |
|---|---|---|
| Duration | Seconds to minutes | Hours to days |
| Relative Intensity | High | Low |
| Nature of antecedent event | Sudden Events<br>Specific event<br>Object focused | General non-specific event<br>Emotions<br>Diffuse |
| Function | Biasing actions | Biasing Cognition |
| Autonomic arousal | Acute<br>Perhaps Specific | Variable<br>Diffuse |
| Neural substrates | Rapid neurochemical changes | Long lasting neurochemincal changes |

Table 2.2: The adapted distinction of emotions and moods [9]

Reviewing the distinctions (see table 2.2) it seems that the relation of music with moods are stronger than emotions. Music can be viewed upon as a general non-specific event that bias cognition rather that actions. The remaining distinctions like the intensity of the response and the autonomic arousal require empirical finding to determine the affective classification of the response.

By the given definition, moods can be interpreted as, what in hypothesis III (see section 1.5) was denoted "*the current affective state*". To verify or falsify either hypothesis IIIa or IIIb, it is therefore crucial to determine the mood of participants prior to the experiment. This can be done trough the use of the self-reports instruments *Profile of Mood States (POMS)* and *Multiple Affective Adjective Checklist (MAACL)* [9].

## 2.2 Description of Emotional States

In order to work with emotions, it is necessary to able to describe the different emotional states. Researchers have taken different approaches in the task to describe emotional states, namely the categorical approach, the dimensional approach, the prototype approach and the vitality affects [16]. In the following section each approach, except vitality affects, will be discussed and evaluated accordingly to emotional responses evoked by music. Vitality affects are not discussed here as they also occur in the absence of emotions [16], and hereby cannot be used to properly determine the presence of an emotional response.

### The categorical approach

In relation to the categorical approach, emotional states are understood by their memberships to categories of similar emotional states, and by the distinction of these categories. The concept of basic emotions is one of the most prominent examples of the categorical approach.

The idea behind basic or primary emotions is that there exist "*a limited number innate and universal emotion categories from which all other emotional states can be derived.*" [2, p. 165]. If for example anger is considered a basic emotional state – which the majority of researchers do – then rage would be considered a secondary emotional state, which is derived from the emotion category anger. Researchers describing emotional states based on the categorical approach, have though not reach a consensus on the amount of basic emotions, and on which emotions that qualifies as basic emotions [2]. Juslin et al. [16] outline a suggestion for the distinction of basic emotions from secondary and complex emotions. Namely that basic emotions [18, p. 77]

- "*have distinct functions that contribute to individual survival*"
- "*are found in all cultures*"
- "*are experienced as unique feeling states*"
- "*appear early in developement*"
- "*are associated with distinct patterns of physiological changes*"
- "*can be inferred in other primates*"
- "*have distinct emotional expressions*"

Heretofore a consensus have been reached on five basic emotions – happiness, sadness, anger, fear and disgust [16,2]. A key person worth mentioning in regards to basic emotions is Paul Ekman, who showed that facial expressions of basic emotions are not culturally dependent. Initially in 1972 he introduced six basic emotions – anger, disgust, fear, happiness, sadness and surprise. Later in the 1990s he revised the list, and included 11 new emotional states [8].

An additional example of the use of basic emotions are the three-dimensional circumplex model by Robert Plutchik [24]. He associated the relations among emotional states with the relations among colours. In the circle he placed similar emotional states close together, and opposite emotional states $180^o$ apart. The model is based on the theory of the eight primary – basic – emotions divided in four pairs of opposite emotional states. The novel part of his model was the addition of a third dimension to represent the intensity of each emotion category (see figure 2.1). On the 2-dimensional representation of the model the basic emotions are positioned in the second circle from the center, and are acceptance, anger, anticipation, disgust, fear, joy, sadness, surprise. Hereby he distinguish the used basic emotions from the reached consensus, as happiness is replaced with joy. The emotional states that are added in between the spread outs of the cone, are refer to as primary dyads, and are mixtures of two primary emotional states.

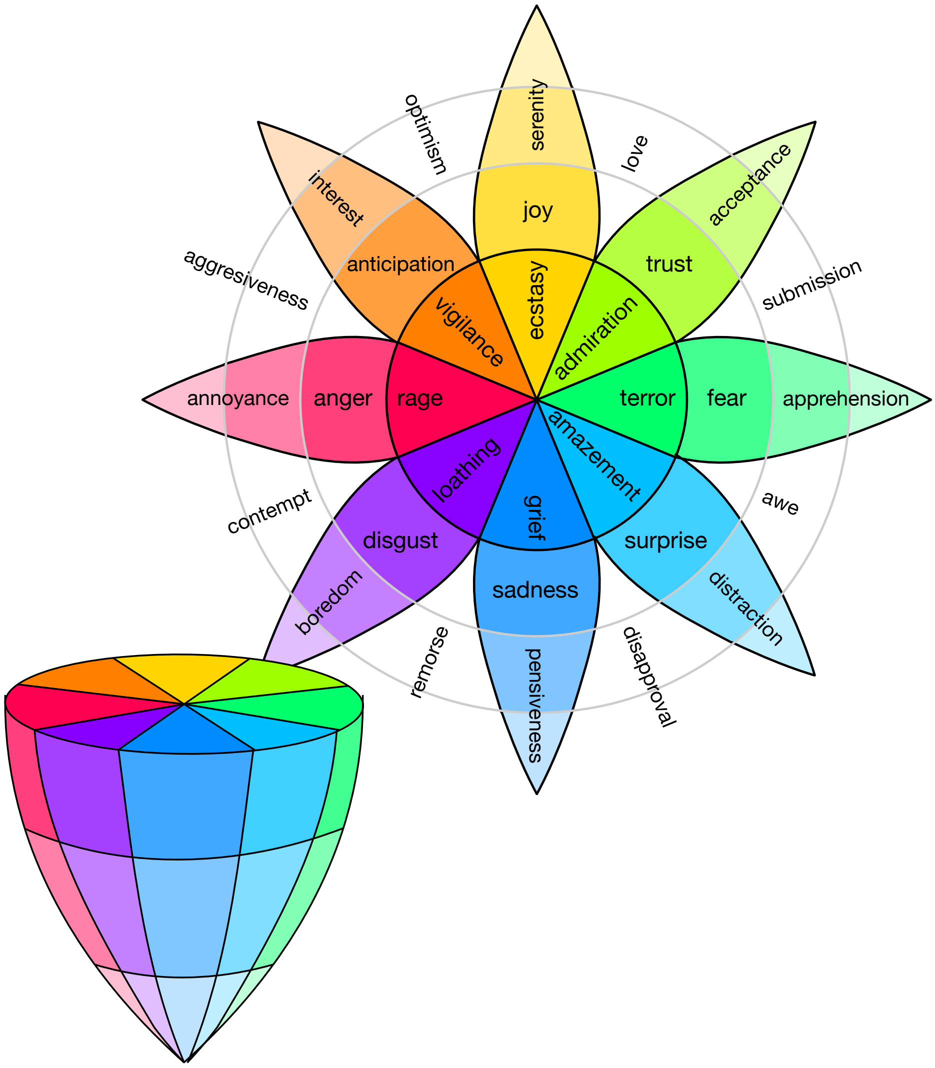


Figure 2.1: The three-dimensional circumplex model of emotional states by Plutchik [24]

Another approach to the caterogisation of emotions is the model of Robert E. Thayer [39]. Thayer identifies four categories of emotions, which are differentiated on their levels of valence[5]and arousal[6](see figure 2.2).

In the case that music does evoke emotional responses in listeners, the used description of emotional states should be suitable for comparison with musical features. The characteristics of the musical features are they commonly change continuously over time. Using the categorical approach it will not be possible to describe emotional states in a similar continuous manner, since with the categorical approach an emotional state is either member of one category or another. The categorical approach is consequently not found suitable to describe emotional states evoked by music.

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[5] The level of valence describes pleasantness, and ranges from either unpleasant to pleasant or negative to positive

[6] The level of arousal describes activation, and ranges from either non-active to active or low arousal to high arousal

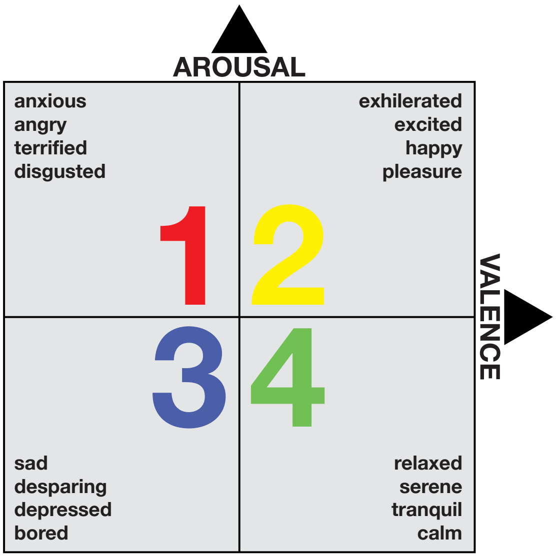


Figure 2.2: Emotion categorisation according to Thayer [39]

### The dimensional approach

The differential factors – valence and arousal – used by Thayer in his categorical approach, are actually widely used dimensions of emotions. According to the dimensional approach emotions are understood by their position on a small number of dimensions. The amount of used dimensions differs mainly from two to three. In 1980 Russell proposed his circumplex model, in which he merely used two dimension to describe emotions, namely valence and arousal [26]. Even though three years earlier Russell in cooperation with Mehrabian provided evidence that emotions can only fully be described by the use of three dimensions, namely valence, arousal and dominance [27]. In other three dimensional models the valence axis might be denoted pleasure, and the dominance axis might be interchanged with control, potency or tension [29]. It is the lack of an identification of the three dimension, that have lead many researchers to limit themselves to use merely two dimensions [29].

An example of the dimensional approach is the previous mentioned 2-dimensional circumplex model proposed by Russell in 1980 (see figure 2.3).Within the 2-dimensional plane, emotional states are situated on the arc of a circle, according to their levels of valence and arousal. The model achieves to both illustrate how emotional states vary in the degree of similarity and that certain emotions, for example angry and clam, are opposites [16].

Applying a third dimension, for example dominance, each emotional state would then be positioned in a three dimensional space (see figure 2.4).

In contrary to the categorical approach, the dimensional approach is a continuous description of emotional states, as any point in the 2-dimensional plane or 3-dimensional space can represent an emotional states. The dimensional approach is therefore found suitable for describing emotional states evoked by music. Gabrielsson et. al. [11] and Juslin [15] all used a 2-dimensional description of emotional states in their studies on emotion expression in music.

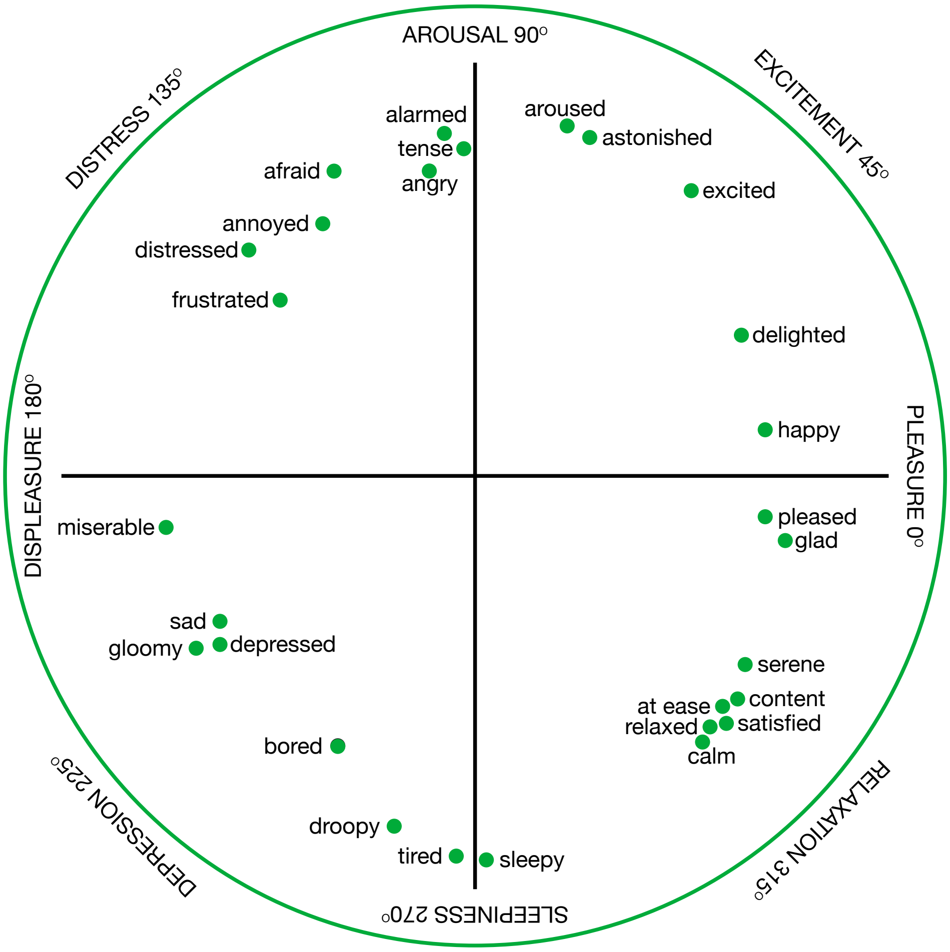


Figure 2.3: The 2-dimensional circumplex model by Russell [26]

### The prototype approach

The prototype approach to the description of emotions is derived from work of Rosch in 1978 [25]. She argues against the categorical approach, as most categories do not have clear-cut boundaries. Instead she determines that a better membership understanding is achieved by the *clearest cases* – prototypes – of memberships to a category. Consequently a membership to a specific category is determined by the similarity to prototypical examples [16]. Additionally the prototype approach focuses on the hierarchical structure of the categories [34].

As seen with the categorical approach, this approach also lack the continuous quality, which is valued in this study to describe emotional response evoked by music.

## 2.3 Measurement of Emotional States

Due to the lack on a consensus on the definition of emotions, it is unclear to what extend the components of emotions are synchronised during an emotional response. Measuring emotions is hereby difficult, as there is no theoretical or empirical evidence of when a measurement actually shows the presence of an emotional response. Prior to an evaluation of this problematic, the measurements of the four widely ac-

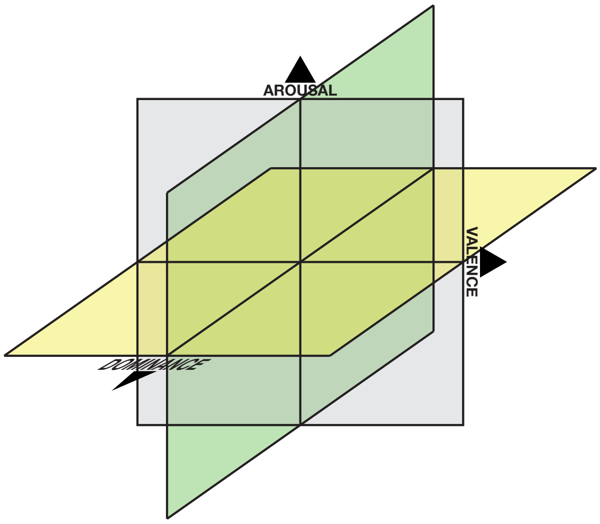


Figure 2.4: An illustration of a three dimensional space for the representation of emotional states.

knowledged components of emotions are presented. These four components are also those discussed by fellow researchers trying to measure emotions [6].

During the evaluation of measurement methods, it is extremely crucial to consider the constrains the measurement methods put on the participants. When measuring emotional responses evoked by music, the method for the measurement can easily destroy what the method is trying to measure – emotional responses – due to the impact on the listening experience.

### Measurement of subjective feeling

To measure the subjective feeling component of an emotional state, theorists argue that it is necessary to establish some sort of communication with the experiment participants, as "*such conscious states can only be reported from a first-person point of view.*" [9, p. 30] [6]. This sort of measurement is known as subjective self-reports.

Subject self-report measurements can be conducted in different ways, for example by the use of free descriptions, questionnaires, checklists or rating scales. Regardless of the used technique the measurement comes with pros and cons. The great thing about self-reports are their clear evidence of emotions – although not always reliable – and their ability to measure certain aspects of emotions, which cannot be measured in other manners [16]. The cons of self-report are the necessity of words, and hereby the complications of both describing emotions in singular words, and choosing which words to use. One way of avoiding this problematic is the self-assessment manikin, that use drawings to describe the three dimensions – valence, arousal and dominance – of emotions [3].

Additionally most self-report measures are non-continuous, which does not meet the requirements of the experiment, as it is intended to measure the change in emotional state against the change in musical features. Luckily Emery Schubert has reviewed methods for continuous self-reports [33]. Initially she emphasises that with digital measurements, which are restricted to amount of samples per second, the measurements are not continuous, but merely continual. The most promising continual measurements are all related to the dimensional description of emotional states, since dimensions, in contrary to categories and prototypes, allow for the exploitation of rating scales. The reason why rating scales are preferable, is the fact that they allow higher sampling rates.

Since the middle Nineteen Nineties researchers have started to measure two dimensions simultaneously, primarily by positioning a point in a two dimensional plane [33], to obtain higher complexity of emotions. Using continuous self-report measures it is crucial to consider the necessary sampling rate, and its influence on the listening experience, as well as the synchronisation of the self-reports and the provided stimulus – the music. Requiring the participants to continuously move a point around in a 2-dimensional plan, in contrary to on one or two 1-dimensional line(s), might require extra considerations of the participants, and hereby interfere with the listening experience.

Another important factor to consider, in the use of self-report when trying to measure emotional responses evoked by music, is the difficulties for experiment participants to separate recognised emotions from emotional responses [28]. Difficulties that do exist even when precise instructions are given.

While self-reports give a great insight to how people are feeling, emotion scientists argue that relying exclusively on self-reports wont provide a measure of emotions, merely a measurement of feelings. Consequently continual self-reports are used to measure the subjective feeling component of emotional states.

### Measurement of physiological arousal

Peoples physiological reactions to emotional responses, are by scientists assumed to be how people from evolution prepare for action tendencies, like running away [9]. The physiological reactions – physiological arousal – are only related to the arousal levels of emotions, as they describe the change in activity of the autonomic nervous system (ANS) [6].

Physiological arousal can be measured on several different physiological reactions, like

- Blood Pressure
- Electrocardiogram – Heart activity – ECG
- Electroencephalograph – Brain waves – EEG
- Electromyography – Muscle activity – EMG
- Pupil Size
- Respiration
- Saliva Production
- Skin Conductance

High arousal levels are for example associated with an acceleration of heart rate and pupil dilation, whereas low arousal levels are associated with a slowed heart rate and pupil constriction [9]. The con of measuring these physiological reactions are the fact that they also occur in the absence of emotions [16], making it difficult to differentiate emotional responses and simply physiological reactions.

A manner of simplifying the differentiation of emotional responses and merely physiological reactions, is to evaluate the experimental conditions against the non-emotional occurrence of the physiological reactions. For example heart rate naturally change under physical movements. During the experiment, the listening experience will be central, which does not directly require movements. The only necessary movements are those associated with the continual self-reports. Using heart rate measurements the possible heart rate changes caused by movements associated with the continual self-reports should hereby be evaluated. Other heart rate changes cause by for example movements could in posterity be counted for by video filming the participants and matching greater movements with the measurements of heart rate.

The first delimitation of measurement methods is according to the constrains on the participants, as great constrains could easily interfere with the listening experience. Hereby blood pressure, EEG, EMG, respiration and saliva production, are excludes as measurement options. The remaining three measurements – ECG, pupil size and skin conduction – are still optional. Measuring pupil size requires either a setup of multiple cameras to recognise the participants eye in all possible view direction, or for the participant to look in the same direction at all times. Even though pupil size have shown to be a good indication of arousal [23], it is excluded as a measurement option in this study. The reasoning for the exclusion is the extensive requirement for a setup that does not force the participants to view in only on direction.

Electrocardiography (ECG) is used to measure heart activity, amongst other heart rate variation (HRV), which reflects "*an individual's capacity to generate regulated physiological responses in the context of emotional expression.*" [1, p. 231]. A great connection exists between the autonomic nervous system (ANS) and the heart rate. The ANS, which produces the physiological arousal, is subdivided into the excitatory sympathetic nervous system (SNS) and the inhibitory parasympathetic nervous system (PNS) [1] The SNS is dominant doing physical or psychological stress, and causes the heart rate to increase. The PNS on the other hand is dominant doing safety and stability, and causes a decrease in heart rate. The rate of change between the SNS and the PNS depends on the direction of the change. A change in heart rate caused by the activation of the SNS occur slowly, as the peak effect is observed after approximately 4 sec., and the return to the baseline after approximately 20 sec.. The activation of the PNS regulates the heart rate with short latency, with a peak effect after approximately 0.5 sec., and a return to the baseline after approximately 1 sec. [1]. As a result the activation of either of the subdivisions of the ANS, can be identified from their the latencies in heart rate, and a measure of HRV is then an indication of the physiological arousal component of emotions. Heart rate is also known to provided a information on the changes in arousal level [9].

To measure HRV with ECG it is only necessary to apply two electrodes on the participants – one on the right hand, and another on the left leg – and a ground. The constrains on the participants are then relative minor, and evaluated as minimum necessary. Consequently measures of HRV with ECG is used to measure the physiological arousal component.

Skin conductance is measured as the electrical resistance between two points on the skin, by emitting current from one point and receiving it at the other point. The resistance then varies dependent on both internal and external stimuli of the body. As with heart rate, skin conductance is connected to the changes in the SNS and the PNS, and seems just as suitable for the measurement task as HRV. For more information on measurement of skin conduction see [37]

Since physiological measures provide information on arousal levels of emotions, it is possible with a combination of a physiological measure and self-reports, to only measure the valence levels through self-report, and hereby obtain less interference with the listening experience.

Furthermore the measurement can differentiate emotions and moods, as the autonomic arousal associated with emotions are acute and specific, whereas with moods they are variable and diffuse (see section 2.1).

### Measurement of expression

Expression or expressive behaviour can be measured through for example facial expression, vocalisations or body language. However neither of these are accompany all experiences of emotional response [16, 9]. A measurement of facial expression, might therefore only occasional or not at all detect the presence of an emotional response evoked by music. Furthermore expressive behaviours can also take place in absence of emotions [16]. Consequently expressions are not used as a measurement of emotions.

### Measurement of action tendency

The measurement of action tendencies in relation to emotions is rare. Scherer [29] mentions action tendencies, but acknowledge the focus on the measurements of subjective feeling, physiological arousal and expression. He lists seven categories of action tendencies, that includes change of attention in relation to the event (towards or from), physical movement in relation to the event (towards or from), attention direction (self-centered or towards others) and information search. Heretofore it is possible that a musically evoked emotional state can cause a person to move his or her attention towards of from the listening experience. The limited amount of research in this field does though not provide suitable methods for determining attentions shift etc. Consequently it will not be attempted to measure action tendencies in this study.

# CHAPTER 3

## Music

The chapter on music serves to investigate western classical music, by subdividing the musical structure into distinct characteristics. Each of these characteristics are described and related to the expression of emotions in music accordingly to the work of Gabrielsson et al. [11]. In the end of the chapter extra-musical influences are discussed.

## 3.1 Western Classical Music

*Western Classical Music* is European music from the classical era (1750 – 1820 CE). It is though common for laymen to also consider music from the Baroque era (1600 – 1750 CE), the Romantic era (1820 – 1910 CE) and the impressionistic era (1890 – 1940 CE) as classical music [31].

Western classical music is based on the chromatic scale, which consists of 12 pitches (notes) – C C$^{\#}$ D D$^{\#}$ E F F$^{\#}$ G G$^{\#}$ A B$^{b}$ B. All the notes are equally spaced with a step size of a semitone, thus the scale is symmetric. The chromatic scale is the diatonic scale – C D E F G A B – with chromatic alternatives. The 12 pitches constitute an octave. In other musical traditions the octave is divided differently, Arabic music is for example based a quarter tone scale, that divides an octave into 24 tones [40], whereas the pentatonic scale, which divides the octave into five tones, and the heptatonic scale, which divides the octave into seven tones, is often used in eastern countries, like Indonesia, China and Japan.

The delimitation to western classical instrumental homophonic music without percussion (see section 1.3) has set a specific definition of the texture for the used musical pieces, namely homophonic. Homophonic music is characterised by having only one melody with accompaniment. Specific for this case accompaniment without percussions.

## 3.2 Music Structure

Music consists of several distinct characteristics – here denoted music features[1]. The combination of these musical features creates the structure of the music.

To empirically investigate a causality between the occurrence of emotional responses in listeners and the musical structure, the states of the musical features should be known at any given time. With knowledge on the state of the musical features, it will be possible to compare the music structure with the occurrence of emotional responses and hereby investigate a possible coherence. Table 3.1 list the most basic musical features, which by Alf gabrielsson and Erik Lindström have been related to the expression of emotions in music [11].

| **Music Feature** | | **Bipolar Range** |
|---|---|---|
| Amplitude Envelope | | Round // Sharp |
| Articulation | | Legato // Staccato |
| Harmony | | Simple // Complex<br>Consonant // Dissonant |
| Loudness | Loudness Level<br>Loudness Variation | Loud // Soft<br>Large // Small<br>Rapid Changes |
| Melody | Melodic (Pitch) Range<br>Melodic Direction<br>(Pitch Contour) | Wide // Narrow<br>Ascending // Descending<br>Up // Down |
| Mode | | Major // Minor |

[1] Other scholars denote the distinct characteristics of music as music fundamentals.

| Music Feature | | Bipolar Range |
|---|---|---|
| Pitch | Pitch Level<br>Pitch Variation | High // Low<br>Large // Small |
| Rhythm | | Regular // Irregular<br>Smooth // Rough<br>Complex, Varied, Firm<br>Flowing |
| Tempo | | Fast // Slow |
| Timbre | | Few // Many Harmonics<br>Soft // Sharp |

Table 3.1: A selection of basic music features and their associated bipolar ranges.

The listed musical features (see table 3.1) are adapted as a foundation for this study, due to their discovered relation to the expression of emotions in music [11]. Additionally it is weighted that rhythm, melody, harmony, timbre and texture are basic elements of music [31]. Each musical feature is subsequently described, combined with its relation to the expression of emotions in music. This serves for a later delimitation of musical features, which should be detected by the developed application, and used for the evaluation of experiment results (see section 4.2).

### Amplitude envelope

The amplitude envelope, describes the development of a sound over a period of time. It is divided into four parts – *attack*, *decay*, *sustain* and *release* (see figure 3.1).

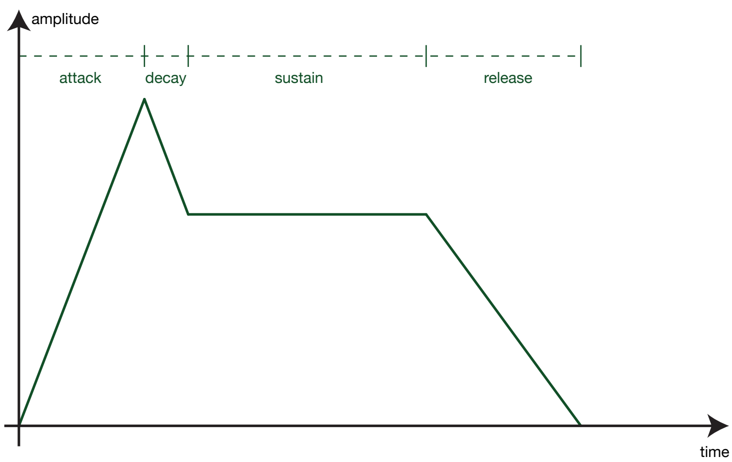


Figure 3.1: The four parts of an amplitude envelope. The attack with a drastic increase in amplitude, followed by the decay, a decrease in amplitude. The sustain is then the period in-which the amplitude remains approximately stable. Finally the amplitude decrease to silence, during the release.

The amplitude envelope of sounds can vary greatly, from having a sharp curve outline, as with the illustration on figure 3.1, to having a round curve outline. Research on musical expression of emotions have shown that a round curve outline is associated with negative valence and low arousal, whereas a sharp outline is associated with positive valence and neutral to high arousal [11].

### Articulation

Articulation refers to the performance of notes – the attack at the beginning of a note, the continuity of a single note and the transition between notes. The varying factors are the attack, the amount of space between the notes and the transition. The two basic and opposite articulations are legato and staccato, but there exists several more. Legato is when each note is played until the next, leaving no space between the played notes. Staccato on the other hand is when the played notes are short in duration and have great space between them (see figure 3.2).

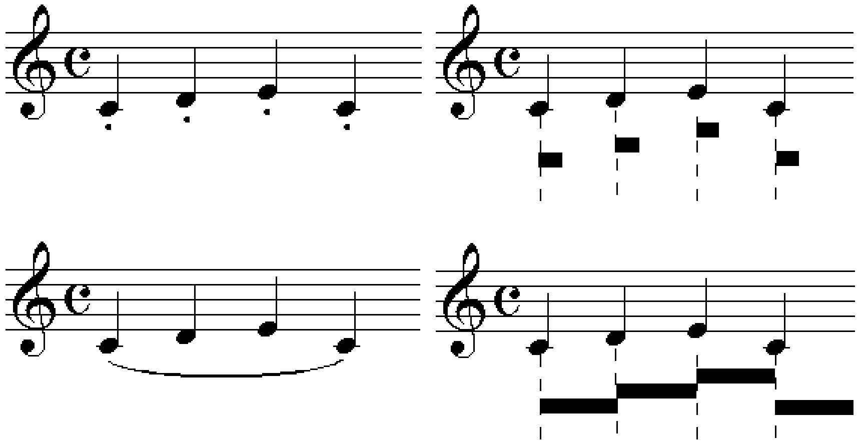

Figure 3.2: The top notations show staccato articulation, and the bottom notations show legato articulation

The staccato and legato articulations refers to the space in between notes, where as accent and slurs refers to the attack of notes. The accent articulation is when an accented note is played louder than the other notes, which means that the accented note has a greater attack at the beginning of the note. The slur articulation is when only the first note is marked, and the following notes connected with the slur, are seamlessly played leaving no space between them [31].

Gabrielsson et al. [11] looked into staccato and legato articulations in relation to the expression of emotions in music. They found that staccato articulations are associated with high arousal, and neutral to negative valence. Legato articulations on the other hand are associated with low arousal and both negative and positive valence.

### Harmony

Harmony is the relation between the combination of several pitches sounding simultaneously. A harmonic can be considered more or less complex (simple vs. complex), and as more or less harmonious (consonant vs. dissonant).

Homophonic music consists of only one melody line, and the remaining of the notes are then either harmony or accompaniment [31]. In western music harmony have been developed greatly. Most of the harmonies in western music are based on chords, which are combination of notes – traditionally three or more – build on major or minor triads [31].

Triads are chords consisting of three notes. A triad consist of a root note and its third and fifth, accordingly to the used scale (see section 3.2 Mode). On the major scale – Ionian – the steps are 1 1 $\frac{1}{2}$ 1 1 1 $\frac{1}{2}$, the third is then 4 semitones up, and the fifth is 7 semitones up. Hereby a C-major chord – where C denotes the root and major the scale – becomes the simultaneously sounding notes C E G. Additionally all chords consisting of C E G are C-major chords despite of the root position. For example the first inversion E G C, where E is note with the lowest frequency (see figure 3.3).

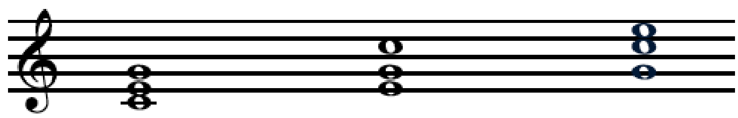

Figure 3.3: From left to right the C-major chord from root position, first inversion and second inversion [31].

The harmonious characteristics of a harmony ranging from consonant to dissonant are related to the intervals, the amount of semitone steps between the combined pitches. The different intervals all have name, like minor third, perfect fourth, etc.. Table 3.2 provides an overview of the division of intervals into consonant and dissonant. The table shows all 12 semitone step of the chromatic scale, and states whether the step combined with the root position creates a consonant or dissonant harmony.

Gabrielsson et al. [11] map consonant harmonies to mainly neutral to positive valence. At neutral arousal consonant harmonies are also mapped to negative valence. Dissonant harmonies are mapped to neutral to negative valence. All in relation to the expression of emotion in music.

### Loudness

Loudness is the perceive sound intensity, which is measured in decibel (dB). The loudness can change not only from one musical piece to another, but also throughout a single musical piece. Gabrielson et al. [11] found that loud loudness are associated with high arousal, and soft loudness with positive valence. Furthermore they looked at loudness variations, and found that small variations are associated with positive valence and high arousal, and rapid changes with positive valence.

### Melody

The melody is a series of pitches (notes) played one after another. In homophonic music the melodic line is the leading part, which is accompanied by harmony. The melody can be described by different characteristics the pitch (melodic) range, the contour / the melodic direction and the melodic motion [11]. The pitch range can range from wide to narrow, depending on the highest and the lowest pitch (note) played in the melodic line. The contour of the melody, or more simplisticly the melody direction, can range from ascending to descending. Figure 3.4 illustrates a melodic

| Semitone Step | Interval | |
|---|---|---|
| 1 | Minor Second | Dissonant |
| 2 | Major Second | Dissonant |
| 3 | Minor Third | Consonant |
| 4 | Major Third | Consonant |
| 5 | Perfect Fourth | Consonant |
| 6 | Tritone | Dissonant |
| 7 | Perfect Fifth | Consonant |
| 8 | Minor sixth | Consonant |
| 9 | Major sixth | Consonant |
| 10 | Minor Seventh | Dissonant |
| 11 | Major Seventh | Dissonant |
| 12 | Octave | Consonant |

Table 3.2: The harmonious characteristics of a root note played simultaneously with either of the 12 semitones in the octave [31].

line, which contour has the shape of an arc, and which direction is ascending till the fifth sound pitch were it starts to descent.

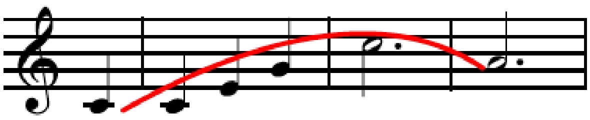

Figure 3.4: An arc shaped melodic line, which is ascending till the fifth sounding pitch, were is then descents.

The motion of the melody describe how fast or slow the melody goes up and down. A melody that for example rises or falls slowly would be step-wise, taking semitone step to increase or decrease the pitch level. A melody that on the other hand rises or falls fast, would be intervallic, as it uses greater sized intervals to increase or decrease the pitch level.

In regards to the expression of emotions in music, the pitch range mainly differentiates between high and low arousal, as a wide pitch range is associated with high arousal, and a narrow with low arousal. The association of the melodic direction, ranging from ascending to descending is a little more diffuse. Here ascending is associated with both positive valence at a neutral arousal level, and negative valence at low arousal. Descending melodic lines are associated with both positive and negative valence at high arousal, and also negative valence at neutral arousal [11].

### Mode

The musical mode is connected to the scale on-which a musical piece is produced. Western classical music is produced on the chromatic scale, which is the diatonic scale with chromatic alternative. In western classical music the seven modes related to the diatonic scale are used. These seven musical modes are *Ionian*, *Dorian*, *Phrygian*, *Lydian*, *Mixylodian*, *Aeolian* and *Locrian*, one for each of the tones on the diatonic scale – C D E F G A B. The Ionian scale – for example C D E F G A B C – corresponds to the major scale, with the example being the C-major scale. The Aeolian scale – for example A B C D E F G A – corresponds to the minor scale, the example being the natural minor scale (see table 3.3).

| **Mode** | **Steps** | **Tonic** | **Diatonic Scale** |
|---|---|---|---|
| Ionian | $1\ 1\ \frac{1}{2}\ 1\ 1\ 1\ \frac{1}{2}$ | C | C D E F G A B C |
| Dorian | $1\ \frac{1}{2}\ 1\ 1\ 1\ \frac{1}{2}\ 1$ | D | D E F G A B C D |
| Phrygian | $\frac{1}{2}\ 1\ 1\ 1\ \frac{1}{2}\ 1\ 1$ | E | E F G A B C D E |
| Lydian | $1\ 1\ 1\ \frac{1}{2}\ 1\ 1\ \frac{1}{2}$ | F | F G A B C D E F |
| Mixylodian | $1\ 1\ \frac{1}{2}\ 1\ 1\ \frac{1}{2}\ 1$ | G | G A B C D E F G |
| Aeolian | $1\ \frac{1}{2}\ 1\ 1\ \frac{1}{2}\ 1\ 1$ | A | A B C D E F G A |
| Locrian | $\frac{1}{2}\ 1\ 1\ \frac{1}{2}\ 1\ 1\ 1$ | B | B C D E F G A B |

Table 3.3: The seven modes of music.

The major scale follows the steps of the Ionian scale, meaning $1\ 1\ \frac{1}{2}\ 1\ 1\ 1\ \frac{1}{2}$, and the minor scale follow the steps of the Aeolian scale $1\ \frac{1}{2}\ 1\ 1\ \frac{1}{2}\ 1\ 1$. Observing all the scales with tonic C the relation between the scales and the major / minor scales clarifies (see table 3.4).

| **Mode** | **Tonic C** |
|---|---|
| Ionian | C D E F G A B C |
| Dorian | C D $E^b$ F G A $B^b$ C |
| Phrygian | C $D^b$ $E^b$ F G $A^b$ $B^b$ C |
| Lydian | C D E $G^b$ G A B C |
| Mixylodian | C D E F G A $B^b$ C |
| Aeolian | C D $E^b$ F G $A^b$ $B^b$ C |
| Locrian | C $D^b$ $E^b$ F $G^b$ $A^b$ $B^b$ C |

Table 3.4: The seven modes of music with tonic C.

The Lydian scale corresponds to the major scale with the fourth degree raised a semitone, and the Mixylodian scale corresponds to the major scale with the seventh degree lowered a semitone. The Dorian and the Phrygian scales on the other hand corresponds to the minor scale with a raised sixth and a lowered second respectively.

Gabrielsson et al. [11] merely relates the two commonly used modes – major and minor – to the expression of emotions in music. They found that the major mode is associated with the expression of mainly neutral to positive valence, and neutral to high arousal. The minor mode is associated with the musical expression of neutral to low arousal, and positive to negative valence.

### Pitch

The pitch level of a musical piece is the subjectively perceived fundamental frequency. As mentioned in the beginning of this chapter, the chromatic scale consists of 12 pitches – C C# D D# E F F# G G# A B$^b$ B – within an octave. The fundamental frequency is the lowest frequency in a harmony. In some case the pitch might though differ from the fundamental frequency, which could be a result of overtones or harmonics in the sound. Nonetheless pitch estimation is normally done by estimating the fundamental frequency [5].

The pitch is a frequency, which is measured in Hz. The pure middle A has the pitch level of 440 Hz. Depending on the playing instrument this frequency will be combined with other frequencies, but it will be the most dominant sounding frequency (see section 3.2 Timbre). Table 3.5 shows the approximated frequencies of commonly used pitched in music.

| | **C** | **C#** | **D** | **D#** | **E** | **F** | **F#** | **G** | **G#** | **A** | **B$^b$** | **B** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 131 | 139 | 147 | 156 | 165 | 175 | 185 | 196 | 208 | 220 | 233 | 247 |
| 4 | 262 | 277 | 294 | 311 | 330 | 349 | 370 | 392 | 415 | 440 | 466 | 494 |
| 5 | 523 | 554 | 587 | 622 | 659 | 698 | 740 | 784 | 831 | 880 | 932 | 988 |

Table 3.5: The approximated frequencies of commonly used pure musical notes.

The frequencies of the pitches are related to the octave, as an octave step correlates with the doubling of the frequencies. More specifically the frequency of a pitch can be described as a function depending on semitone steps from A4 (see equation 3.1). In the equation x is the amount of semitone steps from A4, and f(x) is the frequency of the pitch.

$$f(x) = 440 \cdot 2^{\frac{x}{12}} \tag{3.1}$$

In the musical expression of emotions, a high pitch level is associated with positive valence and a low pitch level with negative valence. In regard the pitch range of a melody, a wide range is associated with high arousal and a narrow range with low arousal [11].

### Rhythm

The rhythm of a musical piece is the pattern of pitches sounding over time [31]. Gabrielsson et al. [11] distinguish rhythm as regular vs. irregular, and describes it with the verbs complex, varied, firm and flowing. A regular rhythm is when the same pattern is repeated over time, whereas an irregular rhythm consists of different rhythmic patterns combined over time.

In the expression of emotions in music, the characteristics complex, varied, firm and flowing distinguish between negative and positive valence, as complex, varied and firm rhythms are associated with negative valence, whereas flowing rhythms are associated with positive valence. The irregularity of the rhythm does not provided a clear distinction, as regular rhythms are associated with positive high and neutral arousal, as well as negative neutral and half low arousal. Irregular rhythms are associated with negative and positive half high arousal [11].

### Tempo

The tempo of a musical piece is the speed of the music, and is measured in bmp (beats per minute). More specifically the tempo is the amount of quarter notes played each minute. This basically means that if the beats are of a duration of a half note, then the tempo is not actually beats per minute, but two times beats per minute.

In relation to the expression of emotions in music, a fast tempo is associated with high arousal and a slow tempo with low arousal [11].

### Timbre

The timbre, which by some are called the colour of music, is the uniqueness of sound. When a saxophone and a trumpet play at the same pitch and loudness, they will still have their own unique sound, this difference is in the timbre [31]. Technical speaking the timbre of a sound is the combination of frequencies, which are not part of the playing notes.

Gabrielsson et al. [11] distinguish the timbre according to amount of harmonics, and whether or not the timbre sounds soft or sharp. They found that few harmonics are mainly associated with the expression of low to neutral arousal, whereas many harmonics are associated with high arousal.

## 3.3 Extra-musical Influences

### Listener features

The listener features are the elements constituting the variety of individualities in the listeners. In section 1.2 the key parameters were listed, namely familiarity, preferences, personality, prior experiences, musical talent, learned associations, motivational state, concentration, mood and auditory sensitivity.

The listed parameters all influence how we experience music to some extend. The familiarity a person has with music, either the familiarity with a specific song, genre or with the scale on which the music is compose, influence the experience. An influence that can be seen in the difference of the experiences in listening to a whole new song, and a song you heard a million times before. The latter might bring memories, or cause you to sing-a-long. The preferences a person has also influences the listening experience. For example if a person finds all hip-hop music terrible, he would have complete different listening experience, than a person preferring this musical genre. The same follows for the remaining parameters.

The listener features can have an influence on emotional responses a listener might experience to music. It is not possible to remove the influences of the listener features, but it is possible to be aware of them. Conducting an experiment based on a listening experience these parameters should therefore be considered as an unavoidable part of the experience.

### Context features

The contextual features include all the elements in the surroundings during the listening experiment. Features like the location, the material properties, the surrounding event, the emitting of sound, and interferences. The location of the experience can influence the surrounding atmosphere and thus the experience. There is for example a different in listening to an outdoor concert in the middle of summer, and listening to an indoor concert. Even when listening to indoor concerts, the experience is effected by the material properties of the building. For example try to image the difference in being at a royal concert hall, and in a warehouse.

As with listener features it is not possible to eliminate the influences of the context, but it is possible to be aware of them, and make an effort to neutralise their influence. Thus the contextual features of a good listening experience is investigated.

#### The listening experience

For knowledge on a good listening experience the HI-FI expert Jon Ram Petersen was consulted. He is an employe at H-FI klubben[2], where he is the primary communicator of acoustics both towards customers and other employes. Through an interview he outlined the main elements to consider when trying to attain great acoustics, which will be summaries here. He initiated the interview by explaining that there is no specific solution, as several elements are balanced accordingly to preference.

The first topic of the interview was the reverb of the sound, which is dependent on the position of the speakers accordingly to surfaces, and on the material of the surfaces. Placing a speaker near a surface, or in a corner, will produce a great amount of reflections of mid-tones and bass, resulting in a more imprecise sound. Furthermore the material type of the surface influences the amount of reflection, as a hard concrete wall reflects more sound, than for example a plaster wall. The position of the speaker up against a back surface should also be considered, as some speakers emit bass and air backwards. His rule of thumb was to position the speakers approximately $30cm$ from the back surface, depending on the size of the speakers. The reflection of sound on a back wall could though also be taken advantage of, in the situation where the used pair of speakers is too small for the environment they are placed in. In general great reverb should be avoided, but it should be remembered that a complete reverb free environment can ruin the variations of the sound, so it becomes more flat.

The mid-tones and bass sounds generally spreads out, whereas the descant is more directional. The direction in which the speakers are pointing in relation to the position of the listener is therefore relevant. Jon Ram Petersen recommended to point the descant approximately $10-15cm$ past the ears of the listener. The height of the speakers are consequently also important, the optimal height is with the descant at ear height, but $\pm 50cm$ is acceptable.

