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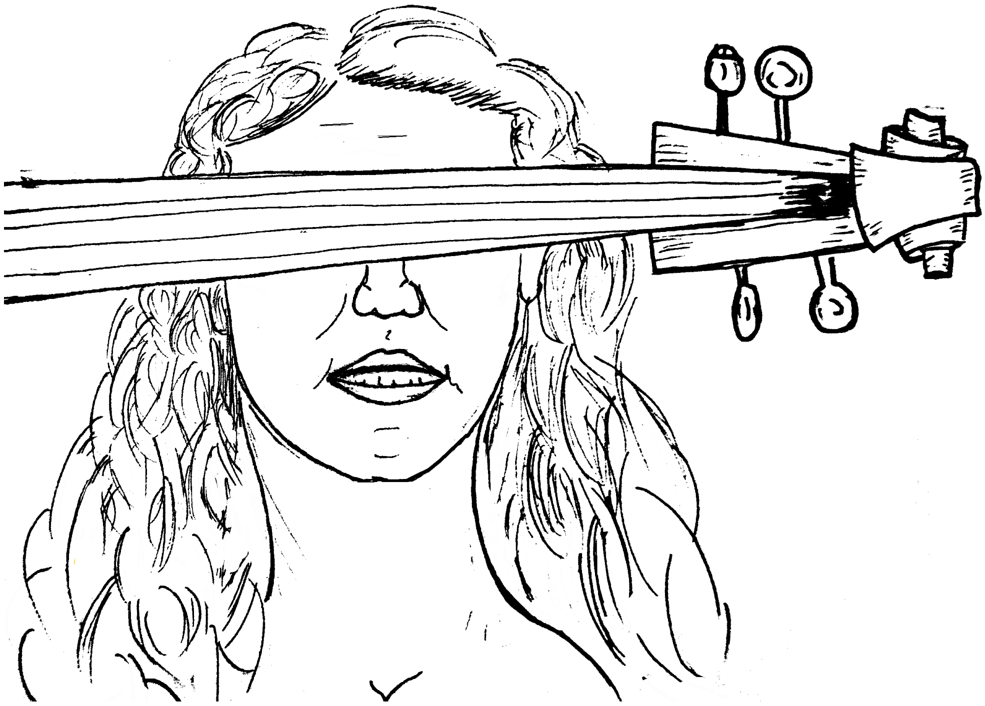

Timing in symphony orchestras

The relative importance of sight and hearing

Master's thesis in the Master's Programme Sound and Vibration

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Gothenburg, Sweden 2016

Master's thesis BOMX02-16-147

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Abstract

The influence of sight and common internal pulse on the musicians experience of stage acoustics are not much investigated. Many acoustic parameters based on impulse response measurements are available to describe the room but few of them correlate well with the musicians' own experiences. This thesis focuses on timing for symphony orchestras. Timing is an important part of stage acoustics for symphony orchestras. The goal for the musicians is that the instruments shall sound tightly synchronised for the audience. Large distances between musicians in symphony orchestras may create sound delays up to 60 ms between different instrument groups and to the audience. If the musicians use hearing, without seeing each other and referring to their internal feeling of pulse, this would result in bad synchronisation and retarding tempo. The senses sight and hearing are investigated to see the relative importance for timing when removing one or both of them. When removing both, the musicians need to trust their own internal pulse. Subjective tests are made with the University of Gothenburg Symphony Orchestra. The orchestra is recorded when playing a piece especially written for this occasion and a piece by Mozart. Onset of every tone is detected and compared to each other, to see the level of synchronicity. The studies show larger deviations between musicians when playing with just sight than with just hearing but both senses are needed to get the best timing. When removing both sight and hearing other cues are used to be able to play in synchrony and vibrations from the bass section were more noticed by musicians in other sections. Different seating arrangements are tested and the the setup where the orchestra sits closest together improve timing in all settings. This investigation indicate that many senses influence the ability to synchronise. Therefore, acoustic measurements alone can not explain the features of the stage, at least not when it comes to playing synchronised.

Keywords: stage acoustics, timing, sight, hearing, symphony orchestra, synchronicity, onset, internal pulse, concert halls, subjective importance.

Acknowledgements

I have really enjoyed writing this thesis as I was able to do it in an office where all nice coworkers of Artifon AB are. Very nice and learning to take part of your daily work. It was cool for me as an amateur musician to collaborate with the University of Gothenburg Symphony Orchestra in the Academy of Music and Drama. For the statistical analysis I had valuable help from my mother Ulla Romild, PhD in statistics and statistical investigator at Folkhälsoinstitutet. The ear cuffs needed for the test was provided by 3M Svenska AB in Värnamo and some other test equipment from Stadsteatern Göteborg. Alf Berntson and Patrik Höstmad were my supervisors and I am thankful for that.

During the work of this thesis, my beloved Julius and I have gotten married, moved to a new apartment and our first child has taken his first steps. I always want to live with you.

Emma Lidar, Gothenburg, November 2016

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1

Introduction

The purpose of this thesis is to investigate how musicians in a symphony orchestra are able to synchronise their playing. The thesis will investigate the relative importance of sight, hearing and internal pulse for timing. In an orchestra, distances between musicians up to around 20 meter are common. The sound may then be delayed up to around 60 milliseconds between musicians, which is too large for good timing in sensitive parts. Therefore, musicians must use other senses or compensate for the delay to be able to synchronise [15]. The subject is interdisciplinary and figure within stage- and psycho acoustics, psychology and music. The authors own experience as an amateur musician has come good in hand.

This thesis investigates how important the sight is for ensemble and timing. In the field of acoustics for concert halls, research of the sound experience for the audience is more investigated than the situation for the performers on stage. Since 1980 more research in stage acoustics has been made, but most investigations focus on acoustics and hearing only. The consensus is that the hearing is most important, but at the same time measurements and subjective tests are often uncorrelated. It could be that the wrong aspects is measured. The results will increase the understanding of the timing mechanism and be helpful for designing stages for symphony orchestras.

1.1 Purpose

The objectives of the work are to

1. Investigate the relative importance of sight and hearing for timing in symphony orchestras.

2. Investigate the importance of common inner pulse for timing in symphony orchestras.

3. Find out how different seating arrangement and features of the room affects the timing in symphony orchestras. Especially, how aural cues from large distances (with large time delays) influence timing.

1.2 Limitations

The thesis will increase knowledge of what parameter is the most important to obtain high precision in timing, it will not present any design propositions. The goal is to increase the knowledge of the timing process and this could give increased knowledge of how timing can be improved. Other qualities of stage acoustics, such as balance, reverberance from the hall, noise levels, lightning and so on, are not considered. Aspects due to vibrations on stage are also left aside of this work. The result deals with timing in chamber and symphony orchestras and may not be applicable for other ensembles. There are some small method adjustments due to the limited time with the orchestra.

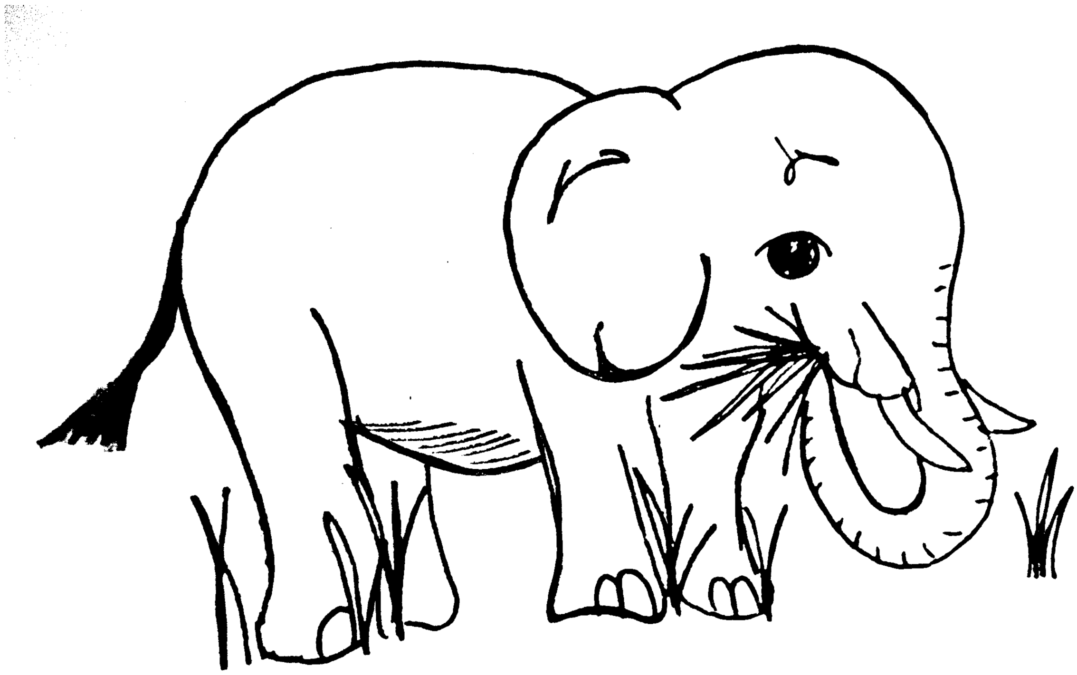

Figure 1.1: Elephant eating grass (Frida Bohman 2016). Elephants have nothing to do with the subject of this thesis but the author is impressed by the matriarchy they live in and the organisations working to protect them from poachers.

1.3 Report structure

The following chapters describe the different parts of the subject. First, the literature review that look in to what have been done earlier. The following Methods chapter describes how the subjective tests are prepared and conducted and also the theory behind the analysis. Finally, the the results and conclusions from the tests are presented in the Result and Discussion chapter.

2

Literature Review

In this chapter, literature in the multidisciplinary field is presented and explanations of all fields are included. This forms the background and gives fact that all tests are based upon in this thesis. The literature provide some research where the timing among musicians is tested but just for smaller ensembles, not in an orchestra as in this thesis.

2.1 Music

The tests in this thesis are concentrated to the cause of a symphony orchestra. This ensemble is interesting because of the sometimes large distances between the musicians. Large distances means long travel time for the sound and delay of the music to the other musicians [2]. In this section the practice of music is investigated in the literature, in regards to how timing works in music playing.

2.1.1 Orchestra arrangement

The different distances between musicians within the orchestra differ more than the distances between most of the audience positions and different musicians in the orchestra. Most people in the audience sit so far away that the extra distance, between for example the front and the back of the stage, have a small impact on the sound levels and the arriving of sound. But for the musicians, there is a big difference in level and delay for sound from self and others. In larger halls the stage width is often around 20 meters resulting in delays around 58 milliseconds and somewhat lower levels than in smaller halls. Which sections that are most far apart depend on the seating arrangements on stage [2].There are no written rules in regards to how the orchestra should sit, it may change due to the settings on stage or the piece of music. But most symphony orchestras either use European or American seating, see them in figure 2.1. In American seating the first violins and the celli are on the opposite sides of the stage and in the European seating the celli change places with the second violin [9]. The subjective tests in this thesis are using the European arrangement for the structural test and the American seating for the Mozart test.