Another parameter is the difference in conditions for the speakers. The most optimal is for the conditions of each speaker to be identical, and for a symmetry to exist centred on a line halfway between the speakers leading to the listener (see figure 3.5). The red triangle on the figure, is an even sided triangle determining the relative position between speakers and the listener.

The last comment Jon Ram Petersen left was that the most optimal result of good acoustics is when the sound is emitted into the room, so the speakers "disappear".

2 http://www.hifiklubben.dk/ (Accessed: 2010-05-28)

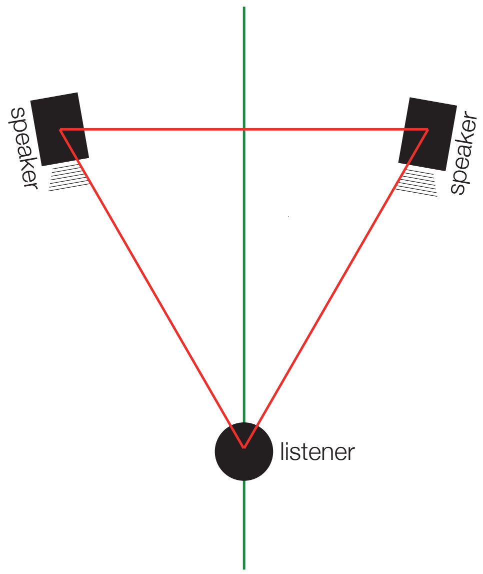


Figure 3.5: The optimal position of speakers to attain good acoustics. The green line is the line of symmetry, and the red triangle is an even sided triangle, determining the position of the speakers related to the listener and each other.

# CHAPTER 4

## Application Developments

The chapter *Application Developments* describes the implementation of two applications. First the application used to measure the continual self-reports of the subjective feeling component of emotions. Last the digital signal processing application used to detect musical features.

## 4.1 Continual Self-reports of Emotional States

To measure the subjective feeling component of emotions, it was decided to use continual self-reports of emotional states. To do so a method was required that allowed for the experiment participants to continual self-report their emotional states without the listening experience being interrupted, and without their heart rate being increased.

The solution was the development of an application, which could be controlled with a wireless XBOX 360 controller. By using a wireless XBOX 360 controller, it was possible for the participants to sit comfortably and relax, while self-reporting their emotional states without physical activity.

It was also necessary to keep the difficulty level of the self-reporting task to a minimum, to maintain the listener experience as central during the experiment. Thus the measurement of self-reports were delimited to the valence dimension. For the rating of current valence level, the use of words was avoided, both to simplify the self-reporting task, by not requiring the participants to read, and to avoid misunderstandings related to the use of words (see section 2.3). As with the self-assessment manikin, illustrations were used for negative and positive valence levels (see figure 4.1). Simple smiley faces to illustrate 3 steps of a 9-leveled valence scale, in similarity to the 2DES instrument for continual 2-dimensional self-reporting [32].

Figure 4.1: The rating scale used to measure self-reports of valence.

### Software architecture

The application was developed in c++ using the openframeworks library[1]. For the use of the wireless XBOX 360 controller with the application, the Mac OSX driver provided by Tattiebogle[2] were installed, and the *GamePad Companion* from CarvWare[3] was used to map the controller buttons to selected keyboard keys.

The application was developed as a collection of pages, through which it could be navigated forth and back with single steps. First an experiment participant was introduced to the valence scale, and how to use it, by the means of trial. When the participant felt comfortable using the scale, he or she could click A to initiate the first musical piece. During the duration of a musical piece and the ensuing continual self-reports, the participant was only provided with the developed valence scale centred on a black background, and the option to move right and left on the scale (see figure 4.2). The current position on the scale was indicated with a colour change from green to grey. At the end of each musical piece, the participant gained the option to continue to the next page, and following to initiate the next musical piece. To view the application interface see appendix A.1.

The applications also managed the playback of the musical pieces, which was used for the experiment. The order in which the selection of musical pieces was

[1] http://www.openframeworks.cc/ (Accessed: 2010-05-23)
[2] http://tattiebogle.net/index.php/ProjectRoot/Xbox360Controller/OsxDriver (Accessed: 2010-05-23)
[3] http://www.carvware.com/gamepadcompanion.html (Accessed: 2010-05-23)


Figure 4.2: The used mapping of buttons on the xbox 360 controller.

played was set to be random. By playing the musical pieces randomly, it possible influences of the playback order on the outcome of the experiment was avoided. To do so the location of the musical pieces were stored into an array, which was randomly reorder between each iteration run of the application – executed by pressing 'n'.

#### Logging

A central task for the application was to simultaneously log the ratings done by the participants, for later reviewal. This task was completed using the output file stream of c++: ofstream. For each iteration run of the application, a new .txt file were created with the current date and time as its name – *yyyymmdd_hhmmss.txt*. In the file the following where stored (see appendix A.1):

- the random order of the musical pieces, for example: "*Playorder: 2 3 1 0*"
- "*Valence:*" to indicate the initialization of a new musical piece
- each new rated valence level, and the elapsed seconds of the playing musical pieces, for example "*44.1707 3*"

## 4.2 Detection of Musical Features

For a later comparison of the measured states of the emotion components – subjective feeling and physiological arousal – an application was developed to detect the state of several musical features. The first step was a delimitation of the basic musical features to a smaller number of features, which have shown strong association with the expression of emotions in music.

In the context of digital signal processing the features can be divided into two categories – *onset related features* and *pitch related features*. The onset related features are *amplitude envelope*, *articulation*, *tempo* and *rhythm*, and the pitch related features are *pitch level*, *pitch (melodic) range*, *mode*, *harmony* and *timbre*. The still not mentioned feature – *loudness* – falls outside these categories. Loudness and variations in loudness have shown to be greatly associated with the expression of emotions, and it is thus one of the detected features.

To retrain computing power for realtime detections without greater delays, it has been chosen to merely focus on one of the two categories of feature. Both onset detection and pitch detection have shown to be difficult task. The current achievements within both detection fields, in regards to homophonic music, are therefore also evaluated for the delimitation choice.

Using onset and offset detection it is possible to detect the staccato and legato characteristics of the articulation, as well as the attack of the amplitude envelope. The detection of tempo is though more complicated, and would have to be delimited to tones pr. second [10]. Both articulation and tempo are related to the expression of arousal in music, similar to the loudness level, though with a more convincing distinction (see section 3.2). The rhythmic complexity and the amplitude envelope are associated with the expression of valence, thus the category provides a great 2-dimensional distinction of emotions. The rhythmic complexity is though a difficult detection task, which might not provided useful measurements [35]. Furthermore the onset detection have shown to meet great difficulties in wind and string instruments [7], which would delimitate the width of timbre in the selection of musical pieces. Complex detection methods, which combines sound and frequency level have though been developed to meet this challenge [10].

Using pitch detections, it is possible to detect the pitch level, the pitch range, the mode, the harmonious characteristics of the harmony and timbre. The amount of harmonics in the timbre have been associated with the expression of arousal, and so has the pitch range. Pitch level, pitch variation and the harmonious characteristics of harmony have on the other hand been associated with the expression of valence, to a more or less precise distinction. Lastly mode have been associated with the distinction of positive high arousal and negative low arousal. Thus the pitch category also provides a distinction of the 2-dimensional emotional space. The musical features – in the pitch related features category – are mainly detected through an interpretation of the fft (fast fourier transforms), which represents the audio signal by the intensity level of several frequency bands. With the increase of texture complexity of the music, follows the increase of the difficulty level of the interpretation of the fft.

Weighing the difficulty level of the detection tasks, it seems the detection of pitch related features will provided more useful expressive measurements of the feature's states. Consequently loudness and the pitch related features are chosen for the detection application.

### Software architecture

The application was developed in c++ using the openframeworks library[4]. The application was divided into 3 segments – the detection of musical features, the logging and the interface.

#### The detection of musical features

##### *Loudness*

The loudness or the sound level intensity is computed over a buffer of $768samples$ at a sampling rate of $44.100Hz$, resulting in a buffer of $\frac{768}{44100} = 0.0174s = 17,4ms$ with a hop size of $1sample$. For the calculations the formula provided by Friberg et al. [10] were used (see equation 4.1). In the equation $SL$ is the loudness level in dB,

[4] http://www.openframeworks.cc/ (Accessed: 2010-05-23)

$x$ is the signal, $w$ is the hanning window of size $N$, which is the amount of samples in one buffer, and $n$ is the sample index.

$$SL = 20 \cdot \log \left( \frac{\sum_{n=i+1}^{i+N} [x(n) \cdot w(n)]^2}{\sum_{n=i+1}^{i+N} w(n)^2} \right) \tag{4.1}$$

***Pitch level***

The detection of pitch level – fundamental frequency – was executed in a similar fashion as the YIN method [5]. Initially the autocorrelation function was calculated for lags between $0 - -256 samples$ $(0 - -5.4ms)$ with the *setAutocorrelationFunction* (see equation 4.2), to determine the frequencies of the sound. In the equation $acf(\tau)$ is the autocorrelation function at time lap $\tau$, $t$ is the current time position, $W$ is the used window width – here $512 samples$ $(11.6ms)$ – and $x$ is the audio signal.

$$acf(\tau) = \sum_{j=t+1}^{t+W-\tau} x(j) \cdot x(j+\tau) \tag{4.2}$$

The basic idea behind the auto correlation function is to multiple the audio signal with a time shifted version of itself to identify the frequencies of the sound. Audio signals are periodic signals, which can be seen by observing the wave of a single sounding frequency. Here it is easily seen that the change in amplitude level is repeated over time (see figure 4.3). The pattern, which is repeated is a cycle, and the time in seconds for one cycle is a period. The period $T$ of one cycle is related to the frequency of the wave, as $f = \frac{1}{T}$. Finding the periods of a signal will thus provide the frequencies of which the signal consists. It is here the autocorrelation function are used. By multiplying the audio signal with a time shifted version of itself, the product at different time lags are related to the period of a sound. For example when multiplying an audio signal with its shifted self at a time lag of half a period, will result in a high magnitude negative number, whereas a multiplication with its shifted self at a time lag of a period would result in the same magnitude, but a positive number (see figure 4.3). Consequently the peaks in the autocorrelation function will be positioned at the periods of the frequencies in the sound, and the frequencies are hereby found as $\frac{1}{T}$.

After the peaks of the autocorrelation function have been identified with the function *getPeaks*, the task was to determine, which peak represented the period of the fundamental frequency $f_0$, and hereby the approximation of the pitch level. The procedure was to identify the period with the highest peak in the autocorrelation function, and use the associated frequency as a first candidate for $f_0$. Following the peaks corresponding to lower frequencies where evaluated as candidates for $f_0$. This was done by detecting if a frequency was an octave lower, than any of the higher frequencies. If this was not the coincidence the frequency would become the new candidate for $f_0$. Subsequently the candidate for $f_0$ were verified by checking if the fft frequency band containing the candidate had a peak. If there was no peak in the frequency band the neighbouring bands were checked for peaks, and the candidate for $f_0$ were adjusted. The used fft was divided in bands based on the frequencies of musical notes, which is future described under the detection of mode.

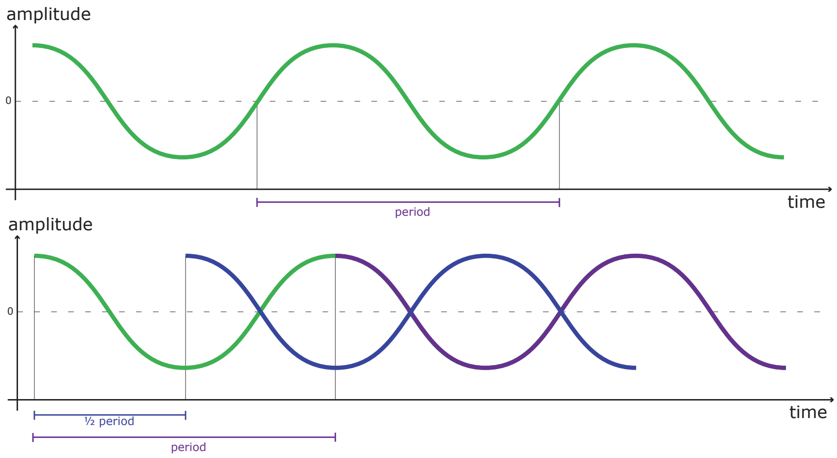


Figure 4.3: Illustration of an audio signal (green) being time shifted by half a period (blue) and by a whole period (purple)

The detection algorithm were tested on two sound recordings, one of the C-major scale played a note at a time in the 4th octave, and another of the C-major chord played four times. In both cases a minimum note duration of $50ms$ was used [10]. In the detection task of the C-major scale, the C4 note was merely detected $45.12\%$ of the time, and the C5 note – one octave above – was detected $19.51\%$, which is a poor result. The detection of a the other notes gave better results though. D4 was detected $96.74\%$ of the time, the error being the initialisation of the note, were C4 was still detected. E4 was detected $91.67\%$ of the time, F4 $92.31\%$, G4 $85.51\%$, A4 $93.51\%$, and B4 was detected $100\%$ of the time. All the errors were at the initialisation of the notes.

The second task was to detect the fundamental frequency during a harmony. The C-major chord – C D E – was played four times at the 4th octave, and the algorithm detect C4 as the fundamental frequency $86.15\%$ of the time, E4 $7.85\%$, G4 $2.27\%$, and C5 $0.24\%$ of the time. Based on these results the implemented detection was accepted for the first iteration of the application.

#### *Pitch range*

The Pitch Range is continuously calculated for the last $200$ detected pitch levels, as the difference between the minimum and maximum pitch level. All detected pitch levels with a duration shorter than $50ms$, the set minimum duration of a note, were neglect as candidates for minimum and maximum pitch level. The pitch range calculation was very sensitive to the errors of the pitch level detection.

#### *Mode*

The detection of the musical mode was based on an interpretation of the fast fourier transform (fft). The fft was obtained through the function *ofSoundGetApectrum*, which is part of the openframeworks library. The obtained fft was initially redivided into to bands centred around the frequencies of the musical notes. The note with the lowest frequency, which was given a band of it own was C1 at $440 \cdot 2^{\frac{-45}{12}} = 32.70\ Hz$. The lower frequencies were kept in the given bandwidth of $5.38Hz$, since $4096 bands$ were requested. The redivided fft was named *fftnotes*.

As previously mentioned (see section 3.2) the musical mode is related to the amount of semitone steps between the sounding notes. The step-size between the frequency bands of *fftnotes* was set to one semitone, which means that the distance between the frequency band of the current pitch level, and frequency bands of other sound notes within an octave, could be used as an indication of the musical mode. Initially one array were stored for each of the seven musical modes, with the semitone steps of the mode, for example Ionian with semitone steps $2, 4, 5, 7, 9, 11, 12$.

The approach was to determine the semitone steps from the pitch level to detected peaks in frequency bands within one octave. The determined semitone steps were following compared to each of the musical mode to find the best match. The musical mode, which was determined the best match, was then converted into a scale ranging from $1 = minor$ (Aoelian) to $6 = major$ (Ionian), with the modes Dorian and Phrygrian set to 2, Locrian to 3 and Lydian and Mixolodian to 5. The number 4 on the scale then represented "*no mode match*".

#### *Harmony*

For the detection of harmony the focus was set on the harmonious characteristic, which ranges from dissonant to consonant. As previously described (see section 3.2) the harmonious characteristic is related to the intervals from the root note to the sounding notes. In table 3.2 it was listed whether an interval was dissonant or consonant. To determine the harmony from a scale ranging from $0 = dissonant$ to $1 = consonant$, the peaks – within one octave of the pitch level – were evaluate as either adding to the measure of dissonant or consonant. Specifically two variables dissonant and consonant, both initiated at 0, were accumulated with 1 when a peak was detected at an associated interval. In the end the magnitude of the consonant variable were divided with the amount of peaks, and the output was used to describe the harmonious characteristic of harmony.

#### *Timbre*

The timbre is referred to as *the colour of sound*, and is what differentiates a piano and a violin, when the note A4 is played on both instruments. From a technical point of view, this makes timbre, the combination of frequencies in the sound, which are not part of the sounding pitches. A measure of timbre could therefore be a combination of factors describing the distribution of sound level in the frequency bands. Here the chosen factors were spectral centroid (median $50\%$) and spectral rolloff $(85\%)$ inspired by [38].

### The logging

The main purpose of the developed application was to obtain the state of the musical features as a time series, for later evaluation. It was therefore essential to implement a logging function, that would store the detected musical features for each played musical piece.

The approach was to create a new file for each musical feature, when a musical pieces was set to play. The created files were given a name according to the musical feature and the current time – *musicalfeature_yyyymmdd_hhmmss.txt* – for example *pitchlevel_20100528_180223.txt*. Subsequently the name of the playing musical piece, and the headings for three columns, namely *TIMESTAMP*, *DELAY* and *VALUE*, were written in the files. Then whenever the application had calculated a new state for a musical feature the values associated with each column where inserted in the respective file.

### The interface

To provide realtime visualisations of the detection performance, an interface consisting of graphs were developed. One graph for each detected musical feature, which shows the state of the musical feature over time (see figure 4.4).

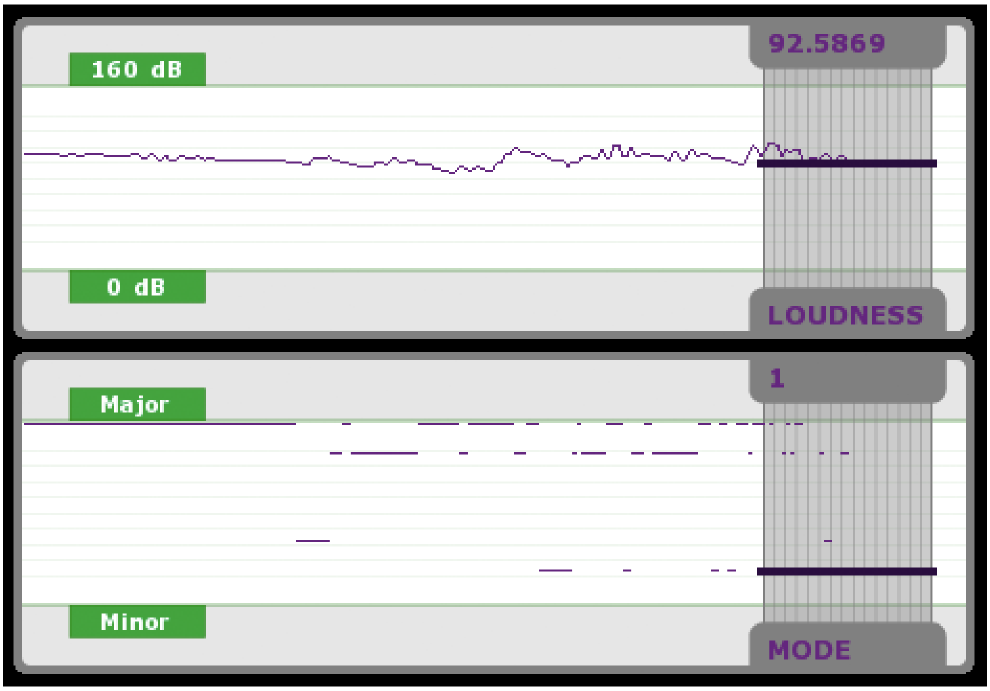


Figure 4.4: The graphical illustration of the detection of musical features.

# CHAPTER 5

## Experiment

In this chapter all aspects of the conducted experiment are presented. Initially the methodology of the experiment, including the selection of musical pieces, the created environment and questions for the participants. Followed by a description of experiment participants, and a presentation and evaluation of the experiment results.

## 5.1 Methodology

The experiment was divided into two separate parts – measuring musical features, and measuring emotional states. The reason for this division was to retrain computing power during the experiment. Both parts of the experiment toke place under the exact same conditions. First the musical features were measured by running the developed application for detection of musical features (see section 4.2). Each of the four selected musical pieces underwent measurements of all features $10 times$.

The second part of the experiment – measuring emotional responses – was conducted over two days. Each participant was shown into the experiment environment and asked to take a seat. The Biopac MP40, which was used to measure ECG, was attached to the participant – the white clip to the right wrist, the red to the left angle and the black to the right angle (ground) – according to the user instructions of the device. Subsequently the device was calibrated, and following the participant was handed the wireless XBOX 360 controller, and informed to follow the instruction on the screen (see appendix B.1).

During the experiment the conductor notated the time position of the ECG measurements at the beginning of each musical piece. The time occurrences of physical movements by the participants were also notated.

### Used musical pieces

For the conductance of the experiment four western classical musical pieces were chosen. The set criteria for the selection of musical pieces, were that they should vary amongst each other, in regards to: the instrument playing the melodic line, the tempo, the interpretation of the emotional expression and the common familiarity.

| Composer | Piece | Performer |
|---|---|---|
| Johann Sebastian Bach (1720) | Cello Suite No. 1 | Yo-yo Ma |
| Ludwig van Beethoven (1798) | Piano Sonata No. 8 | London Symphony Orchestra |
| Claude Debussy (1910) | La Fille Aux Cheveux De Lin | |
| Franz Joseph Haydn (1796) | H.VIIe: 1 – I Allegretto | Wynton Marsalis |

Table 5.1: Musical pieces used in the experiment.

Table 5.1 lists the selection of musical pieces used in the experiment. The *Cello Suite No.1* composed by *Johann Sebastian Bach* around 1720 is though not from the Classical era (1750 – 1820), but from the Baroque era (1600 – 1750). Music from the Baroque, Classical and Romantic eras are though in general by layman refer to, and considered classical music (see section 1.3). The musical piece was chosen, as is a well-known musical piece, due to it's use in television shows and films[1].

Neither is *La Fille Aux Cheveux De Lin*[2] by *Claude Debussy* from the Classical era. This is a modern classical musical piece. The musical piece were initial chosen due to an error on the website http://www.classical.com/ were Wolfgang Amadeus

[1] http://www.imdb.com/name/nm0001925/ (Accessed: 2010-05-22)
[2] English title: *The Girl with the Flaxen Hair*

Mozart was listed as the composer. It was kept as it meets the set delimitations in a broad understanding, and due to its slow tempo and minor common familiarity[3] amongst layman. As with music from the Baroque era, music produced by impressionist of the Romantic era as Debussy, is also by layman considered classical music (see section 1.3).

For the selection of musical pieces, the website http://www.classical.com/ was used to access a wide range of options. The selected musical pieces were then obtained as wave files, which is a lossless audio file format. Each musical pieces were cut in time to last between $90s$ and $120s$, resulting in the following lengths of the pieces: Bach $95s$, Beethoven $111s$, Debussy $107s$ and Haydn $94s$.

### The environment

The environmental setup for the experiment was design based on the requirements of a good listener experience and extra-musical contextual influences. It was the intention to design an environment similar to a home environment where people under normal conditions experience music.

The available room for the experiment was a regular class room at Aalborg University in Copenhagen (Room H1.01). To construct an environment suitable for the experiment inside this class room, a part of the room was closed off with room dividers (see figure 5.1). The used room dividers were of a soft material, which absorbs sound, and consequently delimited the reverb in the environment. A coach was situated in the enclosed environment facing a panoramic view of the green outsides. In front of the coach a coffee table was placed, similar to a standard living room setup.

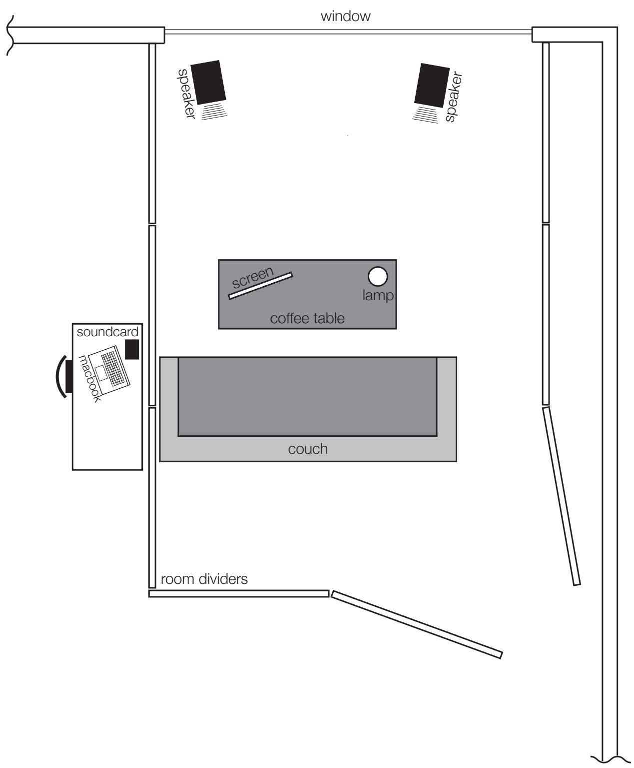


Figure 5.1: The environmental setup used for the experiment

3 http://www.imdb.com/name/nm0006033/ (Accessed: 2010-05-22)

Figure 5.2: Pictures of the environmental setup used for the experiment

The requirements of a good listening experience according to HIFI expert Jon Ram Pedersen (see section 3.3) set a great deal of requirements to the size and the positing of the speakers. The size of the speakers needed to match the size of the environment. Thus Tannoy Reveal R5A 5” active studio monitors were used. The speakers were positioned $46cm$ from the window, and $158cm$ apart, centred on the position of the participant. The distance from the participant to the speakers were approximately $195cm$. Meaning it would have been better to position the participant $37cm$ closer to the speakers, to obtain the even sided triangle (see section 3.3). The main compromise that was made with the speaker setup was the uneven conditions for the speakers, as the left speaker was situated closer to a room divider. This delimitation was necessary due to cable length, and to make it possible to enter the environment.

Prior to the experiment Jon Ram Pedersen inspected the setup to evaluate the create environment for the listening experience. He made small adjustments to the direction of the speakers, to ensure that the descant was pointing $10-15cm$ past the ears of the participants. Furthermore he discovered that when audio was played from the self-report application, the soundscape was not centred between the speakers. To fix this bug the sound in the application was panned to the left, according to trial-and-error. Subsequently he approved the setup as a good listening experience.

The sound level at the position of the participants in the environment was measured for the used setup with a Radioshack sound level meter. The results can be viewed in table 5.2.

| **Musical Piece** | **Standard Range** | **Peak** |
|---|---|---|
| Johann Sebastian Bach | 66 – 74 dB | 79 dB |
| Ludwig van Beethoven | 64 – 70 dB | 78 dB |
| Claude Debussy | 66 – 74 dB | 80 dB |
| Franz Joseph Haydn | 68 – 78 dB | 88 dB |

Table 5.2: The measured sound level for each musical piece at the position of the participants in the environment.

The experiment conductor was then situated outside the environment to cause as little interference with the listener experience as possible. A camera was then used to allow the conductor to view the participants during the experiment (see figure 5.3), as this was a requirement of the measurement method for physiological arousal (see section 2.3).

Figure 5.3: The conductor's point of view during the experiment. The enlargement shows the conductor's view of the environment.

### The questionnaire

The questionnaire was build into the self-report application, so that the questions regard personal information – gender and age – and current mood were answer prior to the listening experiment (see appendix B.2). To obtain the current mood of the participants the Multiple Affective Adjective Checklist – Revised (MAACL–R) were used accordingly to [21].

After listening to each musical piece the participants were then asked two additional questions. They were ask to describe to what extend their rating of the musical piece was how they were actually feeling, and to list their familiarity with the musical piece (see appendix B.2).

### Evaluation of methodology

A small pilot test of the experiment revealed minor necessary adjustment. Despite the instruction on page 5 (see appendix B.1), not all participants informed the conductor of their position in the experiment. This break in the experiment was necessary to allow the experiment conductor to start the recording of heart rate. Thus the conductor informed the participants prior to the experiment to be aware of this break. In later iterations of the continual self-reports application, this break should be forced.

Furthermore the instructions did not – to a sufficient extend – bring across the continual property of the valence scale. Thus in the break requested on page 5, the conductor inform the participants: "*The rating scale that you just had a change to try out, is a continual scale. This means that during the entire length of a musical piece, you can adjust the scale accordingly to how you are feeling in the present*".

Lastly the font used for the instructions should be increased in size, as participants were observed moving closer to the screen, when it was required of them to read. This did though not have any influence on the outcome of the experiment results.

## 5.2 Participants

$36$ people participated in the experiment. Due to technical errors the information details on one of the participants were lost. Of the remaining $35$ participants, $29$ $(80.6\%)$ were male and 6 $(16.7\%)$ were female. The participants ranged in age from $21$ to $32 years$, with an average age of $25 years$.

## 5.3 Results

The results from the experiment is interpreted in steps. First the self-reports and the heart rate levels of ECG measurements of each participant are matched, to determine if the measurements are in fact signs of emotional responses. For a measurement to be a sign of an emotional response, the measured physiological arousal (heart rate) and subjective feeling (continual self-report) should be synchronised (see section 2.3). To determine if two measurements are synchronised the delay of the measurements should be taken into consideration. According to the reviewed article [1], the peak of an increase in heart rate is delayed with approximately $4s$, were as a decrease is only delayed with approximately $1s$. With the self-reports the delay is unknown, and could easily vary between participants. Consequently the two time series are cross-correlated, and a plot of the cross-correlation is used to analyse the data for randomness.

For the interpretation of the measurements, the sample rate is downsampled to $1 sample/s$, both for the continual self-reports, the heart rate measurements and the state of detected musical features. For the continual self-reports and the state of musical features, the downsampling was done manually, due to the logging approach of the developed applications. The heartrate wavedata provided by the Biopac consisted of $1 sample$ each $0.00001667 min$, which is a sample rate of $\frac{1}{0.00001667*60} = 1000\ samples/s$. Here Matlab was used to downsample the wavedata with $1000$, to gain a sample rate of $1 sample/s$. To view the results from the self-reports see appendix C.1. To view the result from the heart rate measurements and the detected states of musical features see appendix C.5.

### Synchronisation of self-reports and heart rate measurements.

To examine each pair of self-reports and heart rate measurements, for a possible time synchronisation in changes, it is necessary to describe the measurements by their changes. The approach was here to create binary time series, where 1 represents change and 0 represents no change. The definition of change were set differently depending on the measurement type. For the continual self-reports a change was simply defined as a change in value. With the heart rate measurements a change was defined as a significantly different heart rate, since a constant minor variation in heart rate is normal. From a statistical point of view the standard deviation of a data set can be used to show the general variation from the average. Thus is can be used to show when a heart rate measurement is outside the general variation, which is here used as an indication of a significantly different heart rate.

The binary time series for both the continual self-reports and the heart rate measurements have been plotted for each participant. Furthermore a cross-correlation of the series have been calculated and plotted, to visualise the possibility of a synchronisation at delays from 0-10 s (see appendix C.2) .

For each musical piece the following approach is taken. First the participants for whom one of the measurements types are without changes are left out of the evaluation. Second the participants for whom the data did not show signs of a synchronisation is left out as well. Last the participants for whom the data showed sign of of a synchronisation is evaluated. All the calculations were preformed using Matlab (see appendix C.4).

### Johann Sebastian Bach - Musical Piece 0

A few participants ($8.3\%$) chose not to change the valence scale throughout this musical piece – participants 3, 7 and 10 – and these participants can therefore not be evaluated for the occurrence of an emotional response. For participant 22 the cross-correlation showed no synchronisations within $+10s$. Participant 3 and 8 stated that "*they rated the emotions they recognised in the musical piece*", participant 3 have already been excluded from evaluation, but participant 8 will be evaluated.

Musical Piece 0: LENGTH: 95

| # | HRC | SRC | SYNC | DELAY | % HR | % SR | RATING | | Likelihood |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 23 | 4 | 2 | 4 | 8.70% | 50.00% | 100.00% | -50.00% | 20.20% |
| 2 | 36 | 20 | 5 | 2 | 13.89% | 25.00% | 75.00% | -50.00% | 9.56% |
| 3 | 27 | 0 | 0 | | 0.00% | 0.00% | 0.00% | 0.00% | 100.00% |
| 4 | 25 | 2 | 2 | 2 | 8.00% | 100.00% | 25.00% | 75.00% | 6.93% |
| 5 | 34 | 26 | 14 | 4 | 41.18% | 53.85% | | | 2.68% |
| 6 | 25 | 2 | 1 | 0 | 4.00% | 50.00% | 100.00% | -50.00% | 38.78% |
| 7 | 11 | 0 | 0 | | 0.00% | 0.00% | 50.00% | -50.00% | 100.00% |
| 8 | 29 | 13 | 6 | 1 | 20.69% | 46.15% | 0.00% | 46.15% | 10.85% |
| 9 | 30 | 2 | 2 | 6 | 6.67% | 100.00% | 75.00% | 25.00% | 9.97% |
| 10 | 15 | 0 | 0 | | 0.00% | 0.00% | 75.00% | -75.00% | 100.00% |
| 11 | 24 | 1 | 1 | 0 | 4.17% | 100.00% | 75.00% | 25.00% | 25.26% |
| 12 | 28 | 1 | 1 | 6 | 3.57% | 100.00% | 100.00% | 0.00% | 29.47% |
| 13 | 33 | 2 | 2 | 0 | 6.06% | 100.00% | 75.00% | 25.00% | 12.07% |
| 14 | 3 | 2 | 1 | 2 | 33.33% | 50.00% | 100.00% | -50.00% | 6.12% |
| 15 | 32 | 5 | 3 | 1 | 9.38% | 60.00% | 25.00% | 35.00% | 16.81% |
| 16 | 19 | 9 | 2 | 0 | 10.53% | 22.22% | 75.00% | -52.78% | 30.20% |
| 17 | 25 | 1 | 1 | 3 | 4.00% | 100.00% | 100.00% | 0.00% | 26.32% |
| 18 | 5 | 12 | 2 | 1 | 40.00% | 16.67% | 75.00% | -58.33% | 10.65% |
| 19 | 23 | 2 | 2 | 4 | 8.70% | 100.00% | 75.00% | 25.00% | 5.86% |
| 20 | 22 | 2 | 1 | 0 | 4.55% | 50.00% | 75.00% | -25.00% | 35.59% |
| 21 | 25 | 6 | 3 | 1 | 12.00% | 50.00% | 75.00% | -25.00% | 14.58% |
| 22 | 24 | 1 | 0 | | 0.00% | 0.00% | 25.00% | -25.00% | 74.74% |
| 23 | 14 | 20 | 4 | 3 | 28.57% | 20.00% | 100.00% | -80.00% | 17.83% |
| 24 | 3 | 11 | 1 | 10 | 33.33% | 9.09% | 75.00% | -65.91% | 25.20% |
| 25 | 20 | 3 | 2 | 0 | 10.00% | 66.67% | 100.00% | -33.33% | 10.50% |
| 26 | 25 | 2 | 2 | 1 | 8.00% | 100.00% | 100.00% | 0.00% | 6.93% |
| 27 | 27 | 4 | 2 | 0 | 7.41% | 50.00% | 100.00% | -50.00% | 24.83% |
| 28 | 27 | 2 | 2 | 4 | 7.41% | 100.00% | 25.00% | 75.00% | 8.08% |
| 29 | 21 | 3 | 3 | 4 | 14.29% | 100.00% | 100.00% | 0.00% | 1.08% |
| 30 | 34 | 3 | 3 | 0 | 8.82% | 100.00% | 100.00% | 0.00% | 4.58% |
| 31 | 28 | 6 | 1 | 3 | 3.57% | 16.67% | 100.00% | -83.33% | 30.86% |
| 32 | 6 | 4 | 1 | 0 | 16.67% | 25.00% | 50.00% | -25.00% | 20.77% |
| 33 | 18 | 6 | 3 | 6 | 16.67% | 50.00% | 75.00% | -25.00% | 7.24% |
| 34 | 32 | 4 | 3 | 3 | 9.38% | 75.00% | 50.00% | 25.00% | 10.14% |
| 35 | 22 | 3 | 1 | 7 | 4.55% | 33.33% | 75.00% | -41.67% | 41.02% |
| 36 | 26 | 7 | 3 | 0 | 11.54% | 42.86% | 75.00% | -32.14% | 19.97% |

Figure 5.4: The synchronisation results from the musical piece composed by Johann Sebastian Bach

Figure 5.4 summarises the results from the experiment (see appendix C.2). In the right most column $Likelihood$, the likelihood of the synchronisation happening is listed. The likelihood $L$ is calculated according to equation 5.1. In the equation $S = \frac{HRC}{Length}$ is the percentage for success, $F = 1 - S$ is the percentage for failure, $SYNC$ is the amount of synchronisations (successes) and $C$ is the possible combinations for the amount of successes and failures. These calculations were done as multiple changes in heart rate – which could be the cause of other stimuli – increase the possibility of synchronisation by chance.

$$L = S^{SYNC} \cdot F^{SRC-SYNC} \cdot C \tag{5.1}$$

All the cases in which the likelihood of the synchronisation is above $25\%$ – mark with red – are not further evaluated, as the chance of coincidence is regarded too great. Cases with a likelihood of occurrence between $10 - 25\%$ are marked yellow, and cases with likelihoods below $10\%$ as green.

The percentage of the synchronisations in relation to the amount of changes in the self-reports (see column $\%\ SR$), is now related to the participants ratings (see column $RATING$). After each musical piece the participants were asked to describe their ratings on a scale from 1 to 5. With 1 being "*I rated the emotional states I recognised in the musical piece*", and 5 being "*I rated the emotional states I was feeling at the time*". By comparing these two values it might be more comprehendible why not all of the self-reports are necessarily synchronised with the heart rates. This comparison is though only a guideline, due to the difficulty level of the task at hand for the participants.

The synchronisations with shorter lags ($\leq 5s$) are interpreted as a better sign of synchronisation. The criteria for the first proposal of synchronisations are yellow or green likelihoods, a delay $\leq 5s$, and at least $50\%$ of the self-reports or a higher percentage than the rating. Hereby the first proposal for participants with synchronisations of the subjective feeling component and the physiological arousal component (see table 5.3).

| Participant # | # of sync | Time of sync |
|---|---|---|
| 4 | 2 | 34 44 |
| 5 | 14 | 3 6 26 27 28 32 51 53 68 72 75 80 81 90 |
| 8 | 6 | 12 16 34 35 74 87 |
| 13 | 2 | 33 74 |
| 14 | 1 | 18 |
| 15 | 3 | 53 66 81 |
| 19 | 2 | 6 7 |
| 21 | 3 | 3 47 55 |
| 25 | 2 | 8 92 |
| 26 | 2 | 5 27 |
| 27 | 2 | 22 50 |
| 28 | 2 | 6 35 |
| 29 | 3 | 5 6 49 |
| 30 | 3 | 24 60 76 |
| 34 | 3 | 4 31 63 |
| 36 | 3 | 8 15 35 |

Table 5.3: The first proposal for synchronisations during the musical piece composed by Bach (0).

These proposals should now be matched with the notation of physical movements during the experiment, to ensure that the change in heart rate is not cause by physical movements. For participants 4, 5 and 8 no notations were made, due to the lack of streaming video. Participants 13, 15, 21, 26, 27, 28, 34 and 36 were not notated for any physical movements during the duration of the musical piece. Participant 14 moved at $15s$, $37s$ and $91s$, and the registered synchronisation for the participant was at $18s$, merely $3s$ after a physical movement, and participant 14 is thus left out. Participant 19 moved at $4s$, also fairly close to the found synchronisations, and is likewise left out. Participant 25 moved at $28s$, which is $64s$ before the next registered synchronisation, and participant 25 is thus kept. Participant 29 moved at $3s$ and $38s$, the first movement is fairly close to the two first registered synchronisations, and these are therefore disregarded, but due to the $10s$ period from the last movement to the following synchronisation, this synchronisation is kept. Participant 30 was notated for movement at $26s$, which does not interfere with the registered synchronisations. Consequently participants 4, 5, 8, 13, 15, 21, 25, 26, 27, 28, 29, 30, 34 and 36 are the final proposal for participants with registered synchronisations during the musical piece by Bach. With the remarks that participants 4, 5 and 8 were not checked for movements, and participant 29 was only registered for a synchronisation at $49s$.

#### Ludwig van Beethoven - Musical Piece 1

Figure 5.5 summarises the results from the musical piece produced by Ludwig van Beethoven. During this musical piece participants 3, 10 and 12 ($8.3\%$) chose not to change their self-report ratings, and can therefore not be evaluated for the occurrence of an emotional response. Participants 31 and 34 ($5.6\%$), both changed their self-reports during the musical piece, but the cross-correlation showed that their were no synchronisation of changes within $+10s$. None of the participants described their self-reports during this musical piece as "*I rated the emotional states I recognised in the musical piece*".

Based on the same criteria as with musical piece 0, the first proposal consists of participants with a yellow or green likelihoods, a delay $\leq 5s$, and at least $50\%$ of the self-reports or a percentage higher than the rating (see table 5.4).

| Participant # | # of sync | Time of sync |
|---|---|---|
| 2 | 24 | 5 11 22 27 32 35 36 38 40 41 42 43 57 58 62 63 73 74 81 82 83 89 96 |
| 4 | 2 | 32 77 |
| 6 | 2 | 24 65 |
| 9 | 5 | 6 17 65 78 106 |
| 15 | 8 | 14 56 60 63 68 71 76 102 |
| 16 | 5 | 35 46 60 78 101 |
| 19 | 2 | 18 36 |
| 30 | 1 | 11 |
| 35 | 2 | 56 98 |

Table 5.4: The first proposal for synchronisations during the musical piece composed by Beethoven (1).

These proposals are now matched against the notations of physical movements for the participants during the musical piece. For participants 2, 4 and 6 no notations were made, due to the lack of streaming video. Participants 9, 15, 16 and 19 were

Musical Piece 1: LENGTH: 111

| # | HRC | SRC | SYNC | DELAY | % HR | % SR | RATING | | Likelihood |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 36 | 1 | 1 | 1 | 2.78% | 100.00% | 50.00% | 50.00% | 32.43% |
| 2 | 31 | 75 | 24 | 4 | 77.42% | 32.00% | 25.00% | 7.00% | 7.28% |
| 3 | 25 | 0 | 0 | | 0.00% | 0.00% | 25.00% | -25.00% | 100.00% |
| 4 | 24 | 5 | 2 | 1 | 8.33% | 40.00% | 25.00% | 15.00% | 22.51% |
| 5 | 27 | 41 | 12 | 2 | 44.44% | 29.27% | | | 10.47% |
| 6 | 31 | 2 | 2 | 2 | 6.45% | 100.00% | 100.00% | 0.00% | 7.80% |
| 7 | 7 | 2 | 1 | 8 | 14.29% | 50.00% | 75.00% | -25.00% | 11.82% |
| 8 | 31 | 6 | 2 | 2 | 6.45% | 33.33% | 75.00% | -41.67% | 31.57% |
| 9 | 44 | 7 | 5 | 4 | 11.36% | 71.43% | 50.00% | 21.43% | 7.49% |
| 10 | 11 | 0 | 0 | | 0.00% | 0.00% | 75.00% | -75.00% | 100.00% |
| 11 | 36 | 1 | 1 | 0 | 2.78% | 100.00% | 75.00% | 25.00% | 32.43% |
| 12 | 36 | 0 | 0 | | 0.00% | 0.00% | 75.00% | -75.00% | 100.00% |
| 13 | 42 | 1 | 1 | 0 | 2.38% | 100.00% | 50.00% | 50.00% | 37.84% |
| 14 | 28 | 2 | 1 | 4 | 3.57% | 50.00% | 25.00% | 25.00% | 37.72% |
| 15 | 30 | 18 | 8 | 2 | 26.67% | 44.44% | 25.00% | 19.44% | 5.33% |
| 16 | 37 | 10 | 5 | 3 | 13.51% | 50.00% | 75.00% | -25.00% | 13.66% |
| 17 | 36 | 1 | 1 | 1 | 2.78% | 100.00% | 100.00% | 0.00% | 32.43% |
| 18 | 10 | 9 | 3 | 0 | 30.00% | 33.33% | 100.00% | -66.67% | 3.49% |
| 19 | 11 | 4 | 2 | 2 | 18.18% | 50.00% | 50.00% | 0.00% | 4.78% |
| 20 | 31 | 14 | 5 | 2 | 16.13% | 35.71% | 75.00% | -39.29% | 17.85% |
| 21 | 27 | 3 | 1 | 2 | 3.70% | 33.33% | 100.00% | -66.67% | 41.79% |
| 22 | 22 | 1 | 1 | 6 | 4.55% | 100.00% | 75.00% | 25.00% | 19.82% |
| 23 | 25 | 15 | 4 | 0 | 16.00% | 26.67% | 100.00% | -73.33% | 21.21% |
| 24 | 38 | 22 | 8 | 0 | 21.05% | 36.36% | 100.00% | -63.64% | 17.08% |
| 25 | 28 | 3 | 1 | 0 | 3.57% | 33.33% | 75.00% | -41.67% | 42.31% |
| 26 | 34 | 4 | 1 | 0 | 2.94% | 25.00% | 100.00% | -75.00% | 40.90% |
| 27 | 15 | 6 | 1 | 4 | 6.67% | 16.67% | 100.00% | -83.33% | 39.23% |
| 28 | 23 | 3 | 1 | 3 | 4.35% | 33.33% | 75.00% | -41.67% | 39.07% |
| 29 | 33 | 4 | 2 | 0 | 6.06% | 50.00% | 50.00% | 0.00% | 26.19% |
| 30 | 27 | 1 | 1 | 1 | 3.70% | 100.00% | 100.00% | 0.00% | 24.32% |
| 31 | 6 | 17 | 0 | | 0.00% | 0.00% | 50.00% | -50.00% | 38.88% |
| 32 | 6 | 7 | 2 | 0 | 33.33% | 28.57% | 100.00% | -71.43% | 4.65% |
| 33 | 28 | 2 | 1 | 2 | 3.57% | 50.00% | 100.00% | -50.00% | 37.72% |
| 34 | 5 | 1 | 0 | | 0.00% | 0.00% | 75.00% | -75.00% | 95.50% |
| 35 | 7 | 4 | 2 | 0 | 28.57% | 50.00% | 75.00% | -25.00% | 2.09% |
| 36 | 35 | 4 | 2 | 4 | 5.71% | 50.00% | 100.00% | -50.00% | 27.97% |

Figure 5.5: The synchronisation results from the musical piece composed by Ludwig van Beethoven

not notated for any physical movements during the duration of this musical piece. Participant 30 was notated for movement in the interval $81 - 88s$, which did not interfere with the registered synchronisation. Participant 35 was registered for movement at $48s$, $53s$, $79s$, $86s$ and $92s$, which interfere with the registered synchronisations, and the participant is thus left out.