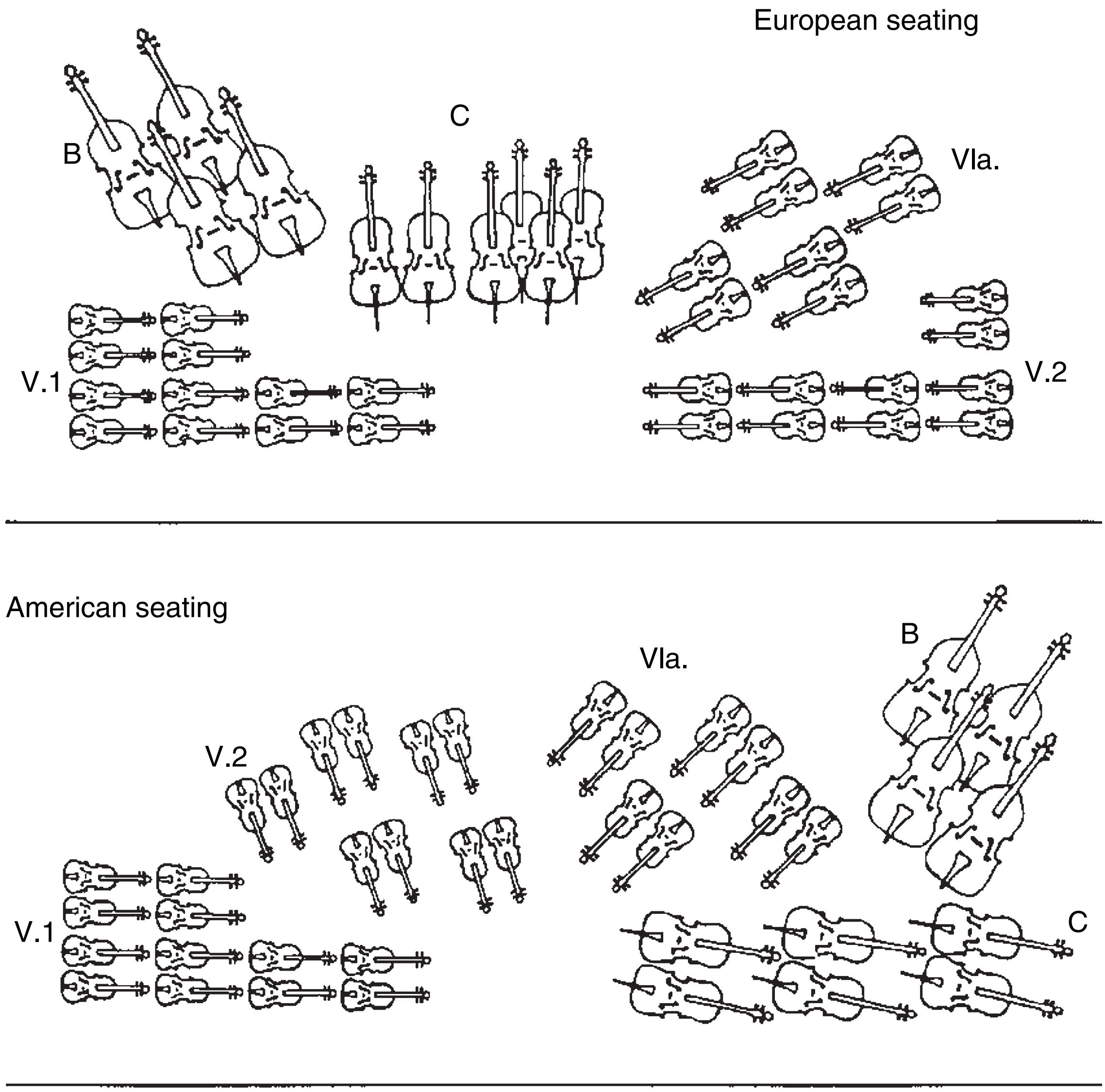

Figure 2.1: European and American orchestra seating [9].

Both the arrangement of the orchestra and the directivity affects the direct sound levels on stage from the different instruments. Compared to the brass and woodwinds the strings sits further apart. The stages are more wide than they are deep and traditionally strings sit in the front. This is partially because of their weaker sound power level. Due to this the outermost string musicians sit further apart than the outermost musicians in the brass and woodwind sections [2].

2.1.2 Visual and aural cues

Every member of an orchestra looks at the conductor to follow the music. A single member of the ensemble can also rely on the leader of the voice to have contact with the concertmaster who have the best access to see what the conductor does. The conductor's communication is purely visual and the beat and expression is visualised with a baton or just body language. The conductor's whole body shows with gestures what character the music have. Elaine Goodman [4] describes how the musicians in an ensemble, with or without conductor, also use their body to communicate in their playing. Some things are decided in advance, who makes eye contact with whom to start after a long pause or who gives the tempo in the beginning of the piece. Other things comes intuitive. For example a slow passage in the piece of music might make the performers retain still while a more lively passage will make the performers move more. This comes more naturally over a period of time when making music together and the musicians are hardly aware of some visual signals.

Aural communication to ensure that the tones are played in synchronicity consists of listening, anticipation and reaction to the signal and cues from other ensemble members. The individual musician needs to both concentrate and listen to her own play and at the same time adjust to the music produced from the rest of the ensemble [4]. The human auditory system, which are the hearing system and the psychological processing of what is heard, are able to centre its attention to one of many competing sounds. This is important on stage when for example one section must synchronise with the soloist but have both the background from other sections and the reflected and reverberant sound. The musicians use a primitive and schema-based processing to isolate the specific section from the whole sound field. This is called a perceptual stream [5].

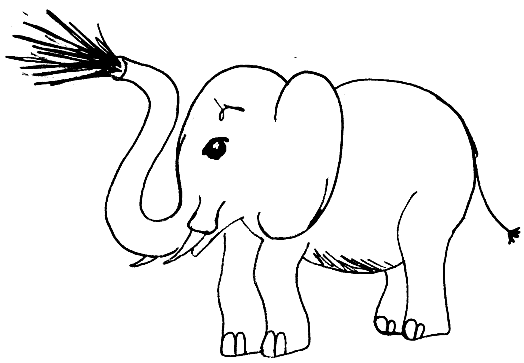

Figure 2.2: Elephant with water (Frida Bohman 2016).

2.2 Timing

The onset time difference that is consciously perceptive as asynchronised by humans is around 20 milliseconds. Deviations smaller than that are not noticed in the performance [15]. In this section literature are reviewed about how synchronisation for single persons and ensembles works. Both string quartets and piano duetts have been investigated by other researchers but not symphony orchestras.

2.2.1 Human timing

Meter, pulse, tactus and rhythm are several worlds that describe elements in music that can be synchronised to. Synchronisation, or timing, consists of many parts and cannot be addressed to just one ability of humans [16]. Roeckelein [13] concludes that time perception for humans is an ability where attention is needed for several stimuli simultaneously. This is how Large [6] describes it: "The neural resonance theory of pulse and meter holds that listeners experience dynamic temporal patterns, and hear musical events in relation to these patterns, because they are intrinsic to the physics of neural systems involved in perceiving, attending, and responding to auditory stimuli."

Timing is requested in many fields. As been said earlier, deviations from the common tempo in music can be detected when they are over 20 milliseconds. For a tennis player the limit is four milliseconds between the best hit and not and a baseball player need to get the attention for the ball, prepare the swing and hit the ball in less than 600 milliseconds (0.6 seconds). To be able to do this, in sports as well as in music, the time before the action is the most important. When a movement or other action should be synchronised with an external event, such as other musicians or the conductor, it is sometimes called coincident timing. The changing environment provides the receptor with information that makes it possible to anticipate and know when the action should take place. The information is continually updated [16].

Humans sometimes adjust their timing to deviations above their consciousness. Madison and Merker [7] investigate this in an experiment with 22 participant using a beating drumstick on a drum when hearing the short sound of a cowbell in their ears. The purpose is to show their timing to isochronic tones, i.e regular beats of a single tone. The result show that they can adjust to the small deviations oblivious. There were no difference between musically trained participants and participants with limited musical experience. When the deviations where above the perceptual threshold for timing deviations, i.e. 20 milliseconds, the musicians though had a small advantage.

2.2.2 Timing in ensemble

An ensemble is a group of people performing together and can be anything from a duo to a full symphony orchestra. Goodman [4] concludes that the most fundamental for the performing group is that the different voices fit together in the ensemble as well for the listener in the audience. Keeping timing is one of the bridge stones for this. To keep the timing musicians will play by their body's internal pulse that is adjusted to the main tempo. The whole ensemble shares a common clock which makes the musicians play synchronised. The piece of music often has bars and the individual musician could subdivide or lengthen her beats as long as it fits in the bar that is in the main tempo. Timekeeping depend on anticipation and reaction. The note played is a reaction to the previous note and is also formed by an anticipation on when it should be played to synchronise.

Rasch [12] claims that the investigation of timing and synchronisation is primary an investigation of the onset of the tone. The notes in a piece of music could have different lengths but still start at the same moment. In that moment the onset decides if the voices are synchronised or not. Goodman [4] continues with that there will always be asynchronous in music. A group of people are not able to play the note exactly at the same time but will more or less affect the performance. Skilled musicians can create an illusion of perfect ensemble so that this is what the audience hear. Problems in timing can come when playing different instruments or sitting in different distances from the audience. The orchestra members adapt their onset of notes to where they sit. Players in the front make sure that they are together and players in the back play ahead of the beat to be synchronised with the players in front.

As the aural cues can be misleading when the sound is delayed the visual cues are important. It is easier to synchronise faster tempos than slower because the individual players need to subdivide by them selves in slower tempos. A long pause creates more difficulties in timing for the same reason. For these parts of the piece visual cues are important for the ensemble [2]. Goodman [4] claims that the reason aural communication is more important in ensemble than visual is because "we hear music, we don't see it". But she also points out the importance of visual communication in music and how it contributes to more possibilities of cooperative performances. The conductor's role is purely visual and helps the ensemble to improve the timing. The conductor makes moves and lets the musician react to it and learn what to anticipate from it [4]. The role of the conductor is not further investigated in this thesis.

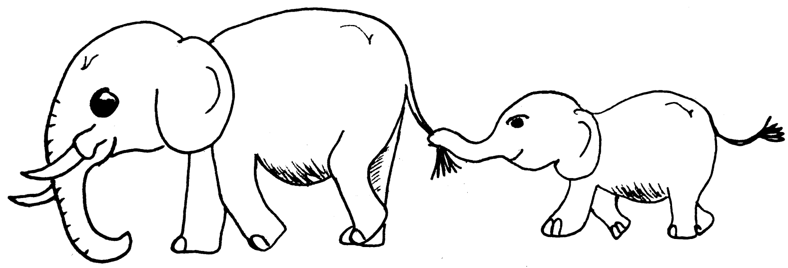

Figure 2.3: Elephant with calf (Frida Bohman 2016).

Timing is examined in different types of ensembles. Wing et al. [15] investigated the ensemble playing of a string quartet. When playing string quartet there is variability that often is intentional but sometimes unintentional and cannot be eliminated by practice. Gain can be used to hide or boost the asynchronicity. Timing can depend on which instrument has the most important melody. The string quartet members tends to adjust more to the first violin and the first violin could vary more in timing than the others. Palmer and Goebl[11] test synchronisation of timing with a pair of pianists. The pianists sit at the same piano and play together. There is one leader which the pianist playing the second voice should follow. The musicians get different ways of auditory feedback, from just hearing one self to hearing everything from both. Motion analysis show that when having no auditory feedback the motions are more concise and clear. The leader raise fingers higher, to show more, and the pair of pianists' head movements became more synchronised. This probably helps them play together despite the lack of auditory feedback.

Playing in synchrony with the beat makes the next sequence predictable and even when producing ritardando and rubato, the musicians in an ensemble can be together in good synchrony. This is shown by finger tapping experiments. Merker and Madison[8] show that when providing participants in the study with a beat with changing tempo, the participant will proceed changing the tempo but in the opposite direction when turning the sequence off and continuing by them selves. This is regardless of if the participant have musical training or not. The need to synchronise with others and with external cues are common in musical performance. The music has a musical pulse, called tactus, which underlies the rhythmic. When playing in pulse the synchrony helps the performer to be in time and eliminate some reaction time and not lag behind. Merker and Madison show both how well the participants can synchronise when the sequences are changing tempo and also how well the continuation after the sequences is done. The continuation is the production directly after the sequences and is influenced by the synchronisation of them. In the tapping experiment the participants that are musically trained tend to decrease their tempo when coming to the end of the sequence, whereas non musical trained did not.

Dammerud[2] state that when there is masking going on with timing or level from other instruments it is the cochlea that can not define what the wanted instrument is playing. This can not be trained away. The masking is enhanced by louder sound levels from other instruments but is also dependent on when the onset of the tone is. The brass need to be ahead of the beat so that the sound for the audience arrive at the same time as the rest of the orchestra. But because of their loud sound level, arriving to early to the strings can entail masking their string colleagues sound from the other side of the stage. Aural and visual cues cooperate and if they differ it is easier to play if the delay is consistent.

2.3 Stage acoustics design

The stage in a concert hall is often developed to be good for symphony orchestras. The musicians should hear oneself and other ensemble members sufficiently well to be able to adjust timing, dynamics and tone. The sound heard by the conductor

Figure 2.4: Picture from the recording session for this thesis (Annakarin Berntson 2016).

in the front of the stage should equal to the sound heard by the audience. For rehearsals good speech communication is important across the stage and especially from the conductor[5]. This section treats the subject of stage acoustics and summarise aspects influencing the building of stages for symphony orchestras.

2.3.1 Surfaces surrounding the stage

The variables affecting the stage acoustics are the geometry and acoustic properties, such as absorption and diffusion, of walls, reflectors, shielding and seating arrangement of the musicians. The surfaces design with different reflection, angle, diffusion and absorption collaborate to get the best result. A good stage design would enhance the sound for weak instruments and lower the sound from the strongest instruments [9]. Dammerud [2] has in his PhD thesis gathered all research there is about stage acoustics and among other things concluded that the people on stage have an impact of the propagation of sound within the symphony orchestra. Below 500 Hz this is not distracting the propagation too much.

For frequencies in the 63 and 125 octave bands the direct sound and floor reflections have contributing interference. If the musicians are more than three meter apart the floor reflections have higher level than the direct sound. These frequencies are for example found in the cello and bass section. For frequencies above 500 Hz do the orchestra have an great impact for attenuation of sound propagation. For 14 meter it can be 12 dB. A high frequency loss of the direct sound makes it more difficult for the musicians to play together. For 1 kHz the loss is 9 dB and for 2 kHz, 12 dB. These are levels for flat floor. The sound levels in the string section are relatively low and the sound between them is stopped by humans, music stands, chairs and instruments. If the outer most players are placed on risers it will improve both sight lines and the sound propagation from these sections, but especially for cello and double bass, sitting on risers can lead to less valuable resonance from the floor. The floor reflections will also be reduced, particularly in the 250 Hz band [2].

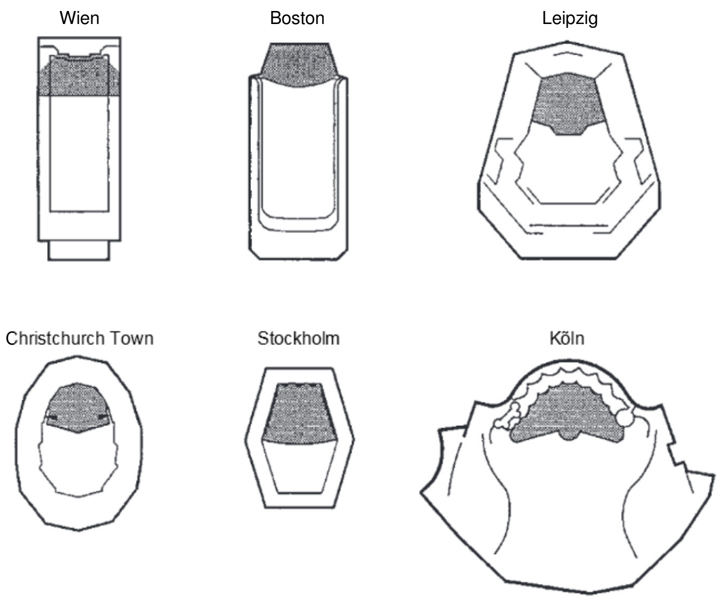

Figure 2.5: The floors of different types of concert halls [9]. The shadowed area marks the stage.

Sound energy on stage has been measured in several ways, mostly in a scale model. Wenmaekers and Hak [14] did not have access to a real orchestra but did an experiment on real scale with dummies with pink fleece pyjamas on, formed and absorbing as male persons to see what effect the orchestra members have on the reflections. The conclusions from the measurements are that the humans in the orchestra have a great impact on both the direct sound and early reflected sound. Dammerud's [2] findings agree with that the measurements done without the orchestra on stage result in significant errors. The errors are most significant with sound-receiver distances larger than one meter. For stage measurements the orchestra is needed for them to be valid. Especially for the early part of the impulse response. After 100 milliseconds the influence is not important. When not having an orchestra the scale model or computer model is the most cost efficient way to measure, but the most valid studies involves a full symphony orchestra.

3

Methods

This chapter describes all the aspects on this thesis' way of finding out how sight and hearing affect timing in symphony orchestras. Tests with musicians, a questionnaire and some small interviews are conducted.

Figure 3.1: Musicians in black clothes, ear cuffs and sunglasses (Annakarin Berntson 2016).

The main part of the investigation is a systematic test, recording the orchestra playing a short piece of music written for this test. The orchestra also makes a test when playing a piece by Mozart and fills in a questionnaire after each try-out. Before the tests two preparing tests are conducted to test how sight and hearing could be removed and also enables the author to test how it feels playing in ensemble with these features. The results from them are found in chapter 4. The synchronisation is analysed by numerical onset detection of close microphone recordings on musicians and two dummy heads. This analysis is made in Matlab, a software for numerical programming. The data is treated with the statistical analyse software SPSS and data from the questionnaires are treated in the spreadsheet program Microsoft Excel. These analyses methods are used to make the relative comparison between sight and hearing. Listening to the recordings is also an important method of analysis, this is done in all results.

3.1 Parameters and try-outs

The test with the orchestra is a systematic test that combine different parameters to get a result for the relative importance of sight and hearing. The parameters are:

1. sight (eye1)/ no sight (eye0)

2. hearing (ear1)/ no hearing (ear0)

3. starting with clicks from one side (click)/ starting by the conductor (dir)

4. different seating arrangements (arr1, arr2, arr3)

For masking the hearing of others (parameter ear0) the participants wear ear cuffs with pink noise when playing. The ear cuffs are of the model Peltor HTM79A. Each ear cuff is coupled to a receiver which gets pink noise generated from a computer in to the transmitter in a wireless in-ear system, see equipment list in section 3.7. The isolation and the noise mask the surrounding musicians sound but is quiet enough for the participants to hear them selves. To eliminate sight (parameter eye0) the lightning is switched off after the conductor have started the orchestra. This is not sufficient to hide all movements from the musicians so they wear sunglasses and black clothes as seen in figure 3.1, to be certain they do not see each other. The conductor of the orchestra starts the piece by conducting two measures before the first tone. In the other way of starting, a loudspeaker with metronome clicks on the right side of the orchestra is ticking two measures before the first tone. This is to simulate cues from another musician on an other position on stage.

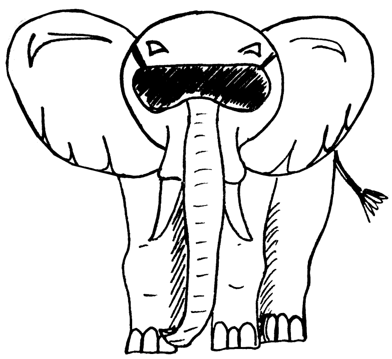

Figure 3.2: No sight eye0 (Frida Bohman 2016).

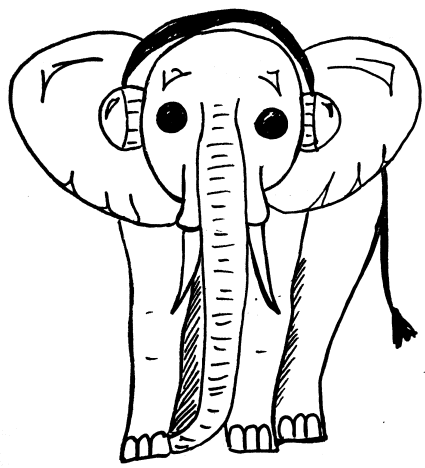

Figure 3.3: No hearing ear0 (Frida Bohman 2016).

In figure 3.4 the four different seating arrangements are shown. Arr1 is to simulate everybody sitting on the last desk. This causes the musicians having the largest distance between each other. The distance between the left and right parts of the orchestra is 12.44 meter resulting in a delay of 36.25 milliseconds. In arr2, the musicians are sitting almost normal for strings. Arr3 makes the musicians sit as closely together as possible and is made as a comparison to arr1 where the musicians sits very far apart. The fourth seating arrangement shows how the musicians are seated when playing the second piece of music.

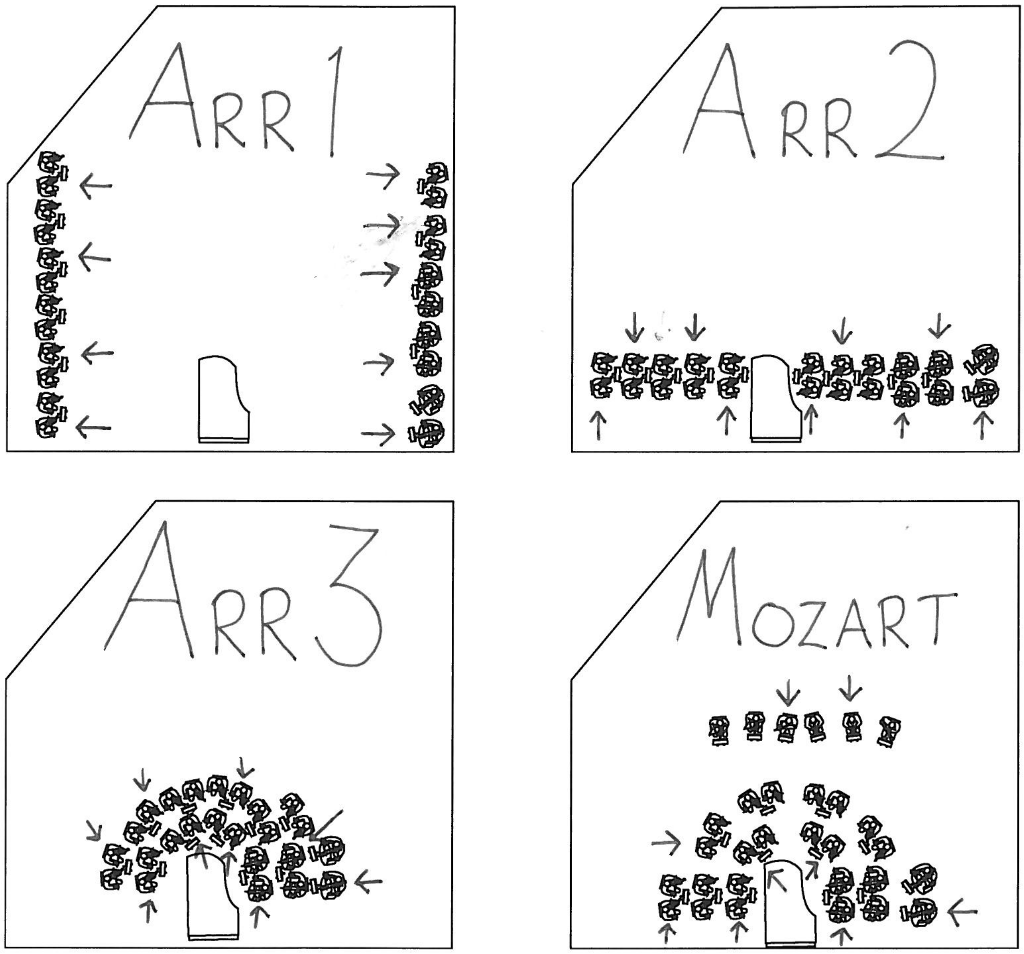

Figure 3.4: Seating arrangements and recording positions

All these parameters are combined with each other into 24 try-outs. They are listed in table 3.1. All try-outs in one position are made after each other. The order of the try-outs within one position are randomised. To see if the method of recording is resistant and check reliability, four of the try-outs from arr1 are played once more in the end of the session. The result is that the second recordings are better. The first ones can be seen as rehearsing the piece.