Consequently participants 2, 4, 6, 9, 15, 16, 19 and 30 are the final proposal for participants with registered synchronisations during the musical piece by Beethoven. With the remarks that participants 2, 4 and 6 were not checked for movements.

### Franz Joseph Haydn - Musical Piece 2

Figure 5.6 summarises the results from the musical piece produced by Franz Joseph Haydn. During this musical piece, participant 31 did not how he was feeling, as he did not understand the task, and started a communication flow with the experiment conductor. Consequently the participant is excluded from the evaluation. Participants 10 and 19 ($5.6\%$) chose not to change their self-reports during this musical piece, and can therefore neither be used for the evaluation. Participants 22, 29, 34 and 36 ($11.1\%$) was not registered for any synchronisations of changes within $+10s$. None of the participants described their self-reports during this musical piece as "*I rated the emotional states I recognised in the musical piece*".

Musical Piece 2: LENGTH: 94

| # | HRC | SRC | SYNC | DELAY | % HR | % SR | RATING | | Likelihood |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 16 | 6 | 3 | 2 | 18.75% | 50.00% | 100.00% | -50.00% | 5.64% |
| 2 | 23 | 37 | 7 | 1 | 30.43% | 18.92% | 50.00% | -31.08% | 11.93% |
| 3 | 25 | 3 | 2 | 0 | 8.00% | 66.67% | 50.00% | 16.67% | 15.58% |
| 4 | 24 | 2 | 1 | 2 | 4.17% | 50.00% | 25.00% | 25.00% | 38.03% |
| 5 | 26 | 27 | 11 | 3 | 42.31% | 40.74% | | | 5.32% |
| 6 | 24 | 3 | 2 | 2 | 8.33% | 66.67% | 100.00% | -33.33% | 14.56% |
| 7 | 9 | 7 | 1 | 0 | 11.11% | 14.29% | 75.00% | -60.71% | 36.64% |
| 8 | 21 | 17 | 7 | 0 | 33.33% | 41.18% | 75.00% | -33.82% | 4.31% |
| 9 | 2 | 3 | 1 | 5 | 50.00% | 33.33% | 75.00% | -41.67% | 6.11% |
| 10 | 23 | 0 | 0 | | 0.00% | 0.00% | 50.00% | -50.00% | 100.00% |
| 11 | 22 | 1 | 1 | 0 | 4.55% | 100.00% | 75.00% | 25.00% | 23.40% |
| 12 | 34 | 2 | 1 | 2 | 2.94% | 50.00% | 100.00% | -50.00% | 46.17% |
| 13 | 25 | 4 | 2 | 0 | 8.00% | 50.00% | 75.00% | -25.00% | 22.87% |
| 14 | 38 | 4 | 1 | 0 | 2.63% | 25.00% | 100.00% | -75.00% | 34.19% |
| 15 | 19 | 26 | 8 | 2 | 42.11% | 30.77% | 25.00% | 5.77% | 7.47% |
| 16 | 19 | 9 | 2 | 0 | 10.53% | 22.22% | 25.00% | -2.78% | 30.28% |
| 17 | 27 | 6 | 4 | 3 | 14.81% | 66.67% | 100.00% | -33.33% | 5.19% |
| 18 | 27 | 7 | 5 | 4 | 18.52% | 71.43% | 75.00% | -3.57% | 2.09% |
| 19 | 22 | 0 | 0 | | 0.00% | 0.00% | 25.00% | -25.00% | 100.00% |
| 20 | 31 | 6 | 4 | 0 | 12.90% | 66.67% | 50.00% | 16.67% | 7.97% |
| 21 | 31 | 6 | 1 | 0 | 3.23% | 16.67% | 75.00% | -58.33% | 26.76% |
| 22 | 28 | 1 | 0 | | 0.00% | 0.00% | 25.00% | -25.00% | 70.21% |
| 23 | 16 | 13 | 3 | 0 | 18.75% | 23.08% | 100.00% | -76.92% | 21.83% |
| 24 | 27 | 11 | 3 | 1 | 11.11% | 27.27% | 75.00% | -47.73% | 26.05% |
| 25 | 23 | 2 | 1 | 0 | 4.35% | 50.00% | 100.00% | -50.00% | 36.96% |
| 26 | 25 | 2 | 2 | 2 | 8.00% | 100.00% | 75.00% | 25.00% | 7.07% |
| 27 | 29 | 3 | 3 | 2 | 10.34% | 100.00% | 100.00% | 0.00% | 2.94% |
| 28 | 26 | 3 | 1 | 0 | 3.85% | 33.33% | 50.00% | -16.67% | 43.42% |
| 29 | 9 | 1 | 0 | | 0.00% | 0.00% | 100.00% | -100.00% | 90.43% |
| 30 | 28 | 2 | 1 | 2 | 3.57% | 50.00% | 100.00% | -50.00% | 41.83% |
| 31 | | | | | | | 50.00% | | |
| 32 | 5 | 6 | 1 | 1 | 20.00% | 16.67% | 50.00% | -33.33% | 24.28% |
| 33 | 16 | 4 | 3 | 2 | 18.75% | 75.00% | 100.00% | -25.00% | 1.64% |
| 34 | 4 | 1 | 0 | | 0.00% | 0.00% | 75.00% | -75.00% | 95.74% |
| 35 | 6 | 3 | 1 | 2 | 16.67% | 33.33% | 50.00% | -16.67% | 16.78% |
| 36 | 5 | 7 | 0 | | 0.00% | 0.00% | 100.00% | -100.00% | 68.21% |

Figure 5.6: The synchronisation results from the musical piece composed by Franz Joseph Haydn

Based on the same criteria as with musical piece 0 and 1, the first proposal for participants with synchronisations consists of participants with a yellow or green likelihoods, a delay $\leq 5s$, and at least $50\%$ of the self-reports or a percentage higher than the rating (see table 5.5).

The synchronisation times are now compared with notated physical movements of the participants during the musical piece. No movement notations were made for the participants 1, 3 and 6, due to lack of video streaming. Participants 11, 13, 15, 17, 26, 27 and 33 were not notated for any movements during this musical piece.

| Participant # | # of sync | Time of sync |
|---|---|---|
| 1 | 3 | 46 47 66 |
| 3 | 2 | 38 39 |
| 6 | 2 | 9 22 |
| 11 | 1 | 6 |
| 13 | 2 | 20 43 |
| 15 | 8 | 16 33 43 49 51 87 90 91 |
| 17 | 4 | 15 35 46 77 |
| 20 | 4 | 3 5 8 38 |
| 26 | 2 | 4 77 |
| 27 | 3 | 6 19 89 |
| 33 | 3 | 5 11 12 |

Table 5.5: The first proposal for synchronisations during the musical piece composed by Haydn (2).

Participant 20 was notated for movement at $72s$, which does not interfere with the registered synchronisations. Consequently all participants are kept for the final proposal for participants with registered synchronisations during the musical piece by Haydn. With the remarks that participants 1, 3 and 6 were not checked for movements.

**Claude Debussy - Musical Piece 3**

Figure 5.7 summarises the results from the musical piece produced by Claude Debussy. During this musical piece participants 3, 12, 14, 17, 19 and 20 $(16.7\%)$ chose not to change the state of the valence scale, and are therefore not used for the synchronisation evaluation. For participants 10 and 36 $(5.6\%)$ no synchronisations where found within $+10s$. Participant 8 described his self-reports during this musical piece as "*I rated the emotional states I recognised in the musical piece*".

Based on the same criteria as with musical piece 0, 1 and 2, the first proposal for participants with synchronisations consists of participants with a yellow or green likelihoods, a delay $\leq 5s$, and at least $50\%$ of the self-reports or a percentage higher than the rating (see table 5.6).

In similar fashion as with the other musical pieces, the first proposals are now evaluated against the notations of movements during the musical piece by Debussy. The movements of participants 4, 6, 7 and 8 could not be notated, due to the lack of video streaming. Participants 13, 15 and 24 were not registered for any physical movements during this musical piece. Participant 9 was notated for movement at $1-2s$, which does not interfere with the synchronisations. Neither does the movements of participant 21 at $53-54s$. Participant 29 was notate to move at $31s$, and the registered synchronisation at $35s$ is therefore left out. Participant 30 was notated for movements at $22s$, $41s$ and $73s$, which does not interfere with the registered synchronisations. Consequently the final proposal for registered synchronisation consists of all the participants from the first proposal, with the remarks that participants 4, 6, 7 and 8 were not checked for movements, and that the synchronisation at $35s$ for participant 29 have been left out.

Musical Piece 3: LENGTH: 107

| # | HRC | SRC | SYNC | DELAY | % HR | % SR | RATING | | Likelihood |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 23 | 12 | 3 | 2 | 13.04% | 25.00% | 75.00% | -50.00% | 24.75% |
| 2 | 29 | 49 | 17 | 3 | 58.62% | 34.69% | 50.00% | -15.31% | 6.04% |
| 3 | 29 | 0 | 0 | | 0.00% | 0.00% | 25.00% | -25.00% | 100.00% |
| 4 | 2 | 2 | 1 | 4 | 50.00% | 50.00% | 50.00% | 0.00% | 3.67% |
| 5 | 33 | 39 | 14 | 2 | 42.42% | 35.90% | | | 10.53% |
| 6 | 31 | 3 | 2 | 0 | 6.45% | 66.67% | 75.00% | -8.33% | 17.89% |
| 7 | 12 | 2 | 1 | 1 | 8.33% | 50.00% | 50.00% | 0.00% | 19.91% |
| 8 | 16 | 14 | 3 | 0 | 18.75% | 21.43% | 0.00% | 21.43% | 20.49% |
| 9 | 8 | 5 | 2 | 5 | 25.00% | 40.00% | 25.00% | 15.00% | 4.43% |
| 10 | 15 | 1 | 0 | | 0.00% | 0.00% | 75.00% | -75.00% | 85.98% |
| 11 | 27 | 2 | 1 | 0 | 3.70% | 50.00% | 25.00% | 25.00% | 37.73% |
| 12 | 28 | 0 | 0 | | 0.00% | 0.00% | 100.00% | -100.00% | 100.00% |
| 13 | 30 | 3 | 2 | 1 | 6.67% | 66.67% | 75.00% | -8.33% | 16.97% |
| 14 | 33 | 0 | 0 | | 0.00% | 0.00% | 100.00% | -100.00% | 100.00% |
| 15 | 27 | 20 | 8 | 1 | 29.63% | 40.00% | 25.00% | 15.00% | 6.32% |
| 16 | 34 | 12 | 5 | 0 | 14.71% | 41.67% | 50.00% | -8.33% | 17.65% |
| 17 | 28 | 0 | 0 | | 0.00% | 0.00% | 100.00% | -100.00% | 100.00% |
| 18 | 20 | 8 | 3 | 1 | 15.00% | 37.50% | 100.00% | -62.50% | 13.00% |
| 19 | 33 | 0 | 0 | | 0.00% | 0.00% | 25.00% | -25.00% | 100.00% |
| 20 | 29 | 0 | 0 | | 0.00% | 0.00% | 75.00% | -75.00% | 100.00% |
| 21 | 29 | 4 | 2 | 3 | 6.90% | 50.00% | 100.00% | -50.00% | 23.42% |
| 22 | 25 | 2 | 1 | 0 | 4.00% | 50.00% | 75.00% | -25.00% | 35.81% |
| 23 | 24 | 11 | 5 | 0 | 20.83% | 45.45% | 100.00% | -54.55% | 5.71% |
| 24 | 38 | 11 | 8 | 3 | 21.05% | 72.73% | 100.00% | -27.27% | 1.12% |
| 25 | 34 | 2 | 1 | 1 | 2.94% | 50.00% | 50.00% | 0.00% | 43.36% |
| 26 | 25 | 3 | 1 | 2 | 4.00% | 33.33% | 100.00% | -66.67% | 41.17% |
| 27 | 23 | 4 | 1 | 0 | 4.35% | 25.00% | 75.00% | -50.00% | 41.60% |
| 28 | 37 | 2 | 1 | 0 | 2.70% | 50.00% | 75.00% | -25.00% | 45.24% |
| 29 | 24 | 3 | 2 | 1 | 8.33% | 66.67% | 100.00% | -33.33% | 11.71% |
| 30 | 27 | 4 | 2 | 0 | 7.41% | 50.00% | 100.00% | -50.00% | 21.36% |
| 31 | 32 | 20 | 9 | 0 | 28.13% | 45.00% | 50.00% | -5.00% | 6.45% |
| 32 | 8 | 12 | 1 | 0 | 12.50% | 8.33% | 25.00% | -16.67% | 38.16% |
| 33 | 29 | 7 | 3 | 1 | 10.34% | 42.86% | 100.00% | -57.14% | 19.68% |
| 34 | 6 | 13 | 1 | 2 | 16.67% | 7.69% | 50.00% | -42.31% | 36.47% |
| 35 | 35 | 8 | 2 | 0 | 5.71% | 25.00% | 75.00% | -50.00% | 27.81% |
| 36 | 2 | 15 | 0 | | 0.00% | 0.00% | 50.00% | -50.00% | 75.35% |

Figure 5.7: The synchronisation results from the musical piece composed by Claude Debussy

### Correlation of synchronised registrations across participants

For each musical piece, participants with synchronisations has been determined, and it is now of interest to see if there is a correlation amongst the time occurrence of the participant's registered synchronisations. If such a correlation exist, a causality between the measurements of subjective feeling / physiological arousal and the state of musical features can be investigated.

To investigate the correlation, binary arrays are used again, in which 1 indicated a synchronised change at the time $t$. For each musical piece one array pr. participant in the final proposals is created with the amounts of columns equal to the length of the musical piece in seconds. The arrays belonging to the same musical piece are then combined in a matrix, where the columns are the participants, and the rows are the seconds of the musical piece. This matrix is then past to the *corrcoef* function in matlab, to retrain the correlation coefficients between participants, and the p-values

| Participant # | # of sync | Time of sync |
|---|---|---|
| 4 | 1 | 70 |
| 6 | 2 | 37 84 |
| 7 | 1 | 9 |
| 8 | 3 | 57 62 71 |
| 9 | 2 | 19 62 |
| 13 | 2 | 80 82 |
| 15 | 8 | 4 45 57 69 72 77 78 101 |
| 21 | 2 | 11 74 |
| 24 | 8 | 2 5 22 23 35 45 49 75 |
| 29 | 2 | 35 75 |
| 30 | 2 | 6 56 |

Table 5.6: The first proposal for synchronisations during the musical piece composed by Debussy (3).

of the correlations, which determine if a correlation is significant.

**Johann Sebastian Bach - Musical Piece 0**

For the musical piece by Bach the p-values are listed in table 5.7

| P# 4 | P# 5 | P# 8 | P# 13 | P# 15 | P# 21 | P# 25 | P# 26 |
|---|---|---|---|---|---|---|---|
| 1 | 0.55726 | 0.0099192 | 0.83612 | 0.79893 | 0.79893 | 0.83612 | 0.83612 |
| 0.55726 | 1 | 0.29777 | 0.55726 | 0.009579 | 0.36114 | 0.55726 | 0.15835 |
| 0.0099192 | 0.29777 | 1 | 0.0099192 | 0.65185 | 0.65185 | 0.71411 | 0.71411 |
| 0.83612 | 0.55726 | 0.0099192 | 1 | 0.79893 | 0.79893 | 0.83612 | 0.83612 |
| 0.79893 | 0.009579 | 0.65185 | 0.79893 | 1 | 0.75374 | 0.79893 | 0.79893 |
| 0.79893 | 0.36114 | 0.65185 | 0.79893 | 0.75374 | 1 | 0.79893 | 0.79893 |
| 0.83612 | 0.55726 | 0.71411 | 0.83612 | 0.79893 | 0.79893 | 1 | 0.83612 |
| 0.83612 | 0.15835 | 0.71411 | 0.83612 | 0.79893 | 0.79893 | 0.83612 | 1 |
| 0.83612 | 0.55726 | 0.71411 | 0.83612 | 0.79893 | 0.79893 | 0.83612 | 0.83612 |
| 0.83612 | 0.15835 | 0.0099192 | 0.83612 | 0.79893 | 0.79893 | 0.83612 | 0.83612 |
| 0.88433 | 0.6799 | 0.79671 | 0.88433 | 0.85782 | 0.85782 | 0.88433 | 0.88433 |
| 0.79893 | 0.46964 | 0.65185 | 0.79893 | 0.75374 | 0.75374 | 0.79893 | 0.79893 |
| 0.79893 | 0.46964 | 0.65185 | 0.79893 | 0.75374 | 0.75374 | 0.79893 | 0.79893 |
| 0.79893 | 0.46964 | 0.051309 | 0.79893 | 0.75374 | 0.75374 | 8.2365e-05 | 0.79893 |

| P# 27 | P# 28 | P# 29 | P# 30 | P# 34 | P# 36 |
|---|---|---|---|---|---|
| 0.83612 | 0.83612 | 0.88433 | 0.79893 | 0.79893 | 0.79893 |
| 0.55726 | 0.15835 | 0.6799 | 0.46964 | 0.46964 | 0.46964 |
| 0.71411 | 0.0099192 | 0.79671 | 0.65185 | 0.65185 | 0.051309 |
| 0.83612 | 0.83612 | 0.88433 | 0.79893 | 0.79893 | 0.79893 |
| 0.79893 | 0.79893 | 0.85782 | 0.75374 | 0.75374 | 0.75374 |
| 0.79893 | 0.79893 | 0.85782 | 0.75374 | 0.75374 | 0.75374 |
| 0.83612 | 0.83612 | 0.88433 | 0.79893 | 0.79893 | 8.2365e-05 |
| 0.83612 | 0.83612 | 0.88433 | 0.79893 | 0.79893 | 0.79893 |
| 1 | 0.83612 | 0.88433 | 0.79893 | 0.79893 | 0.79893 |
| 0.83612 | 1 | 0.88433 | 0.79893 | 0.79893 | 8.2365e-05 |
| 0.88433 | 0.88433 | 1 | 0.85782 | 0.85782 | 0.85782 |
| 0.79893 | 0.79893 | 0.85782 | 1 | 0.75374 | 0.75374 |
| 0.79893 | 0.79893 | 0.85782 | 0.75374 | 1 | 0.75374 |
| 0.79893 | 8.2365e-05 | 0.85782 | 0.75374 | 0.75374 | 1 |

Table 5.7: The p-values for the correlation between the registered synchronisation for participants in association with musical piece 0.

When a p-value is $< 0.05$, the correlation is interpreted as being significant. The list of p-values therefore show that there is no significant correlation between all the participants, but a pattern exist between several of the participants. None of the participants 21, 27, 30 and 34 was found to correlate with others. Participants 5 and 15 was only found to correlate with each other, and the remaining participants created the correlation pattern illustrated in figure 5.8.

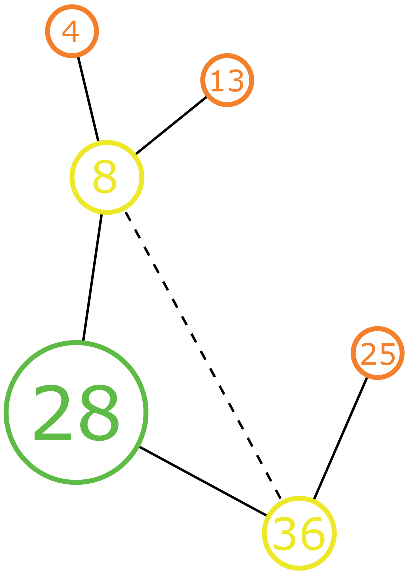


Figure 5.8: The correlation pattern found amongst participants in relation to musical piece 0.

### Ludwig van Beethoven - Musical Piece 1

In comparison with musical piece 0, the amount of significant correlations between participants during this musical piece, is small. Merely the correlation between participants 6 and 9 was found to be significant (see table 5.8).

| P# 2 | P# 4 | P# 6 | P# 9 | P# 15 | P# 16 | P# 19 | P# 30 |
|---|---|---|---|---|---|---|---|
| 1 | 0.3069 | 0.47017 | 0.24598 | 0.55568 | 0.96791 | 0.3069 | 0.050008 |
| 0.3069 | 1 | 0.84841 | 0.75922 | 0.69405 | 0.75922 | 0.84841 | 0.89298 |
| 0.47017 | 0.84841 | 1 | 0.0015406 | 0.69405 | 0.75922 | 0.84841 | 0.89298 |
| 0.24598 | 0.75922 | 0.0015406 | 1 | 0.528 | 0.088849 | 0.75922 | 0.8292 |
| 0.55568 | 0.69405 | 0.69405 | 0.528 | 1 | 0.26171 | 0.69405 | 0.78191 |
| 0.96791 | 0.75922 | 0.75922 | 0.088849 | 0.26171 | 1 | 0.75922 | 0.8292 |
| 0.3069 | 0.84841 | 0.84841 | 0.75922 | 0.69405 | 0.75922 | 1 | 0.89298 |
| 0.050008 | 0.89298 | 0.89298 | 0.8292 | 0.78191 | 0.8292 | 0.89298 | 1 |

Table 5.8: The p-values for the correlation between the registered synchronisation for participants in association with musical piece 1.

### Franz Joseph Haydn - Musical Piece 2

Table 5.9 shows the p-values for the correlations between participants during musical piece 2 composed by Haydn. Here the correlation between participants 11 and 27 is significant, as well as between participants 13 and 15. Participant 7 has a significant correlation with both participant 1 and 26, as do participant 20 with participants 3 and 33.

### Claude Debussy - Musical Piece 3

As with musical piece 1, only a few correlations were found to be significant, namely the correlation between participants 8 and 9, and the correlation between participants 24 and 29 (see table 5.10).

| P# 1 | P# 3 | P# 6 | P# 11 | P# 13 | P# 15 | P# 17 | P# 20 |
|---|---|---|---|---|---|---|---|
| 1 | 0.79785 | 0.79785 | 0.85706 | 0.79785 | 0.59602 | 0.01088 | 0.71415 |
| 0.79785 | 1 | 0.83525 | 0.88372 | 0.83525 | 0.66692 | 0.76616 | 0.00099661 |
| 0.79785 | 0.83525 | 1 | 0.88372 | 0.83525 | 0.66692 | 0.76616 | 0.76616 |
| 0.85706 | 0.88372 | 0.88372 | 1 | 0.88372 | 0.76219 | 0.83434 | 0.83434 |
| 0.79785 | 0.83525 | 0.83525 | 0.88372 | 1 | 0.03376 | 0.76616 | 0.76616 |
| 0.59602 | 0.66692 | 0.66692 | 0.76219 | 0.03376 | 1 | 0.53809 | 0.53809 |
| 0.01088 | 0.76616 | 0.76616 | 0.83434 | 0.76616 | 0.53809 | 1 | 0.67058 |
| 0.71415 | 0.00099661 | 0.76616 | 0.83434 | 0.76616 | 0.53809 | 0.67058 | 1 |
| 0.79785 | 0.83525 | 0.83525 | 0.88372 | 0.83525 | 0.66692 | 0.00099661 | 0.76616 |
| 0.75243 | 0.79785 | 0.79785 | 1.8473e-09 | 0.79785 | 0.59602 | 0.71415 | 0.71415 |
| 0.75243 | 0.79785 | 0.79785 | 0.85706 | 0.79785 | 0.59602 | 0.71415 | 0.01088 |

| P# 26 | P# 27 | P# 33 |
|---|---|---|
| 0.79785 | 0.75243 | 0.75243 |
| 0.83525 | 0.79785 | 0.79785 |
| 0.83525 | 0.79785 | 0.79785 |
| 0.88372 | 1.8473e-09 | 0.85706 |
| 0.83525 | 0.79785 | 0.79785 |
| 0.66692 | 0.59602 | 0.59602 |
| 0.00099661 | 0.71415 | 0.71415 |
| 0.76616 | 0.71415 | 0.01088 |
| 1 | 0.79785 | 0.79785 |
| 0.79785 | 1 | 0.75243 |
| 0.79785 | 0.75243 | 1 |

Table 5.9: The p-values for the correlation between the registered synchronisation for participants in association with musical piece 2.

| P# 4 | P# 6 | P# 7 | P# 8 | P# 9 | P# 13 | P# 15 | P# 21 |
|---|---|---|---|---|---|---|---|
| 1 | 0.891 | 0.92317 | 0.86607 | 0.891 | 0.891 | 0.77771 | 0.891 |
| 0.891 | 1 | 0.891 | 0.8106 | 0.8456 | 0.8456 | 0.68826 | 0.8456 |
| 0.92317 | 0.891 | 1 | 0.86607 | 0.891 | 0.891 | 0.77771 | 0.891 |
| 0.86607 | 0.8106 | 0.86607 | 1 | 2.6042e-05 | 0.8106 | 0.085623 | 0.8106 |
| 0.891 | 0.8456 | 0.891 | 2.6042e-05 | 1 | 0.8456 | 0.68826 | 0.8456 |
| 0.891 | 0.8456 | 0.891 | 0.8106 | 0.8456 | 1 | 0.68826 | 0.8456 |
| 0.77771 | 0.68826 | 0.77771 | 0.085623 | 0.68826 | 0.68826 | 1 | 0.68826 |
| 0.891 | 0.8456 | 0.891 | 0.8106 | 0.8456 | 0.8456 | 0.68826 | 1 |
| 0.77771 | 0.68826 | 0.77771 | 0.62142 | 0.68826 | 0.68826 | 0.5786 | 0.68826 |
| 0.92317 | 0.891 | 0.92317 | 0.86607 | 0.891 | 0.891 | 0.77771 | 0.891 |
| 0.891 | 0.8456 | 0.891 | 0.8106 | 0.8456 | 0.8456 | 0.68826 | 0.8456 |

| P# 24 | P# 29 | P# 30 |
|---|---|---|
| 0.77771 | 0.92317 | 0.891 |
| 0.68826 | 0.891 | 0.8456 |
| 0.77771 | 0.92317 | 0.891 |
| 0.62142 | 0.86607 | 0.8106 |
| 0.68826 | 0.891 | 0.8456 |
| 0.68826 | 0.891 | 0.8456 |
| 0.5786 | 0.77771 | 0.68826 |
| 0.68826 | 0.891 | 0.8456 |
| 1 | 0.00031592 | 0.68826 |
| 0.00031592 | 1 | 0.891 |
| 0.68826 | 0.891 | 1 |

Table 5.10: The p-values for the correlation between the registered synchronisation for participants in association with musical piece 3.

### Causality between synchronisations and detected musical features

In the musical piece composed by Johann Sebastian Bach, the synchronisations of participant 28 were found to correlate with next most participants, and these synchronisations are used to do a cross-correlation with the detected musical features. Only participant 8 was found to correlation with more participants, but this participant was not checked for movements, and therefore participant 28 is used instead.

Initially the states of the musical features were interpreted by their change. For harmony and mode, a change was simply defined as a change in value, as with the self-reports. With the other musical feature, a significant change was defined, in the same manners as with the heart rate measurements. The results from the cross-correlation results can be view in the appendix C.3.

Figure 5.9 summarises the findings of the cross-correlations for no delays and for delays of $1s$ and $2s$. Without delay the likelihoods for the correlations are all above $25\%$. For a delay of $1s$ the likelihood for the correlation with the change in pitch level is $17.89\%$. Whereas for a delay of $2s$, the correlations with two feature are below $25\%$, namely loudness at $13.57\%$ and pitch range at $54.29\%$

Musical Piece 0: LENGTH: 95

| MF | MFC | SRC | SYNC | DELAY | % MF | % SR | Likelihood |
|---|---|---|---|---|---|---|---|
| Harmony | 77 | 2 | 2 | 0 | 2.60% | 100.00% | 65.70% |
| Loudness | 35 | 2 | 0 | 0 | 0.00% | 0.00% | 39.89% |
| Mode | 65 | 2 | 1 | 0 | 1.54% | 50.00% | 43.21% |
| Pitch Level | 17 | 1 | 0 | 0 | 0.00% | 0.00% | 82.11% |
| Pitch Range | 30 | 2 | 0 | 0 | 0.00% | 0.00% | 46.81% |
| Spectral Centroid | 18 | 2 | 0 | 0 | 0.00% | 0.00% | 65.70% |
| Spectral Rolloff | 25 | 2 | 0 | 0 | 0.00% | 0.00% | 54.29% |
| Harmony | 77 | 2 | 2 | 1 | 2.60% | 100.00% | 65.70% |
| Loudness | 35 | 2 | 0 | 1 | 0.00% | 0.00% | 39.89% |
| Mode | 65 | 2 | 2 | 1 | 3.08% | 100.00% | 46.81% |
| Pitch Level | 17 | 1 | 1 | 1 | 5.88% | 100.00% | 17.89% |
| Pitch Range | 30 | 2 | 1 | 1 | 3.33% | 50.00% | 43.21% |
| Spectral Centroid | 18 | 2 | 0 | 1 | 0.00% | 0.00% | 65.70% |
| Spectral Rolloff | 25 | 2 | 1 | 1 | 4.00% | 50.00% | 38.78% |
| Harmony | 77 | 2 | 1 | 2 | 1.30% | 50.00% | 30.71% |
| Loudness | 35 | 2 | 2 | 2 | 5.71% | 100.00% | 13.57% |
| Mode | 65 | 2 | 1 | 2 | 1.54% | 50.00% | 43.21% |
| Pitch Level | 17 | 1 | 0 | 2 | 0.00% | 0.00% | 82.11% |
| Pitch Range | 30 | 2 | 2 | 2 | 6.67% | 100.00% | 9.97% |
| Spectral Centroid | 18 | 2 | 1 | 2 | 5.56% | 50.00% | 30.71% |
| Spectral Rolloff | 25 | 2 | 0 | 2 | 0.00% | 0.00% | 54.29% |

Figure 5.9: The cross-correlation results from the musical piece composed by Johann Sebastian Bach and the change synchronisations from participant 28.

Due to the weak correlations of synchronised changes and changes in the musical features, no further investigations are made to try and enlighten a causality.

### Comments from Participants

Shortly after the participation in the experiment several of the participants chose to comment on their experience to the experiment conductor. These comments was notated for evaluation and are following summarised, as they are considered noticeable informations.

**Recognition remark.** A few of the participants clearly misunderstood the use of the word recognition, as two participants stated that it was really hard to determine whether or not they felt an emotion due to the music, or due to elements the musical pieces reminded them of.

**Mood related remarks.** Several of the participants mentioned that they enjoyed the experiment, due to the fact that they were feeling more relaxed and less stressed afterwards. A conversation with 4 of the participants the following day, revealed that they after the experiment succeeded in solving problems with a prototype they were building, which prior to the experiment were causing them stress and frustrations.

**Other remarks.** One participant stated that he found the smiley faces on the valence scale disturbing, but that he just closed his eyes. Others stated that is was nice to get to think of something else, and that the experience cleared their minds.

### Observations

Despite the precautions taken to avoid the participants missing the break in the application, as mentioned in the evaluation of the methodology (see section 5.1), $25\%$ did continue from page 5 without informing the experiment conductor.

During the first 8 peoples participation in the experiment it was not possible to use the video streaming of the environment, meaning the experiment conductor was not able to note physical movements during the experiment.

# CHAPTER 6

# Discussion

The experiment results were evaluated in relation to the synchronisations of the two components of emotions, namely the subject feeling and the physiological arousal. For the musical piece composed by Johann Sebastian Bach, synchronisations assumed to be valid were registered in $38.9\%$ of the participants. For the musical piece by Ludwig van Beethoven synchronisations were registered in $22.2\%$ of the participants, for Franz Joseph Haydn $31.4\%$, and for Claude Debussy $30.6\%$. So in average for $30.8\%$ of the participants. Additional synchronisations were found by the cross-correlation, but rule out, due to great likelihoods for the occurrence of the results, a delay $> 5s$, or a low percentage of synchronisations in relation to self-report changes. The likelihoods for the occurrence of the synchronisations do increase with the amount of heart rate changes. Thus the low percentage of synchronisations could be the result of a bad distinction of significant heart rate changes, or the reliability of short term heart rate measurements. It should therefore be ensured that the low percentage of synchronisations in participants are not related to heart rate measurements. Disregarding the likelihood estimations synchronisations were found in $88.9\%$, $86.11\%$, $82.9\%$ and $77.8\%$ for Bach, Beethoven, Haydn and Debussy respectively.

During the musical piece by Bach $8.3\%$ of the participants chose not to change the state on the valence scale, and the reason why remains unknown. In the self-report application the valence scale was always initiated at 5 (neutral), even though this might not have been the current mood of the participant. Thus the missing change in valence state could either be because the listening experience did not evoke any emotional responses in the participants, or because the valence level they felt prior to the musical piece were not neutral, and that the listening experience then evoked a more neutral valence level. For the musical pieces by Beethoven, Haydn and Debussy the percentage of participants were $8.3\%$, $5.7\%$ and $16.7\%$.

The low percentages of synchronisations could also be related to the task of self-reporting. The experiment revealed that not all the participants comprehended the continual self-report idea. A few participants waiting during the first musical piece they heard, and tuned into how they were feeling, changed the scale, and tried to continue in the application, which was not possible. If a few participants for each musical piece, as the musical pieces were played randomly, did not report continual, but instead over all, this would have a great impact on the results of the cross-correlation.

Investigating the self-report results, it can also been seen that participants continued to rate after the ending of a musical piece, which support the misunderstanding of the continuity of the valence scale, and how it is used to only rate the current emotional state.

Following the participants for whom the synchronisations were assumed to be valid was correlated, to investigate common occurrences of changes within each musical piece. The correlation coefficients for each musical piece showed that amongst all the selected participants, there were no significant correlation, but for each musical piece a few of the participants were significantly correlated. Comparing the correlations with the tables showing the time of the synchronisations, it will be discover that a significant correlation only means that two participants have one or more synchronisations at the exact same second. Heretofore it possible and likely that participants would respond at different delays to the occurrence of an emotional response. It is thus not enough to directly correlated the time of changes, but the correlation should include a time shift of a few seconds in each direction for each participant.

Finally the synchronisations of participant 28 was correlated with the change in the detected musical features. The correlations was investigated at no delay, and with a $1s$ and a $2s$ delay. Only in three case a correlation was assumed to be valid, namely pitch level at a $1s$ delay, and loudness and range at a $2s$ delay. Due to the lack of correlations it was evaluated as premature to try and determine a causality between the musical features and the synchronisation changes of the participants. The bad correlation results could easily be a result of the above mentioned factors, which might have interfered with with measurement of the self-reports and the heart rate. The existence of a causality should therefore not yet be ruled out.

The comments related to mood from the participants after their participation in the experiments, should not be neglected. Several participants gave statements, which strongly indicate mood changes due to the experiment. They reported to feel more relaxed, and with a more clear mind. The following day, participants even reported that the experiment had such a strong influence on their state of mind, that they subsequently with success handled the task at hand, that prior to the experiment had caused them great frustrations.

# CHAPTER 7

# Conclusion

The problem investigated in this study was divided into three hypotheses, which will now individually be evaluated. The first hypothesis stated:

> Western classical music can evoke emotional responses in listeners.

The results showed that if an emotional response is defined by the synchronisation of the two emotion components – subjective feeling and physiological arousal – then an average of $30.8\%$ of the listeners were found to respond emotionally to the listening experience. The correlation of the synchronisations showed that the time occurrence were not common across listeners. Based on these results it seem that western classical music can evoke emotional responses in some listeners from the western culture.

The second hypothesis stated:

> The musical features of western classical music are causally connected to the evoked emotional responses in the listeners.

Due to the missing correlation of the time occurrence of the synchronisations across listeners, it was not possible to do a thorough investigation of this hypothesis. The correlation between one listener and the state of the musical features were executed, and resulted in a significant correlation with the change in pitch level, loudness and pitch range. These results indicates the possibility of for a later verification of the hypothesis, but first it is essential to gain better correlation results across listeners.

The third hypothesis was divided into 2, which stated:

> The emotional responses evoked in listeners by western classical music are absolute emotional responses, which are relative to the current affective state of the listener. (See figure 1.1 A)
>
> The emotional responses evoked in listeners by western classical music are relative emotional responses, which are relative to the current affective state of the listener. (See figure 1.1 B)

Since the time occurrence of the synchronisations did not correlate across listeners, the direction of the emotional change was not investigated. Consequently it is not possible to evaluate these two hypotheses.

The evaluation of these hypotheses now allow for an evaluation of the investigated problem, which stated:

> Does western classical instrumental homophonic music evoke emotional responses in listeners from the western culture? If so how are the evoked emotional responses causally connect to the musical structure?

Based on the results of this study it can not be conclude whether or not western classical instrumental homophonic music does evoke emotional responses in listeners from it western culture. The study can only encourage further investigations of the problem, as the cross-correlation results for the determination of synchronisations seem promising.

# CHAPTER 8

## Future Perspectives

The discussion of possible future perspective is divided into sections – the self-report application, detection of musical features, evaluation of experiment results and moods.

## 8.1 The Self-report Application

The conductance of the experiment reveal several possible adjustment for the self-report application, which was used to measure the subjective feeling component of emotions. One of the main issues was the missing comprehension of the usability of the valence scale. Despite the instruction, the trial of the scale and the option to communicate with the experiment conductor, an unknown amount of participants did not comprehend the continual property of the valence scale. It is therefore propose to improve the guides of the self-report application, and submit it to extensive usability testing.

Additional the comments of the participants reveal that some of the participants misunderstood the phrasing "*recognition of emotions in music*". Thus it is proposed in combination with the usability test, to perform an investigation of people's understanding of the task, and their behaviour and choices during the task.

Minor technical improvements should also be made. The experiment showed that several participants, did not inform the experiment conductor of their position when instructed to do so. Thus it is proposed to force the stop in the application, so a continual requires the interaction of the experiment conductor. Furthermore an investigating of the self-report results showed that participants continued to rate after the ending of a musical piece, this option should not be possible, which could enhance the understanding of the continual rating.

In the current version of the application the valence scale is always initiated at neutral, in contrary to the current mood of the participant. This means that an emotional response to a neutral valence level wont be measured. Therefore it is proposed to ask the participants prior to each musical piece to rate who they are feeling.

## 8.2 Detection of Musical Features

The detection of musical features were not done simultaneously with the measurements of emotional responses, and thus it can be argued that the detection does not need to be real-time. As of now, the detection is done is real-time, and the amount of musical features detected was delimited to retrain computing power, and avoid great delays. It is now proposed to design an automatic detection of musical features, which does not run real-time. Hereby the application can evaluated each musical piece several times, and post evaluation output the detected time series of feature's states. A first run could for example determine loudness, a second run onset and offset, and a third run pitch related features.

## 8.3 Evaluation of Experiment Results

The evaluation of experiment results showed that the interpretation of heart rate changes, caused the measured heart rates to change roughly approximated $30\%$ of the time. This magnitude has a great influence on the likelihood of the synchronisation correlations. Consequently it is proposed to investigate heart rate changes in general, to determine if the interpretation is valid.

The evaluation of a correlation across participants proved to be insufficient, as it did not consider the possible delays between participants. A more sufficient evaluation method should be found, and the results reprocessed.

Finally it is proposed to improve the measurement methods, before the continuing of evaluations of the experiment results. With the proposed new iteration of the self-report application, unanswered questions might be answered, such as why did some participants not change the valence level at all. The application changes might influence the results greatly, and the stance is therefore to withhold the evaluation to new measurements are obtained.

## 8.4 Moods

Several experiment participants made post-statements, which are strongly related to mood changes. These statements encourage a directional change of the investigation to the evaluation of mood changes, and whether or not these are cause by evoked emotional responses during the experiment. One option could be to evaluated the heart rate measurements to see if there across one musical piece is a general change.

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# CHAPTER A

## Application Details

## A.1 Continual Self-reports

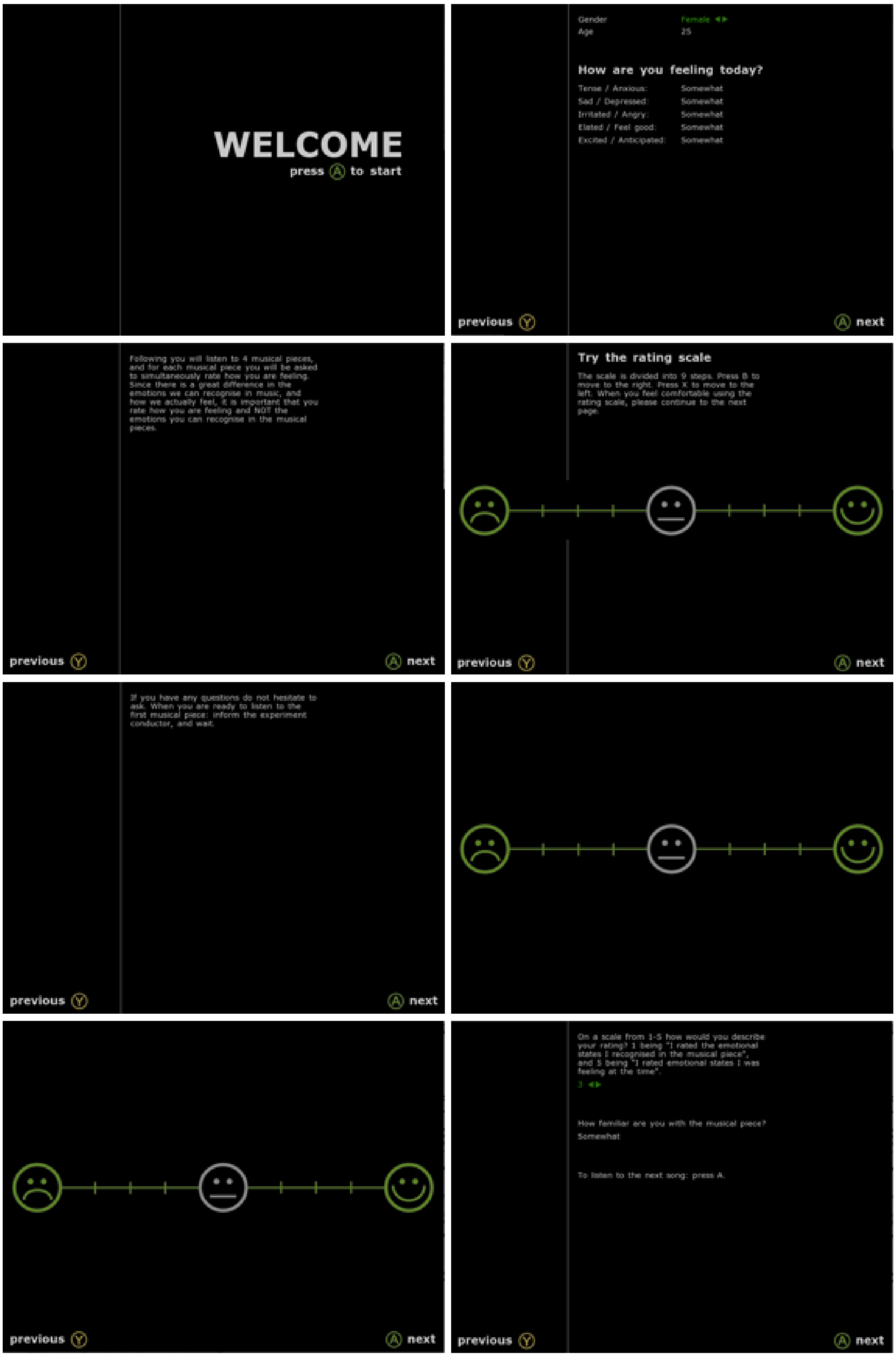



Figure A.1: The main pages implemented in the continual self-reports application. The order of the pages are from left to right and top to bottom, with pages 6 - 8 duplicated for each used musical piece.

### Output file: 20100520_212019.txt

Playorder: 2 3 1 0

Valence:
14.72 6
15.5413 7
26.2933 8
49.088 7
52.5227 8
73.7387 7
90.4107 6
0 7

Valence:
34.112 4
37.3973 3
41.1627 2
44.1707 3
44.8853 4
49.184 5
51.4453 6
51.7653 7
52.608 6
58.208 7
88.576 6
89.0666 5
89.6107 4
90.1866 5
90.464 6
95.6587 7

99.264 8
99.8187 9
104.309 8
106.944 7
0 6
0 7

Valence:
19.7973 4
21.696 5
25.9093 4
46.7627 3

Valence:
7.552 4
7.93599 5
8.20265 6
15.0933 5
34.88 4
35.872 5
36.128 6
52.9387 5
55.8827 4

Information: 1 23 3 0 3 0 2 4 0 2 0 4 0 3 2

# CHAPTER B

## Experiment Methodology

## B.1 Instructions

### Page 1

WELCOME
press A to continue

### Page 3

Following you will listen to 4 musical pieces, and for each musical piece you will be asked to simultaneously rate how you are feeling. Since there is a great different in the emotions we can recognise in music, and how we actually feel, it is important that you rate how you are feeling and NOT the emotions you can recognise in the musical pieces.

### Page 4

**Try the rating scale**
The scale is divided into 9 steps. Press B to move to the right. Press X to move to the left. When you feel comfortable using the rating scale, please continue to the next page.

Figure B.1: The rating scale used to measure self-reports of valence.

### Page 5

If you had any questions do not hesitate to ask. When you are ready to listen to the first musical piece: inform the experiment conductor, and wait.

### Page 7, 9, 11,

To listen to the next song: press A.

### Page 14

Thank you for participating,
it is greatly appreciated

## B.2 Questionnaire

In the implementation for continual self-reports the following questions were added. The values listed in square brackets [ ] are the values from which the participants could choose.

### Page 2

Gender [Female, Male]
Age [0 - 100] years

How are you feeling today?
Tense / Anxious [Not at all, A little bit, Somewhat, Quite a bit, Very much so]
Sad / Depressed [Not at all, A little bit, Somewhat, Quite a bit, Very much so]
Irritated / Angry [Not at all, A little bit, Somewhat, Quite a bit, Very much so]
Elated / Feel Good [Not at all, A little bit, Somewhat, Quite a bit, Very much so]
Excited / Anticipated [Not at all, A little bit, Somewhat, Quite a bit, Very much so]

### Page 7, 9, 11, 13

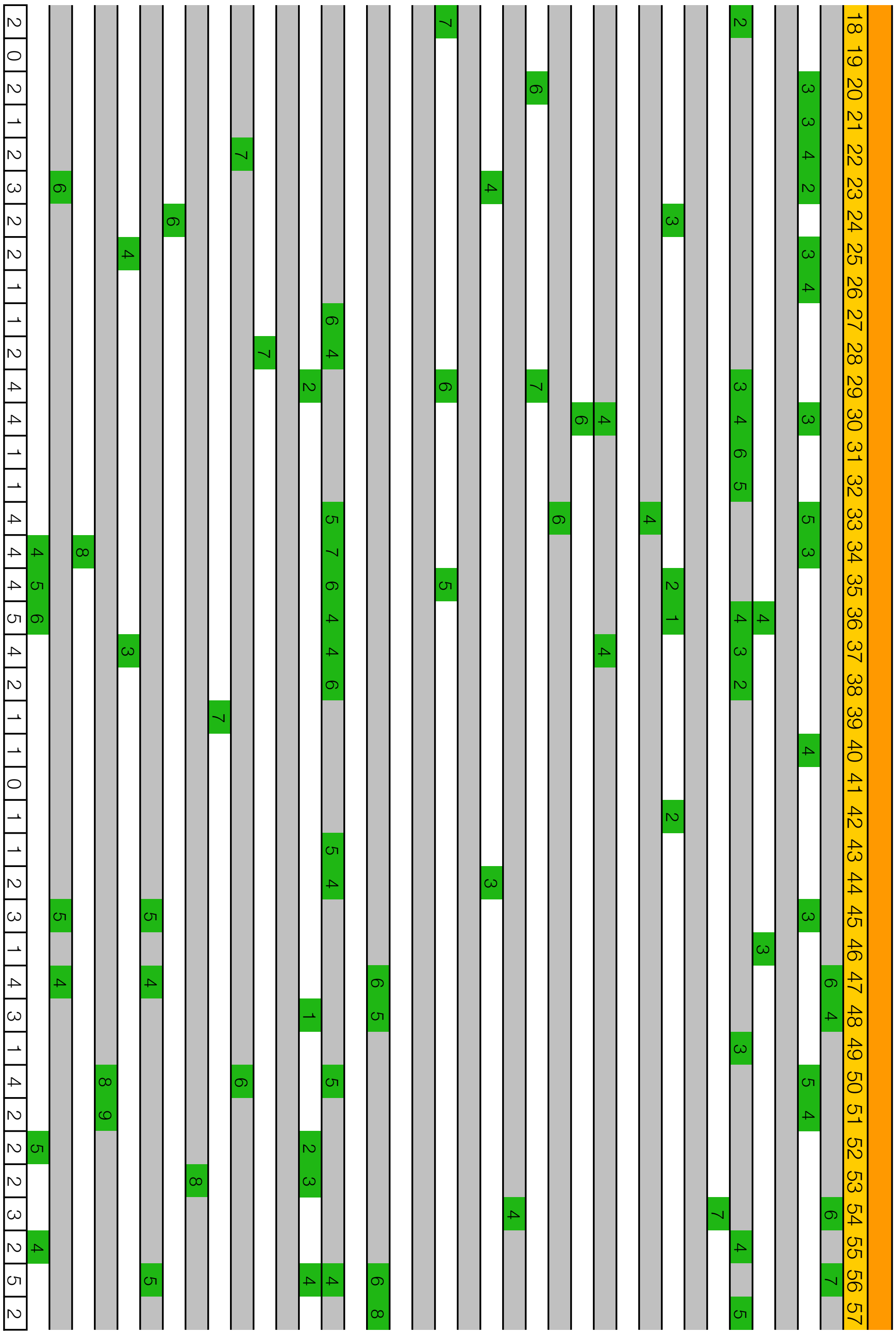
On a scale from 1-5 how would you describe your rating? 1 being "I rated the emotional states I recognised in the musical piece". 5 being "I rated the emotional states I was feeling at the time." [1-5]
How familiar are you with the musical piece? [Not at all, A little bit, Somewhat, Quite a bit, Very much so]

# Chapter C

Experiment Results

## C.1 Self-reports

| | | | | Mood | | | | | 0: Johann Sebastian Bach | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | Gender | Age | Order | T / A | S / D | I / A | E / F | E / A | R | F | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| 1 | Female | 26 | 3012 | 3 | 0 | 0 | 3 | 1 | 4 | 0 | | | | | | | | | | | | | | | | | |
| 2 | Male | 27 | 2310 | 4 | 1 | 0 | 2 | 2 | 3 | | 4 | | | | | | | | | | 3 | | | | | | |
| 3 | Male | 30 | 1320 | 0 | 0 | 1 | 1 | 0 | 0 | 2 | | | | | | | | | | | | | | | | | |
| 4 | Male | 25 | 1302 | 3 | 0 | 0 | 3 | 3 | 1 | | | | | | | | | | | | | | | | | | |
| 5 | | | 3120 | | | | | | | | 3 | 2 | | | | | 3 | | | 4 | 5 | | | | | | 3 |
| 6 | Male | 27 | 1302 | 1 | 0 | 1 | 3 | 2 | 4 | 2 | | | | 6 | | | | | | | | | | | | | |
| 7 | Male | 24 | 2130 | 2 | 1 | 0 | 2 | 3 | 2 | 3 | | | | | | | | | | | | | | | | | |
| 8 | Male | 23 | 1320 | 1 | 1 | 0 | 0 | 1 | 0 | 4 | | 4 | 5 | | 4 | | | | | | | | 5 | | | | 4 |
| 9 | Male | 25 | 1230 | 2 | 0 | 1 | 1 | 2 | 3 | 0 | | | | | | | | | | | | | | | | | |
| 10 | Male | 27 | 3102 | 1 | 0 | 0 | 2 | 2 | 3 | 2 | | | | | | | | | | | | | | | | | |
| 11 | Male | 24 | 0231 | 0 | 0 | 0 | 4 | 3 | 3 | 0 | | | | | | | | | | | | | | | | | |
| 12 | Female | 25 | 0231 | 0 | 0 | 0 | 2 | 1 | 4 | 3 | | | | | | | | | | | | | | | | | |
| 13 | Female | 24 | 2130 | 3 | 0 | 0 | 2 | 2 | 3 | 0 | | | | | | | | | | | | | | | | | |
| 14 | Male | 24 | 2031 | 0 | 0 | 0 | 2 | 0 | 4 | 1 | | | | | | | | | | | | | | | | | |
| 15 | Male | 31 | 1320 | 1 | 1 | 1 | 3 | 3 | 1 | 0 | | | | | | | | | | | | | | | | | |
| 16 | Male | 21 | 3102 | 1 | 0 | 0 | 2 | 2 | 3 | 0 | | | | | 6 | | | | | 5 | | | | | | | |
| 17 | Male | 22 | 2103 | 1 | 0 | 0 | 4 | 1 | 4 | 1 | | | | | | | | | | | | | | | | | |
| 18 | Male | 31 | 0321 | 3 | 0 | 0 | 4 | 3 | 3 | 1 | | | 6 | 7 | | | | | | 8 | | | | | | | |
| 19 | Male | 28 | 1023 | 1 | 0 | 0 | 3 | 2 | 3 | 4 | | | | | | | | | | 6 | 9 | | | | | | |
| 20 | Female | 21 | 1230 | 1 | 0 | 1 | 3 | 2 | 3 | 0 | | | | | | | | | | | | | | | | | |
| 21 | Female | 21 | 0312 | 0 | 0 | 1 | 4 | 2 | 3 | 1 | | | | 6 | 7 | | | | | | | | | | | | |
| 22 | Male | 25 | 1032 | 1 | 0 | 0 | 3 | 3 | 1 | 3 | | | | | | | | | | 6 | | | | | | | |
| 23 | Male | 26 | 3201 | 2 | 3 | 1 | 1 | 0 | 4 | 2 | | | | 5 | 6 | | | | | | | | 7 | | | | |
| 24 | Male | 28 | 2103 | 2 | 0 | 1 | 2 | 3 | 3 | 0 | | | | | | | | | | | | | | | | 3 | |
| 25 | Female | 29 | 0231 | 2 | 1 | 3 | 1 | 2 | 4 | 2 | | | | | | | | 6 | | | | | | | | | |
| 26 | Male | 23 | 0231 | 3 | 1 | 3 | 1 | 1 | 4 | 4 | | | | | | 6 | | | | | | | | | | | |
| 27 | Male | 21 | 2013 | 4 | 3 | 3 | 1 | 0 | 4 | 0 | | | | | | 6 | | | | | | | | | | | |
| 28 | Male | 24 | 0231 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | | | | | | | | | | 6 | | | | | | | |
| 29 | Male | 23 | 1320 | 4 | 2 | 3 | 2 | 2 | 4 | 4 | | | | | | | | | 6 | 7 | | | | | | | |
| 30 | Male | 23 | 3021 | 2 | 3 | 3 | 1 | 0 | 4 | 2 | | | | | | | | | | | | | | | | | |
| 31 | Male | 32 | 2310 | 1 | 0 | 0 | 3 | 4 | 4 | 3 | | | | | 6 | | | | | | | | | | | | |
| 32 | Male | 24 | 1203 | 2 | 0 | 0 | 1 | 3 | 2 | 1 | | | 6 | | | | | | | | | | | | | 5 | |
| 33 | Male | 28 | 0231 | 1 | 0 | 1 | 3 | 3 | 3 | 3 | | | | | 7 | | 8 | | 9 | | | | | | | | |
| 34 | Male | 23 | 3210 | 3 | 1 | 1 | 2 | 0 | 2 | 3 | | | | | | | 6 | 7 | | | | | | | | | |
| 35 | Male | 22 | 3021 | 3 | 2 | 2 | 3 | 3 | 3 | 1 | | | | | | | | | | | | | | | | | |
| 36 | Male | 23 | 2310 | 3 | 0 | 3 | 0 | 2 | 3 | 2 | | | | | | | 5 | 6 | | | | | | | 5 | | |
| Male: | 29 | 25.14 | | | | | | | | | 2 | 2 | 3 | 4 | 6 | 2 | 4 | 3 | 2 | 7 | 3 | 0 | 2 | 0 | 1 | 2 | 2 |
| Female: | 6 | 9.24 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Male % | 80.56 | 21 | | | | | | | | | | | | | | | | | | | | | | | | | |
| Female % | 16.67 | 32 | | | | | | | | | | | | | | | | | | | | | | | | | |


18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57

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| 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | R | F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | 7 | | | | | | | | | | | | | | | | | | | | | | | | | 2 | 0 |
| | | | | | | | 5 | 6 | 4 | | | | | | 3 | 4 | 5 | 4 | 6 | 4 | | | | 4 | | | | | | | | | | | | | | 1 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 0 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | |
| | | | | | | | | | | | | | | 2 | | | | 3 | 5 | 3 | 2 | | | | | 3 | 4 | | 1 | | | | | | 2 | 4 | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 0 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 0 |
| | 3 | | | | | | | | | | | | | | | | 4 | | | | | | | | | | | | 3 | 2 | | | | | | | | 3 | 0 |
| | | | | | | | 3 | | | | | | | | | | | | | | | | | | | | | | | | | 2 | | | | | | 2 | 0 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 0 |
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| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 0 |
| | | | | | | | | | | | | | | | | 7 | | | | | | | | | | | | | | | | | | | | | | 2 | 0 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 0 |
| | | | | | | | | | 5 | | | | | | | | | | 6 | | | | 5 | 6 | | | | | | | | | | | | | | 1 | 0 |
| | | | | | 4 | | | | | | | | 3 | | | | 4 | | | 5 | | | | | | | | | | 4 | | | | | | | | 3 | 2 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 6 | | | 4 | 0 |
| 6 | | | | | | | | 5 | | | | | | 4 | | | 5 | | | | | | | | | | | | | 4 | | 3 | | | | | | 4 | 0 |
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| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 0 |
| 3 | | | | 2 | 3 | | | | | | | | | | 5 | | | | | | | | 4 | | | | | 3 | | | | | | | 4 | | | 4 | 2 |
| | | | | 3 | 2 | | | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | 4 | | 4 | 4 |
| 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 6 | | | | 3 | 0 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 0 |
| | | | | | | | | | | | | | | 7 | | | | | | | | | | | | | | | | | | | | | | | | 4 | 0 |
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| | | | 6 | | | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | 3 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 0 |
| | | | | | | | | | | | | 8 | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 1 |
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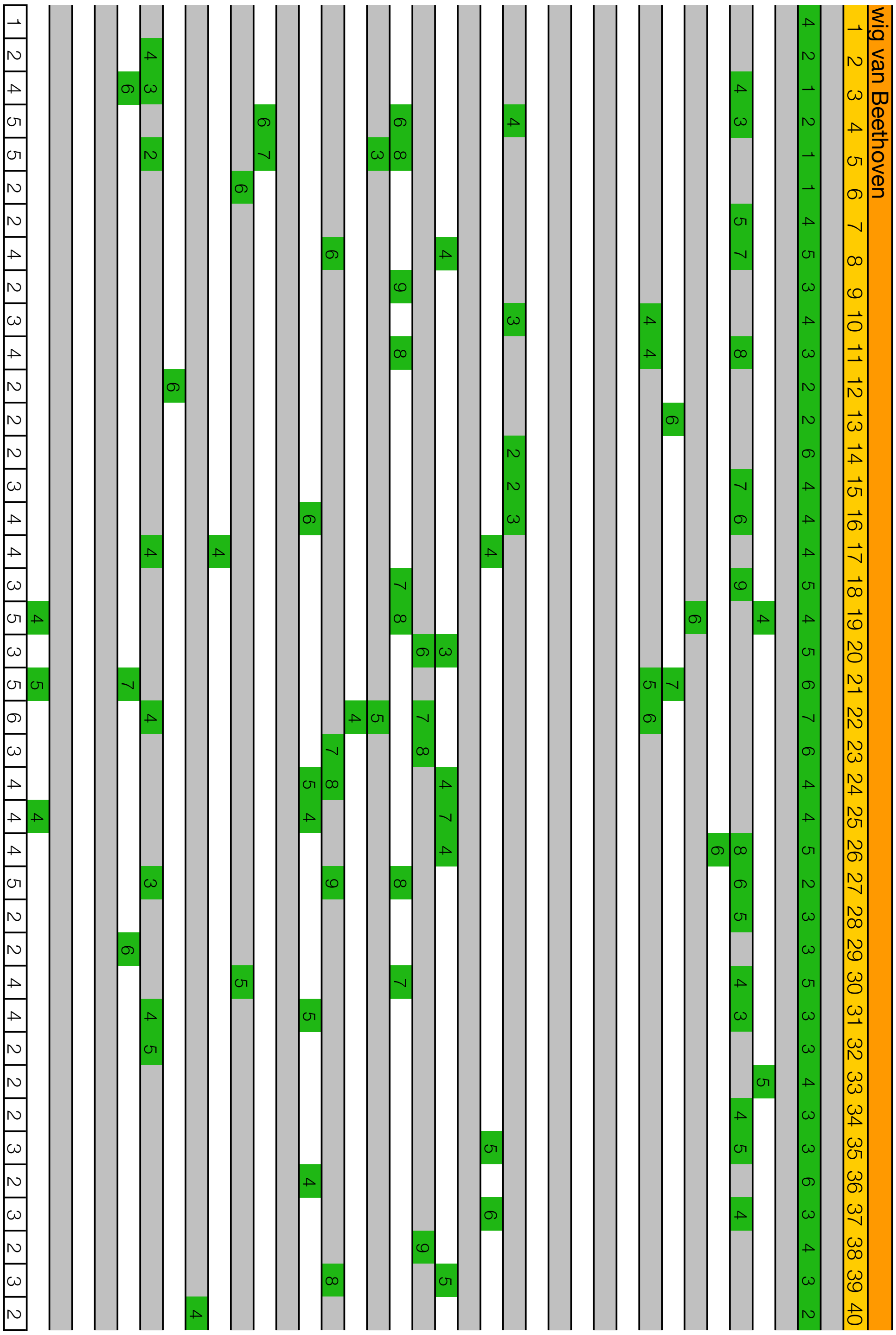
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 0 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 0 |
| 3 | 1 | 1 | 1 | 2 | 3 | 1 | 2 | 4 | 2 | 0 | 0 | 1 | 2 | 3 | 2 | 2 | 4 | 3 | 3 | 3 | 1 | 0 | 2 | 2 | 0 | 1 | 1 | 1 | 2 | 3 | 0 | 2 | 1 | 1 | 4 | 3 | 0 | | |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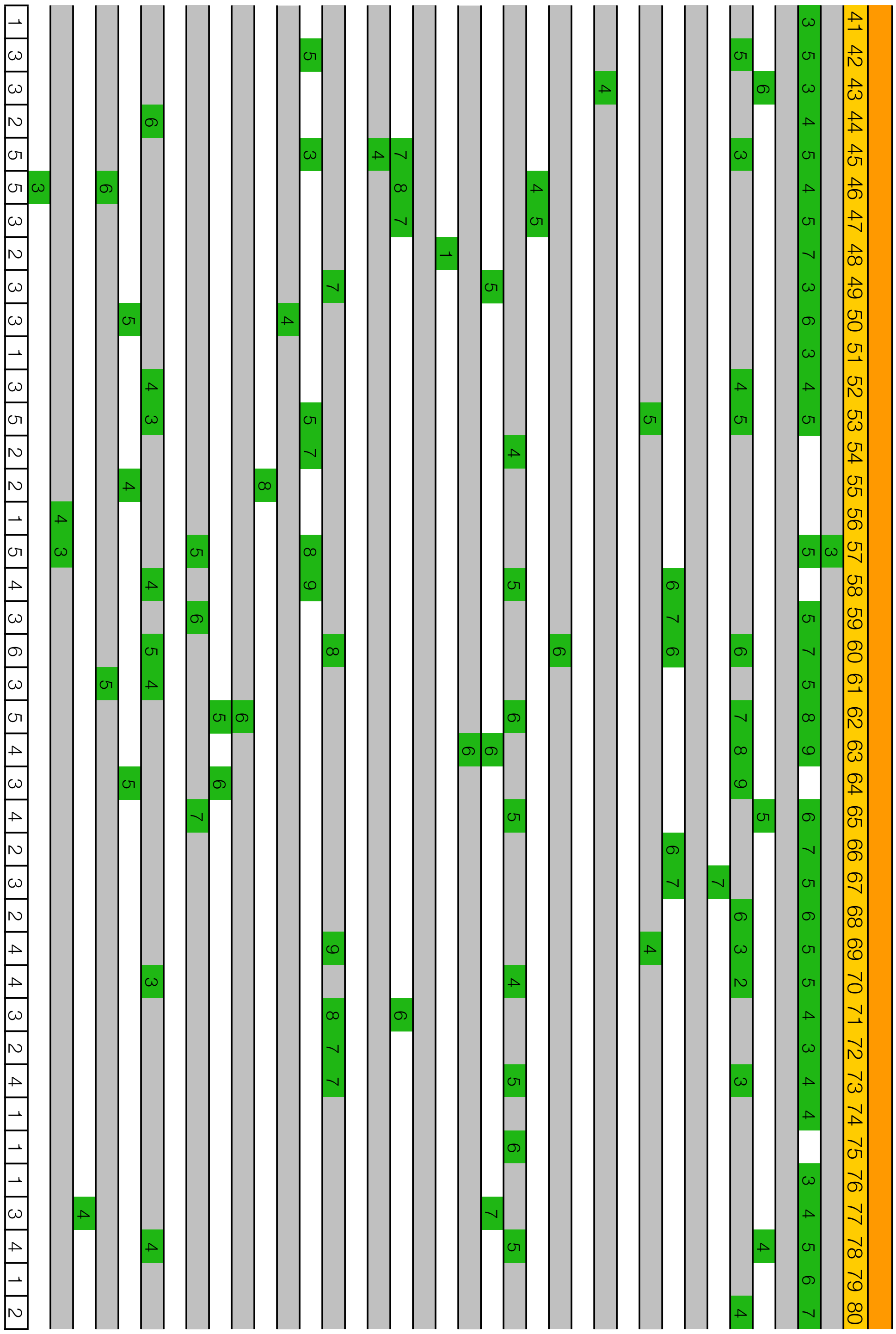
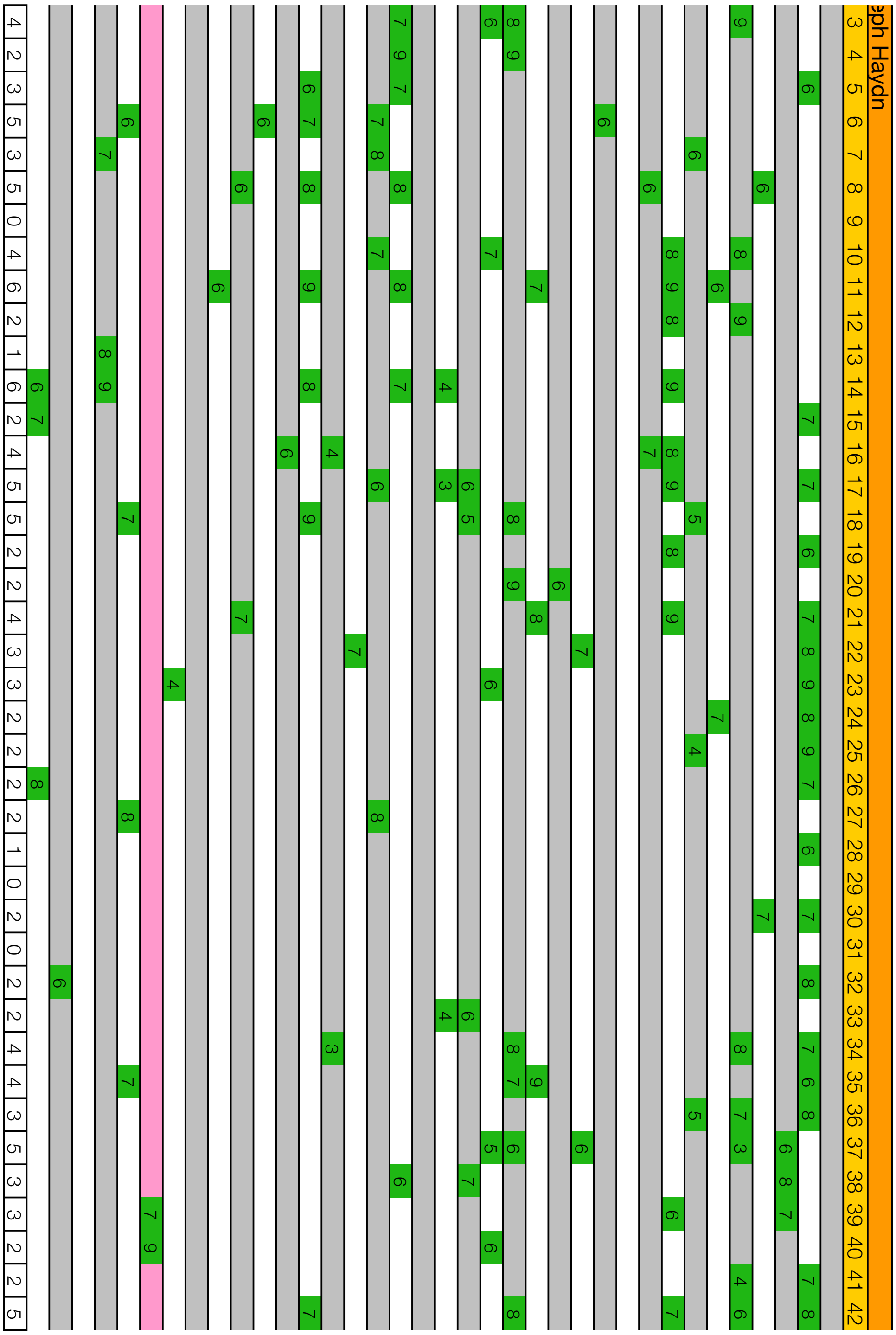
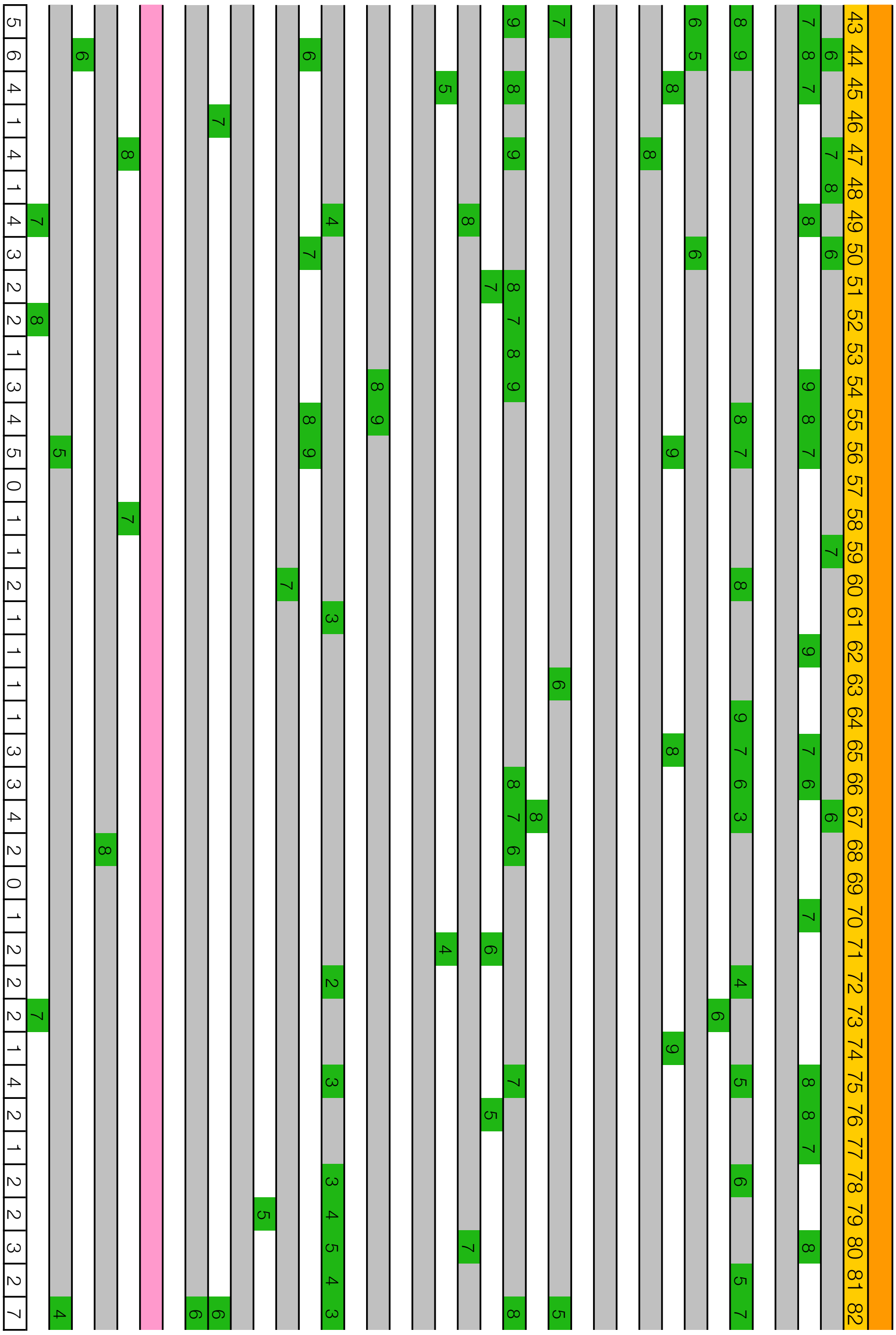


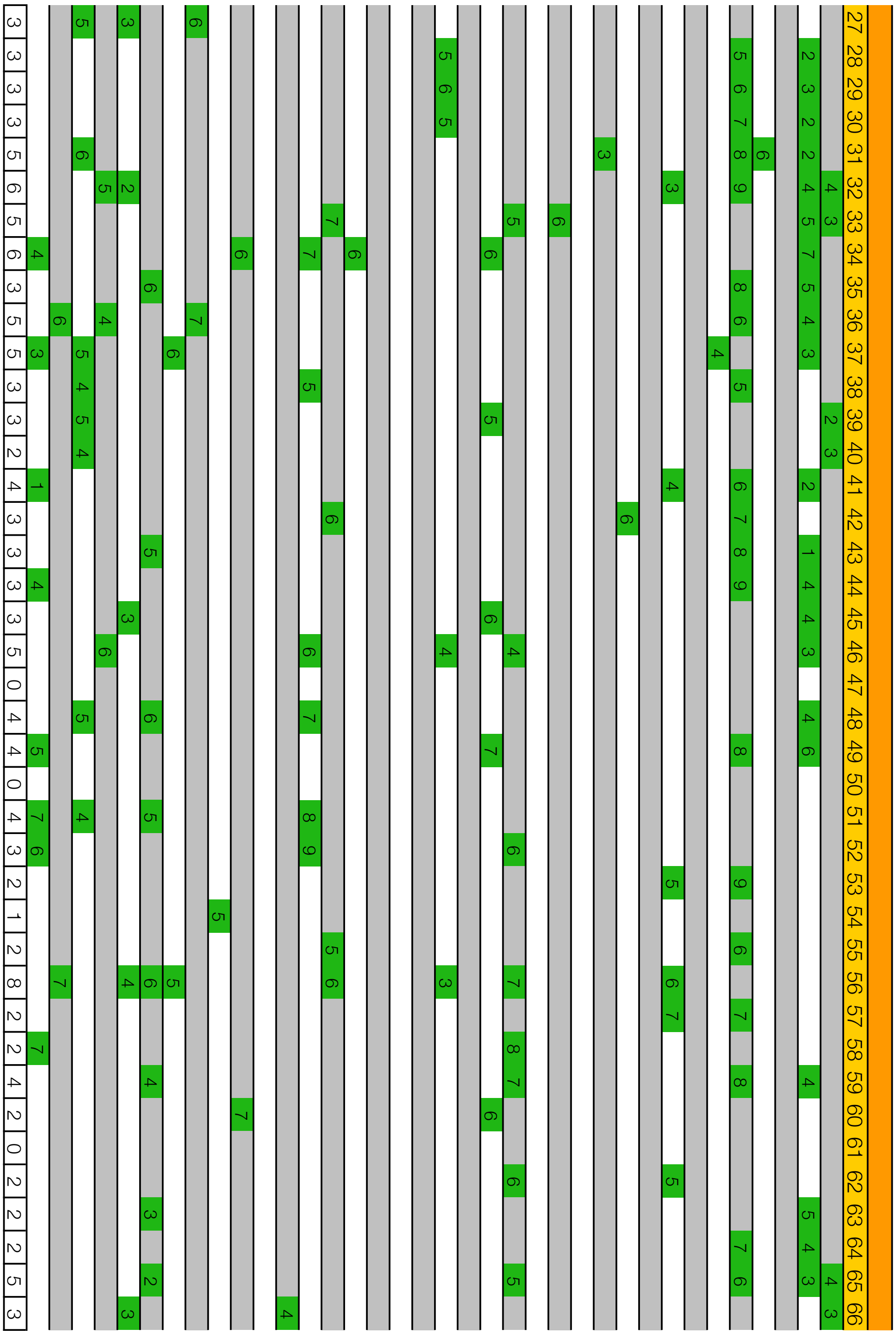
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2: Franz Jose | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | R | F | 1 | 2 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 0 | | |
| 4 | 4 | 4 | 6 | 3 | 4 | 2 | 3 | 3 | 5 | 3 | | 2 | 3 | 4 | | | | | 3 | | 4 | | | | 3 | | | | 4 | | 2 | | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | 0 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | | |
| | | 5 | 6 | | 7 | | 8 | | 9 | | | | | | | | 8 | 6 | 4 | | 3 | | | | 4 | 2 | | | 3 | 4 | | | | 7 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 1 | | |
| | | | | | | | | | 7 | | | | | | | | | | | | | | | | | | | | | | 3 | 0 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 2 | 6 | 7 |
| | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | | 3 | 0 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | 0 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 0 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 0 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 2 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 1 | | |
| | | | | | | | 6 | 7 | | | | 8 | | | 7 | | | | | | | | 6 | | 5 | | | | | | 1 | 1 | | 7 |
| 6 | | | | | | | | 7 | | | | | | | | | | | | | 6 | | 7 | | | | | | | | 1 | 2 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 0 | | |
| | | | | | | | | 2 | | | | | | | | | | | | | 5 | | | | | | | | | | 3 | 0 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 2 | | |
| | | | | | | | 7 | | 8 | 7 | | | | | | | | | | | 8 | | | | | | | | | | 2 | 0 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 0 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 0 | | |
| | | | | | | | | | | | | | | | | 8 | | 5 | 4 | | | | | | 5 | | 6 | | | | 4 | 0 | | |
| | 7 | 7 | | | | | 8 | | | | | | 9 | | | | 8 | 7 | | 6 | | 7 | | | 8 | 7 | 5 | 4 | | | 3 | 0 | | |
| | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | 6 | | | | 4 | 0 | | |
| | | | | | | | | | | | | | | | | | | | | | 9 | | | | | | | | | | 3 | 0 | | |
| 5 | | | | | | | 6 | | | | | | | | 7 | | | | | | | | | | | | | | | | 4 | 0 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | 0 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 0 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 2 | | |
| | | | | | | | | | 5 | | | | | | | | | | | | | | | | | | | | | | 2 | 3 | | |
| | | | | | 6 | | | | | | | | | | | | | | | | | | | | | | | | | | 2 | 0 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 2 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 3 | 0 | | |
| | | | | | | | | | | | | | | | | | 4 | | | | | | | | | | | | 3 | | 2 | 1 | | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 4 | 0 | | |
| 3 | 4 | 3 | 2 | 1 | 3 | 1 | 6 | 4 | 5 | 2 | 0 | 2 | 2 | 1 | 2 | 1 | 3 | 3 | 3 | 1 | 6 | 1 | 2 | 0 | 5 | 2 | 3 | 1 | 4 | 1 | | | 1 | 3 |

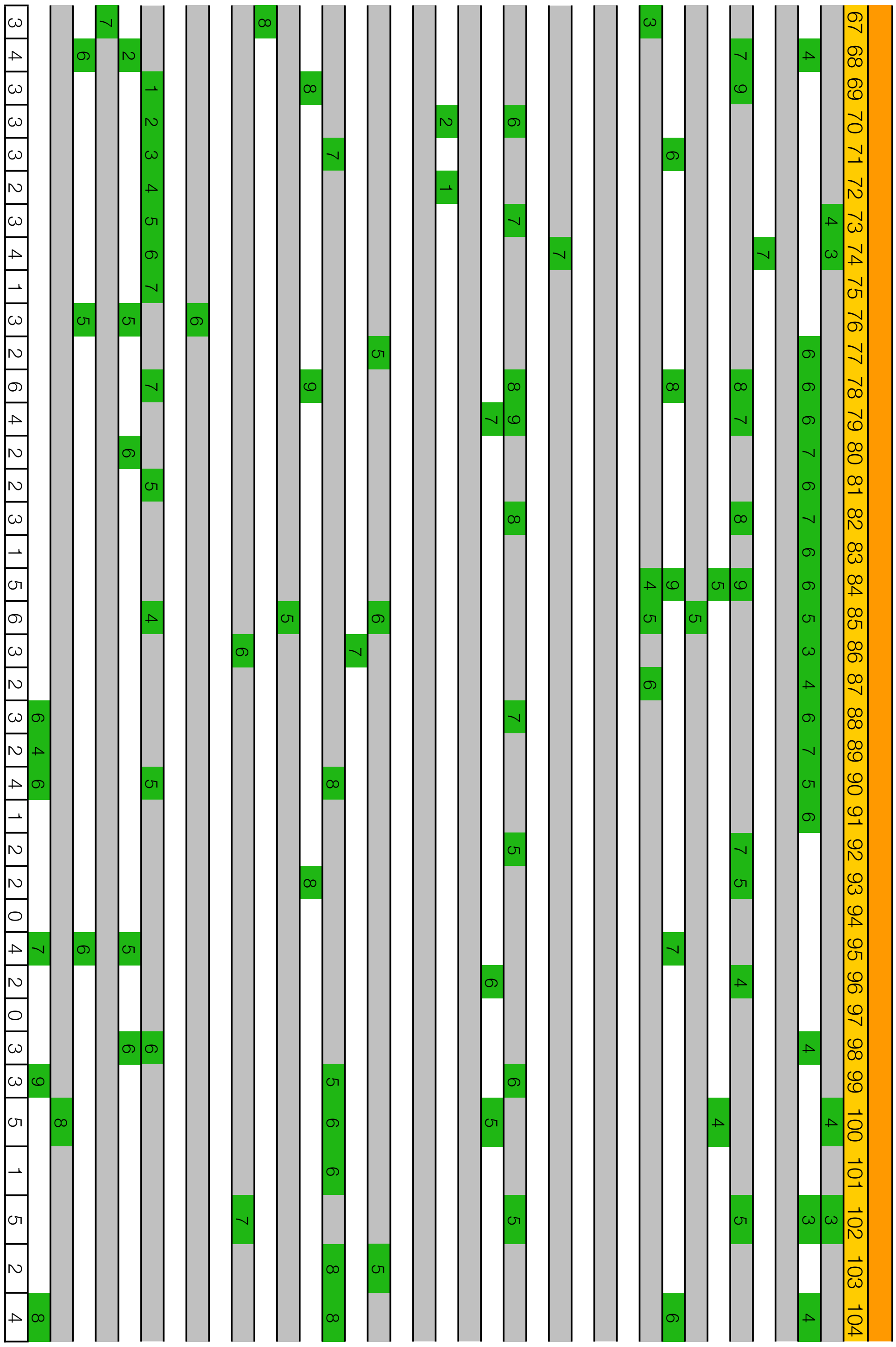

eph Haydn



3: Claude Debussy

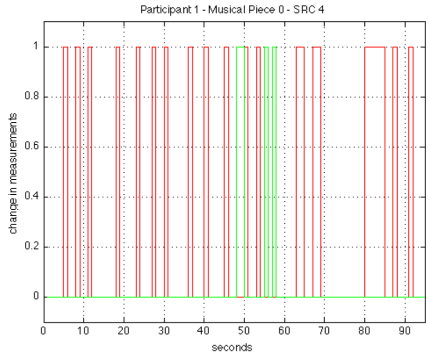
| 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | R | F | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | 3 | 0 | | | | | | | | 4 | 3 | | | | | | | | | | | | | | | | | |
| 7 | | | 8 | | | | 9 | 8 | 7 | 6 | | 2 | | | | | 4 | 3 | | | | 4 | 5 | | | 4 | 2 | 1 | 2 | 2 | 3 | | 4 | | 3 | | | 2 | 4 |
| | | | | | | | | | | | | 1 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | 2 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | 6 | 5 | | | 7 | 8 | | | | | | | | | | | | 4 | 4 | 7 | | | | | | 5 | | | 3 | | 5 | 7 | 8 | | | | | 6 |
| | | | | | | | | | | | | 3 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | 2 | 0 | | | | | | | | | | 6 | | | | | | | | | | | | | | | | |
| | | 8 | | | | | | 9 | | | | 0 | 0 | | | | 4 | | | | | | | | | 5 | | | | | | | | | | | | | 4 |
| | | | | | | | | | | | | 1 | 0 | | | | | | | | | | | | | | | | | | | | | | | 4 | | | |
| | | | | | | | | | | | | 3 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | 3 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | 4 | |
| | | | | | | | | | | | | 4 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | 3 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | 4 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | | | | | | 8 | | | 9 | 8 | 7 | 1 | 0 | 4 | | | | 5 | 6 | | | | | | | | | | | | | | | | | | | | |
| | | | | | | 6 | | | | | | 2 | 1 | | | | | | | | 6 | | | | | 5 | | 6 | | | | | 7 | | | | | | |
| | | | | | | | | | | | | 4 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 | | | | | | | 2 | | | | | 4 | 0 | | | | | | | | | | | | | | | | | 4 | | | | | | | | | |
| | | | | | | | | | | | | 1 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | 6 | 3 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | 4 | 0 | | | | | | | | | | | | | | 4 | | | | | | | | | | | | |
| | | | | | | | | | | | | 3 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | | | | 3 | | 4 | | | | | | 4 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | 6 |
| | | | | | | | | | | | | 4 | 0 | | | | | 6 | | | 7 | | | | | | | | | | | 8 | | | | | | 7 | 6 |
| | | | | | | | | | | | | 2 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | 4 | 0 | | | | | | 6 | | | | 7 | | | | | | | | | | | | | | | | |
| | | | | | | | | 6 | | | | 3 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | 3 | 0 | | | | | | | | | | | | | | | | | | | | | | 6 | | | | |
| | | | | | | | | | | | | 4 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | 5 | | | 4 | 0 | | | | | | 6 | | | | | | | | | | | | | | 7 | | | | | | |
| | | | | | | | | | | | | 2 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | 1 | 0 | | | | | | | 4 | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | 4 | 2 | | | 4 | | | | | | | | | | | | | | | | | 5 | | 6 | | | | |
| | | | | | | | | | | | | 2 | 2 | | | | | | | | | | | | | | | | | | | | | | | | | 6 | 4 |
| | | | | | | | | | | | | 3 | 0 | | 4 | 3 | 4 | | 5 | 6 | | | | | | | | | | | | 7 | | | | | | | |
| | | | | | | | 6 | | | | | 2 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 | 0 | 2 | 2 | 1 | 0 | 4 | 4 | 3 | 3 | 2 | 2 | | | 1 | 1 | 2 | 3 | 3 | 5 | 3 | 4 | 2 | 3 | 0 | 0 | 3 | 3 | 2 | 1 | 3 | 1 | 3 | 5 | 1 | 3 | 1 | 0 | 4 | 6 |

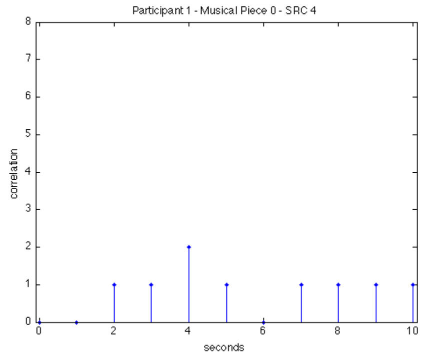


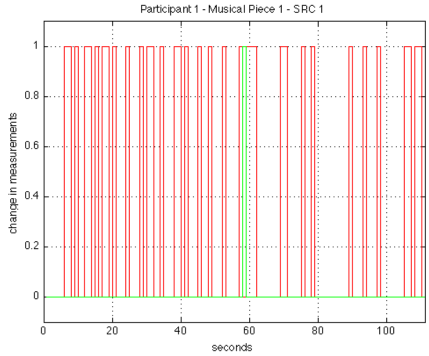


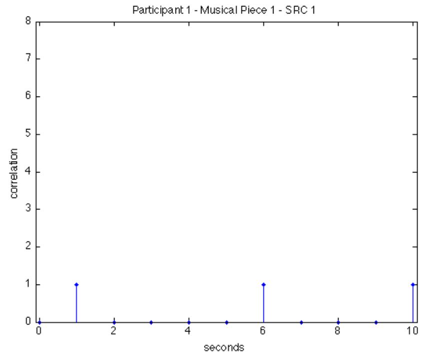
| 105 | 106 | 107 | Comments |
|---|---|---|---|
| | | | Never heard it before. Don't like clssical |
| 3 | | | |
| | | | Knew the last piece. Not really interested in classical music. |
| | | | |
| 7 | 8 | | Had heard some of the pieces. Really like when the music was peaking. Found the smiley a little distrubing. |
| | | | |
| | | | |
| | | | The pad on the right had fell of at the end of the second played musical piece |
| | | | |
| | | | After 0 the rating was set to 3. After 1 the rating was set to 7. Not continual rating |
| | | | |
| | | | |
| | | | Did not know the second played piece |
| | | | |
| | | | Did not notice the rating was dynamic until the middle of the first played piece |
| | | | |
| | | | After 3 the rating was set to 6. Not continual rating |
| | | | During the last played song, the participant put down the controller, and start to make greater physical movements |
| | | | After 2 the rating was set to 8. After 3 the rating was set to 6. Not continual. Knew first played piece quite a bit. |
| | | | |
| | | | |
| | | | Didnot know the first played piece at all. |
| | | 7 | Didnot understand that the scale was continual during the first played piece |
| | | | Didnot know the first and last played piece at all. |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | First played song cannot be used, due to movements and missing rating. The paricipant stated that he is always consious about music and analysiing it. |
| | 5 | | |
| | | | Didnot report continual during the first played song |
| | | | |
| | | | |
| | 7 | | The pad didnot stick as well on the right wrist during the first played song |
| 2 | 3 | 1 | |

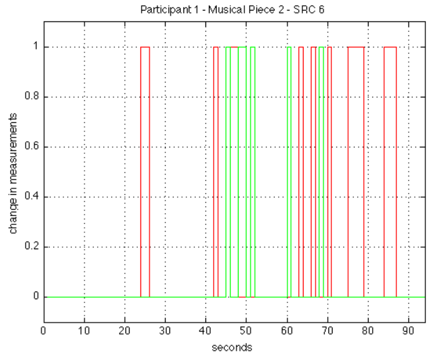
## C.2 Synchronisation of self-reports and heart rate measurements.