Table 3.1: Try-outs

arr1eye0ear0click	arr2eye0ear0click	arr3eye0ear0click
arr1eye0ear0dir	arr2eye0ear0dir	arr3eye0ear0dir
arr1eye0ear1click	arr2eye0ear1click	arr3eye0ear1click
arr1eye0ear1dir	arr2eye0ear1dir	arr3eye0ear1dir
arr1eye1ear0click	arr2eye1ear0click	arr3eye1ear0click
arr1eye1ear0dir	arr2eye1ear0dir	arr3eye1ear0dir
arr1eye1ear1click	arr2eye1ear1click	arr3eye1ear1click
arr1eye1ear1dir	arr2eye1ear1dir	arr3eye1ear1dir

After the systematic try-outs the most interesting settings are chosen and applied on a full orchestra playing Mozart Piano concerto number 23. This enables comparisons between different types of music and also tests the timing when the orchestra plays a piece they normally play.

Figure 3.5: Sjöströmssalen in Artisten (Karl Tillberg 2016).

3.2 Room and orchestra arrangement

The tests are conducted in Sjöströmsalen in Artisten, the home of the Academy of Music and Drama. See a picture of the hall in figure 3.5. To describe the acoustic condition in the hall impulse responses are measured. The impulse responses of the concert hall are measured according to ISO 3382 with the measurement program Room Capture where all common acoustic measures are achieved [1]. Twelve measurements are conducted and the reverberation time that is displayed in chapter 4.1 is the mean from these. In figure 3.6 is a picture from the measurement.

Figure 3.6: The loudspeaker that play the sound when measuring impulse response in the hall (Karl Tillberg 2016).

In the systematic test and the Mozart test the participating musicians belong to The University of Gothenburg Symphony Orchestra. The musicians in this orchestra are students in the Master's program in Symphonic Orchestra Performance. They have degrees of Bachelor of Fine Arts or the equivalent full time professional musicians studies and have played their instruments 15-20 years. The strings from the symphony orchestra plays in the systematic test. These are ten violins, six violas, four celli and two double basses. Together 22 musicians. The onset of tones are different for different instruments [9] so it is important to only use one type of onset for the test. It is a good choice to use the string section to test on. As mentioned in 2.1.1 the strings are a large group used to sit together but further apart than other sections of the orchestra. Therefore only strings are included in the systematic test. For the Mozart test the winds and one pianist are added, forming an orchestra of 29 people. The winds are one flute, two clarinets, one bassoon and two french horns. 50 extra chairs and music stands are placed on the stage to simulate the acoustic influence of an symphony orchestra with 70 musicians. For an even more accurate orchestra situation there would be more people on stage as they are absorbing and screening. This is not possible in practice for this test but the situation is considered sufficient for this study.

3.3 Test piece

The piece of music played by the orchestra in the systematic test is composed by the author and is found in Appendix A. When composing the piece several components are considered to make it as useful for the test as possible. The beginning and the end of the piece have the same rhythm to see the difference in timing when played the second time - whether the participants are more or less synchronised in the end compared to the beginning. The piece has a very simple rhythm and tones so it can be learnt fast. There should be no difference between playing it the third time or the 20Th time and the musicians need to learn the music by heart to be able to play with no sight. In the middle, the voices have a little difference in rhythm and the piece changes between pizzicato and arco. Pizzicato is when a string instrument is played by being plucked by a finger. Arco is when the musician uses the bow to play their string instrument. The pizzicato gives a short tone and therefore a distinct onset which helps the analysis of the test but it is also interesting to see the change from arco to pizzicato and the opposite. All musicians tend to increase the tempo when playing pizzicato and the time it takes changing from arco to pizzicato could be something that affects timing [3]. 12 measures takes about 30 seconds when playing 100 bpm and is a suitable time for the test. If the voices are spread in frequency and spatial cue they are easier to distinguish between and this is considered when writing the arrangement. The other piece played is Concerto in A major by Wolfgang Amadeus Mozart, in this report called Mozart. This is a piece for pianoforte and orchestra. It can also be seen in Appendix A.

3.4 Questionnaire

The questionnaires in appendix B are made to complement the measured results and to give a subjective view from the musicians. Each musician is asked how difficult it was to play in synchronicity with each special setting. Immediately after each try-out every musician fills in the questionnaire. This is asked in the questionnaire:

> How well is your playing today? With answers: bad, medium, good, very good.
>
> How difficult was timing (playing synchronised together) in this situation? 1 is very easy and 6 is very difficult. With answers: 1 to 6.

Both questions have an even number of answer alternatives to force the participants not to choose the middle, something that they are likely to do when that option is possible. The first question is to be able to eliminate participants that may have a bad day and therefore play with less timing than they normally do. The result from the questionnaires are combined with small interviews and comments from individual musicians in the orchestra.

3.5 Numerical onset detection

Close microphone recordings are made on a couple of instruments in every voice, the positions seen in 3.4. Every try-out has its own project with 13 channels each. Two violin 1, two violin 2, two viola, two cello, one double bass, two channels binaural conductor position and two channels binaural audience position. When playing Mozart one flute and one clarinett are also recorded. Wave audio files from each try-out are achieved from the digital audio workstation. Numerical onset detection are made on every wave file from the instruments. This is to find the onset of every tone and compare them to each other. The original signal from the wave audio file looks like figure 3.7. The signal is squared to get only positive numbers and to see where the maximum levels are. This makes it easier to use only one threshold when detecting the onsets in a later step.

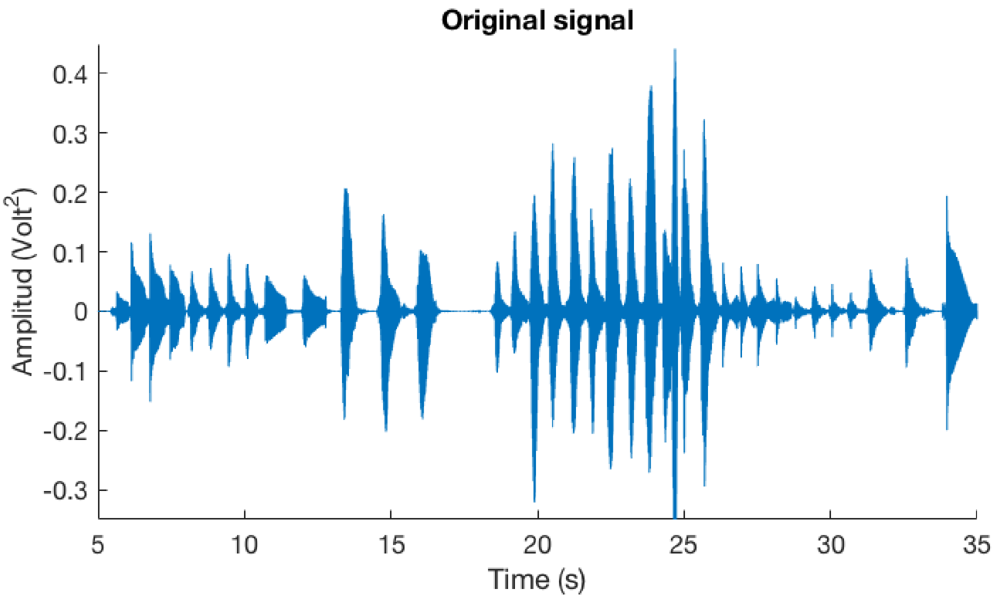

Figure 3.7: Original signal from Cello1 playing arr3ear0eye1.

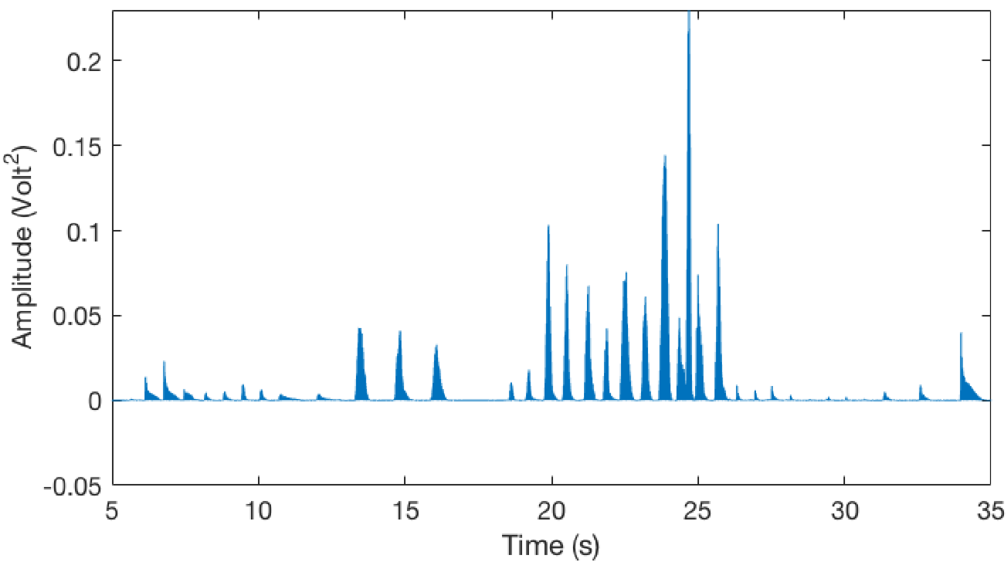

Figure 3.8: Squared signal from Cello1 playing arr3ear0eye1.

A lowpass filter is applied on the signal to make a more smooth curve and get rid of blur in the signal. This filter is a windows sinc filter with a cut of frequency of 35 Hz. The cutoff frequency is when the curve in the low pass filter has decreased three decibels from when it starts to cut in the levels. All frequencies below 35 Hz go through the filter without any reduce. In figure 3.9 is this lowpass fiter and in 3.10 a part of the signal that has been filtered are displayed. The later figure shows both the original signal and the filtered one.