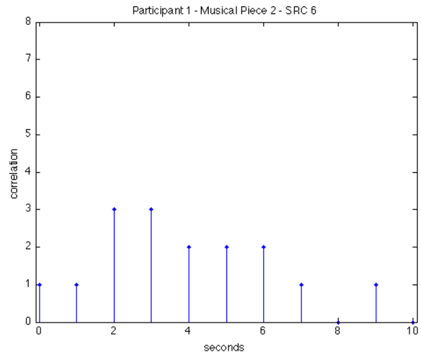


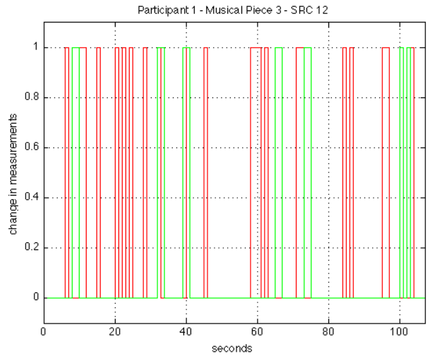



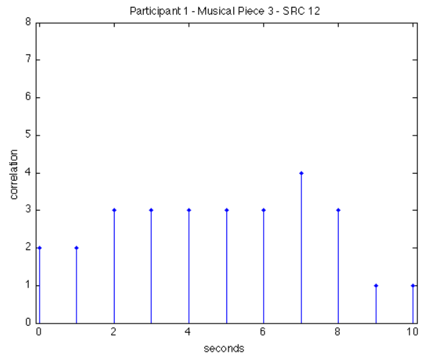



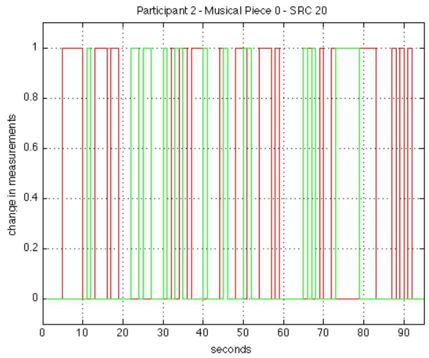



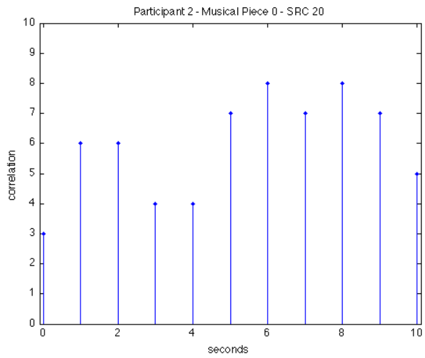



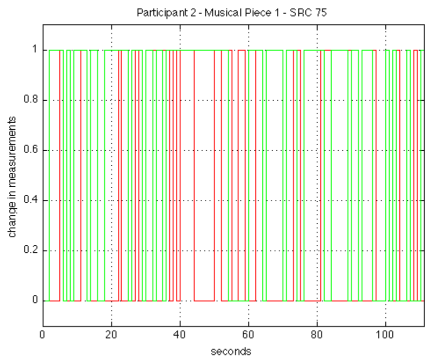



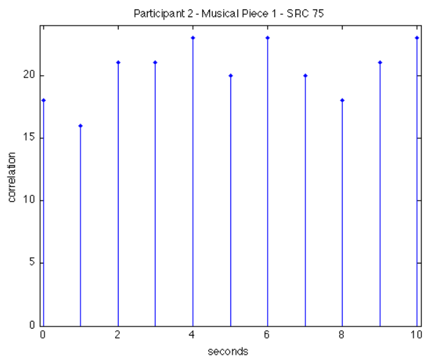




Participant 2 - Musical Piece 0 - SRC 20
change in measurements
seconds


Participant 2 - Musical Piece 0 - SRC 20
correlation
seconds


Participant 2 - Musical Piece 1 - SRC 75
change in measurements
seconds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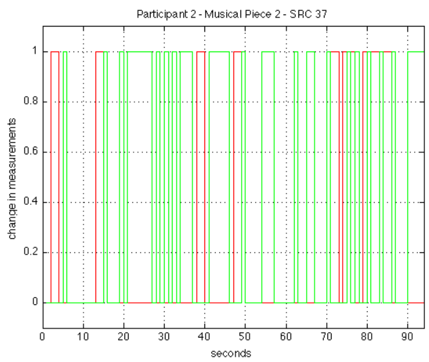
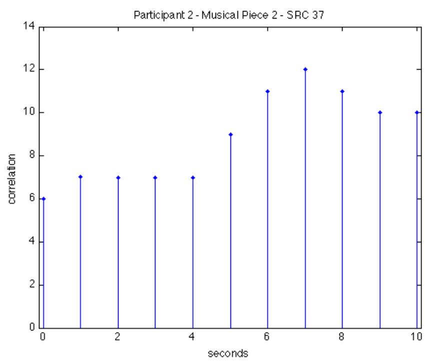
correlation
seconds


Participant 2 - Musical Piece 2 - SRC 37
change in measurements
seconds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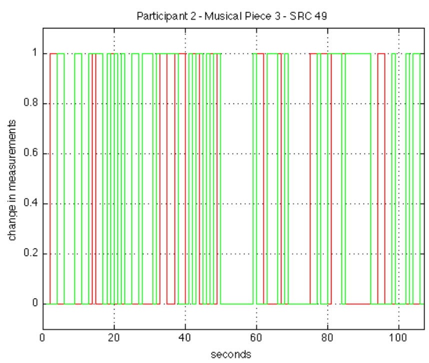
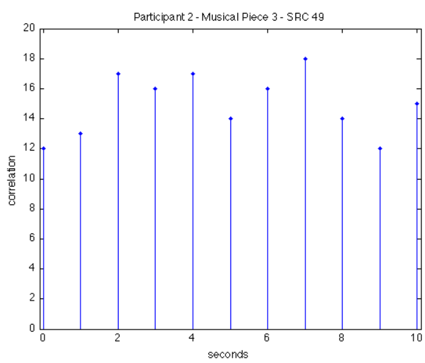
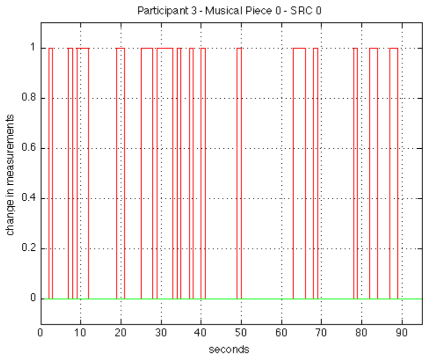
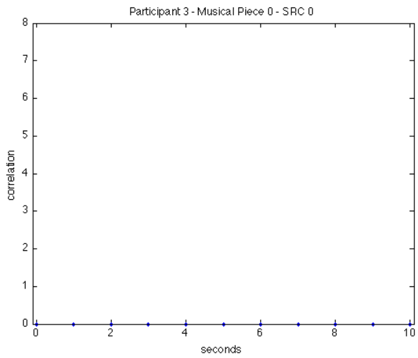
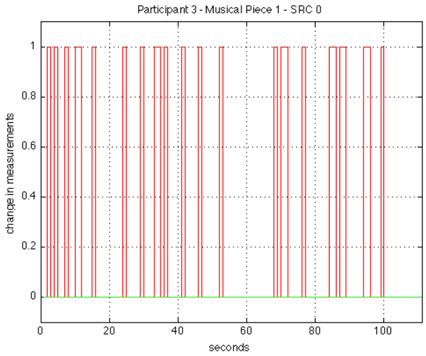
correlation
seconds

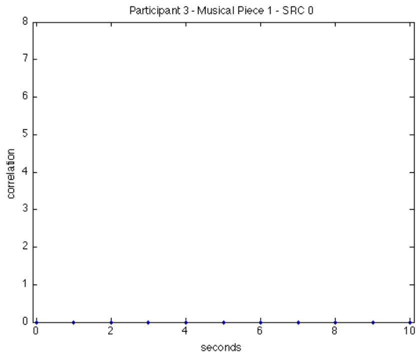

Participant 2 - Musical Piece 3 - SRC 49
change in measurements
seconds

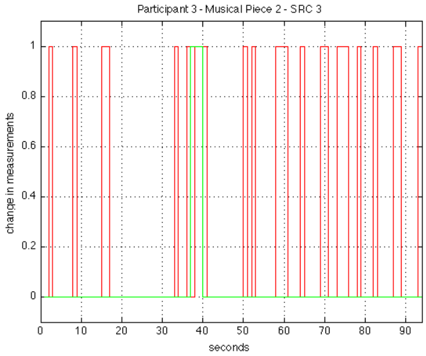

Participant 2 - Musical Piece 3 - SRC 49
correlation
seconds

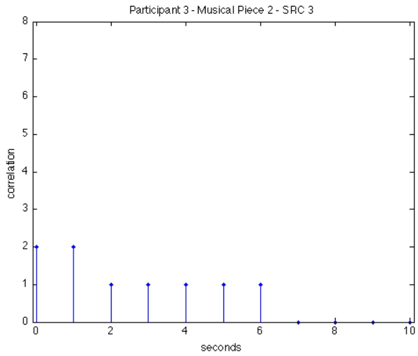

Participant 3 - Musical Piece 0 - SRC 0
change in measurements
seconds

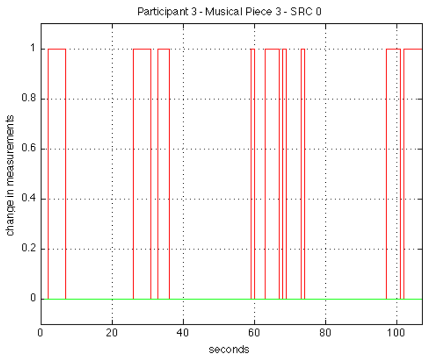

Participant 3 - Musical Piece 0 - SRC 0
correlation
seconds

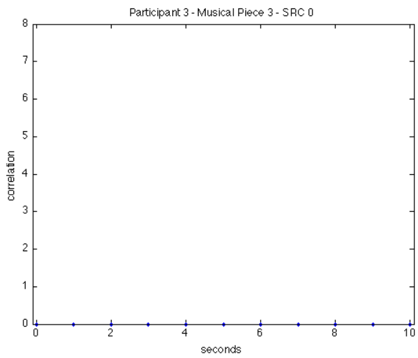

Participant 3 - Musical Piece 1 - SRC 0
change in measurements
seconds

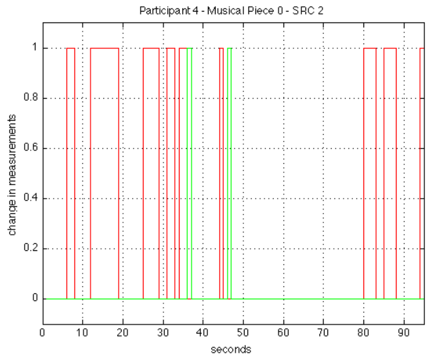
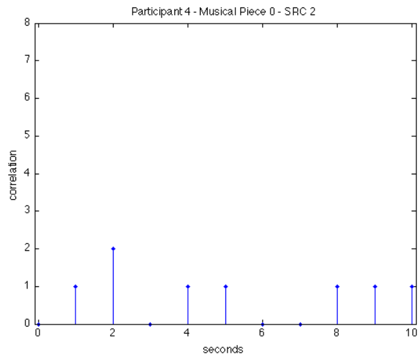
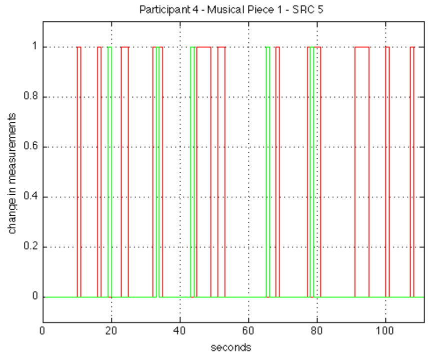
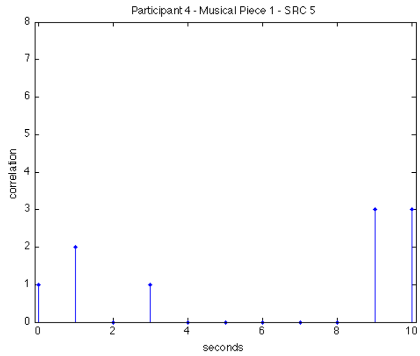

Participant 3 - Musical Piece 1 - SRC 0
correlation
seconds


Participant 3 - Musical Piece 2 - SRC 3
change in measurements
seconds


Participant 3 - Musical Piece 2 - SRC 3
correlation
seconds


Participant 3 - Musical Piece 3 - SRC 0
change in measurements
seconds


Participant 3 - Musical Piece 3 - SRC 0
correlation
seconds


Participant 4 - Musical Piece 0 - SRC 2
change in measurements
seconds

Participant 4 - Musical Piece 0 - SRC 2
correlation
seconds

Participant 4 - Musical Piece 1 - SRC 5
change in measurements
seconds

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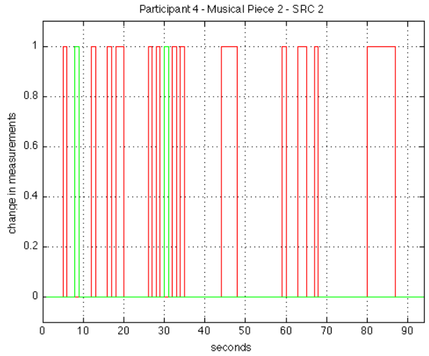
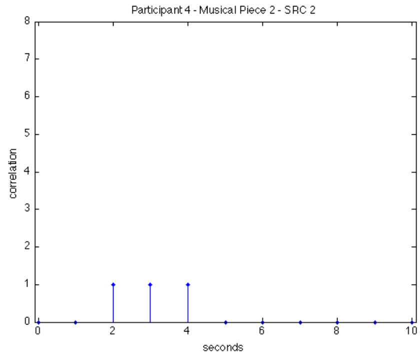
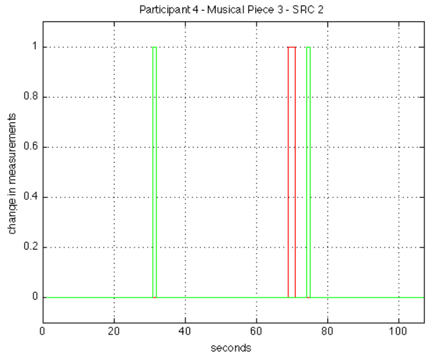
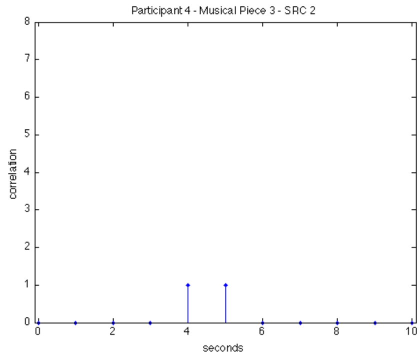
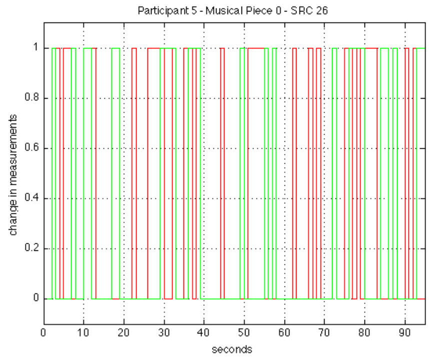
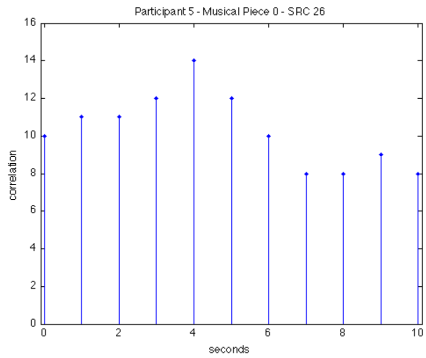
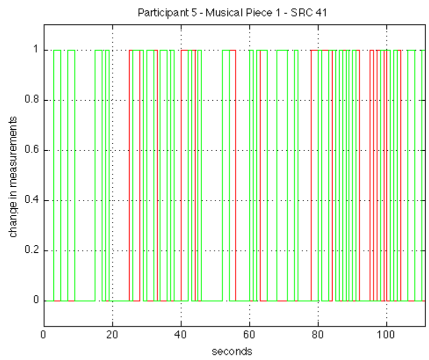
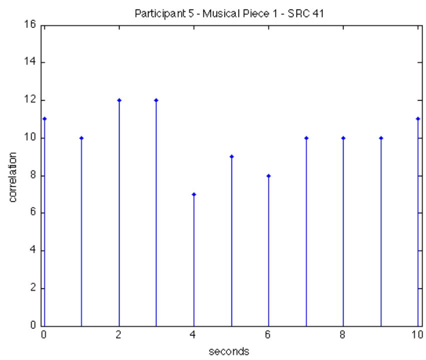
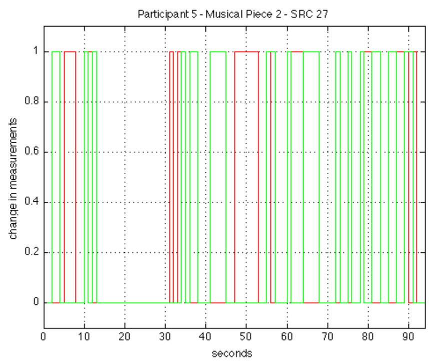
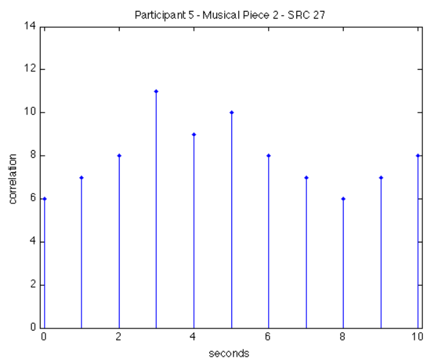
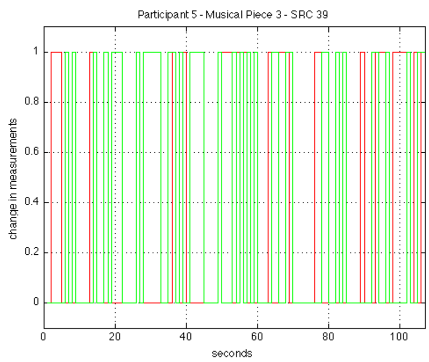
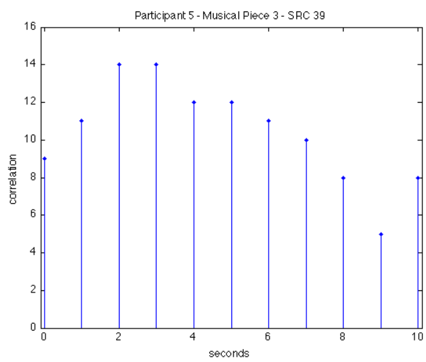
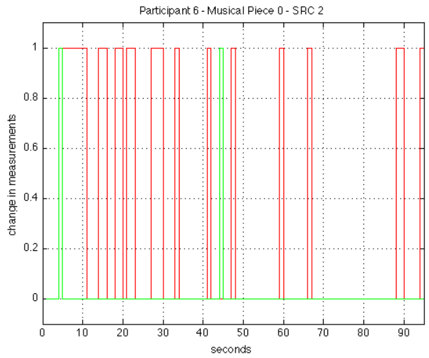
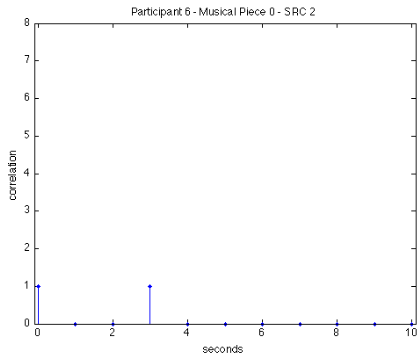
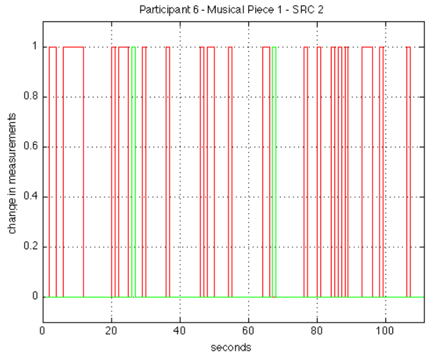
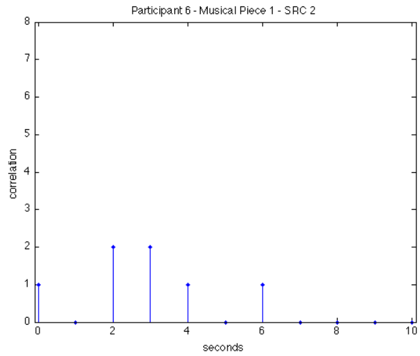

Participant 4 - Musical Piece 2 - SRC 2
change in measurements
seconds

Participant 4 - Musical Piece 2 - SRC 2
correlation
seconds

Participant 4 - Musical Piece 3 - SRC 2
change in measurements
seconds

Participant 4 - Musical Piece 3 - SRC 2
correlation
seconds

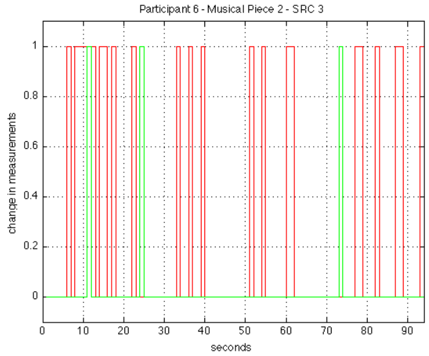

Participant 5 - Musical Piece 0 - SRC 26
change in measurements
seconds

Participant 5 - Musical Piece 0 - SRC 26
correlation
seconds

Participant 5 - Musical Piece 1 - SRC 41
change in measurements
seconds

Participant 5 - Musical Piece 1 - SRC 41
correlation
seconds

Participant 5 - Musical Piece 2 - SRC 27
change in measurements
seconds

Participant 5 - Musical Piece 2 - SRC 27
correlation
seconds

Participant 5 - Musical Piece 3 - SRC 39
change in measurements
seconds

Participant 5 - Musical Piece 3 - SRC 39
correlation
seconds

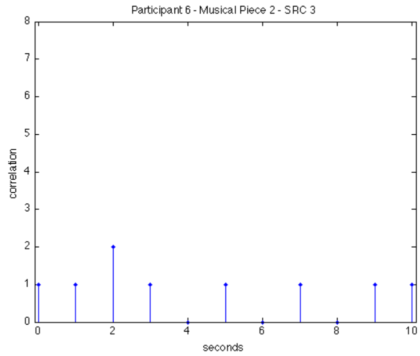

Participant 6 - Musical Piece 0 - SRC 2
change in measurements
seconds

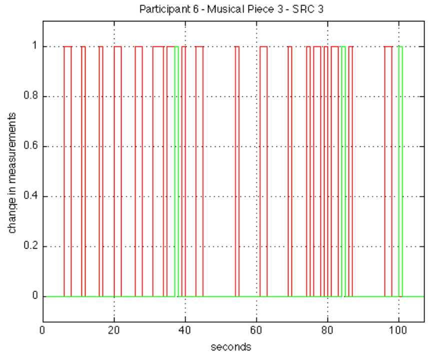

Participant 6 - Musical Piece 0 - SRC 2
correlation
seconds

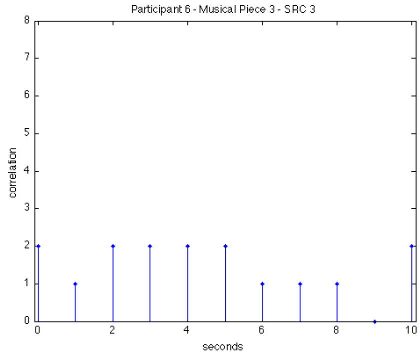

Participant 6 - Musical Piece 1 - SRC 2
change in measurements
seconds

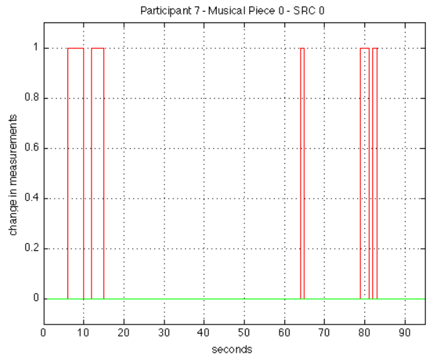

Participant 6 - Musical Piece 1 - SRC 2
correlation
seconds

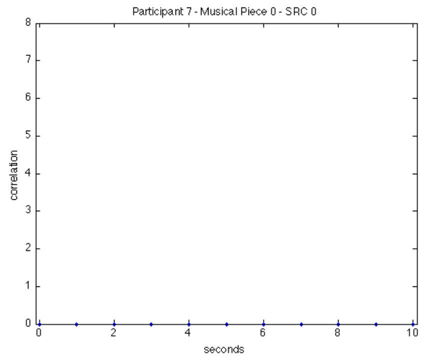

Participant 6 - Musical Piece 2 - SRC 3
change in measurements
seconds

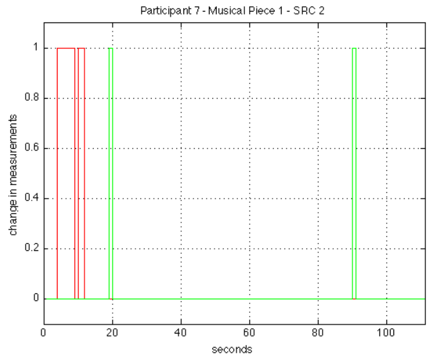

Participant 6 - Musical Piece 2 - SRC 3
correlation
seconds

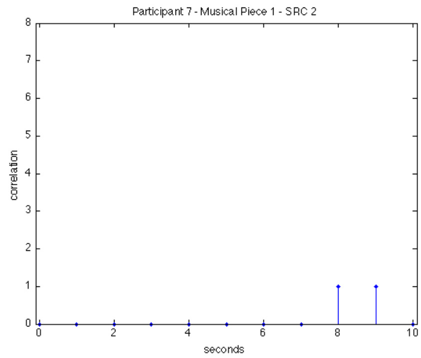

Participant 6 - Musical Piece 3 - SRC 3
change in measurements
seconds

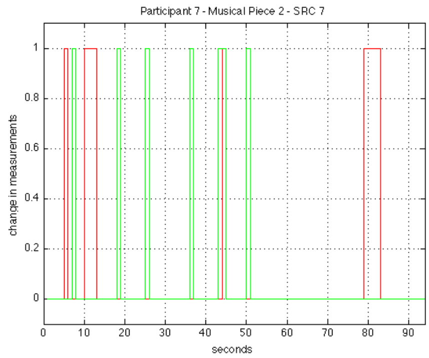

Participant 6 - Musical Piece 3 - SRC 3
correlation
seconds

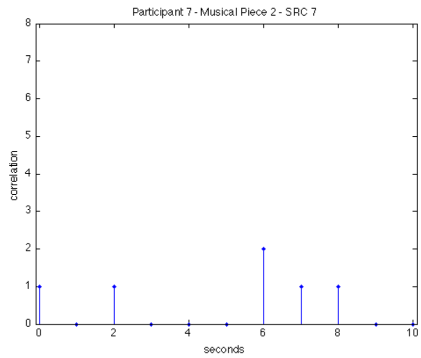

Participant 7 - Musical Piece 0 - SRC 0
change in measurements
seconds

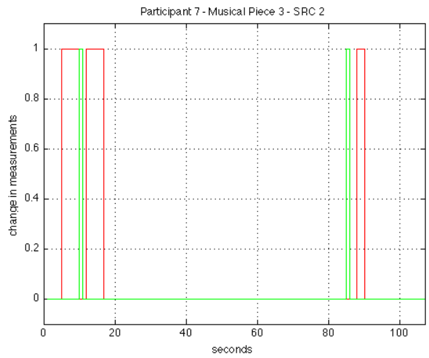

Participant 7 - Musical Piece 0 - SRC 0
correlation
seconds

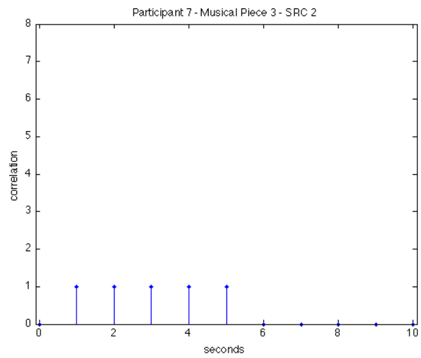

Participant 7 - Musical Piece 1 - SRC 2
change in measurements
seconds

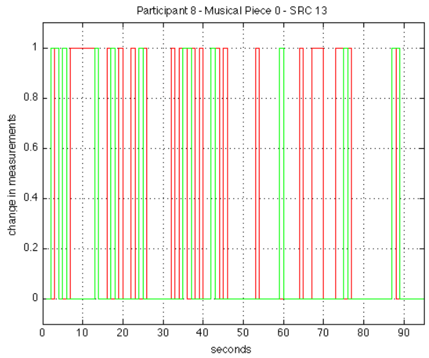

Participant 7 - Musical Piece 1 - SRC 2
correlation
seconds

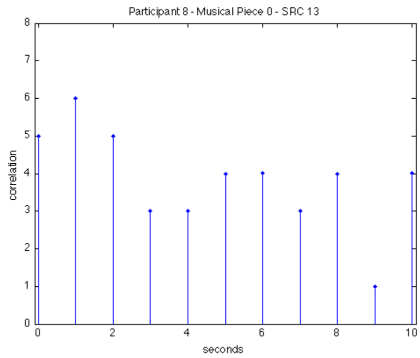

Participant 7 - Musical Piece 2 - SRC 7
change in measurements
seconds

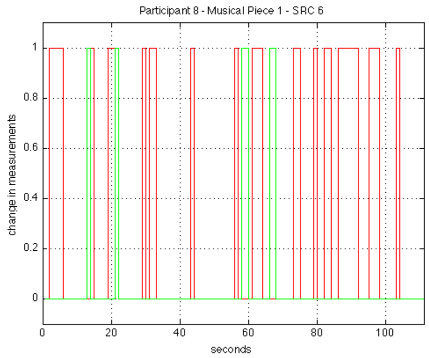

Participant 7 - Musical Piece 2 - SRC 7
correlation
seconds

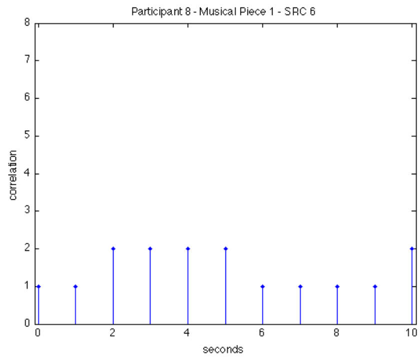

Participant 7 - Musical Piece 3 - SRC 2
change in measurements
seconds

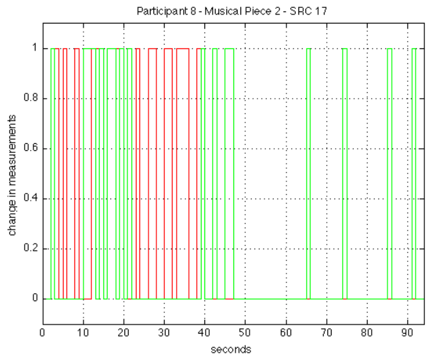

Participant 7 - Musical Piece 3 - SRC 2
correlation
seconds

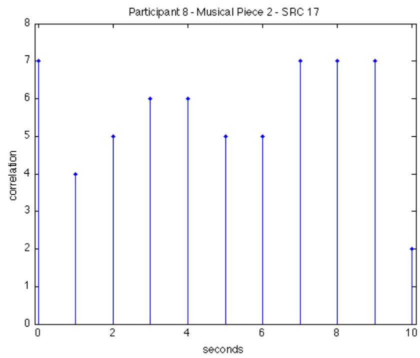

Participant 8 - Musical Piece 0 - SRC 13
change in measurements
seconds

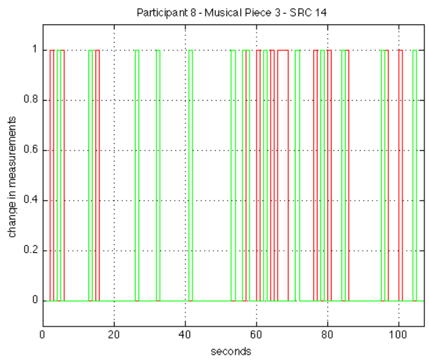

Participant 8 - Musical Piece 0 - SRC 13
correlation
seconds

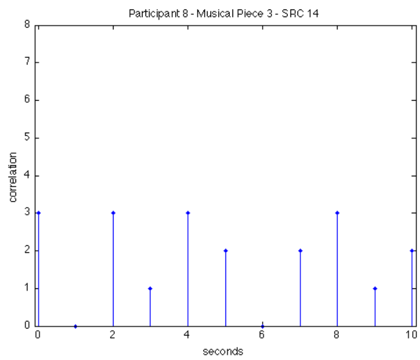

Participant 8 - Musical Piece 1 - SRC 6
change in measurements
seconds

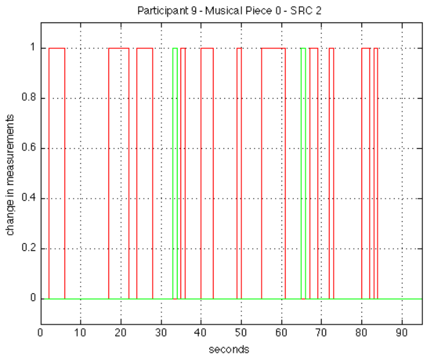

Participant 8 - Musical Piece 1 - SRC 6
correlation
seconds

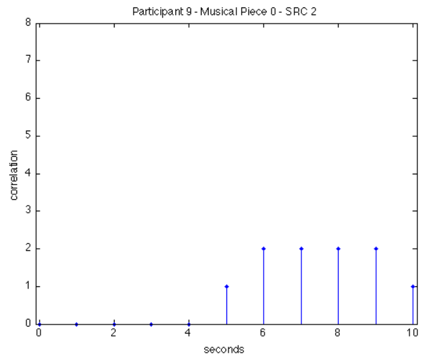

Participant 8 - Musical Piece 2 - SRC 17
change in measurements
seconds

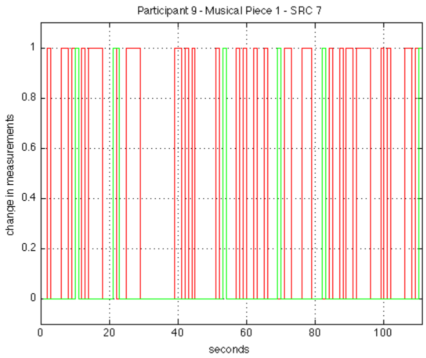

Participant 8 - Musical Piece 2 - SRC 17
correlation
seconds

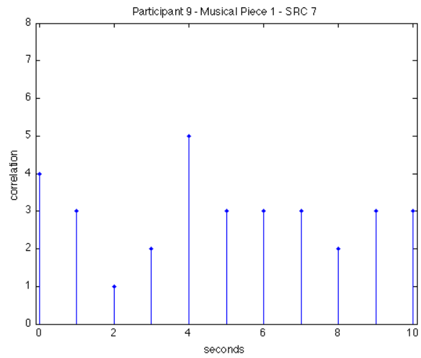

Participant 8 - Musical Piece 3 - SRC 14
change in measurements
seconds

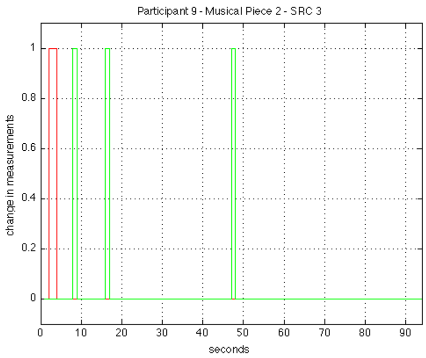

Participant 8 - Musical Piece 3 - SRC 14
correlation
seconds

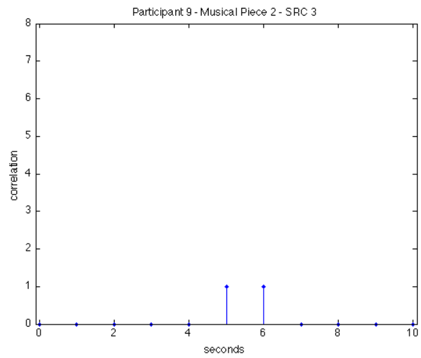

Participant 9 - Musical Piece 0 - SRC 2
change in measurements
seconds

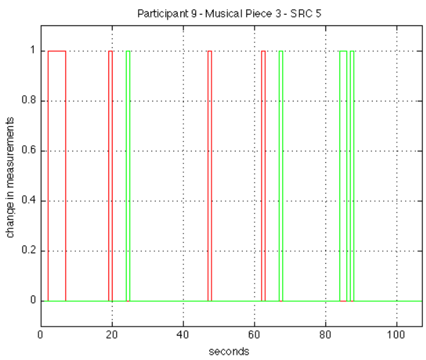

Participant 9 - Musical Piece 0 - SRC 2
correlation
seconds

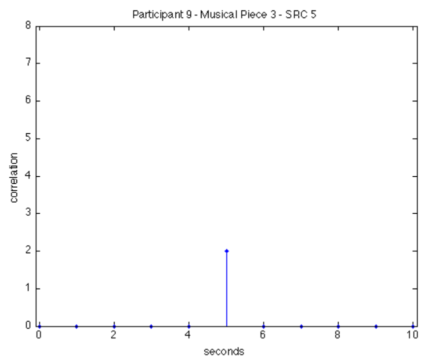

Participant 9 - Musical Piece 1 - SRC 7
change in measurements
seconds

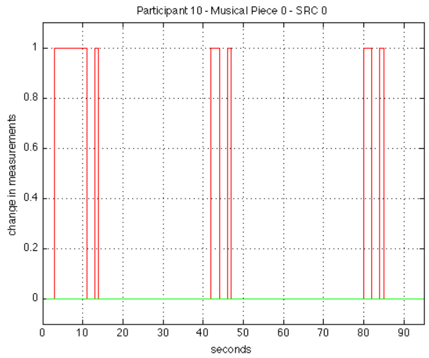

Participant 9 - Musical Piece 1 - SRC 7
correlation
seconds

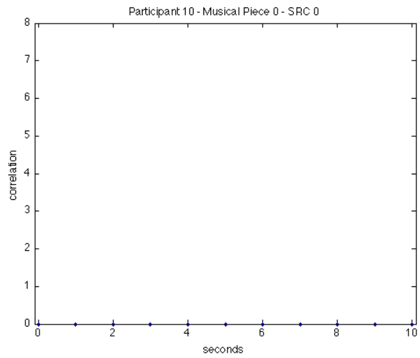

Participant 9 - Musical Piece 2 - SRC 3
change in measurements
seconds

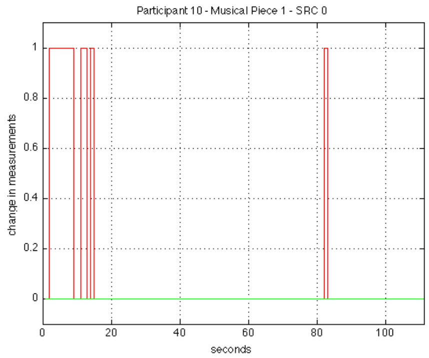

Participant 9 - Musical Piece 2 - SRC 3
correlation
seconds

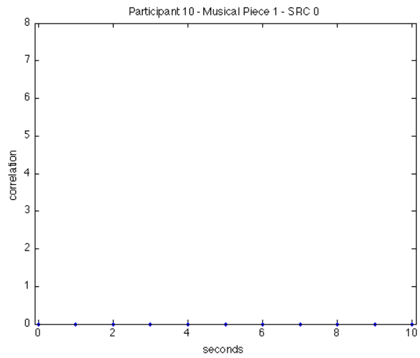

Participant 9 - Musical Piece 3 - SRC 5
change in measurements
seconds

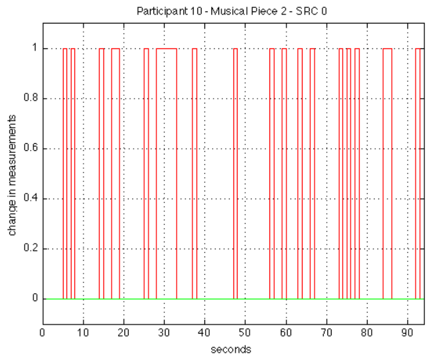

Participant 9 - Musical Piece 3 - SRC 5
correlation
seconds

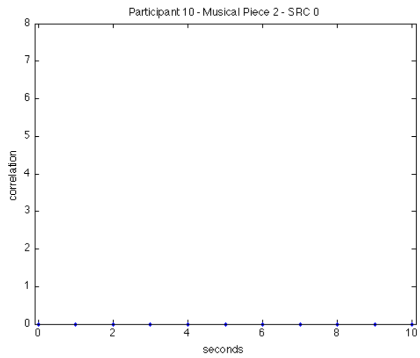

Participant 10 - Musical Piece 0 - SRC 0
change in measurements
seconds

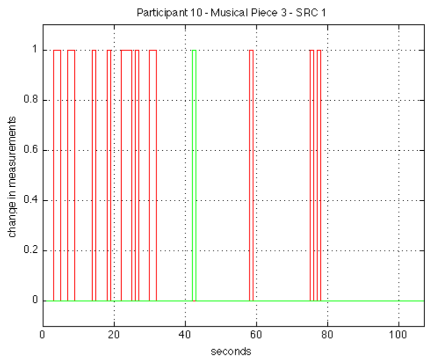

Participant 10 - Musical Piece 0 - SRC 0
correlation
seconds

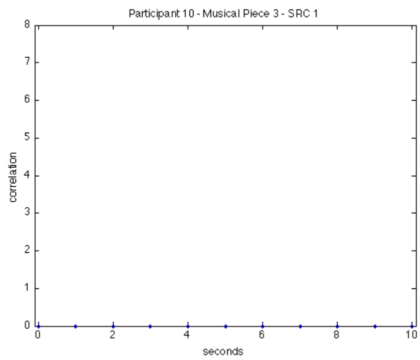

Participant 10 - Musical Piece 1 - SRC 0
change in measurements
seconds

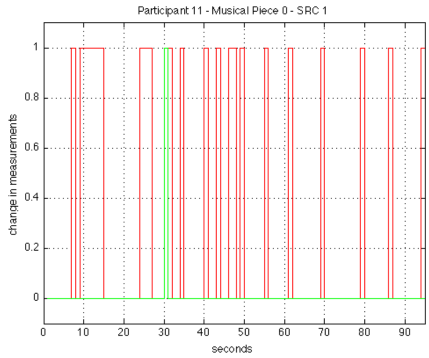

Participant 10 - Musical Piece 1 - SRC 0
correlation
seconds

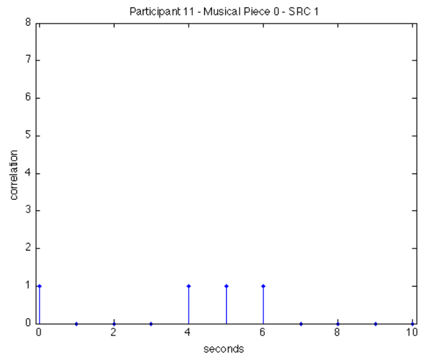

Participant 10 - Musical Piece 2 - SRC 0
change in measurements
seconds

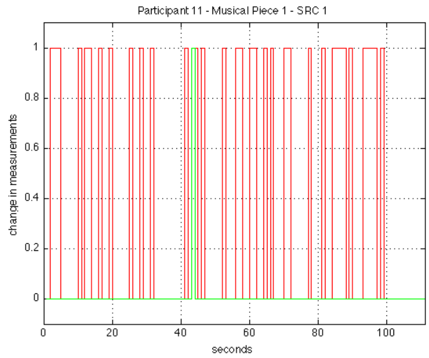

Participant 10 - Musical Piece 2 - SRC 0
correlation
seconds

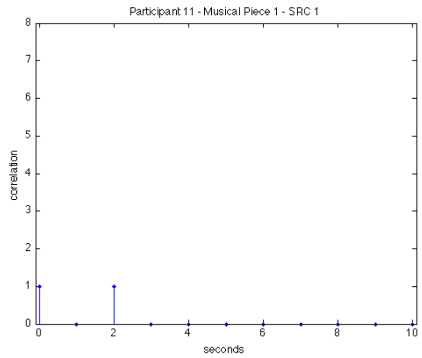

Participant 10 - Musical Piece 3 - SRC 1
change in measurements
seconds

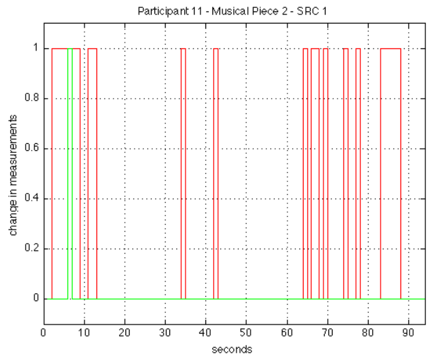

Participant 10 - Musical Piece 3 - SRC 1
correlation
seconds

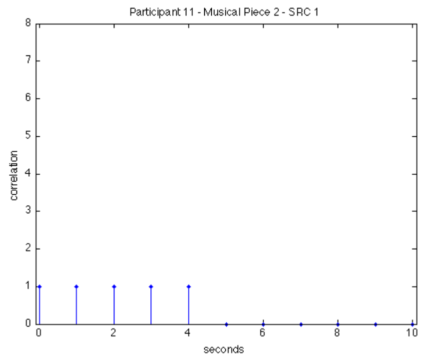

Participant 11 - Musical Piece 0 - SRC 1
change in measurements
seconds

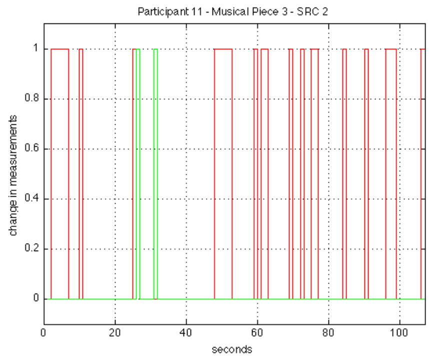

Participant 11 - Musical Piece 0 - SRC 1
correlation
seconds

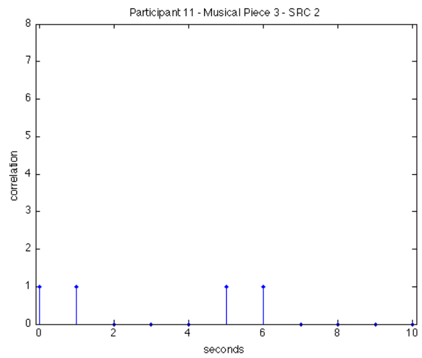

Participant 11 - Musical Piece 1 - SRC 1
change in measurements
seconds

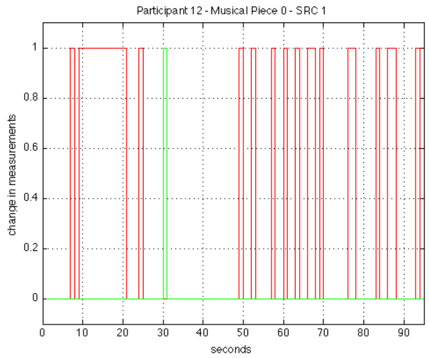

Participant 11 - Musical Piece 1 - SRC 1
correlation
seconds

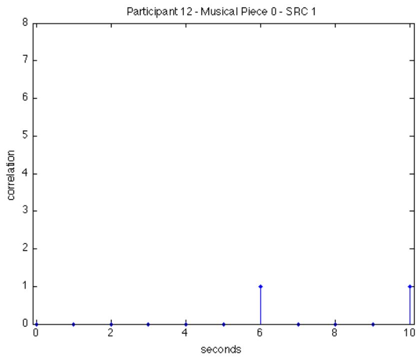

Participant 11 - Musical Piece 2 - SRC 1
change in measurements
seconds

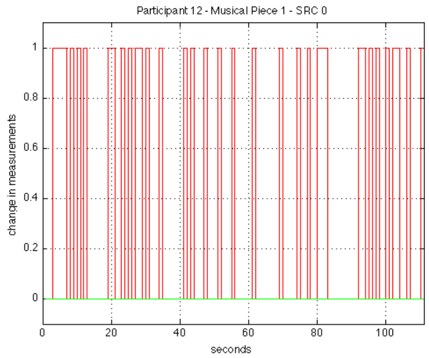

Participant 11 - Musical Piece 2 - SRC 1
correlation
seconds

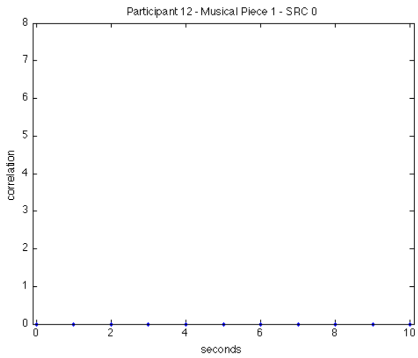

Participant 11 - Musical Piece 3 - SRC 2
change in measurements
seconds

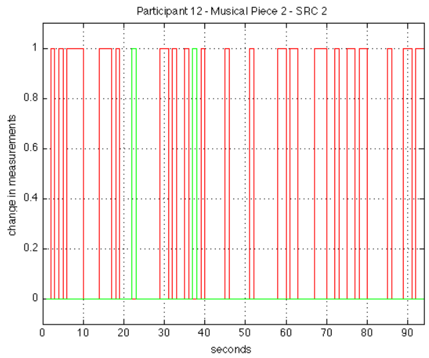

Participant 11 - Musical Piece 3 - SRC 2
correlation
seconds

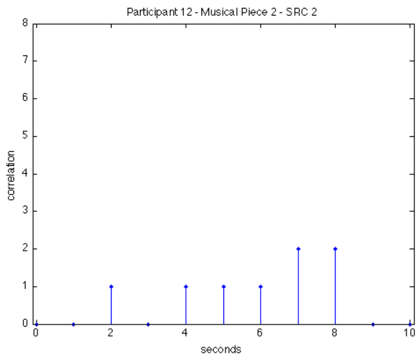

Participant 12 - Musical Piece 0 - SRC 1
change in measurements
seconds

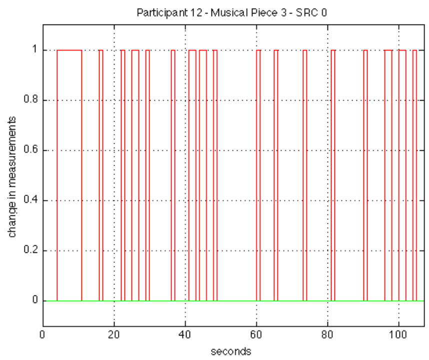

Participant 12 - Musical Piece 0 - SRC 1
correlation
seconds

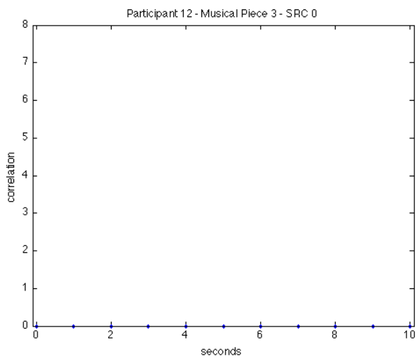

Participant 12 - Musical Piece 1 - SRC 0
change in measurements
seconds

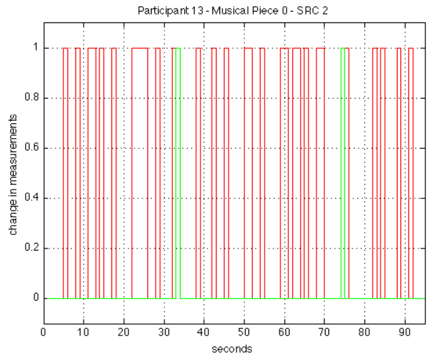

Participant 12 - Musical Piece 1 - SRC 0
correlation
seconds

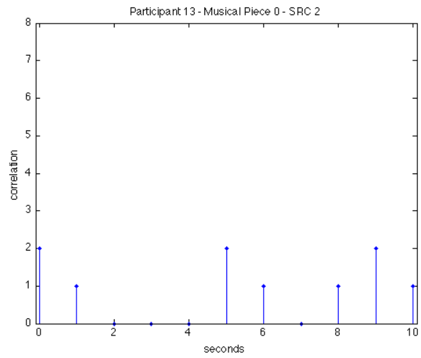

Participant 12 - Musical Piece 2 - SRC 2
change in measurements
seconds

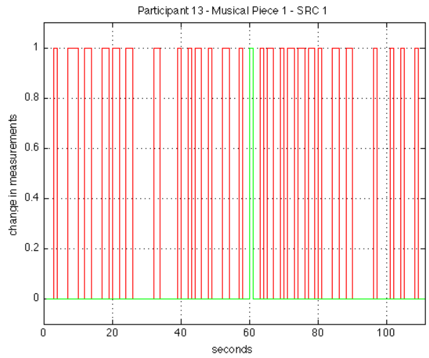

Participant 12 - Musical Piece 2 - SRC 2
correlation
seconds

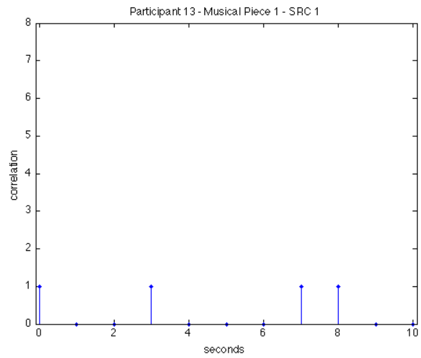

Participant 12 - Musical Piece 3 - SRC 0
change in measurements
seconds

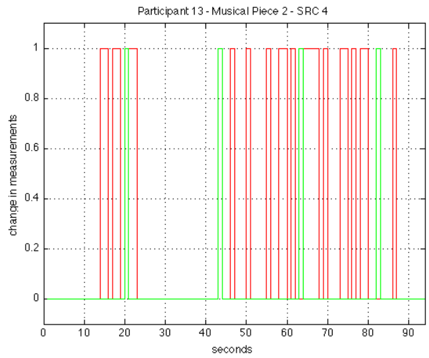

Participant 12 - Musical Piece 3 - SRC 0
correlation
seconds

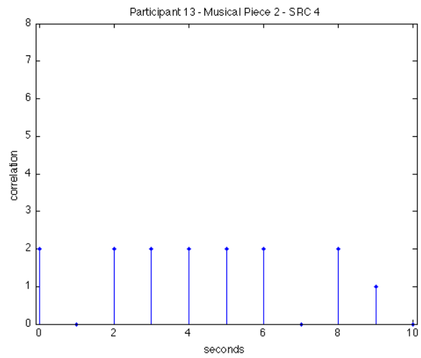

Participant 13 - Musical Piece 0 - SRC 2
change in measurements
seconds

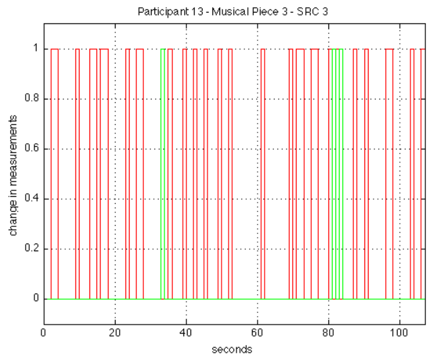

Participant 13 - Musical Piece 0 - SRC 2
correlation
seconds

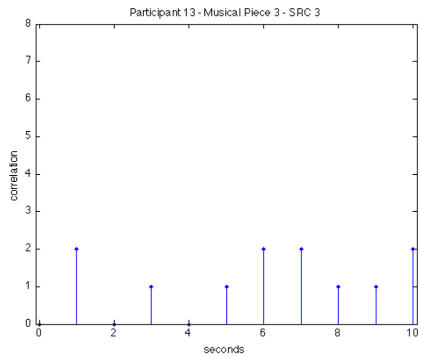

Participant 13 - Musical Piece 1 - SRC 1
change in measurements
seconds

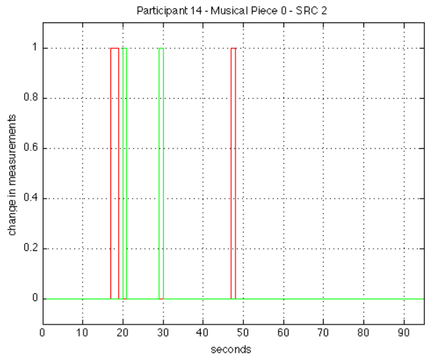

Participant 13 - Musical Piece 1 - SRC 1
correlation
seconds

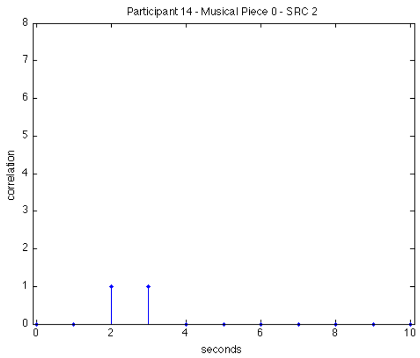

Participant 13 - Musical Piece 2 - SRC 4
change in measurements
seconds

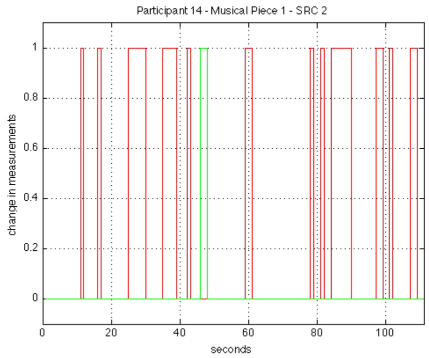

Participant 13 - Musical Piece 2 - SRC 4
correlation
seconds

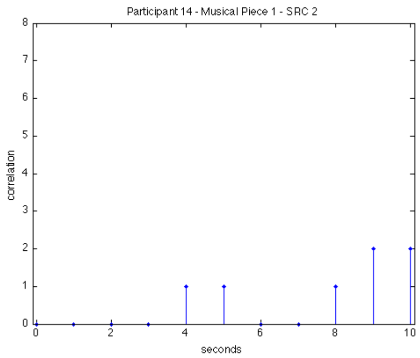

Participant 13 - Musical Piece 3 - SRC 3
change in measurements
seconds

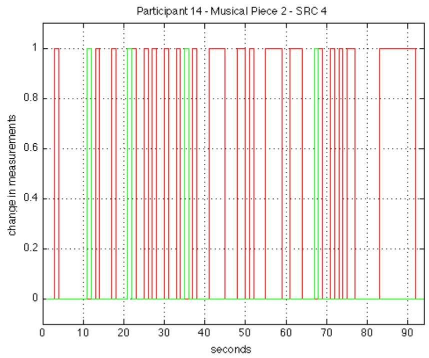

Participant 13 - Musical Piece 3 - SRC 3
correlation
seconds

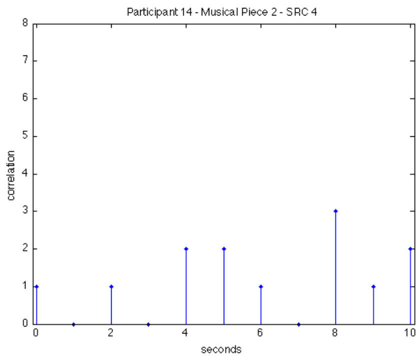

Participant 14 - Musical Piece 0 - SRC 2
change in measurements
seconds

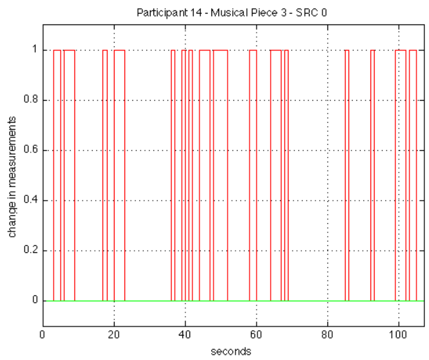

Participant 14 - Musical Piece 0 - SRC 2
correlation
seconds

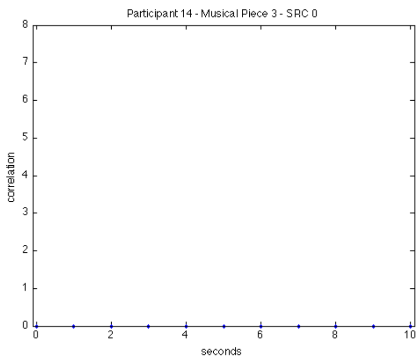

Participant 14 - Musical Piece 1 - SRC 2
change in measurements
seconds

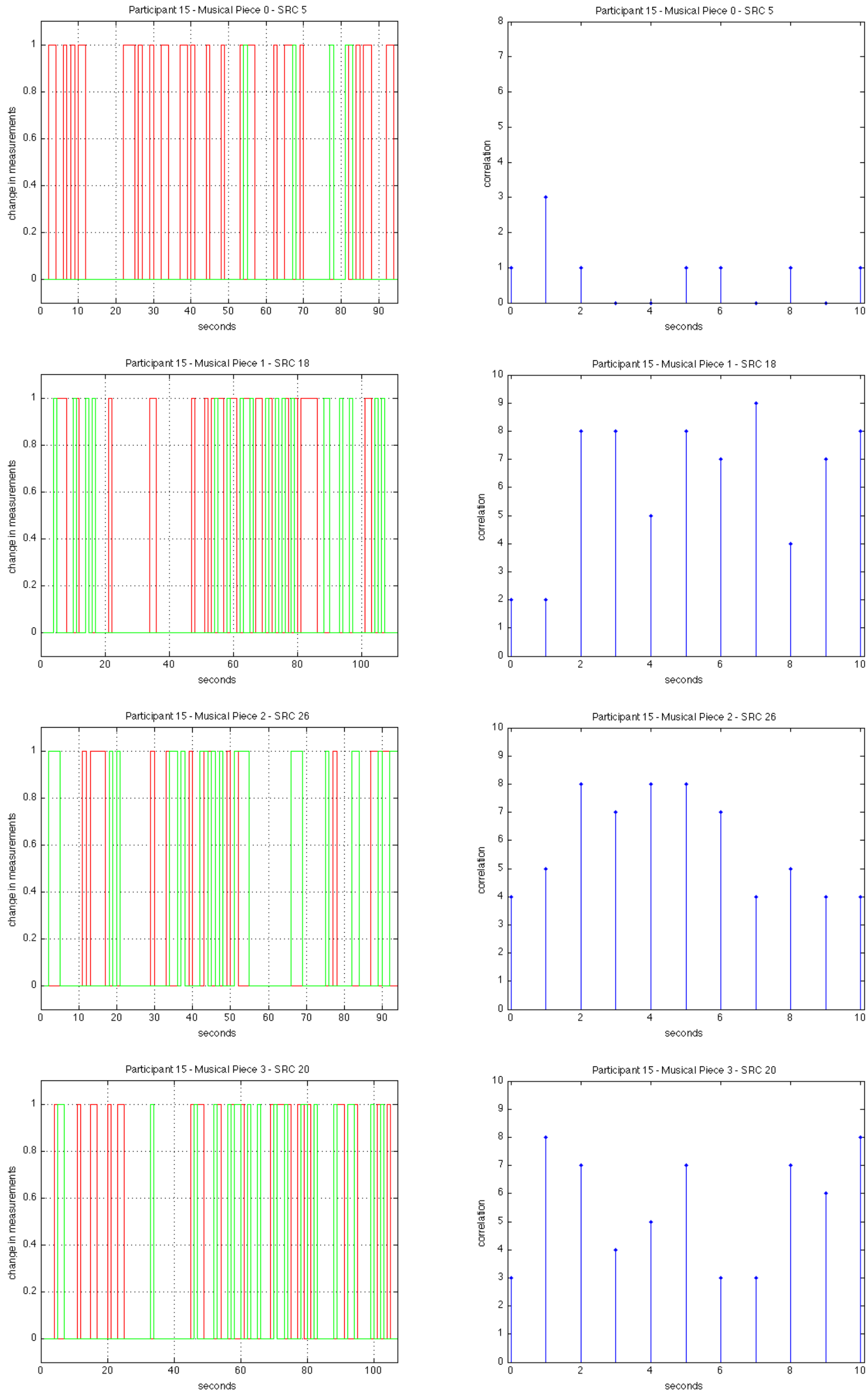

Participant 14 - Musical Piece 1 - SRC 2
correlation
seconds

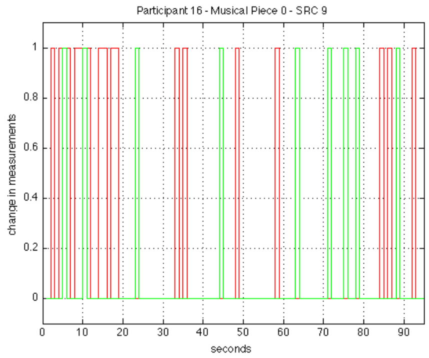

Participant 14 - Musical Piece 2 - SRC 4
change in measurements
seconds

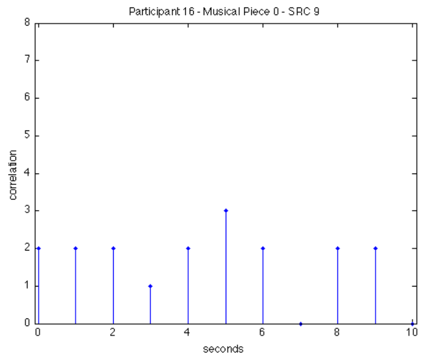

Participant 14 - Musical Piece 2 - SRC 4
correlation
seconds

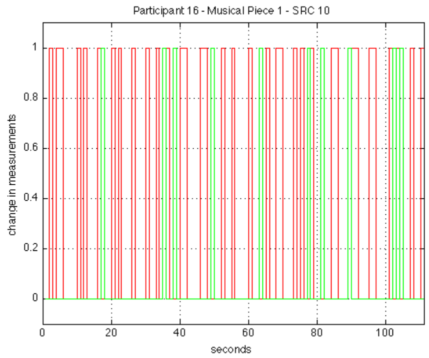

Participant 14 - Musical Piece 3 - SRC 0
change in measurements
seconds

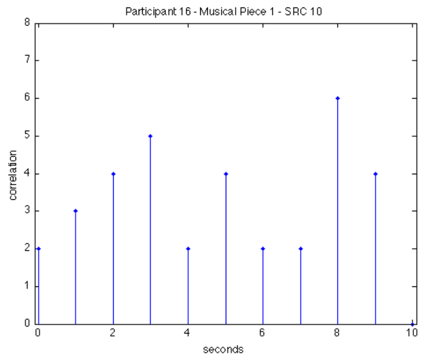

Participant 14 - Musical Piece 3 - SRC 0
correlation
seconds

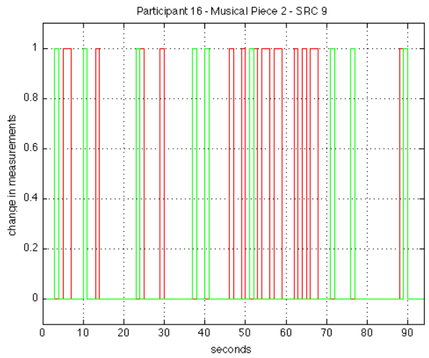

Participant 15 - Musical Piece 0 - SRC 5
change in measurements
seconds
correlation
Participant 15 - Musical Piece 1 - SRC 18
Participant 15 - Musical Piece 2 - SRC 26
Participant 15 - Musical Piece 3 - SRC 20

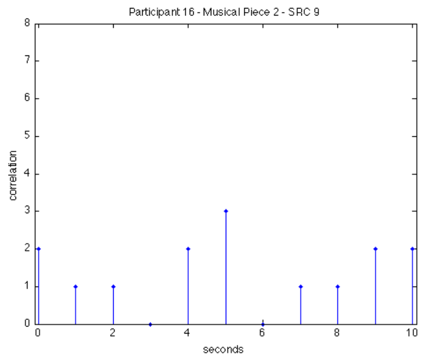

Participant 16 - Musical Piece 0 - SRC 9
change in measurements
seconds

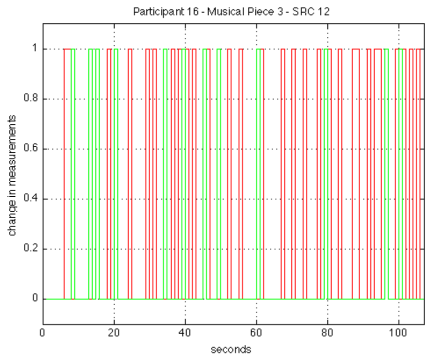

Participant 16 - Musical Piece 0 - SRC 9
correlation
seconds

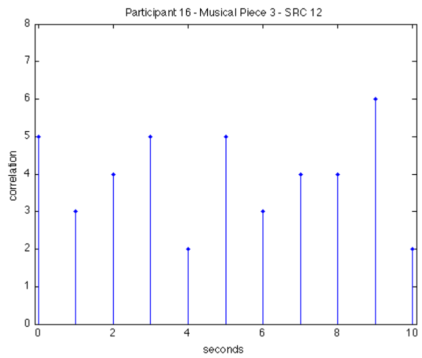

Participant 16 - Musical Piece 1 - SRC 10
change in measurements
seconds

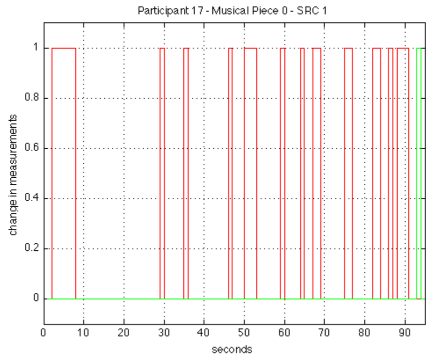

Participant 16 - Musical Piece 1 - SRC 10
correlation
seconds

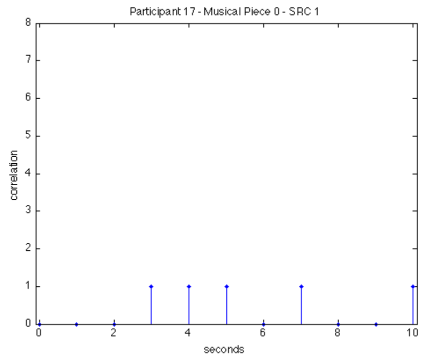

Participant 16 - Musical Piece 2 - SRC 9
change in measurements
seconds

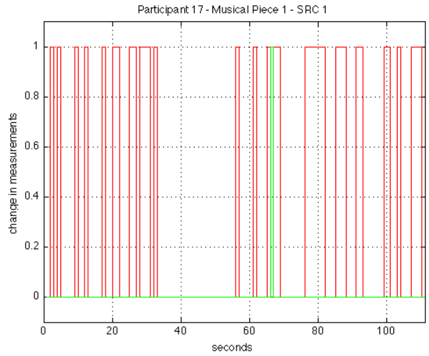

Participant 16 - Musical Piece 2 - SRC 9
correlation
seconds

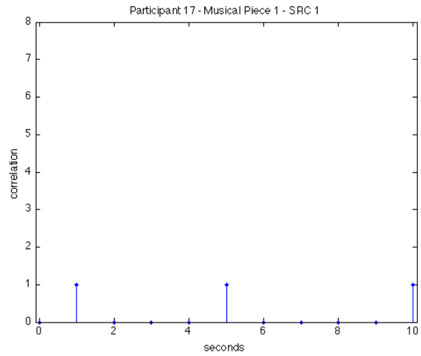

Participant 16 - Musical Piece 3 - SRC 12
change in measurements
seconds

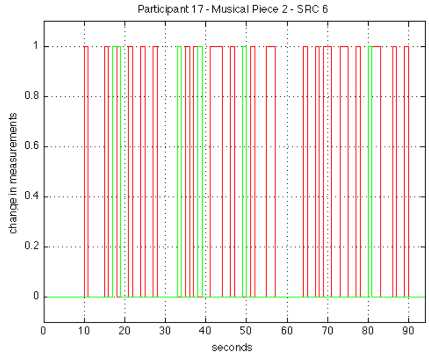

Participant 16 - Musical Piece 3 - SRC 12
correlation
seconds

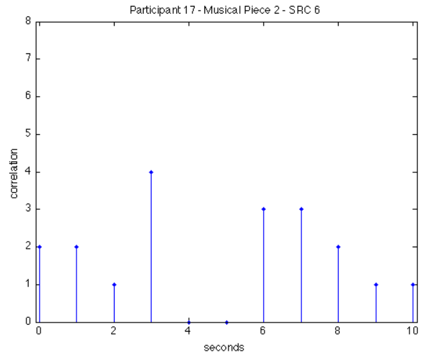

Participant 17 - Musical Piece 0 - SRC 1
change in measurements
seconds

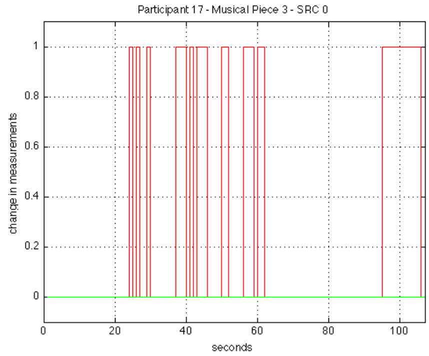

Participant 17 - Musical Piece 0 - SRC 1
correlation
seconds

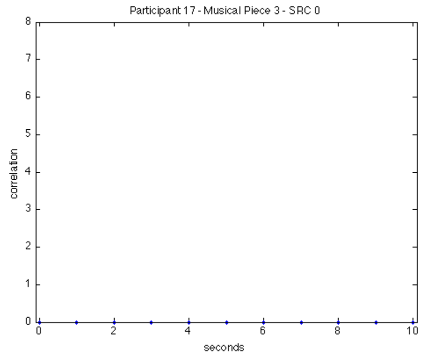

Participant 17 - Musical Piece 1 - SRC 1
change in measurements
seconds

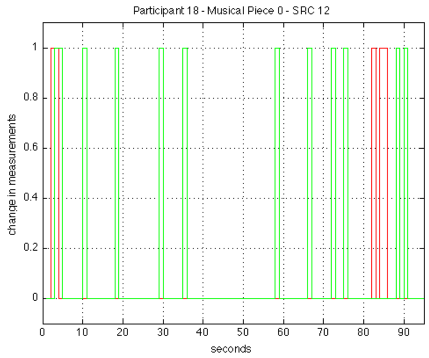

Participant 17 - Musical Piece 1 - SRC 1
correlation
seconds

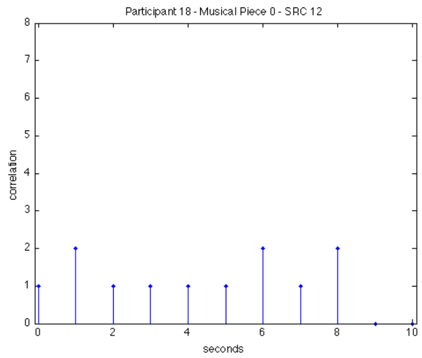

Participant 17 - Musical Piece 2 - SRC 6
change in measurements
seconds

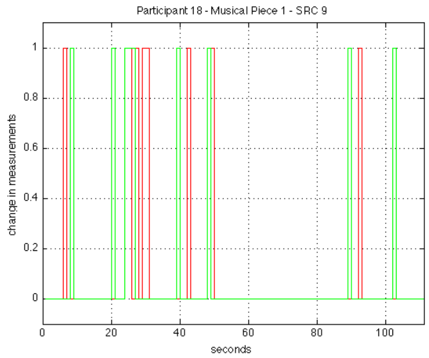

Participant 17 - Musical Piece 2 - SRC 6
correlation
seconds

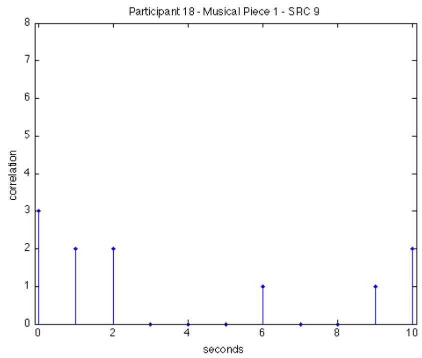

Participant 17 - Musical Piece 3 - SRC 0
change in measurements
seconds

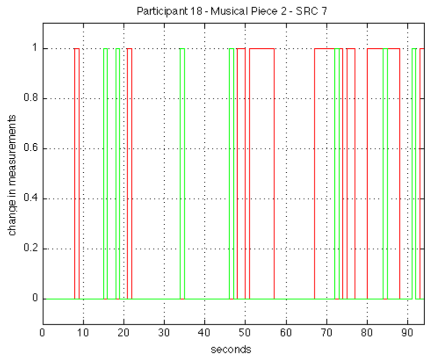

Participant 17 - Musical Piece 3 - SRC 0
correlation
seconds

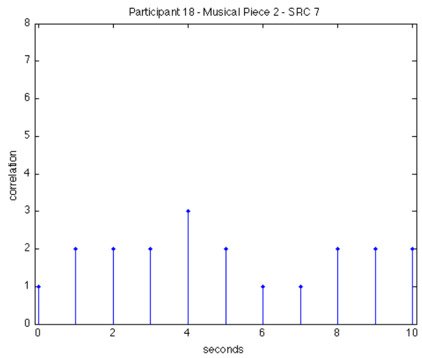

Participant 18 - Musical Piece 0 - SRC 12
change in measurements
seconds

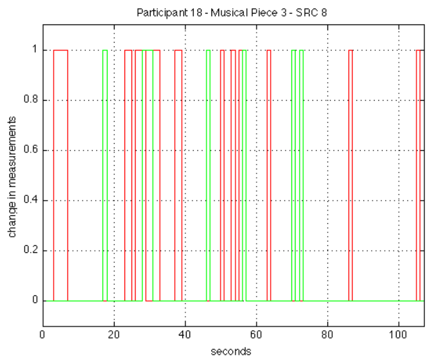

Participant 18 - Musical Piece 0 - SRC 12
correlation
seconds

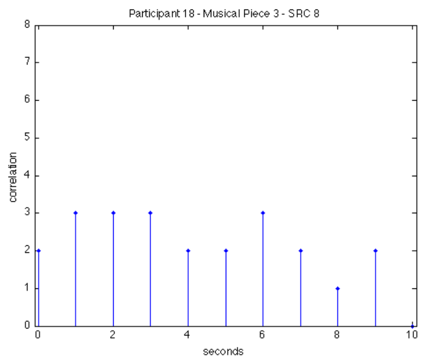

Participant 18 - Musical Piece 1 - SRC 9
change in measurements
seconds

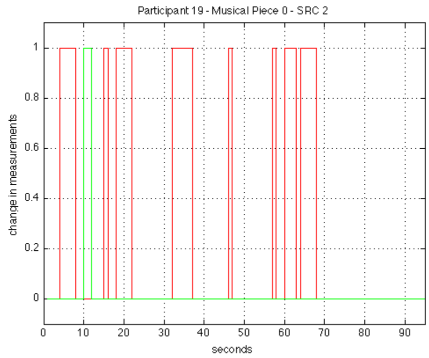

Participant 18 - Musical Piece 1 - SRC 9
correlation
seconds

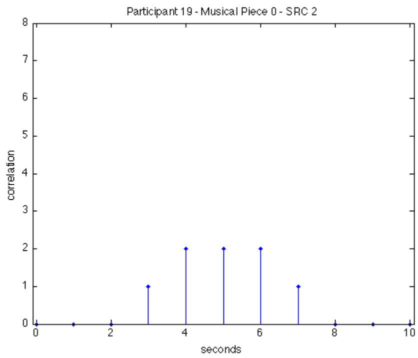

Participant 18 - Musical Piece 2 - SRC 7
change in measurements
seconds

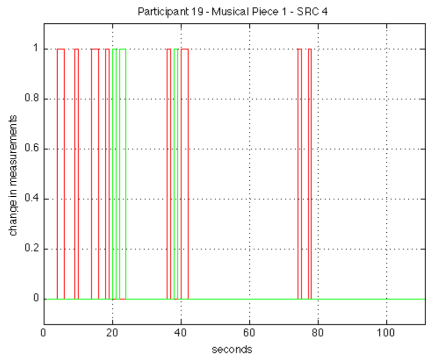

Participant 18 - Musical Piece 2 - SRC 7
correlation
seconds

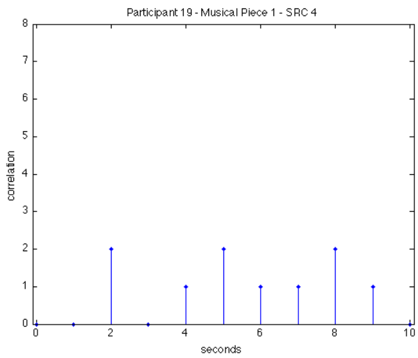

Participant 18 - Musical Piece 3 - SRC 8
change in measurements
seconds

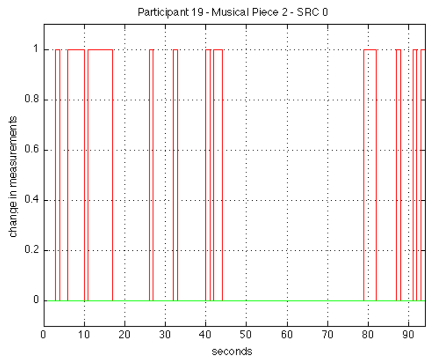

Participant 18 - Musical Piece 3 - SRC 8
correlation
seconds

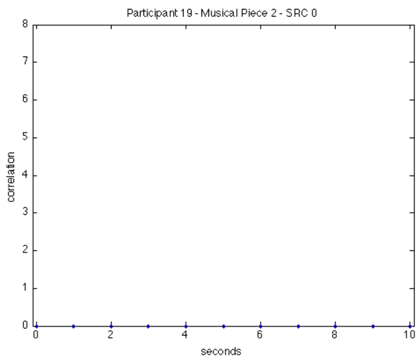

Participant 19 - Musical Piece 0 - SRC 2
change in measurements
seconds

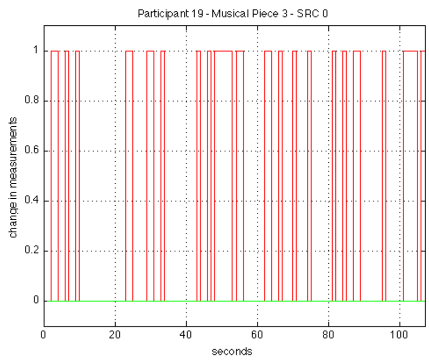

Participant 19 - Musical Piece 0 - SRC 2
correlation
seconds

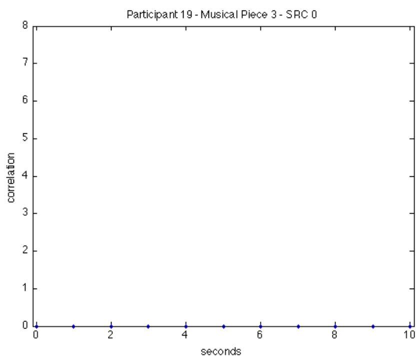

Participant 19 - Musical Piece 1 - SRC 4
change in measurements
seconds

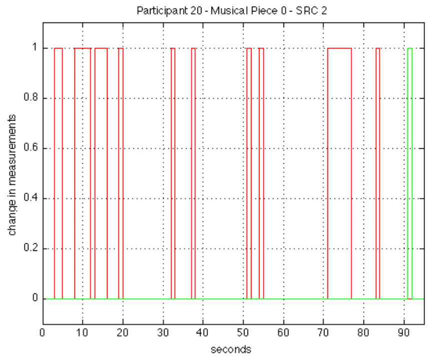

Participant 19 - Musical Piece 1 - SRC 4
correlation
seconds

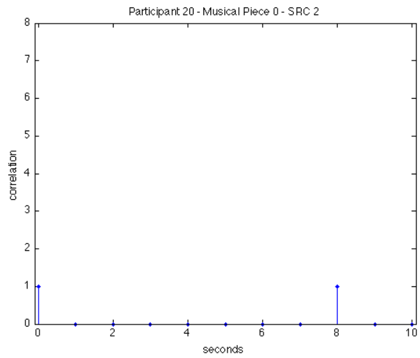

Participant 19 - Musical Piece 2 - SRC 0
change in measurements
seconds

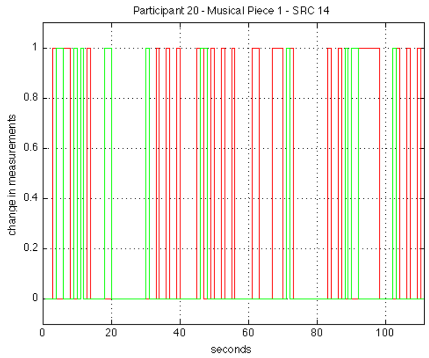

Participant 19 - Musical Piece 2 - SRC 0
correlation
seconds

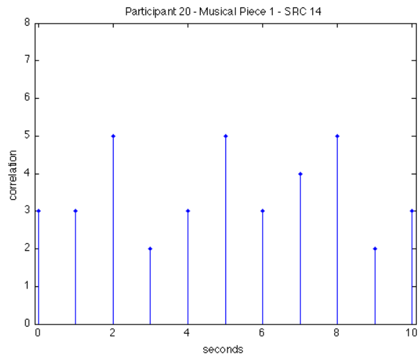

Participant 19 - Musical Piece 3 - SRC 0
change in measurements
seconds

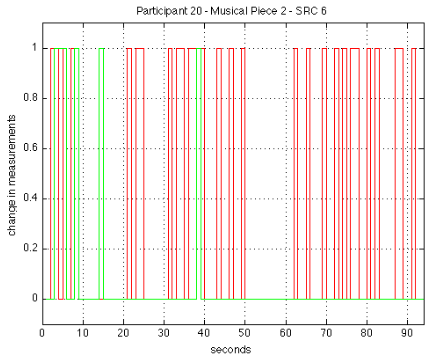

Participant 19 - Musical Piece 3 - SRC 0
correlation
seconds

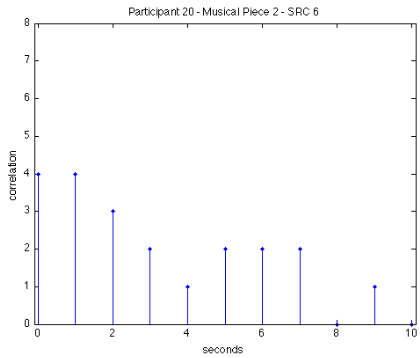

Participant 20 - Musical Piece 0 - SRC 2
change in measurements
seconds

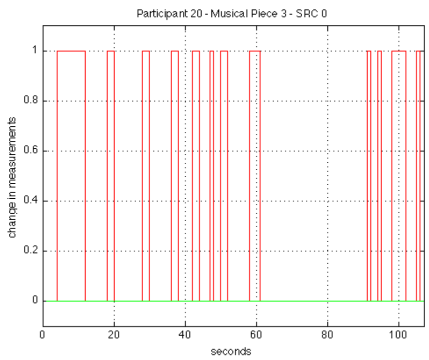

Participant 20 - Musical Piece 0 - SRC 2
correlation
seconds

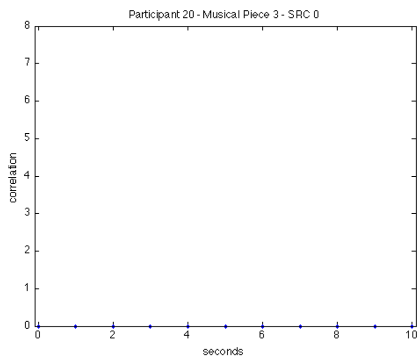

Participant 20 - Musical Piece 1 - SRC 14
change in measurements
seconds

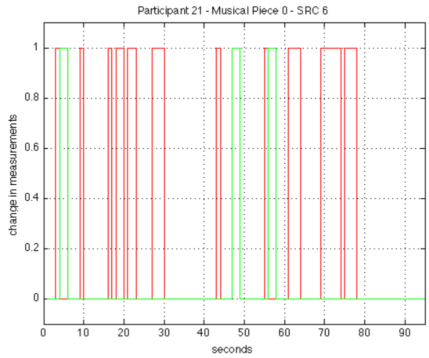
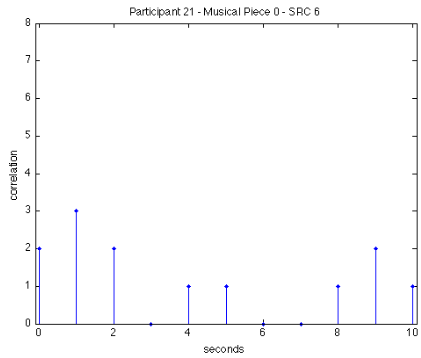
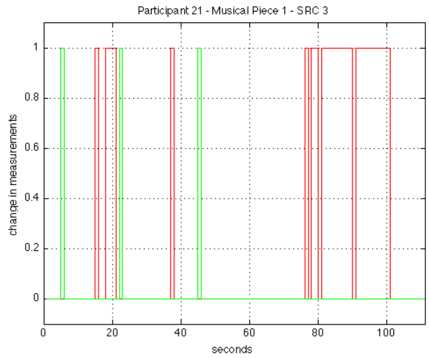
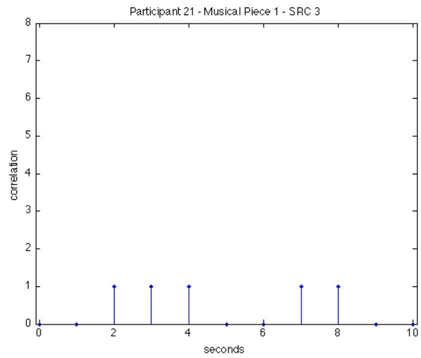
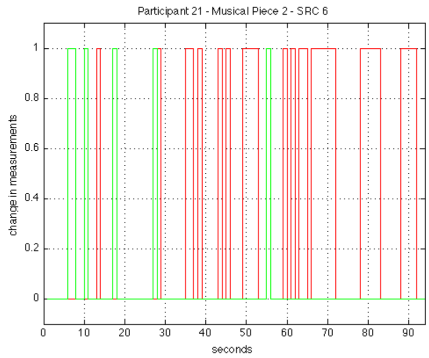
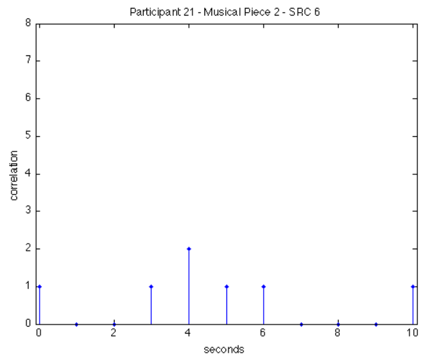
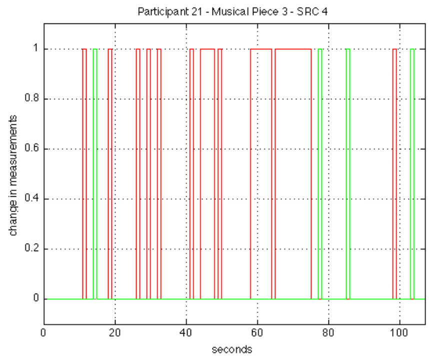
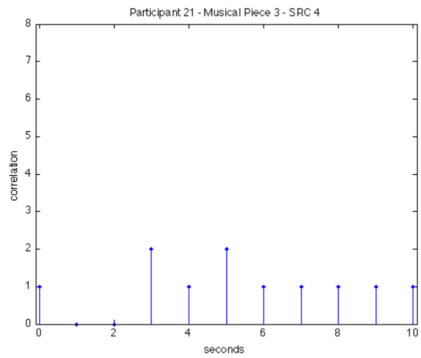