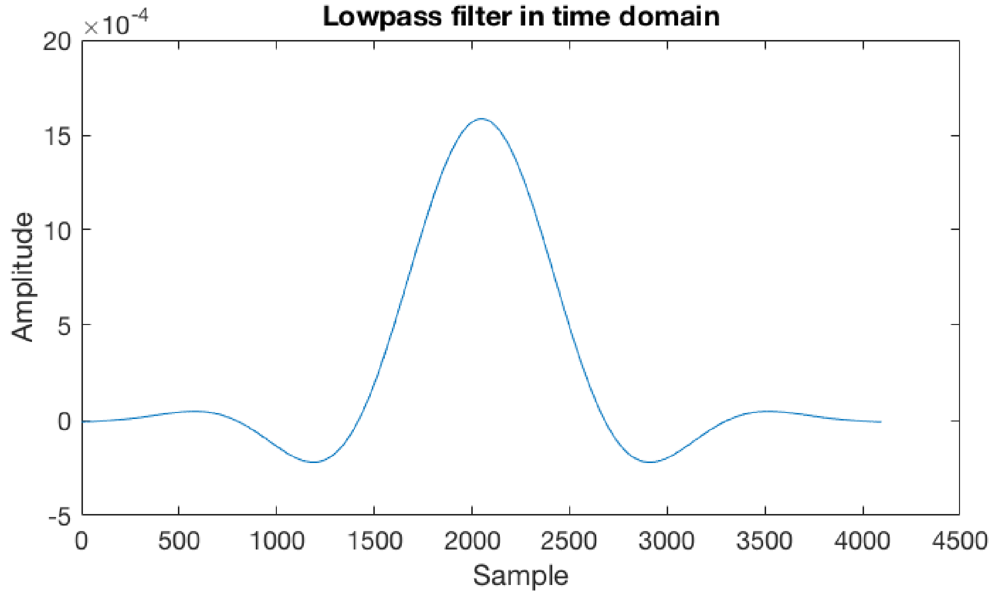

Figure 3.9: Lowpass filter

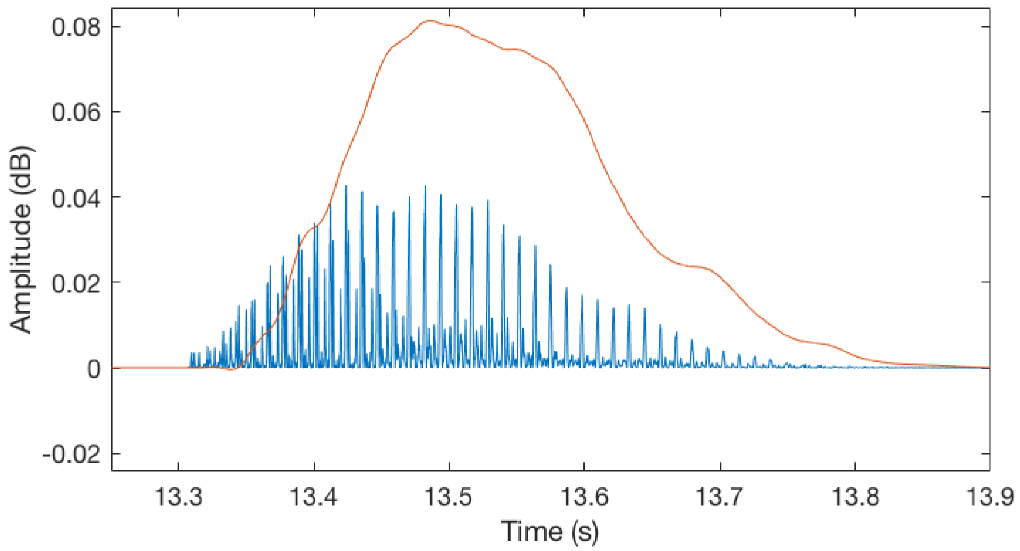

Figure 3.10: Part of signal that have been treated by a lowpass filter. The smooth curve is the treated one.

Taking the signal through a filter makes a delay, see figure 3.10. The delay has no effect on the analysis as all signals are treated with the same filter and therefore get the same delay. The relative distance between the tones of different instruments is interesting here, not the actual time. Then a threshold is applied telling when the amplitude goes over a specified value. Since only the onset time of every tone is interesting, this is a useful method. The onset times are marked with crosses in figure 3.11.

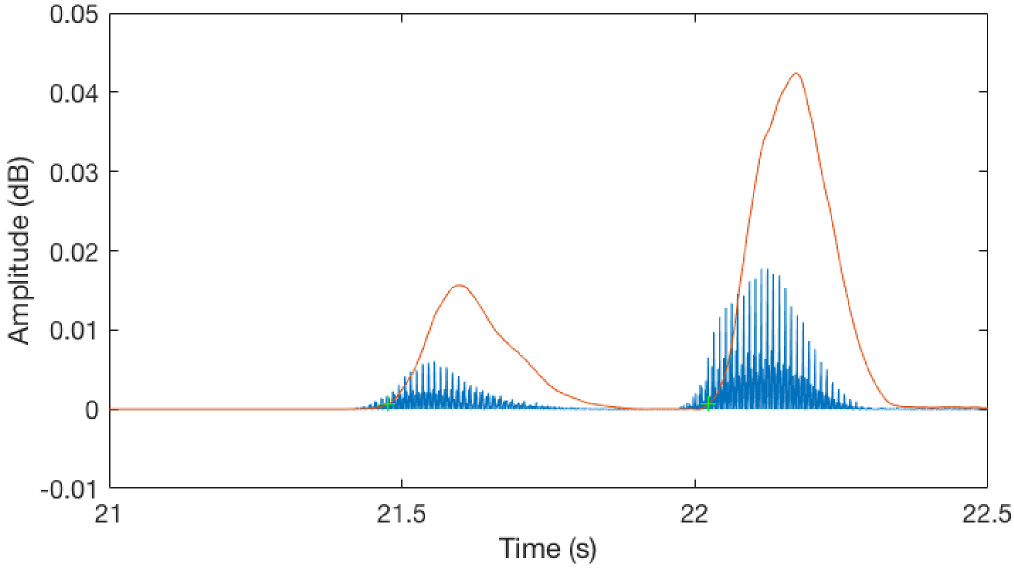

Figure 3.11: Crosses where the threshold marks the onsets.

The data with times of every onset from each instrument recorded is included in a matrix. Sometimes the musician is playing quieter and some tone is not detected and sometimes other sounds may come in to the recording and are detected in the Matlab script as extra tones. The signal must be cleaned up as only the onset of the tone will be analysed. The onset is the most interesting part when it comes to timing according to 2.2.2 and is also the easiest part of the tone to detect. The row of data for every recorded instrument needs to be manually checked and disowned the right direction in the matrix so the columns conform for every tone and wrong detections are removed. Since this is very time consuming only parts of the recordings are analysed. The first five measures and the last four are chosen. In these measures all voices of the orchestra have the same rhythm and it is the same rhythm in the beginning and the end. This makes it easier to compare. The middle part of the piece do affect the other parts and is taken into consideration when listening to the recordings but these measures are not treated in the numerical onset detection. Eight try-outs are chosen to be analysed with the onset detection, which can be seen in 4.3. These are considered most interesting because they contain the orchestra playing with just sight and with just hearing in all three seating arrangements. Having both sight and hearing and having neither of them in arr2 also are analysed. Further are other try-outs, that are not treated with the numerical onset analyse, listened to and conclusions are drawn from that.

3.6 Statistical analysis

The times from the numerical onset detection are merged in to a matrix in figure 3.12 where every instrument are listed in the selected try-outs.

Beat	Vln 1_01	Vln 1_02	Vln 2_01	Vln 2_02	Vla_01	Vla_02	Cello_01	Cello_02	Dbl Bass_01	Mean
1	5,5187	5,6211	5,5852	5,483	5,5833	5,5792	5,6774	5,647	5,5968	5,58796667
2	6,1895	6,1849	6,2348	6,1826	6,1927	6,177	6,1524	6,192	6,2412	6,19412222
3	6,845	6,7988	6,9017	6,854	6,8468	6,7937	6,8081	6,847	6,8585	6,83928889
4	7,4812	7,4172	7,5734	7,4476	7,472	7,491	7,4915	7,4293	7,5459	7,48323333
5	8,1262	8,1044	8,2158	8,1051	8,0671	8,1435	8,2066	8,117	8,1908	8,14183333
6	8,737	8,7521	8,863	8,7493	8,6886	8,7596	8,8385	8,731	8,8603	8,77548889
7	9,3804	9,3327	9,5034	9,3899	9,3494	9,3829	9,47	9,351	9,4569	9,40184444
8	10,07	10,014	10,138	10,043	9,967	10,017	10,087	10,015	10,136	10,0541111
9	10,683	10,709	10,755	10,667	10,63	10,655	10,742	10,671	10,781	10,6992222
10	12	12	12,045	12,001	11,979	11,944	12,048	11,97	12,057	12,0048889
11	13,242	13,319	13,396	13,34	13,355	13,295	13,346	13,376	13,367	13,3373333
12	14,375	14,623	14,639	14,632	14,707	14,6	14,644	14,604	14,661	14,6094444
13	15,802	15,894	15,95	15,946	15,884	15,925	15,932	15,9	16,017	15,9166667
14	26,276	26,356	26,299	26,303	26,188	26,28	26,33	26,261	26,217	26,2788889
15	26,89	26,98	26,963	26,909	26,817	26,94	26,97	26,862	26,862	26,9103333
16	27,492	27,566	27,591	27,566	27,469	27,569	27,54	27,47	27,524	27,5318889
17	28,13	28,176	28,198	28,169	28,131	28,189	28,11	28,108	28,191	28,1557778
18	28,767	28,781	28,819	28,769	28,743	28,813	28,835	28,76	28,854	28,7934444
19	29,39	29,367	29,46	29,379	29,391	29,438	29,423	29,254	29,51	29,4013333
20	30,035	29,994	30,068	30,009	30,003	30,054	30,08	29,95	30,138	30,0367778
21	30,665	30,639	30,732	30,63	30,597	30,662	30,69	30,591	30,78	30,6651111
22	31,295	31,257	31,392	31,274	31,248	31,285	31,331	31,277	31,424	31,3092222
23	32,532	32,597	32,608	32,517	32,584	32,574	32,593	32,552	32,648	32,5783333
24	33,859	33,951	33,945	33,832	33,887	33,896	33,968	33,974	34,035	33,9274444

Figure 3.12: The collected onset times, $t_{onset,i}$, in seconds and the mean value for every beat.

To get a measure at how well synchronised the particular try-out is, the mean absolute deviation, MAD, is calculated for every beat.

$$\frac{t_{onset,1} + t_{onset,2} ... + t_{onset,i}}{i} = t_{onset,mean} \tag{3.1}$$

$$t_{onset,i} - t_{onset,mean} = t_{dev,i} \tag{3.2}$$

$$\frac{|t_{dev,1}| + |t_{dev,2}| ... + |t_{dev,i}|}{i} = t_{MAD} \tag{3.3}$$

where

$t_{onset,i}$ is the actual time the beat is played by one instrument

$t_{onset,mean}$ is the mean time of the onset

$t_{dev,i}$ is the deviation from the mean time of the onset

t_{MAD} is the Mean Absolute Deviation

In figure 3.13 t_{MAD} is calculated for every beat in one try-out. The mean absolute deviation is not equal to the more common standards deviation, nor the absolute value, it is the actual mean deviation in time from the mean value of the onset times. In music played by humans there is no absolute correct time where the beat should be but this makes a time to relate to. There is no correct time since there are always small variations in interpretation. The mean absolute deviation t_{MAD}, is calculated for the beginning and ending part of every try-out. The onset times from eye1ear0dir and eye0ear1click for all three seating arrangements and for eye1ear1 and eye0ear0 for arr2 are treated this way. See equations 3.1 to 3.3.