Participant 20 - Musical Piece 1 - SRC 14
correlation
seconds

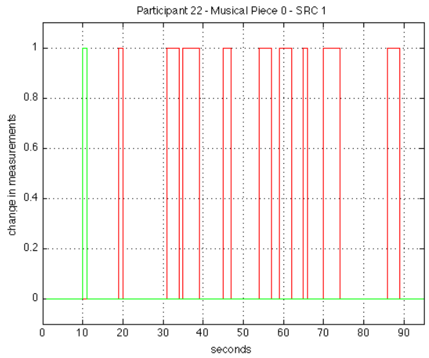

Participant 20 - Musical Piece 2 - SRC 6
change in measurements
seconds

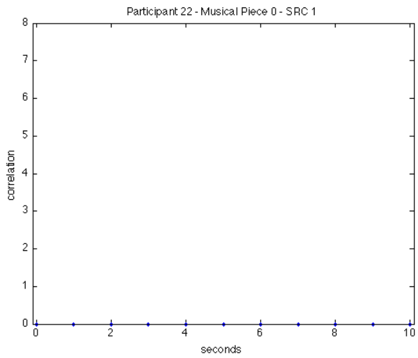

Participant 20 - Musical Piece 2 - SRC 6
correlation
seconds

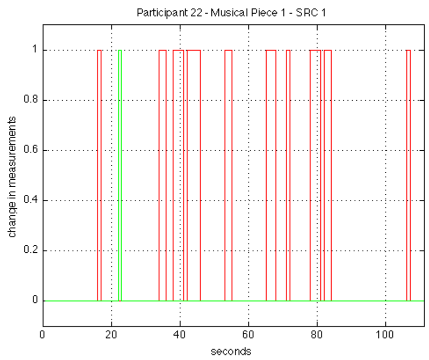

Participant 20 - Musical Piece 3 - SRC 0
change in measurements
seconds

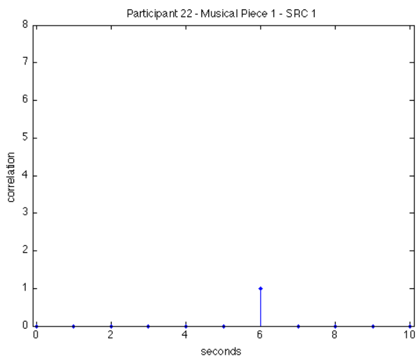

Participant 20 - Musical Piece 3 - SRC 0
correlation
seconds

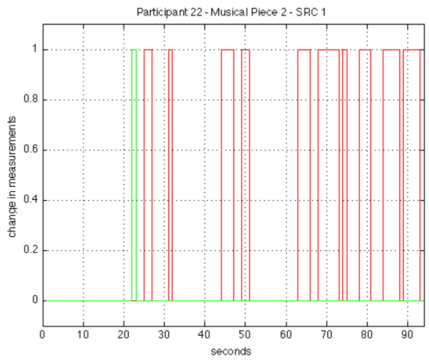

Participant 21 - Musical Piece 0 - SRC 6
change in measurements
seconds

Participant 21 - Musical Piece 0 - SRC 6
correlation
seconds

Participant 21 - Musical Piece 1 - SRC 3
change in measurements
seconds

Participant 21 - Musical Piece 1 - SRC 3
correlation
seconds

Participant 21 - Musical Piece 2 - SRC 6
change in measurements
seconds

Participant 21 - Musical Piece 2 - SRC 6
correlation
seconds

Participant 21 - Musical Piece 3 - SRC 4
change in measurements
seconds

Participant 21 - Musical Piece 3 - SRC 4
correlation
seconds

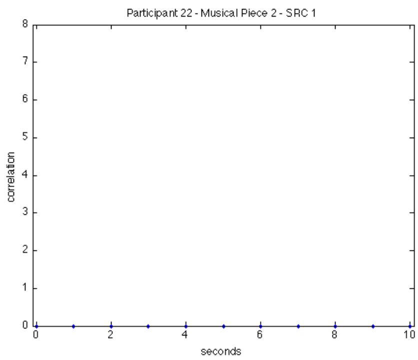

Participant 22 - Musical Piece 0 - SRC 1
change in measurements
seconds

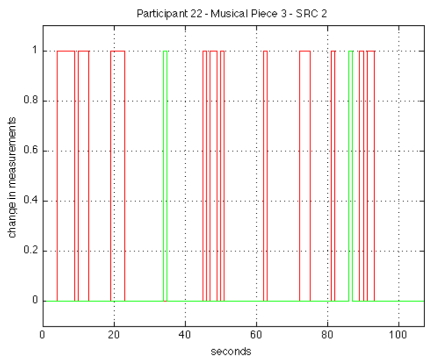

Participant 22 - Musical Piece 0 - SRC 1
correlation
seconds

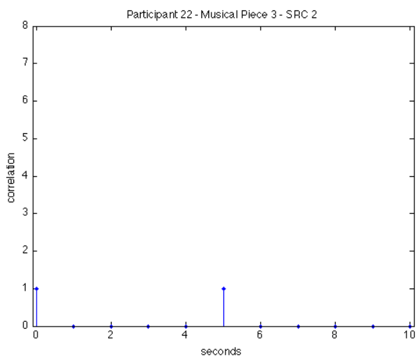

Participant 22 - Musical Piece 1 - SRC 1
change in measurements
seconds

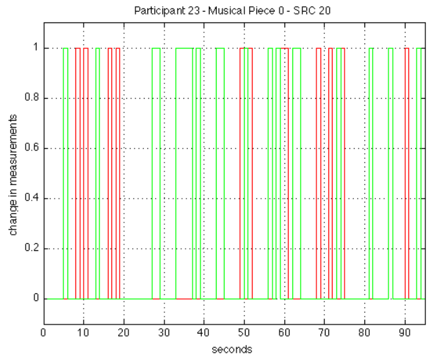

Participant 22 - Musical Piece 1 - SRC 1
correlation
seconds

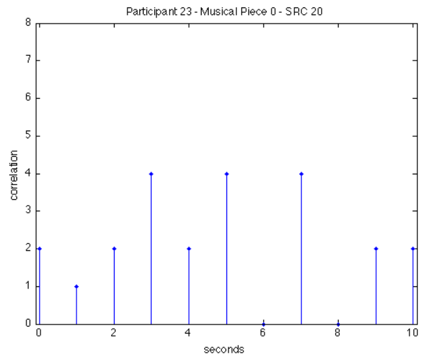

Participant 22 - Musical Piece 2 - SRC 1
change in measurements
seconds

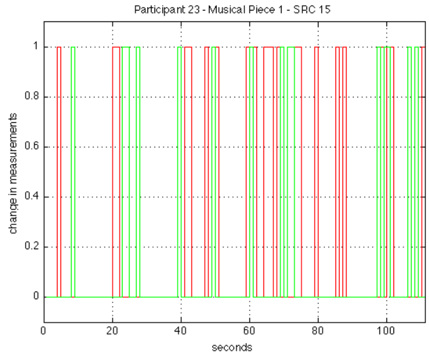

Participant 22 - Musical Piece 2 - SRC 1
correlation
seconds

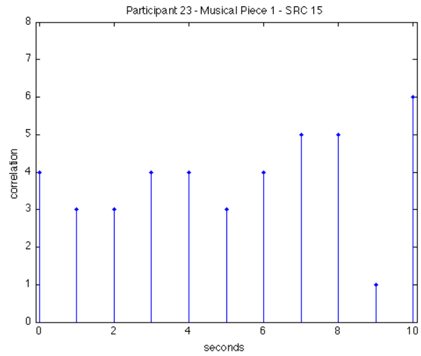

Participant 22 - Musical Piece 3 - SRC 2
change in measurements
seconds

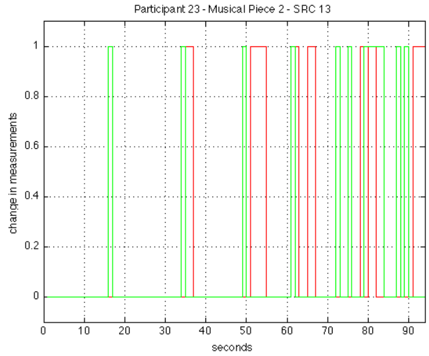

Participant 22 - Musical Piece 3 - SRC 2
correlation
seconds

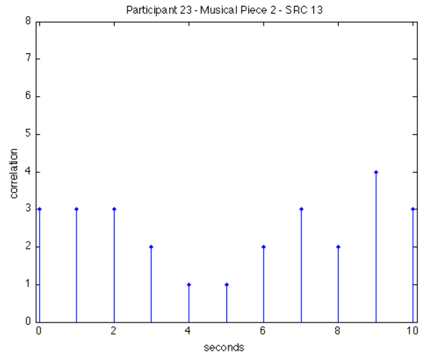

Participant 23 - Musical Piece 0 - SRC 20
change in measurements
seconds

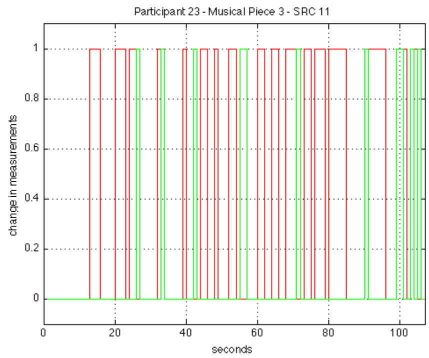

Participant 23 - Musical Piece 0 - SRC 20
correlation
seconds

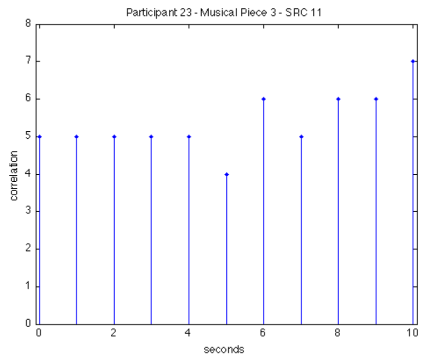

Participant 23 - Musical Piece 1 - SRC 15
change in measurements
seconds

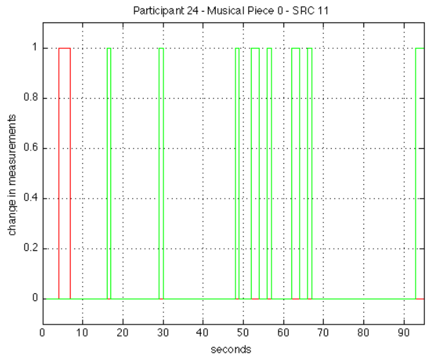

Participant 23 - Musical Piece 1 - SRC 15
correlation
seconds

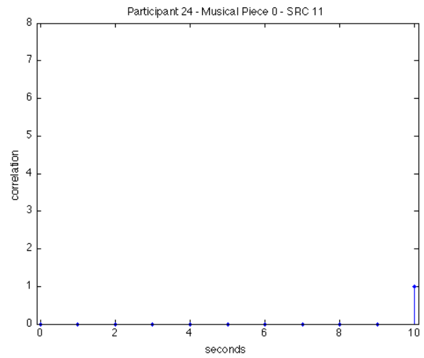

Participant 23 - Musical Piece 2 - SRC 13
change in measurements
seconds

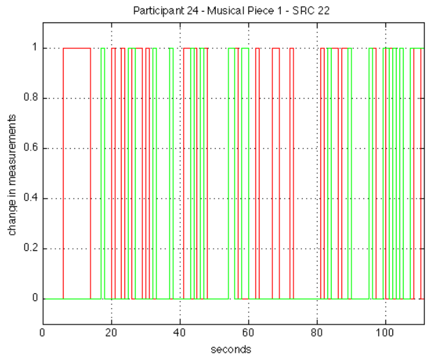

Participant 23 - Musical Piece 2 - SRC 13
correlation
seconds

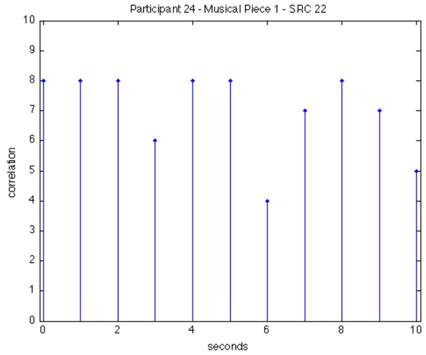

Participant 23 - Musical Piece 3 - SRC 11
change in measurements
seconds

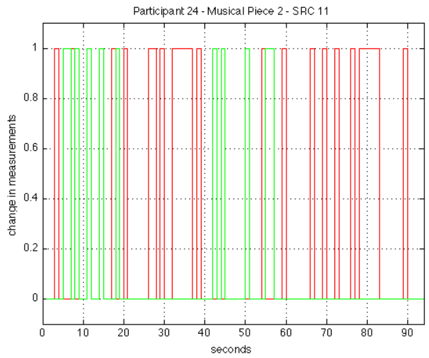

Participant 23 - Musical Piece 3 - SRC 11
correlation
seconds

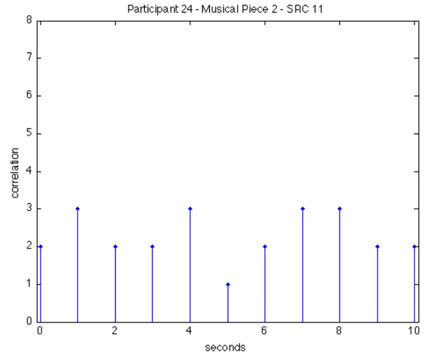

Participant 24 - Musical Piece 0 - SRC 11
change in measurements
seconds

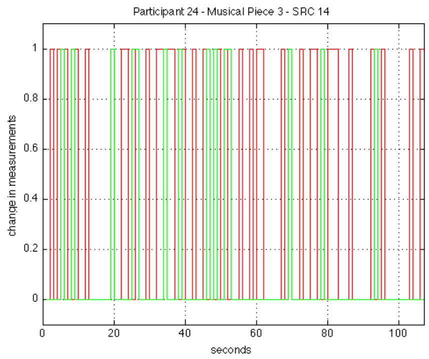

Participant 24 - Musical Piece 0 - SRC 11
correlation
seconds

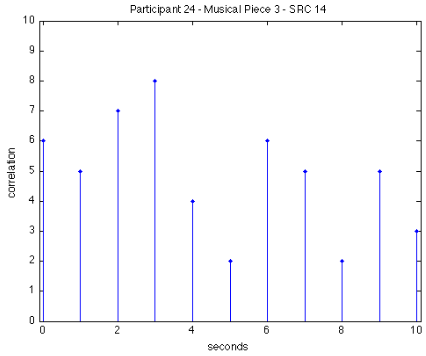

Participant 24 - Musical Piece 1 - SRC 22
change in measurements
seconds

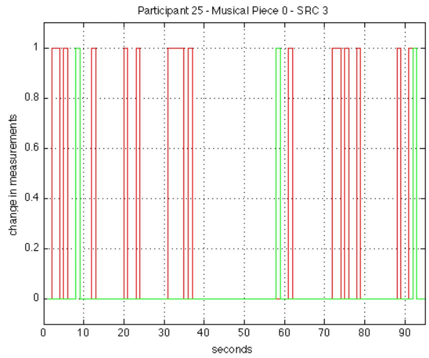

Participant 24 - Musical Piece 1 - SRC 22
correlation
seconds

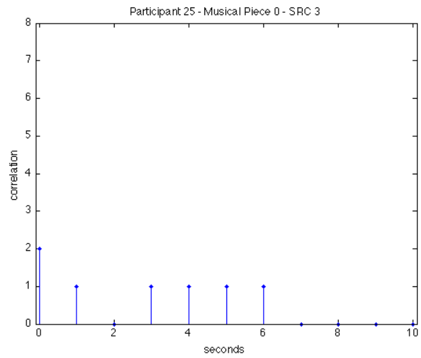

Participant 24 - Musical Piece 2 - SRC 11
change in measurements
seconds

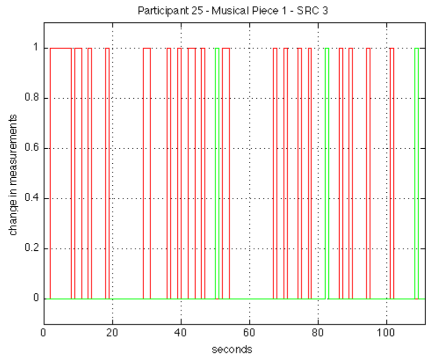

Participant 24 - Musical Piece 2 - SRC 11
correlation
seconds

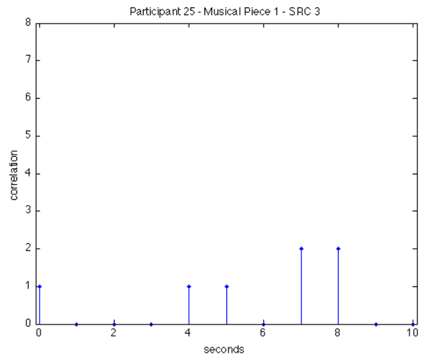

Participant 24 - Musical Piece 3 - SRC 14
change in measurements
seconds

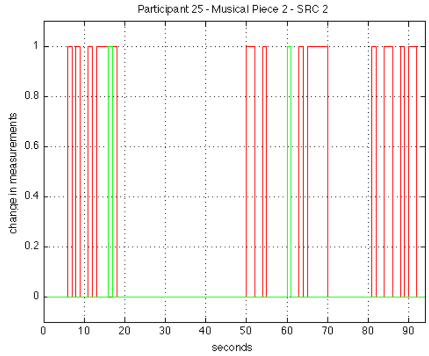

Participant 24 - Musical Piece 3 - SRC 14
correlation
seconds

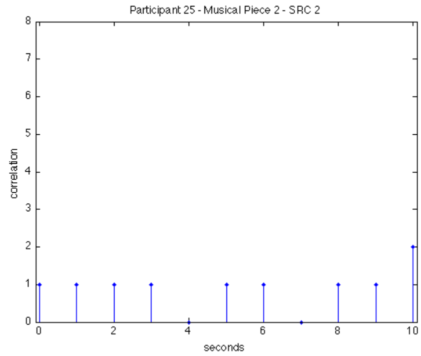

Participant 25 - Musical Piece 0 - SRC 3
change in measurements
seconds

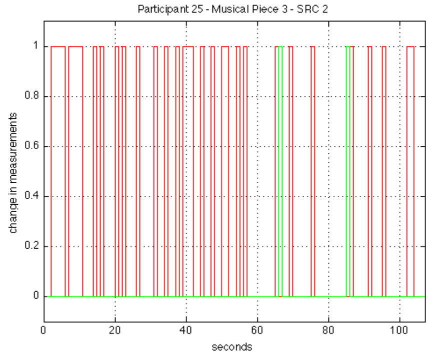

Participant 25 - Musical Piece 0 - SRC 3
correlation
seconds

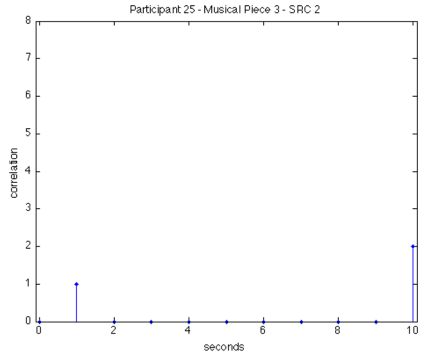

Participant 25 - Musical Piece 1 - SRC 3
change in measurements
seconds

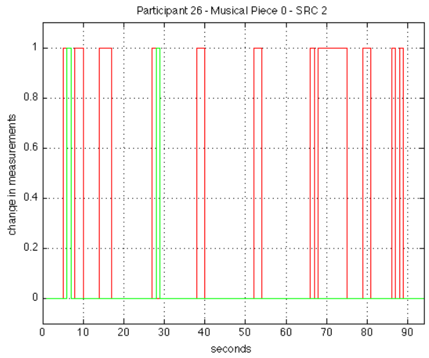

Participant 25 - Musical Piece 1 - SRC 3
correlation
seconds

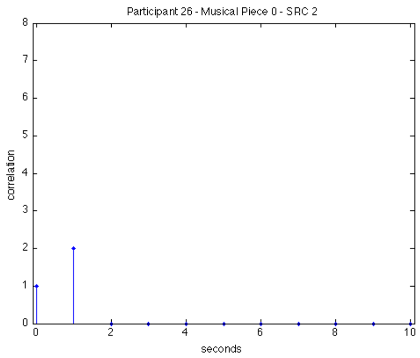

Participant 25 - Musical Piece 2 - SRC 2
change in measurements
seconds

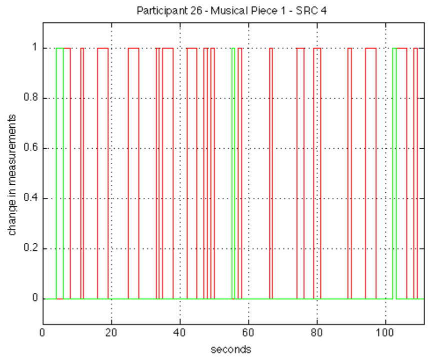

Participant 25 - Musical Piece 2 - SRC 2
correlation
seconds

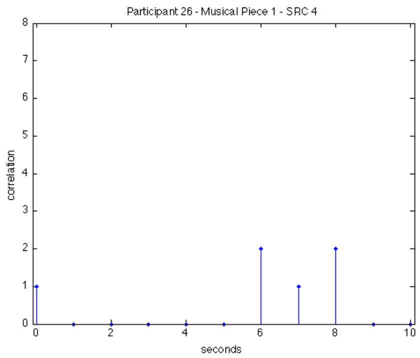

Participant 25 - Musical Piece 3 - SRC 2
change in measurements
seconds

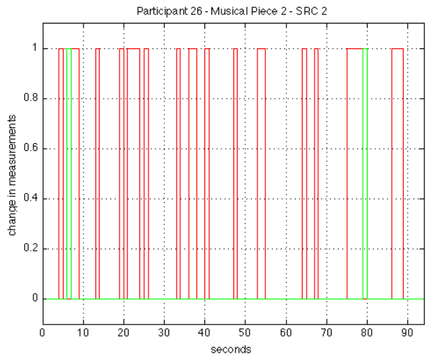

Participant 25 - Musical Piece 3 - SRC 2
correlation
seconds

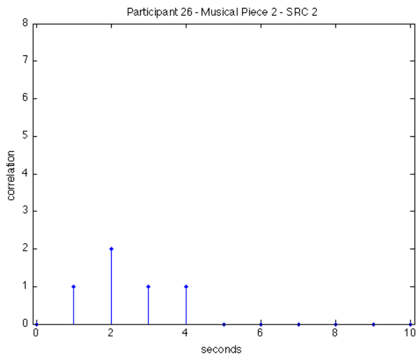

Participant 26 - Musical Piece 0 - SRC 2
change in measurements
seconds

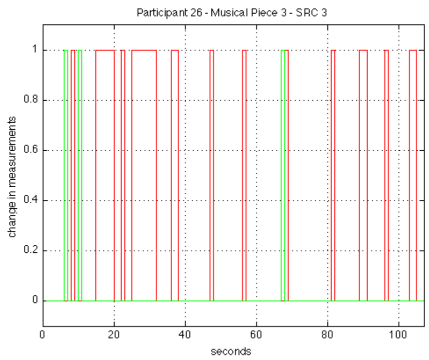

Participant 26 - Musical Piece 0 - SRC 2
correlation
seconds

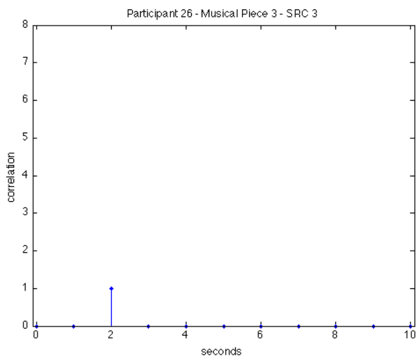

Participant 26 - Musical Piece 1 - SRC 4
change in measurements
seconds

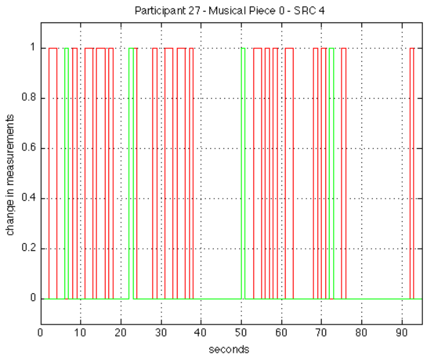

Participant 26 - Musical Piece 1 - SRC 4
correlation
seconds

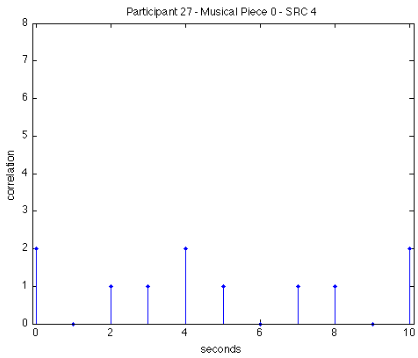

Participant 26 - Musical Piece 2 - SRC 2
change in measurements
seconds

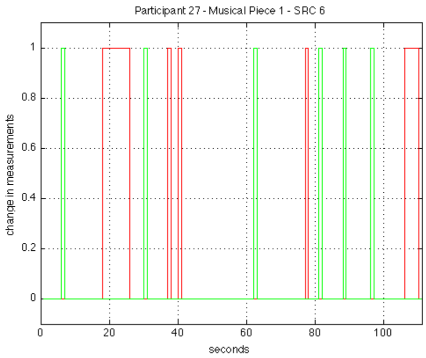

Participant 26 - Musical Piece 2 - SRC 2
correlation
seconds

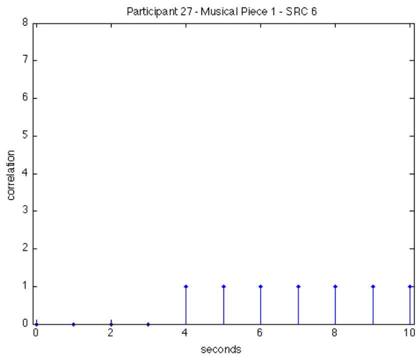

Participant 26 - Musical Piece 3 - SRC 3
change in measurements
seconds

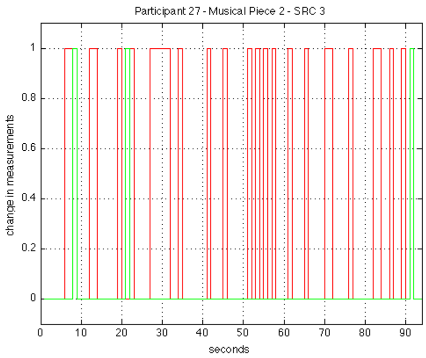

Participant 26 - Musical Piece 3 - SRC 3
correlation
seconds

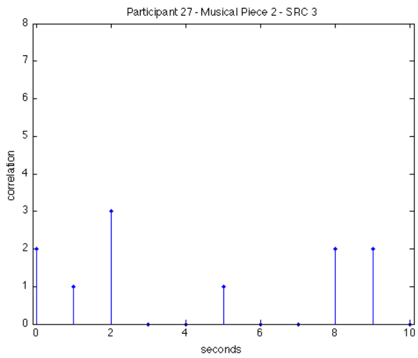

Participant 27 - Musical Piece 0 - SRC 4
change in measurements
seconds

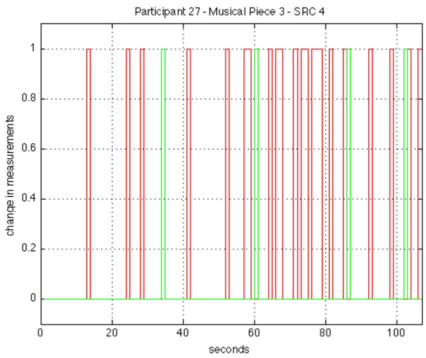

Participant 27 - Musical Piece 0 - SRC 4
correlation
seconds

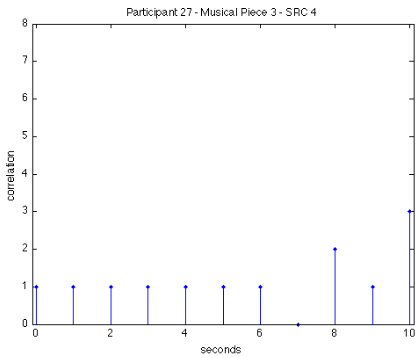

Participant 27 - Musical Piece 1 - SRC 6
change in measurements
seconds

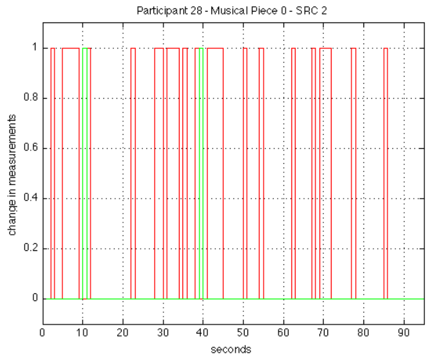

Participant 27 - Musical Piece 1 - SRC 6
correlation
seconds

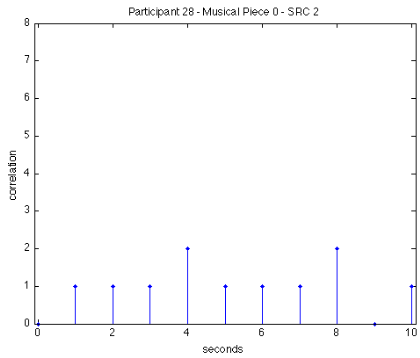

Participant 27 - Musical Piece 2 - SRC 3
change in measurements
seconds

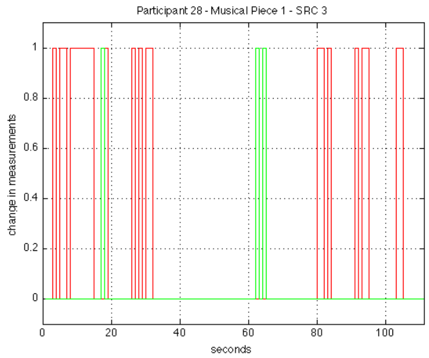

Participant 27 - Musical Piece 2 - SRC 3
correlation
seconds

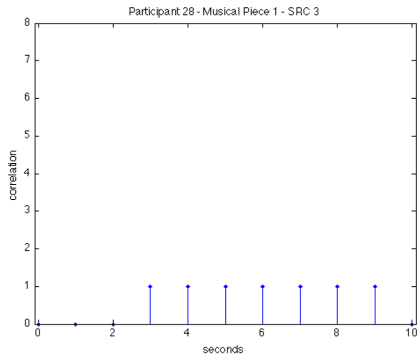

Participant 27 - Musical Piece 3 - SRC 4
change in measurements
seconds

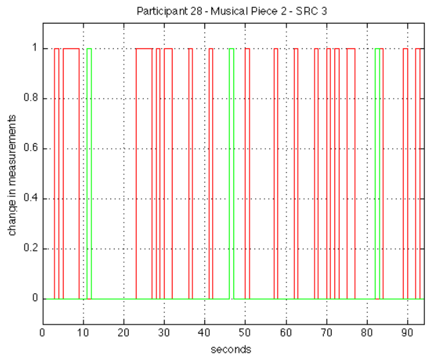

Participant 27 - Musical Piece 3 - SRC 4
correlation
seconds

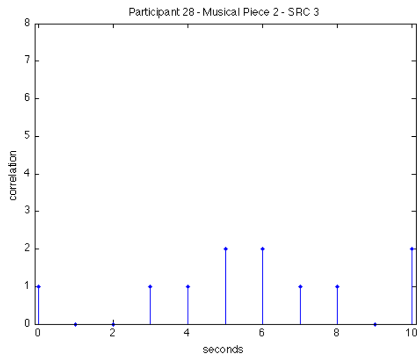

Participant 28 - Musical Piece 0 - SRC 2
change in measurements
seconds

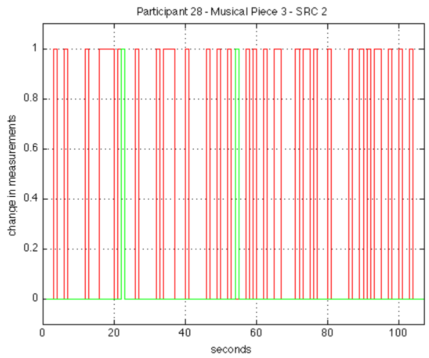

Participant 28 - Musical Piece 0 - SRC 2
correlation
seconds

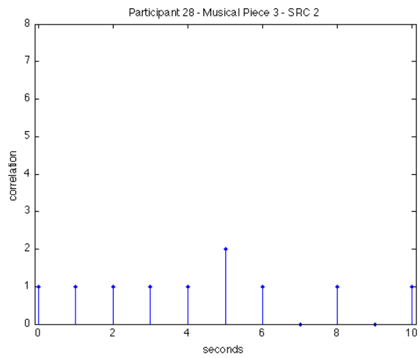

Participant 28 - Musical Piece 1 - SRC 3
change in measurements
seconds

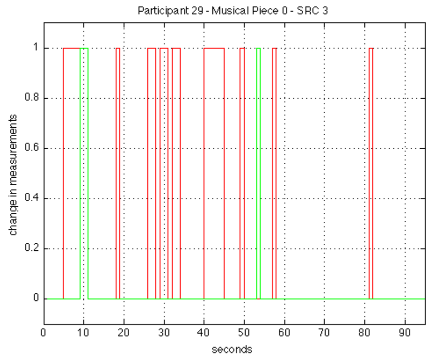

Participant 28 - Musical Piece 1 - SRC 3
correlation
seconds

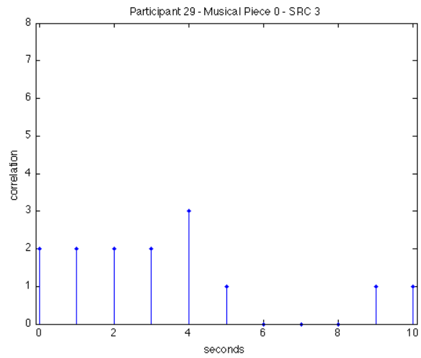

Participant 28 - Musical Piece 2 - SRC 3
change in measurements
seconds

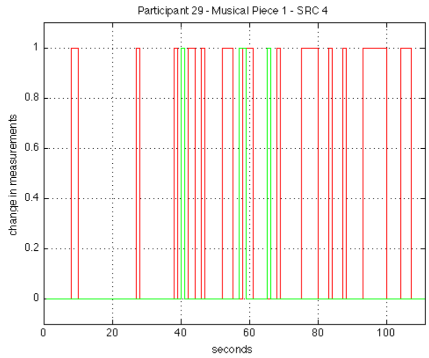

Participant 28 - Musical Piece 2 - SRC 3
correlation
seconds

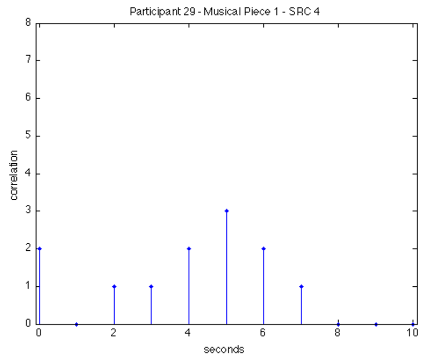

Participant 28 - Musical Piece 3 - SRC 2
change in measurements
seconds

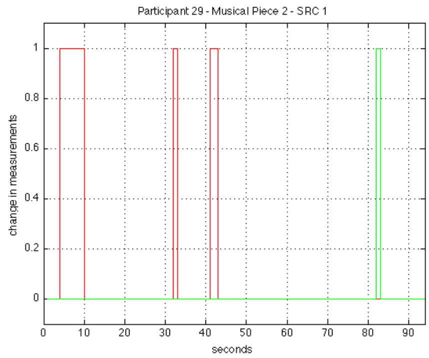

Participant 28 - Musical Piece 3 - SRC 2
correlation
seconds

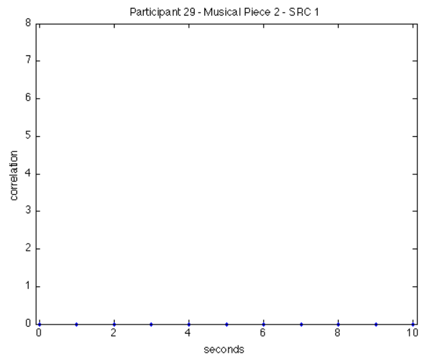

Participant 29 - Musical Piece 0 - SRC 3
change in measurements
seconds
0 10 20 30 40 50 60 70 80 90
0 0.2 0.4 0.6 0.8 1

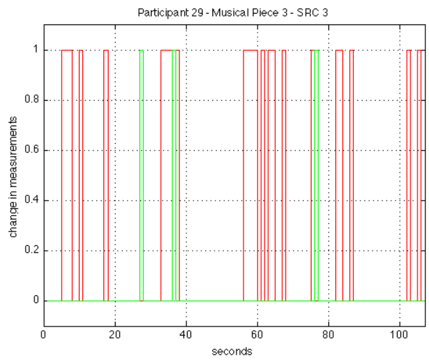

Participant 29 - Musical Piece 0 - SRC 3
correlation
seconds
0 2 4 6 8 10
0 1 2 3 4 5 6 7 8

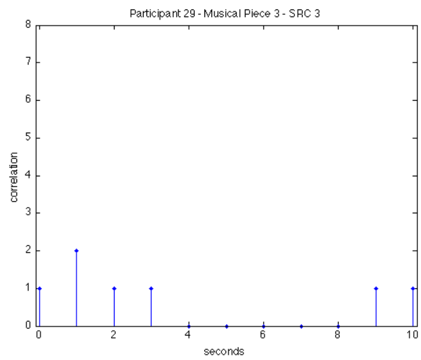

Participant 29 - Musical Piece 1 - SRC 4
change in measurements
seconds
0 20 40 60 80 100
0 0.2 0.4 0.6 0.8 1

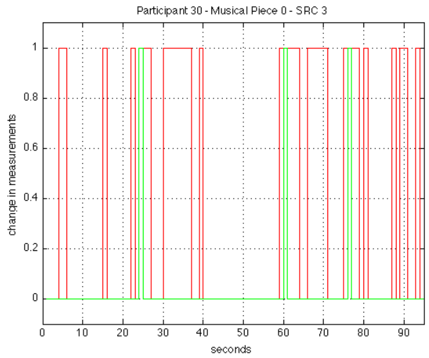

Participant 29 - Musical Piece 1 - SRC 4
correlation
seconds
0 2 4 6 8 10
0 1 2 3 4 5 6 7 8

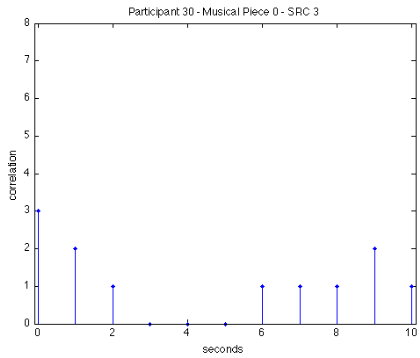

Participant 29 - Musical Piece 2 - SRC 1
change in measurements
seconds
0 10 20 30 40 50 60 70 80 90
0 0.2 0.4 0.6 0.8 1