Vln 1_01_abs	Vln 1_02_ab	Vln 2_01_ab	Vln 2_02_ab	Vla_01_abs	Vla_02_abs	Cello_01_ab	Cello_02_ab	Dbl Bass_01	Beat	Mean abs dev	
0,069266667	0,03313333	0,00276667	0,10496667	0,00466667	0,00876667	0,08943333	0,05903333	0,00883333	1	0,04231852	
0,004622222	0,00922222	0,04067778	0,01152222	0,00142222	0,01712222	0,04172222	0,00212222	0,04707778	2	0,01950123	
0,005711111	0,04048889	0,06241111	0,01471111	0,00751111	0,04558889	0,03118889	0,00771111	0,01921111	3	0,02605926	
0,002033333	0,06603333	0,09016667	0,03563333	0,01123333	0,00776667	0,00826667	0,05393333	0,06266667	4	0,03752593	
0,015633333	0,03743333	0,07396667	0,03673333	0,07473333	0,00166667	0,06476667	0,02483333	0,04896667	5	0,04208148	
0,038488889	0,02338889	0,08751111	0,02618889	0,08688889	0,01588889	0,06301111	0,04448889	0,08481111	6	0,0522963	
0,021444444	0,06914444	0,10155556	0,01194444	0,05244444	0,01894444	0,06815556	0,05084444	0,05505556	7	0,04994815	
0,015888889	0,04011111	0,08388889	0,01111111	0,08711111	0,03711111	0,03288889	0,03911111	0,08188889	8	0,04767901	
0,016222222	0,00977778	0,05577778	0,03222222	0,06922222	0,04422222	0,04277778	0,02822222	0,08177778	9	0,04224691	
0,004888889	0,00488889	0,04011111	0,00388889	0,02588889	0,06088889	0,04311111	0,03488889	0,05211111	10	0,03007407	
0,095333333	0,01833333	0,05866667	0,00266667	0,01766667	0,04233333	0,00866667	0,03866667	0,02966667	11	0,03466667	
0,234444444	0,01355556	0,02955556	0,02255556	0,09755556	0,00944444	0,03455556	0,00544444	0,05155556	12	0,05540741	
0,114666667	0,02266667	0,03333333	0,02933333	0,03266667	0,00833333	0,01533333	0,01666667	0,10033333	13	0,04148148	0,04009896
0,002888889	0,07711111	0,02011111	0,02411111	0,09088889	0,00111111	0,05111111	0,01788889	0,06188889	14	0,0385679	
0,020333333	0,06966667	0,05266667	0,00133333	0,09333333	0,02966667	0,05966667	0,04833333	0,04833333	15	0,04703704	
0,039888889	0,03411111	0,05911111	0,03411111	0,06288889	0,03711111	0,00811111	0,06188889	0,00788889	16	0,03834568	
0,025777778	0,02022222	0,04222222	0,01322222	0,02477778	0,03322222	0,04577778	0,04777778	0,03522222	17	0,03202469	
0,026444444	0,01244444	0,02555556	0,02444444	0,05044444	0,01955556	0,04155556	0,03344444	0,06055556	18	0,03271605	
0,011333333	0,03433333	0,05866667	0,02233333	0,01033333	0,03666667	0,02166667	0,14733333	0,10866667	19	0,05014815	
0,001777778	0,04277778	0,03122222	0,02777778	0,03377778	0,01722222	0,04322222	0,08677778	0,10122222	20	0,0428642	
0,000111111	0,02611111	0,06688889	0,03511111	0,06811111	0,00311111	0,02488889	0,07411111	0,11488889	21	0,04592593	
0,014222222	0,05222222	0,08277778	0,03522222	0,06122222	0,02422222	0,02177778	0,03222222	0,11477778	22	0,04874074	
0,046333333	0,01866667	0,02966667	0,06133333	0,00566667	0,00433333	0,01466667	0,02633333	0,06966667	23	0,03074074	
0,068444444	0,02355556	0,01755556	0,09544444	0,04044444	0,03144444	0,04055556	0,04655556	0,10755556	24	0,05239506	0,04177329
										0,04086636	

Figure 3.13: The deviation, $t_{dev,i}$, in seconds for every instrument and beat and the mean absolute deviation, t_{MAD}, in seconds for every beat.

The analyses of the answers from the questionnaires in Appendix B are conducted for every try-out. The answers are analysed to see common statistical metrics including its mean and median. Mode is also calculated which gives the most common answer. This makes it able to list the try-outs from most difficult to least, as considered by the musicians. To compare the answers for eye1ear0 and eye0ear1 different statistical techniques to compare set or groups are used. Significance test were applied with five percent significance level. The try-outs for eye1ear0 and eye0ear1 in each one of the three seating arrangement are analysed with the statistical non parametric tests Mann-Whitney U Test and Wilcoxon Signed Ranks Test. Non parametric tests are used when there are too few data points to achieve normal distribution or when data is skewed. These specific tests are used when the mean score of a continuous variable is compared between two groups or two sets of data. In the questionnaire data: "How difficult". By doing these tests it is possible to see whether the different seating arrangements have different effects on the timing and to see how the different parameters affect the try-outs in the same seating arrangement. The coefficient Cronbach's Alpha check the consistence between the try-outs. Further information about these statistical techniques are found below.

3.6.1 Mann-Whitney U Test

Mann-Whitney is used to see the differences between two groups where the groups are supposed to be independent of each other. For this thesis is Mann-Whitney U test used for the analysis of the try-outs with Mozart. The first group is eye1ear0 and the other one is eye0ear1, for arr1, arr2 and arr3. For example, is eye0ear1 as difficult as eye1ear0 in arr1? Other tests that are used when there are a larger amount of data compares means of the two groups, while Mann-Whitney uses the median of each group [10]. In the output of the test the significance level is the most interesting. If the significance level from the output of the test are less than or equal 0.05, five percent, the result is significant and there is a statistically significant difference between the two groups.

3.6.2 Wilcoxon Signed Ranked Test

The Wilcoxon test compares two related samples where the same participants have been measured under different conditions. The different conditions in this case are all the try-outs with eye1ear0 and all the try-outs with eye0ear1. The Wilcoxon test does neither compare means as they convert the answers to ranks instead and compare the different conditions with them. If the significance level in the output from this test are less or equal than 0.5 it means that the two samples are significantly different [10].

3.6.3 Cronbach's Alpha

The Cronbach's Alpha is the most commonly used coefficient to show internal consistency within a set of data. It gives a value of how high the equality is between the try-outs in the set. The value is between zero and one where one shows that the set of data is consistent and hang together. If they are measuring the same thing. When the coefficient is one, the different variables have perfect correlation, everything over 0.5 is ok. Cronbach's Alpha when items deleted takes out one try-out at a time in the set to see whether the correlation withing the sets gets better [10].

3.7 Recording equipment

1. Microphones: 13 miniature microphones, DPA 4099 and 4060, placed on instruments in the orchestra. Four of them are placed in pairs on two dummy heads to get a binaural recording from the conductors position and from an audience position (see figure 3.14). Six DPA violin clips to mount the microphone on the instruments, two for violoncello and one for double bass.

2. Soundinterface: Focusrite Sapphire 56, 8 channels. Microphone preamplifier: RME Octomic, 8 channels.

3. Digital audio workstation: Protools

4. Wireless system to send noise to ear cuffs: One transmitter SR 300 IEM G3 and 30 receivers EK 300 IEM G3

5. 29 ear cuffs 3M Peltor HTM79A

Figure 3.14: Dummy head in audience position (Karl Tillberg 2016). See figure 4.3 for position in the audience.

4

Result and Discussion

The aim is to find the answers for the objectives in section 1.1. They could be rewritten to the questions: Is it hearing or sight that have the most relative importance for playing in synchrony? Is there any difference between the beginning of the piece and the end? Is it more difficult to play synchronised with Mozart than one very easy piece of music? Do the different instrument groups behave differently and how do the different seating arrangements and distances between musicians affect the results?

4.1 Measurements of the hall

Impulse response measurement gives a lot of information about the room and here are some information displayed. The orchestra tests are not depending on the room, more than it should be in a normal concert hall for the orchestra. The onset times are just relative to each other, but different acoustics could probably affect the ability to synchronise. No comparison between halls are made to test that. The reverberation time is displayed in octave bands from 125 Hz to 4000 Hz. This is the interval where the loudspeaker used for the measurement is omni-directional and has enough power. T30 is interpolated to get the reverberation time of T60. It is quite short reverberation time in this hall as seen in table 4.1.

Table 4.1: Reverberation time for concert hall used in thesis

Octaveband	125	250	500	1k	2k	4k
$T60$	1,98	1,84	1,72	1,53	1,42	1,23

For this test variable absorptive roller curtains are exposed in the hall. Figure 4.1 shows the impulse response between the first violinist position on one side of the stage and the double base position on the other side of the stage, 15.9 meter apart. The first top in figure 4.1 is the direct sound and some strong reflections are following shortly after. After 10 milliseconds delay there is a strong reflection. That corresponds to an extra distance of 3.43 meter for the reflected sound, compared to the direct sound. These early reflections come from the floor, the nearest wall if the instrument is near to one, the grand piano in the middle of the stage or music

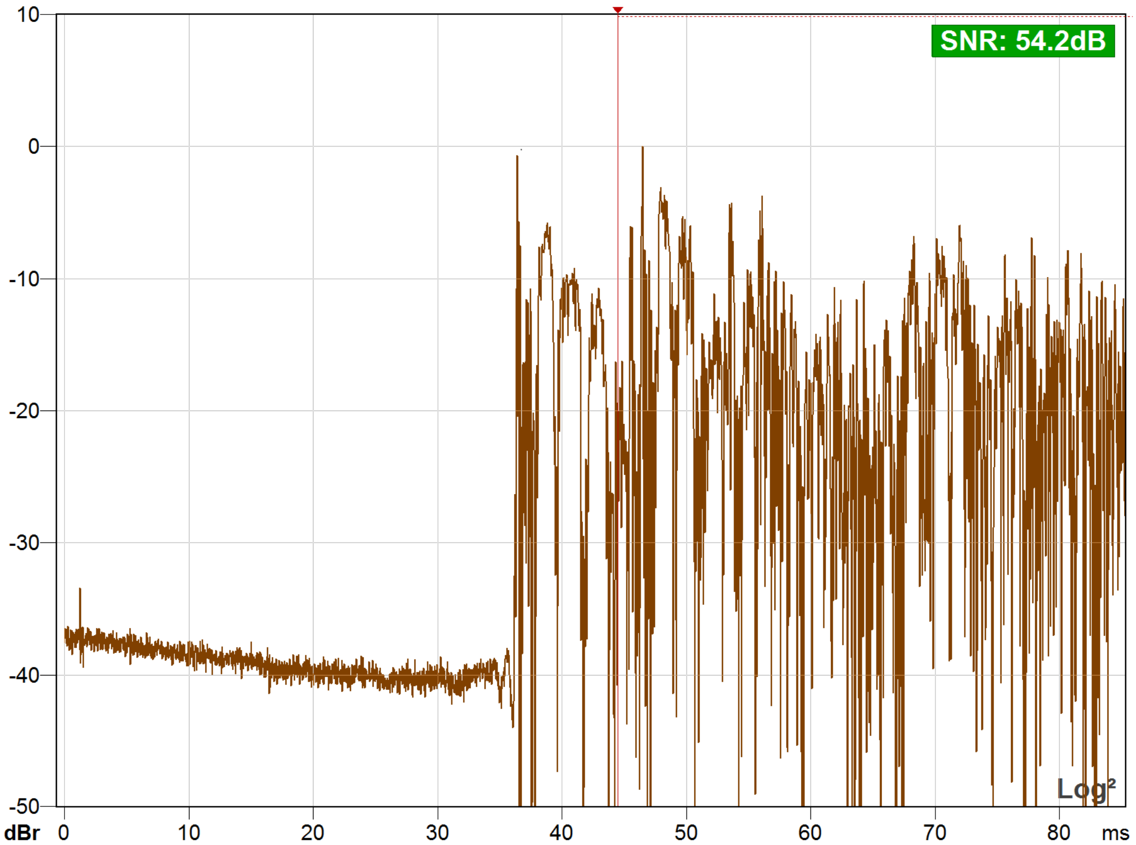

Figure 4.1: Impulse response between the first violin and the double bass in arr1.

stands. Reflection from the ceiling and overhead reflectors comes later as it has larger distance to the orchestra. In figure 4.2 and 4.3 there are drawings of the hall and distances between musicians on stage and audience. Short delay reflections are colouring the sound by changing its interference pattern. All the other clutter reflections are the diffusion and reverberation of the room. The thing that affects the timing most is probably how long time the sound is taking from one side of the stage to the other. It takes 46.23 milliseconds from when the first violin is taking her tone until the double base hears it. When the bass tone has been played and travelled back to the violin $46.23 \times 2 = 92.46$ milliseconds have elapsed.

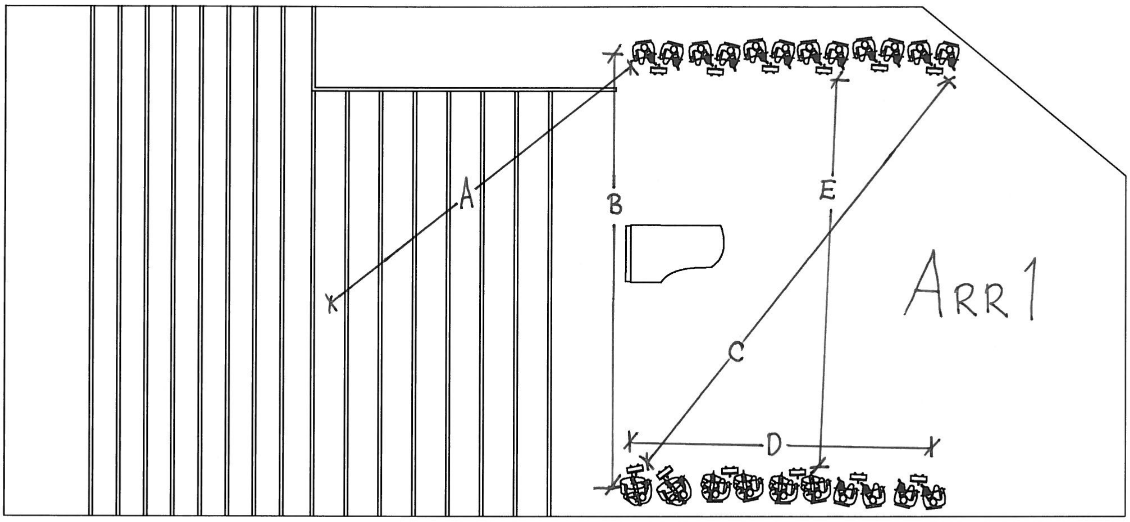

Figure 4.2: Floor plan of the concert hall for arr1. Distances A-E are found in table 4.2.

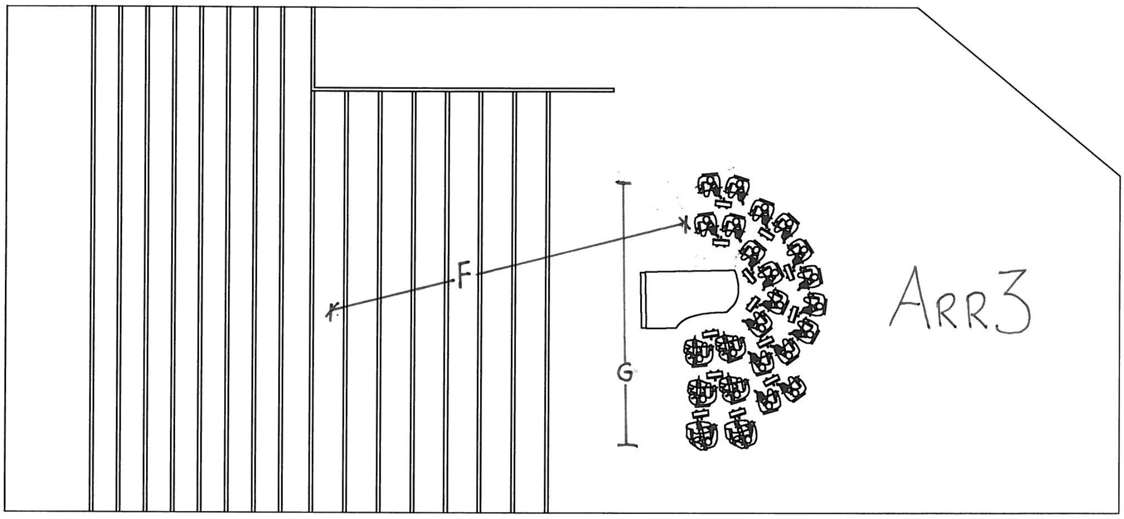

Figure 4.3: Floor plan of the concert hall for arr3. Distances F-G are found in table 4.2.

Table 4.2: How long it takes for the sound to travel

Letterindrawings	A	B	C	D	E	F	G
Distance(m)	13.4	15.9	12.4	11.1	11.8	11.5	9.5
Time(ms)	39.0	46.2	36.2	32.4	34.3	33.6	27.8

4.2 Preparing tests with duo and string quartet

Before the main test the different parameters need to be tested. Both the preparing tests are conducted in the concert hall of Gothenburg School of music and drama. This is the hall were the main test also is conducted. The first test is conducted by two people and the second with a string quartet. The first aim is to find out how the sound from the other musicians can be masked. The hypothesis is that an earmuff will isolate the player from the other musicians playing but not enough and by playing pink noise it can be sufficiently masked. The second aim is to get a subjective feeling on how difficult it is to synchronise when being far apart and removing visible and/or aural cues. The first test is conducted by musician A playing cello or piano and musician B playing the cello. Both trained amateur musicians. The string quartet is playing the real test piece with the right equipment and parameters to prepare for an efficient planning of the main test.

In table 4.3 and 4.4 different positions are tested and how they work. In the first table the different masking methods are tested. Different ear cuffs with different masking sound is tested. The first ear cuff is Peltor Sport Tac Hunting with 26 dB attenuation. The noise is from the radio in those. However these ear cuffs are not sufficient to mask the other player. The other option is a Peltor Optime II with 31 dB attenuation. In these ear cuffs pink noise is played through small headphones. It is possible to adjust the volume so that the noise could mask the other player while hearing of self is sufficient. The setup with head phones in Peltor Optime II is handmade and not possible to do for all ear cuffs needed. Therefor Peltor HTM79A with built-in head phones are obtained from the company 3M and used in the test. One important note is that the noise shall be gradually increased for the test persons. When starting the noise at its full volume the test persons can be frightened.

The results from when the musicians sit on different distances to each other, 10 and 0.9 meters, and test their reaction to the different parameters are displayed in table 4.4. Mostly playing a Russian piece for cello and piano named Im Garten. This is one easy piece with distinct beats. The test shows that the delay that comes with large distances clearly have an effect on the timing in ensemble playing. Synchronisation is much harder in large distances.

Table 4.3: Testing masking methods

Testnumber	Distance (m)	A	B	Music on celli
1	13	eye1ear1	eye1ear0	pizz and arco
2	13	eye1ear1	eye1ear1	pizz

1. B need to concentrate to hear one self and do not hear A playing.
2. One test person is the leader and start playing. The other test person adjust to what is heard but the leader experience the tones to have a disturbing delay.

Table 4.4: Testing parameters in different distances

$Testnumber$	Distance (m)	A	B	Music on piano and cello
3	10	eye1ear1	eye1ear1	piano and cello, quarters
4	10	eye1ear1	eye1ear1	Im Garten
5	10	eye1ear1	eye1ear0	Im Garten
6	10	eye1ear1	eye1ear1	Im Garten
7	10	eye1ear1	eye0ear0	Im Garten
8	0.9	eye1ear1	eye1ear1	Quarter notes
9	0.9	eye1ear1	eye1ear1	Im Garten
10	0.9	eye1ear1	eye1ear0	Im Garten
11	0.9	eye1ear0	eye1ear1	Im Garten
12	0.9	eye0ear1	eye0ear1	Im Garten

3. The follower do lag a bit.
4. The leader starts, follower lag. $\frac{10m}{343m/s} = 29ms$, $29 \times 2 = 58ms$ lag. From A to B, back to A that hears the lag.
5. Not synchronised in the middle. Ends at the same time. B with masked sound follows the movement from head and fingers from A.
6. Person with eye0ear0 plays just by one self. The other person can follow.
7. The leader hears that the other person lags.
8. No problem. Normal setting for chamber music.
9. No problem.
10. Asynchronous from time to time. Person with eye1ear1 is the leader.
11. A start up time where there are much asynchronous but after that is the timing fine.
12. Few problems.

4.3 Main test with the orchestra

In the results for the main test are first the analysis of the numerical onset detection displayed with single values and deviations shown in box plots. Then the analysis of the answers from the questionnaires. In this test are the orchestra playing the piece of music by Lidar.

4.3.1 Results by the onsets times

The try-outs with parameters eye0ear1click (just hearing) are the opposite to eye1ear0dir (just sight). In eye0ear1click is the orchestra started by clicks and in the other by the conductor. These try-outs in all three seating arrangements are compared by analyse of the recorded sound both in Matlab and by listening and also analyse of the answers in the questionnaire. The try-outs are shown in table 4.5:

Table 4.5: Try-outs compared

Just sight	Just hearing	With or without
arr1eye1ear0dir	arr1eye0ear1click	arr2eye0ear0dir
arr2eye1ear0dir	arr2eye0ear1click	arr2eye1ear1dir
arr3eye1ear0dir	arr3eye0ear1click	

In arr1 it is clear that eye1ear0 makes it more difficult to play in synchrony than eye0ear1, having just hearing to rely on. The same thing is detected for seating arrangement two but the difference is not as big. The mean values of deviations for different parts as well as the whole piece, measured as t_{MAD} for every beat, are found in table 4.6. The value corresponds to how many milliseconds the musicians are before or after the beat on average. As told in chapter 2 the smallest deviation detected by humans is 20 milliseconds. All the values are over this mark.

Table 4.6: Mean of mean absolute deviations times (t_{MAD}) for each try-out

Seating arrangement	Beginning (ms)	End (ms)	Whole piece (ms)
1 eye1ear0	59	60	59
1 eye0ear1	31	26	29
2 eye1ear0	55	37	46
2 eye0ear1	31	38	34
2 eye1ear1	29	34	31
2 eye0ear0	43	49	46
3 eye1ear0	40	42	41
3 eye0ear1	27	28	27

Recordings for all instruments from these try-outs are processed in the Matlab script

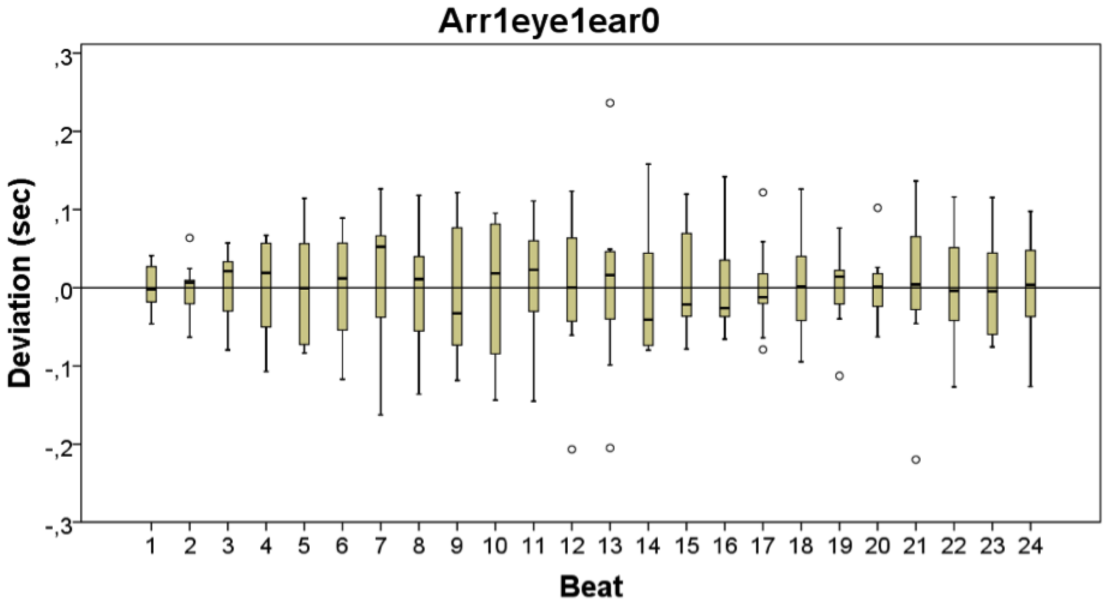

Figure 4.4: Arr1eye1ear0: Deviation around the mean value of onset times in each beat.