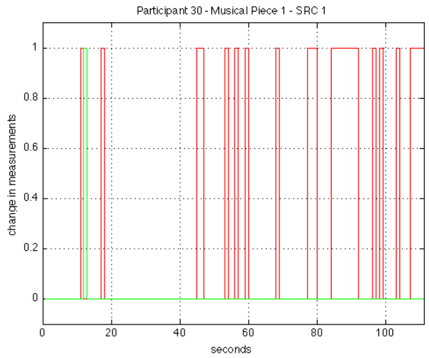

Participant 29 - Musical Piece 2 - SRC 1
correlation
seconds
0 2 4 6 8 10
0 1 2 3 4 5 6 7 8

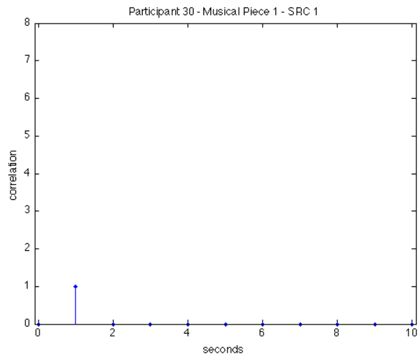

Participant 29 - Musical Piece 3 - SRC 3
change in measurements
seconds
0 20 40 60 80 100
0 0.2 0.4 0.6 0.8 1

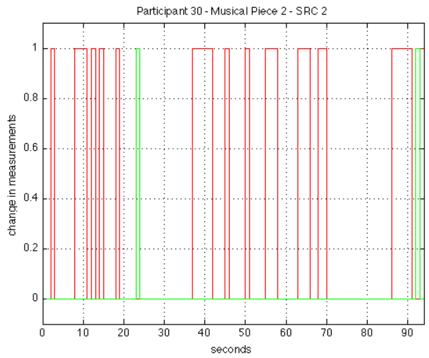

Participant 29 - Musical Piece 3 - SRC 3
correlation
seconds
0 2 4 6 8 10
0 1 2 3 4 5 6 7 8

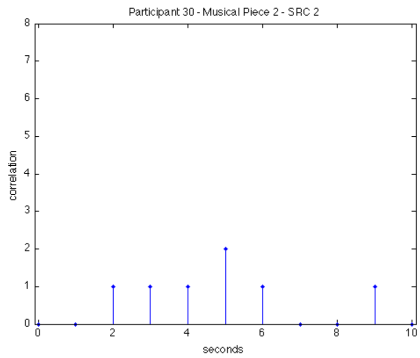

Participant 30 - Musical Piece 0 - SRC 3
change in measurements
seconds

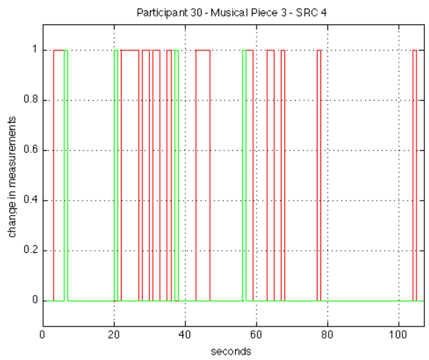

Participant 30 - Musical Piece 0 - SRC 3
correlation
seconds

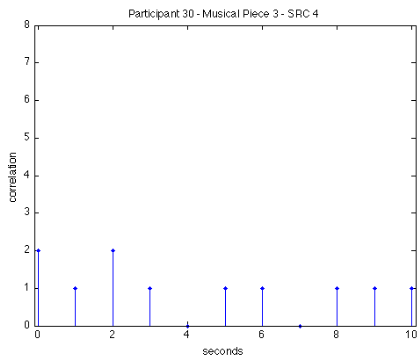

Participant 30 - Musical Piece 1 - SRC 1
change in measurements
seconds

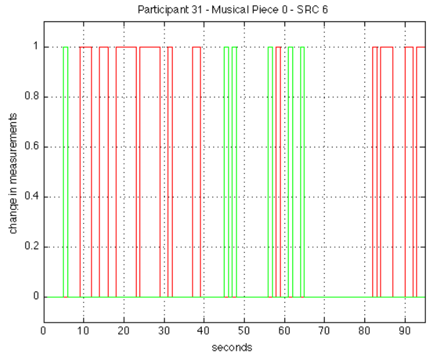

Participant 30 - Musical Piece 1 - SRC 1
correlation
seconds

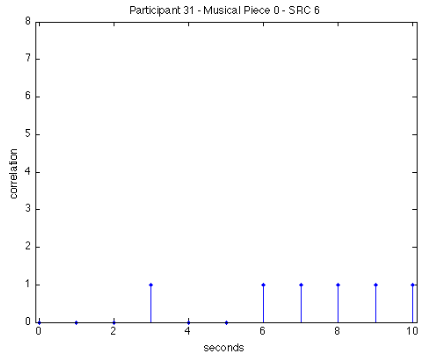

Participant 30 - Musical Piece 2 - SRC 2
change in measurements
seconds

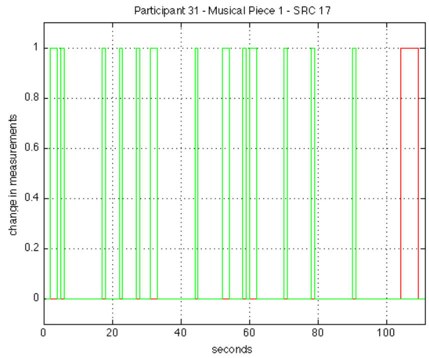

Participant 30 - Musical Piece 2 - SRC 2
correlation
seconds

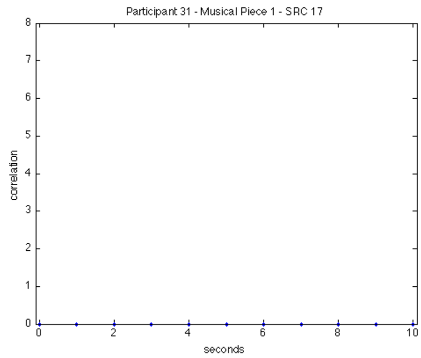

Participant 30 - Musical Piece 3 - SRC 4
change in measurements
seconds

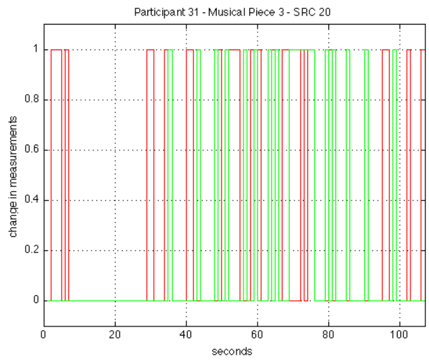

Participant 30 - Musical Piece 3 - SRC 4
correlation
seconds

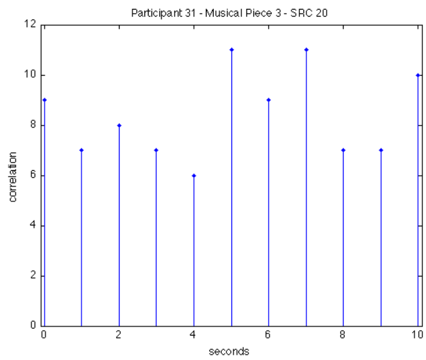

Participant 31 - Musical Piece 0 - SRC 6
change in measurements
seconds

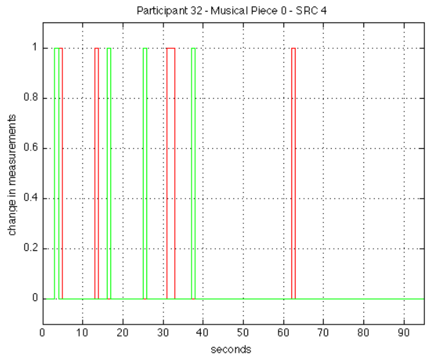

Participant 31 - Musical Piece 0 - SRC 6
correlation
seconds

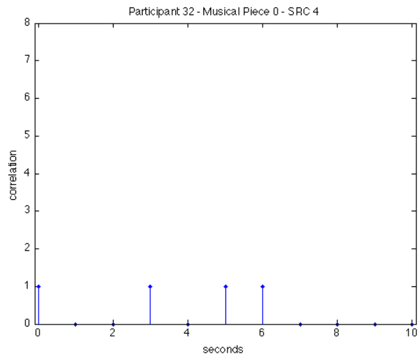

Participant 31 - Musical Piece 1 - SRC 17
change in measurements
seconds

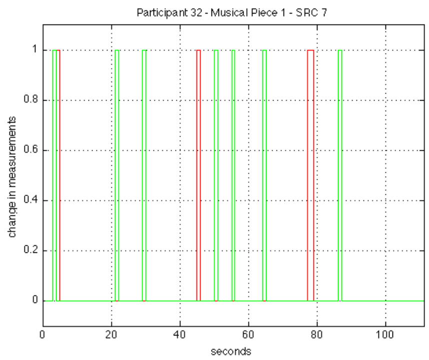

Participant 31 - Musical Piece 1 - SRC 17
correlation
seconds

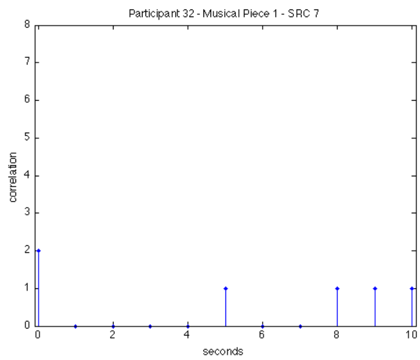

Participant 31 - Musical Piece 3 - SRC 20
change in measurements
seconds

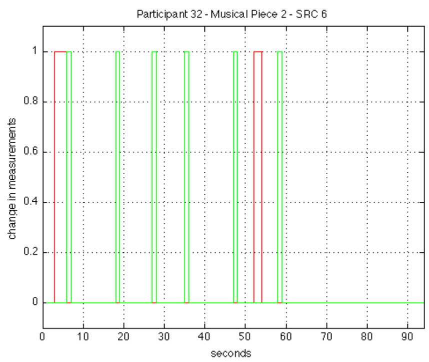

Participant 31 - Musical Piece 3 - SRC 20
correlation
seconds

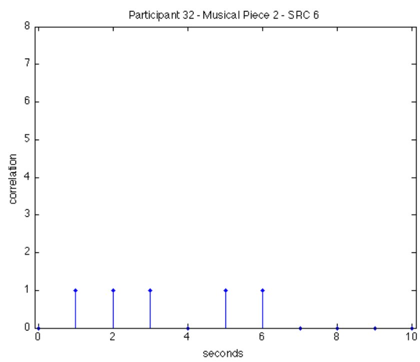

Participant 32 - Musical Piece 0 - SRC 4
change in measurements
seconds

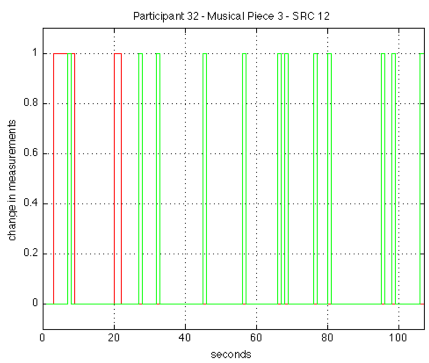

Participant 32 - Musical Piece 0 - SRC 4
correlation
seconds

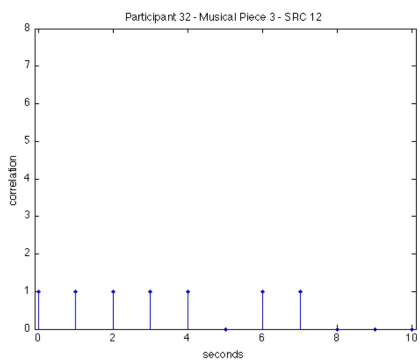

Participant 32 - Musical Piece 1 - SRC 7
change in measurements
seconds

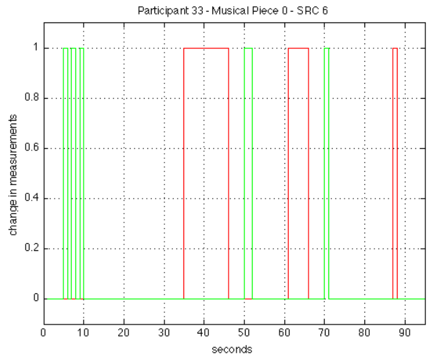

Participant 32 - Musical Piece 1 - SRC 7
correlation
seconds

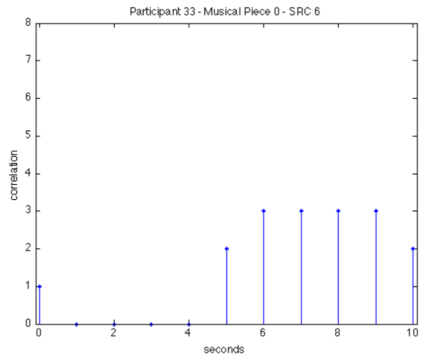

Participant 32 - Musical Piece 2 - SRC 6
change in measurements
seconds

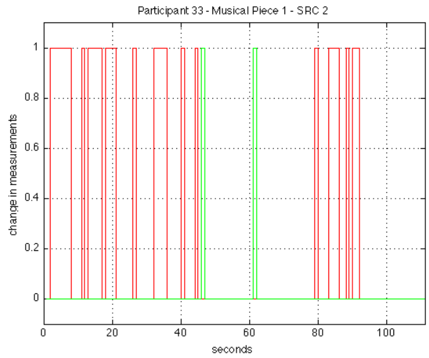

Participant 32 - Musical Piece 2 - SRC 6
correlation
seconds

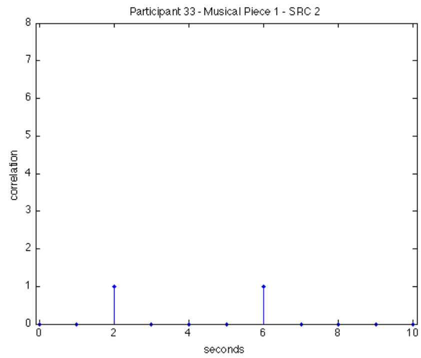

Participant 32 - Musical Piece 3 - SRC 12
change in measurements
seconds

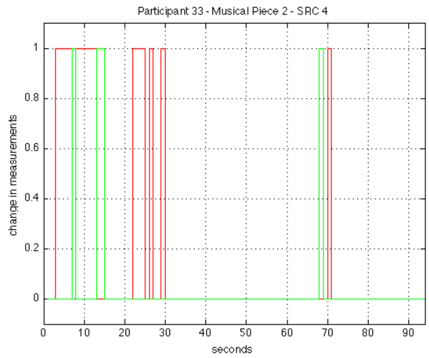

Participant 32 - Musical Piece 3 - SRC 12
correlation
seconds

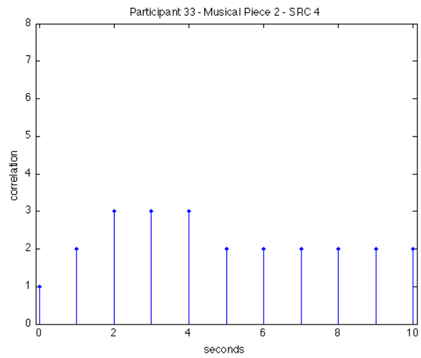

Participant 33 - Musical Piece 0 - SRC 6
change in measurements
seconds

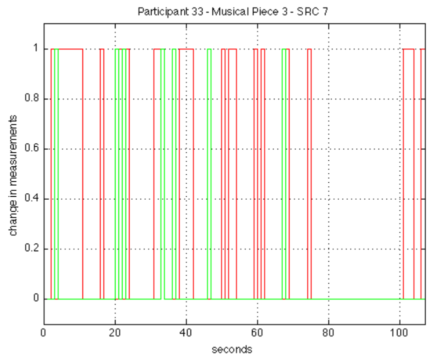

Participant 33 - Musical Piece 0 - SRC 6
correlation
seconds

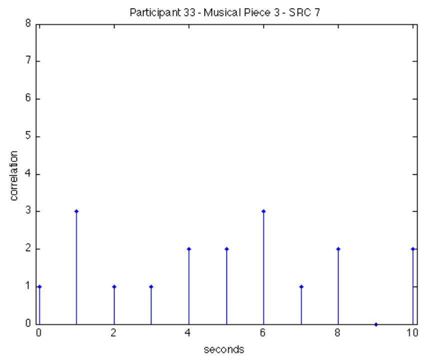

Participant 33 - Musical Piece 1 - SRC 2
change in measurements
seconds

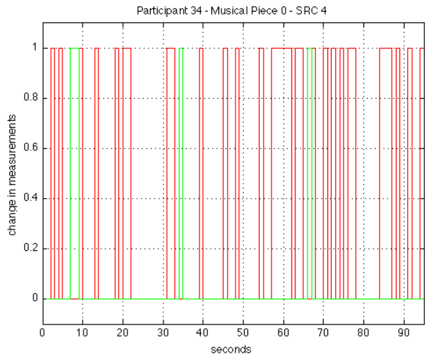

Participant 33 - Musical Piece 1 - SRC 2
correlation
seconds

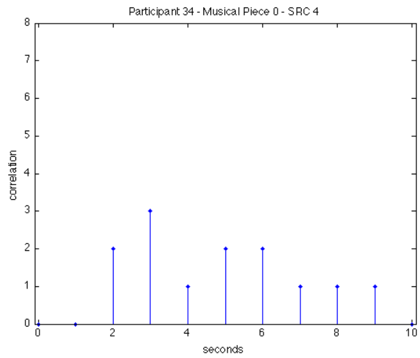

Participant 33 - Musical Piece 2 - SRC 4
change in measurements
seconds

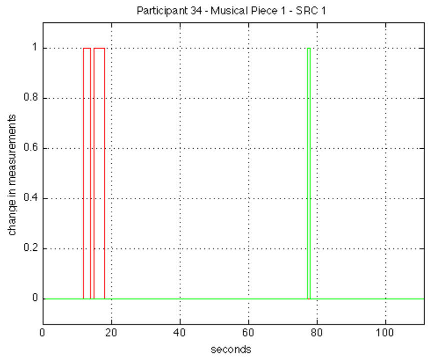

Participant 33 - Musical Piece 2 - SRC 4
correlation
seconds

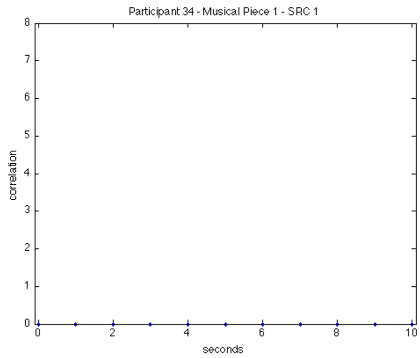

Participant 33 - Musical Piece 3 - SRC 7
change in measurements
seconds

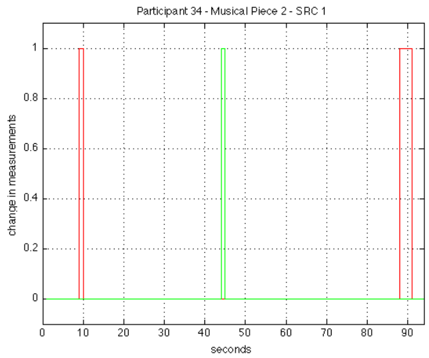

Participant 33 - Musical Piece 3 - SRC 7
correlation
seconds

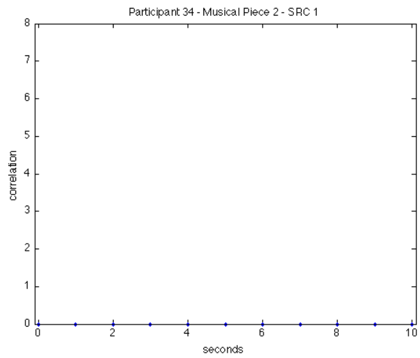

Participant 34 - Musical Piece 0 - SRC 4
change in measurements
seconds

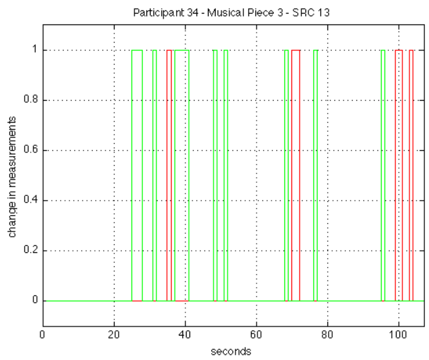

Participant 34 - Musical Piece 0 - SRC 4
correlation
seconds

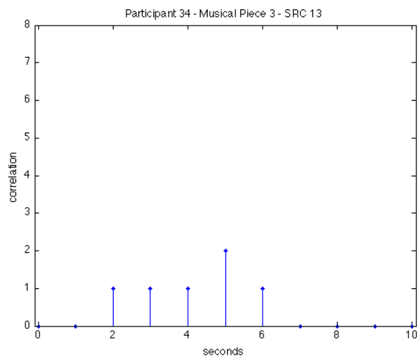

Participant 34 - Musical Piece 1 - SRC 1
change in measurements
seconds

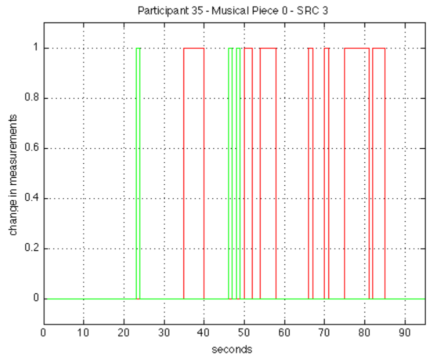

Participant 34 - Musical Piece 1 - SRC 1
correlation
seconds

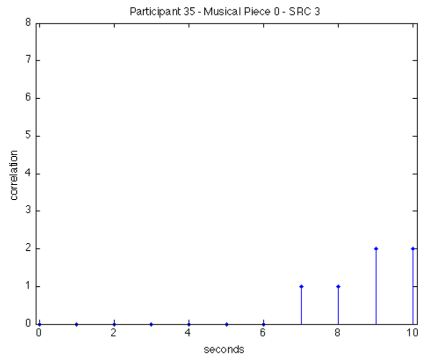

Participant 34 - Musical Piece 2 - SRC 1
change in measurements
seconds

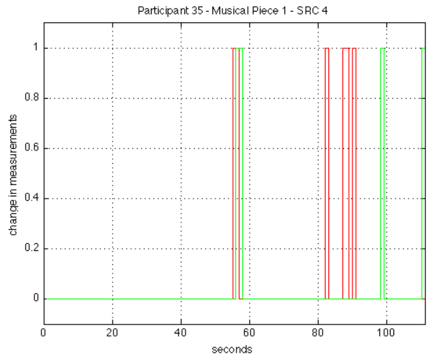

Participant 34 - Musical Piece 2 - SRC 1
correlation
seconds

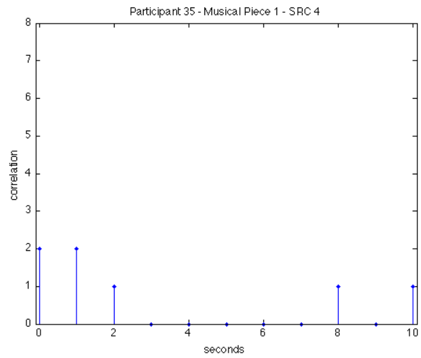

Participant 34 - Musical Piece 3 - SRC 13
change in measurements
seconds

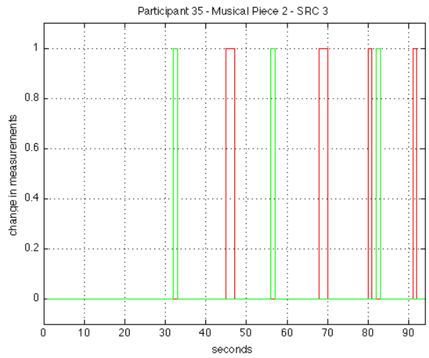

Participant 34 - Musical Piece 3 - SRC 13
correlation
seconds

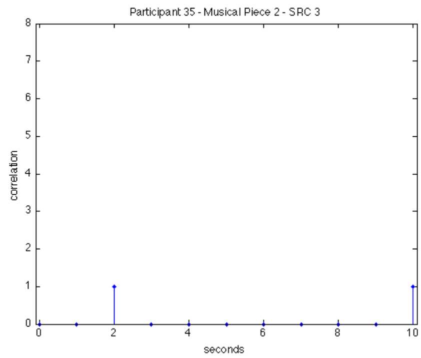

Participant 35 - Musical Piece 0 - SRC 3
change in measurements
seconds

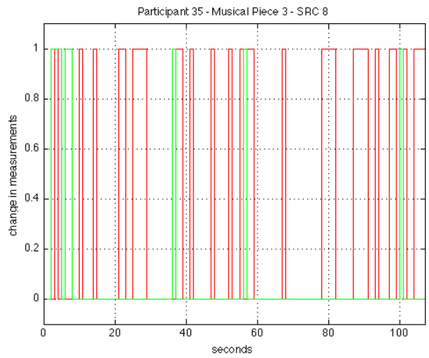

Participant 35 - Musical Piece 0 - SRC 3
correlation
seconds

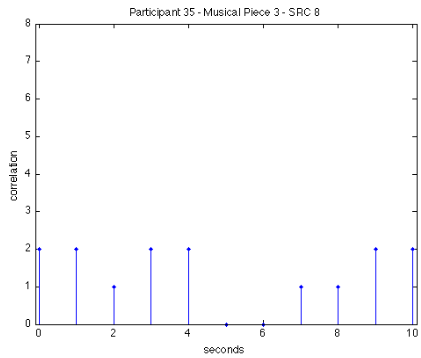

Participant 35 - Musical Piece 1 - SRC 4
change in measurements
seconds

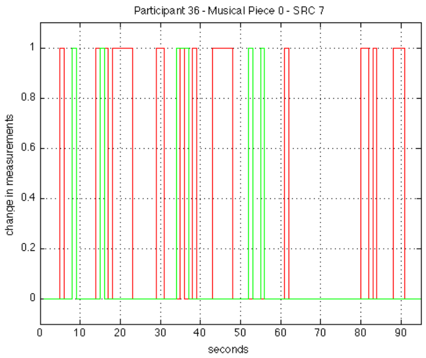

Participant 35 - Musical Piece 1 - SRC 4
correlation
seconds

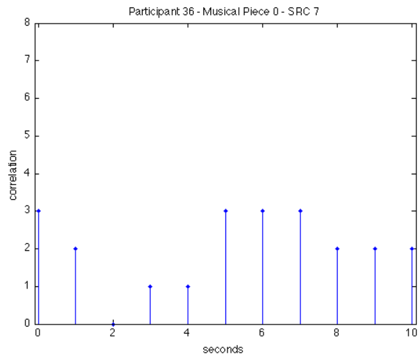

Participant 35 - Musical Piece 2 - SRC 3
change in measurements
seconds

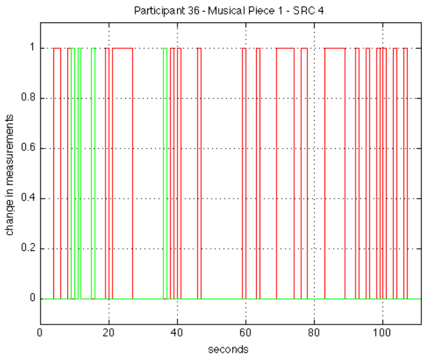

Participant 35 - Musical Piece 2 - SRC 3
correlation
seconds

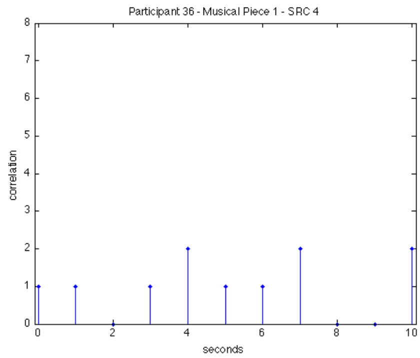

Participant 35 - Musical Piece 3 - SRC 8
change in measurements
seconds

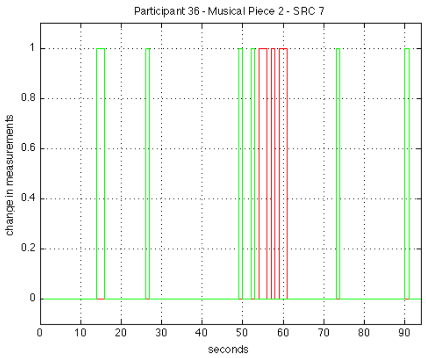

Participant 35 - Musical Piece 3 - SRC 8
correlation
seconds

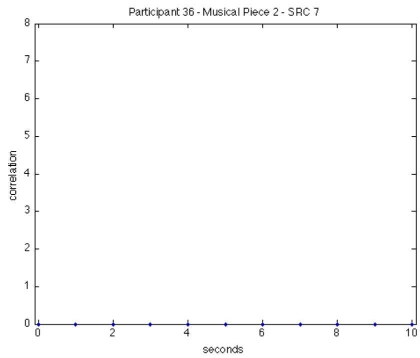

Participant 36 - Musical Piece 0 - SRC 7
change in measurements
seconds

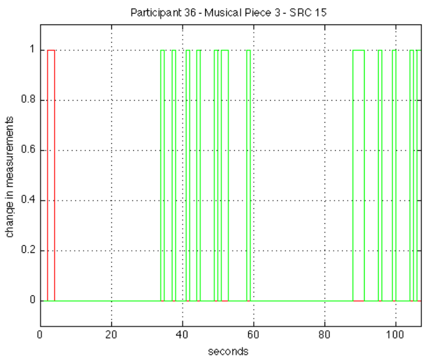

Participant 36 - Musical Piece 0 - SRC 7
correlation
seconds

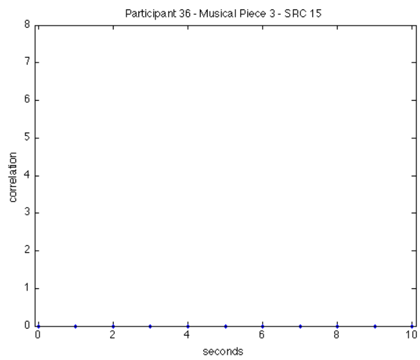

Participant 36 - Musical Piece 1 - SRC 4
change in measurements
seconds


Participant 36 - Musical Piece 1 - SRC 4
correlation
seconds

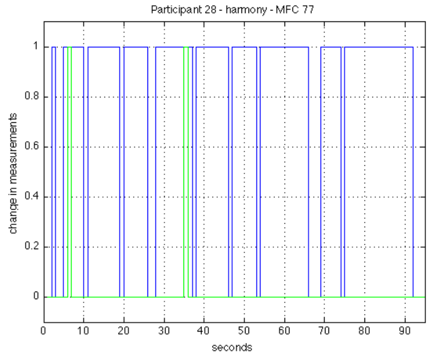

Participant 36 - Musical Piece 2 - SRC 7
change in measurements
seconds

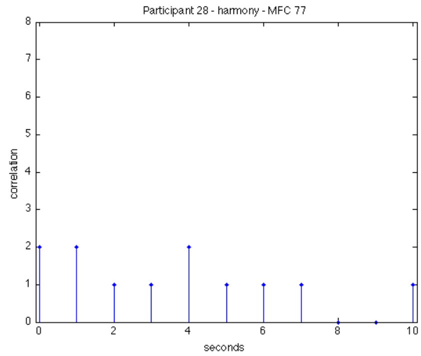

Participant 36 - Musical Piece 2 - SRC 7
correlation
seconds

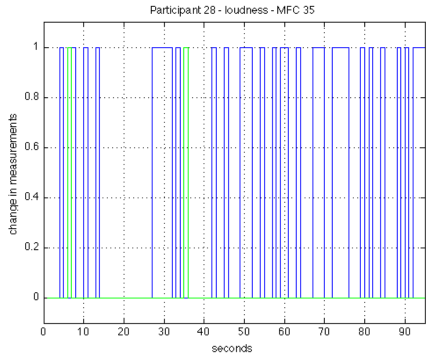

Participant 36 - Musical Piece 3 - SRC 15
change in measurements
seconds

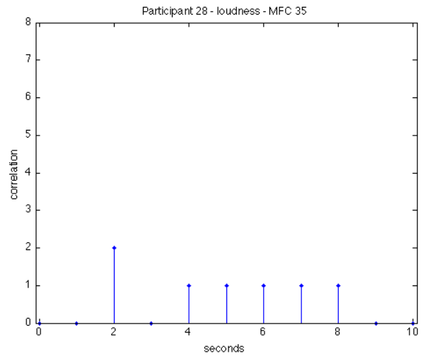

Participant 36 - Musical Piece 3 - SRC 15
correlation
seconds

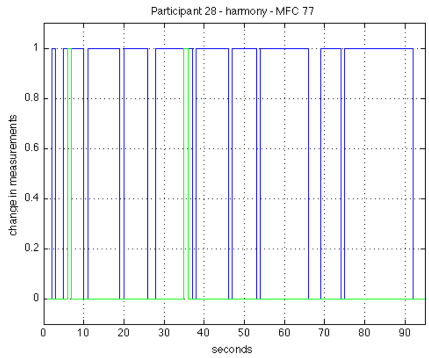
## C.3 Cross-correlation of change synchronisations and musical features

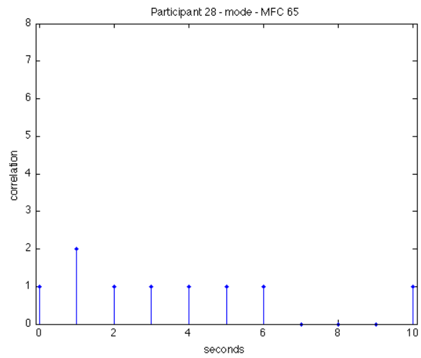


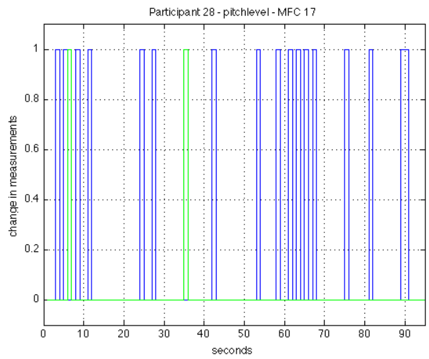



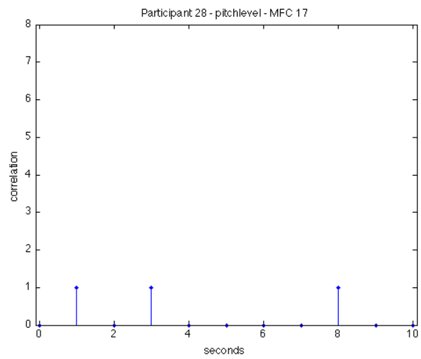



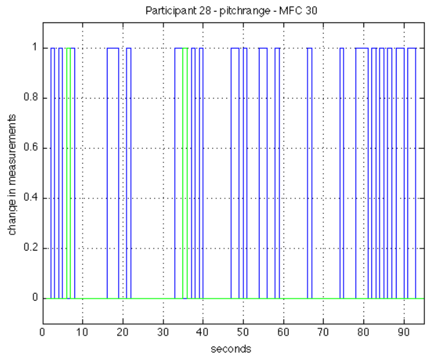
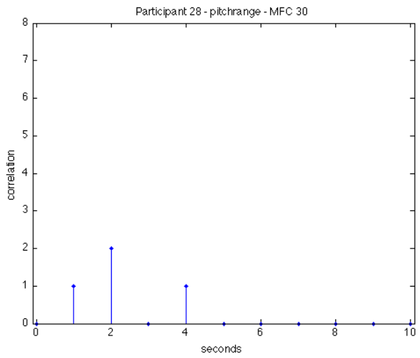
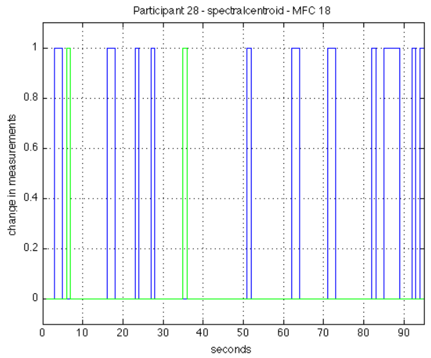
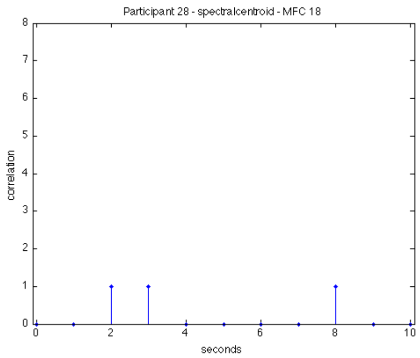
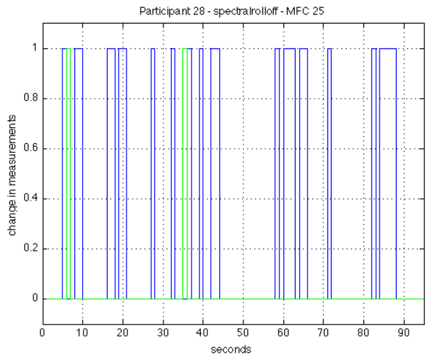
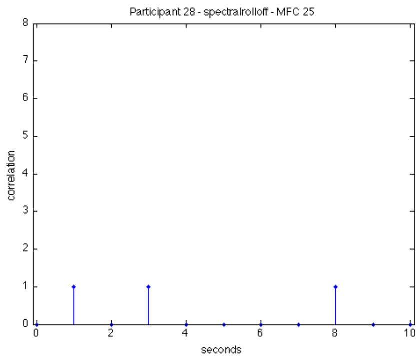




Participant 28 - pitchrange - MFC 30
change in measurements
seconds

Participant 28 - pitchrange - MFC 30
correlation
seconds

Participant 28 - spectralcentroid - MFC 18
change in measurements
seconds

Participant 28 - spectralcentroid - MFC 18
correlation
seconds

Participant 28 - spectralrolloff - MFC 25
change in measurements
seconds

Participant 28 - spectralrolloff - MFC 25
correlation
seconds

## C.4 Matlab Code

### Cross-correlation for synchronisation evaluation

```
p = 18; % Participant number
mp = 2; % Number of musical piece

corrheight = 8;

fileHR = ['P',num2str(p),'_',num2str(mp),'_HR.txt'];
fileSR = ['P',num2str(p),'_',num2str(mp),'_SELF.txt'];

load(fileHR);
HR = P18_2_HR(:,1);

load(fileSR);
SELF = P18_2_SELF(:,1);

[length, col] = size(HR);
threshold = std(HR(find(HR > 0)));
averageHR = mean(HR(find(HR > 0)));

src = 0;

BINARY_S = SELF;
BINARY_S(1) = 0;
BINARY_H = HR;
BINARY_H(1) = 0;
for(j=2:length)
    if(SELF(j) == SELF(j-1))
        BINARY_S(j) = 0;
    else
        BINARY_S(j) = 1;
        src = src + 1;
    end

    if(HR(j) ~= HR(j-1) &&  abs(HR(j) - averageHR) > threshold)
        BINARY_H(j) = 1;
    else
        BINARY_H(j) = 0;
    end
end



figure('Color', [1 1 1]);

stairs(BINARY_H, '-r')
hold on
stairs(BINARY_S, '-g'), grid
hold off
```

```
xlabel('seconds');
ylabel('change in measurements');
title(['Participant ', num2str(p), ' - Musical Piece ',
-> num2str(mp), ' - SRC ', num2str(src)]);
axis([0, length, -0.1, 1.1])

figure('Color', [1 1 1]);
[c, lags] = xcorr(BINARY_S, BINARY_H, 10);
stem(lags, c, '-b.');
xlabel('seconds');
ylabel('correlation');
title(['Participant ', num2str(p), ' - Musical Piece ',
-> num2str(mp), ' - SRC ', num2str(src)]);
axis([-0.1, 10.1, 0, corrheight])
```

### Correlation Coefficients for the Correlation across Participants

```
%delay = [4 0 1 0 5 1 1 3 3 1 0]; %MP#
delay = [2 0 2 0 0 2 3 0 2 2 2]; %MP2
%delay = [4 1 2 4 2 3 2 1]; %MP1
%delay = [2 4 1 0 1 1 0 1 0 4 4 0 3 0]; %MP0


%p = [4 6 7 8 9 13 15 21 24 29 30]; %MP3
p = [1 3 6 11 13 15 17 20 26 27 33]; %MP2
%p = [2 4 6 9 15 16 19 30]; %MP1
%p = [4 5 8 13 15 21 25 26 27 28 29 30 34 36]; %MP0
mp = 2;

length = [95, 111, 94, 107];
[cols, nP] = size(p);

HR = zeros(nP, length(mp+1));
SELF = zeros(nP, length(mp+1));

for(j=1:nP)
    fileHR = ['P',num2str(p(j)),'_',num2str(mp),'_HR.txt'];
    fileSR = ['P',num2str(p(j)),'_',num2str(mp),'_SELF.txt'];

    HR(j, :) = load(fileHR);
    SELF(j, :) = load(fileSR);

    threshold(j) = std(HR(j, find(HR(j,:) > 0)));
    averageHR(j) = mean(HR(j, find(HR(j,:) > 0)));
end

BINARY_S = SELF;
BINARY_S(:, 1) = 0;
```

```
BINARY_H = HR;
BINARY_H(:, 1) = 0;

for(i=1:nP)
    for(j=2:length(mp+1))
        if(SELF(i, j) == SELF(i, j-1))
            BINARY_S(i, j) = 0;
        else
            BINARY_S(i, j) = 1;
        end

        if(HR(i, j) ~= HR(i, j-1) &&  abs(HR(i, j) -
         -> averageHR(i)) > threshold(i))
            BINARY_H(i, j) = 1;
        else
         BINARY_H(i, j) = 0;
        end
    end
end



for(i=1:nP)
    for(j=1:length(mp+1)-delay(i))
        BINARY_S(i,j) = BINARY_S(i, j+delay(i));
    end

    for(j=length(mp+1)-delay(i):length(mp+1))
       BINARY_S(i,j) = 0;
    end
end
col = 1;


synctimes = zeros(length(mp+1), nP);

for(i=1:nP)
    for(j=2:length(mp+1))
       if(BINARY_S(i,j) == 1 && BINARY_H(i,j) == 1)
            synctimes(j, i) = 1;

            if(mp == 0  && p(i) == 29 && (j == 5 ||j == 6))
                synctimes(j, i) = 0;
            end

            if(mp == 3 && p(i) == 29 && (j == 35))
                synctimes(j, i) = 0;
            end

       else
```

```
            SELF(i,j) = SELF(i, j-1);

        end
    end

    col=1;
end

[r, p] = corrcoef(synctimes)
[i,j] = find(p<0.05);  % Significant correlations.
[i,j]
```

### Cross-correlation with Musical Features

```
p = 28;
mp = 0;

corrheight = 8;

%feature = 'harmony';
%feature = 'loudness';
%feature = 'mode';
%feature = 'pitchlevel';
%feature = 'pitchrange';
%feature = 'spectralcentroid';
feature = 'spectralrolloff';

fileMF = ['MF_',feature,'_Bach_downsampled.txt'];

timesync = [6 35];


MF = load(fileMF);

[length, col] = size(MF);


mfc = 0;

threshold = std(MF);
averageMF = mean(MF);


BINARY_SYNC = zeros(1,length);
BINARY_SYNC(6) = 1;
BINARY_SYNC(35) = 1;
BINARY_MF = zeros(1,length);


for(j=2:length)
```

```
    % Harmony and mode
    %{
        if(MF(j) == MF(j-1))
            BINARY_MF(j) = 0;
        else
            BINARY_MF(j) = 1;
            mfc = mfc + 1;
        end
   %}
   % Remaining musical features
        if(MF(j) ~= MF(j-1) && (abs(MF(j) - averageMF) >
        -> threshold))
            BINARY_MF(j) = 1;
            mfc = mfc+1;
        end

end


figure('Color', [1 1 1]);

stairs(BINARY_MF, '-b')
hold on
stairs(BINARY_SYNC, '-g'), grid
hold off


xlabel('seconds');
ylabel('change in measurements');
title(['Participant ', num2str(p), ' - ', feature, ' - MFC ',
-> num2str(mfc)]);
axis([0, length, -0.1, 1.1])


figure('Color', [1 1 1]);

[c, lags] = xcorr(BINARY_SYNC, BINARY_MF, 10);

stem(lags, c, '-b.');
xlabel('seconds');
ylabel('correlation');
title(['Participant ', num2str(p), ' - ', feature, ' - MFC ',
-> num2str(mfc)]);
axis([-0.1, 10.1, 0, corrheight])


for(i=1:10)
   for(j=1:length-i)
        BINARY_SYNC_TEMP(j) = BINARY_SYNC(j+i);
```

```
    end

    for(j=length-i:length)
        BINARY_SYNC_TEMP(j) = 0;
    end

    [r, p] = corrcoef([BINARY_SYNC_TEMP(:) BINARY_MF(:)]);
    [rrr,ccc] = find(p<0.05);
    [rrr,ccc]
end
```

## C.5 CD index

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