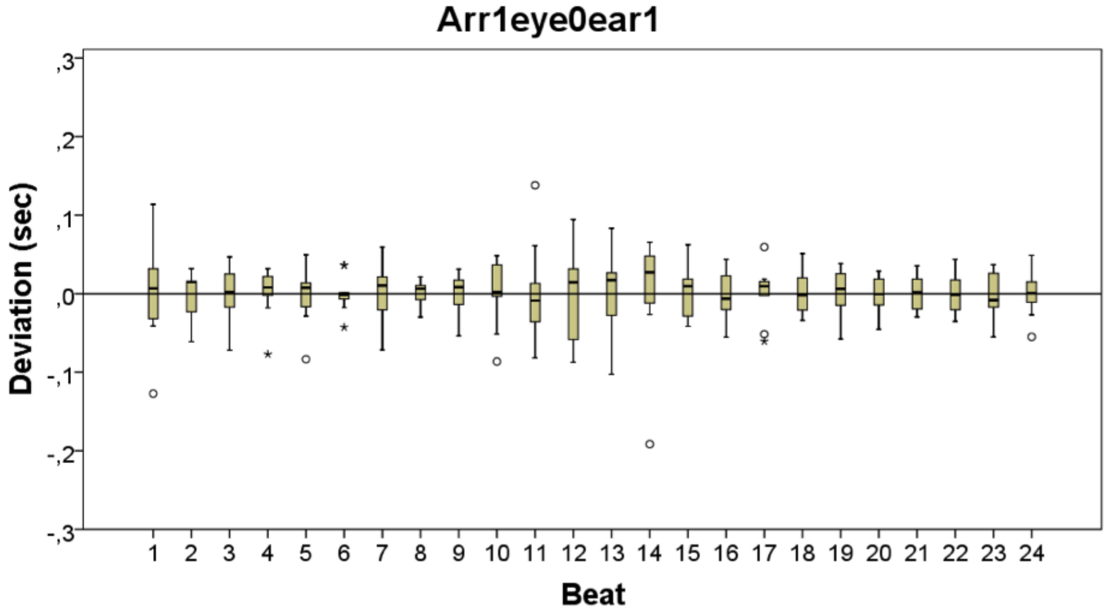

Figure 4.5: Arr1eye0ear1: Deviation around the mean value of onset times in each beat.

where the onset of each tone is achieved. The box plots in figure 4.4, 4.5 and the following figures, show the deviations from the mean value of the onset times for every beat. Beats 1-13 are the first five bars and beat 14-24 are the last four bars of the Lidar piece. The plots paired together are the try-outs for the same seating arrangements.

The deviations become larger with just sight, eye1ear0, than with just hearing, eye0ear1. In the box plot the longer boxes and the longer whiskers that mark the most outer time onsets show this. Every box shows the upper and lower quartile around the median, which is marked as a line inside the box. The deviations can be related to the mean onset time of every beat that is on the zero line. When the median is above the mean line more musicians are before of the mean onset time than after and when having the median below the line many musicians are late relative to the mean onset time. The whiskers will only extend to 1.5 times of the box length. The rings and stars outside the whiskers are outliers that are more distant from the other observations. These onsets are way off from the others and therefore get their own dots and are not included in the whiskers. The mean onset time is the nearest we can come to a correct time of every beat. In the analysis of arr1 time onsets for Viola1 are deleted. It has too large deviations due to some difficulties in the onset detection.

Figure 4.6: First violins and violas on left side of the stage in arr1 (Annakarin Berntson 2016)

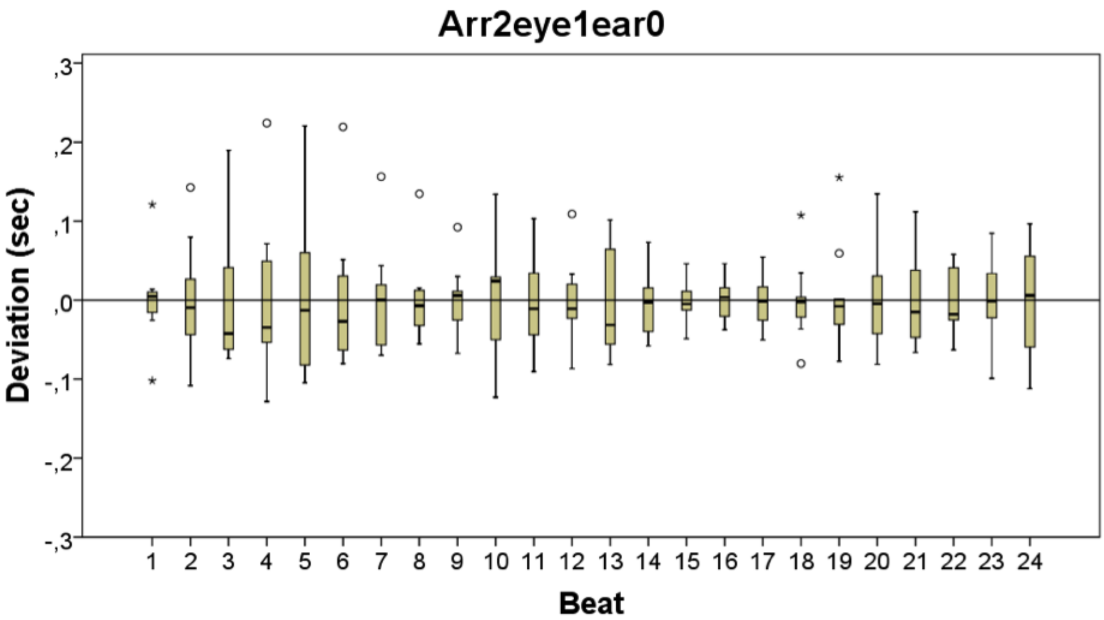

Figure 4.7: Arr2eye1ear0: Deviation around the mean value of onset times in each beat.

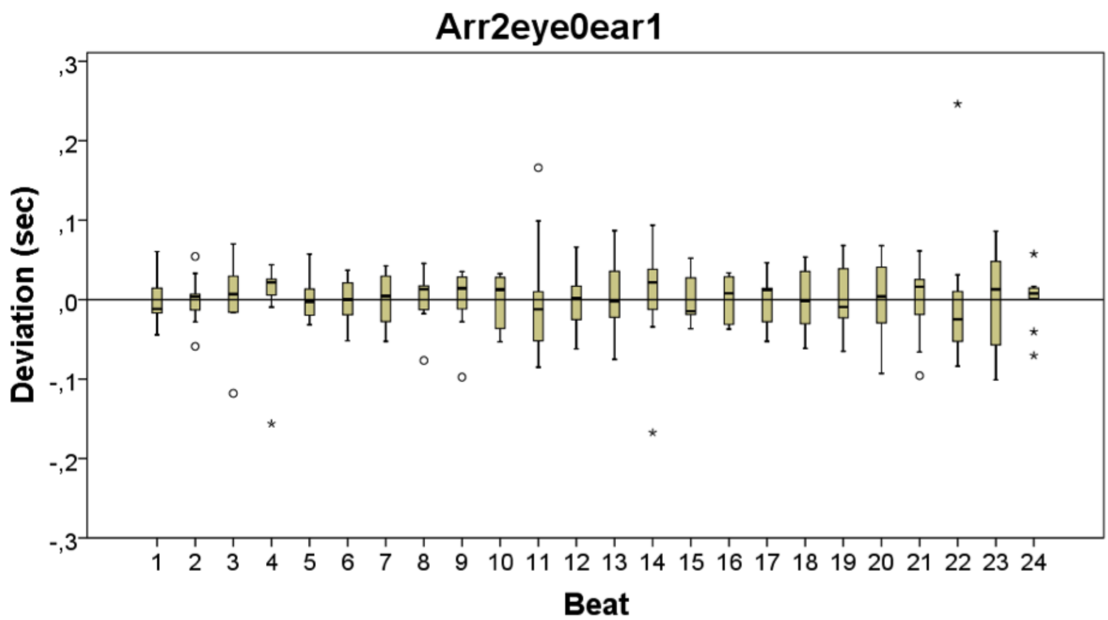

Figure 4.8: Arr2eye0ear1: Deviation around the mean value of onset times in each beat.

A difference is noticed in arr2 compared to the other seating arrangements. The difference between the arr2eye1ear0 and the arr2eye0ear1 is just one millisecond in the end part of the piece, see table 4.6, which means no difference in value of synchronisation. The end part starts with all voices except cello/double bass having three beats brake. The base instruments have some notes leading to the end part and it is normal for the musicians to give extra attention to the voice playing to know when to start playing again. When taking away some senses the senses left are working harder. The musicians could feel the vibrations from cello and double bass through the floor (interview with musicians). This could make them aware of when to start and able to keep the timing throughout the piece. The vibrations are not considered in this thesis but the musicians mentioned the vibrations from the bass section several times. Vibrations that they, when playing normal pieces with all senses, don't notice consciously.

In arr2 the musicians are seated as the strings normally do in a symphony orchestra, on a queue. A normal situation to them and this could be the reason why the end part is as synchronised in both cases. This is also part of the explanation why the beginning part in arr2eye1ear0 is much better than the end part. Another part of the explanation is that in the beginning of the end part it is clear to the musicians where they should look to know when to start, the cello/bass section, and they can follow them until the end.

Figure 4.9: Picture from recording session (Karl Tillberg 2016).

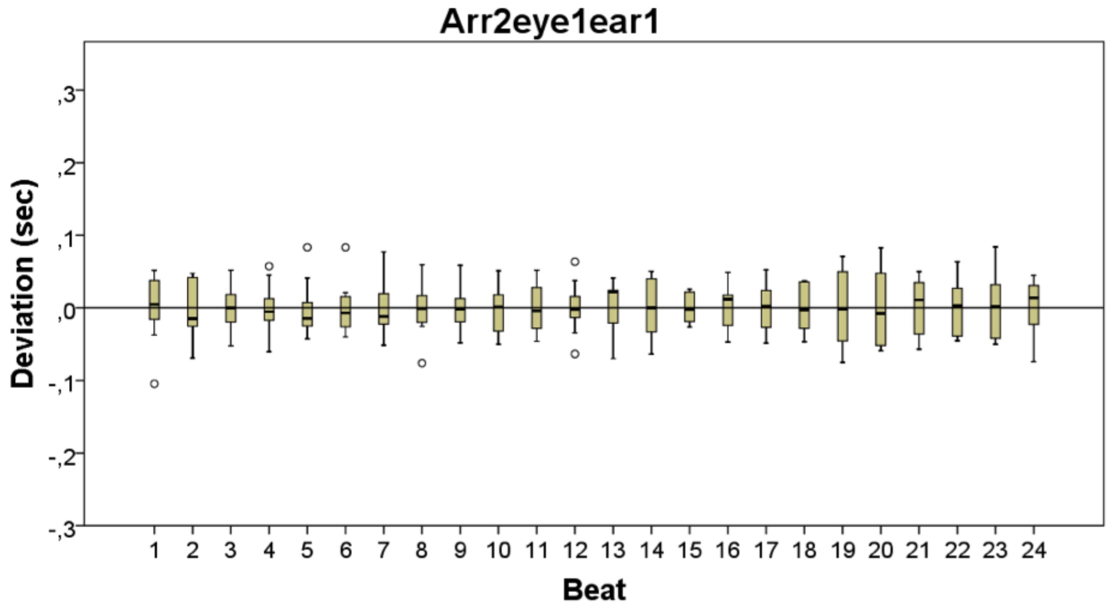

Figure 4.10: Arr2eye1ear1: Using both senses.

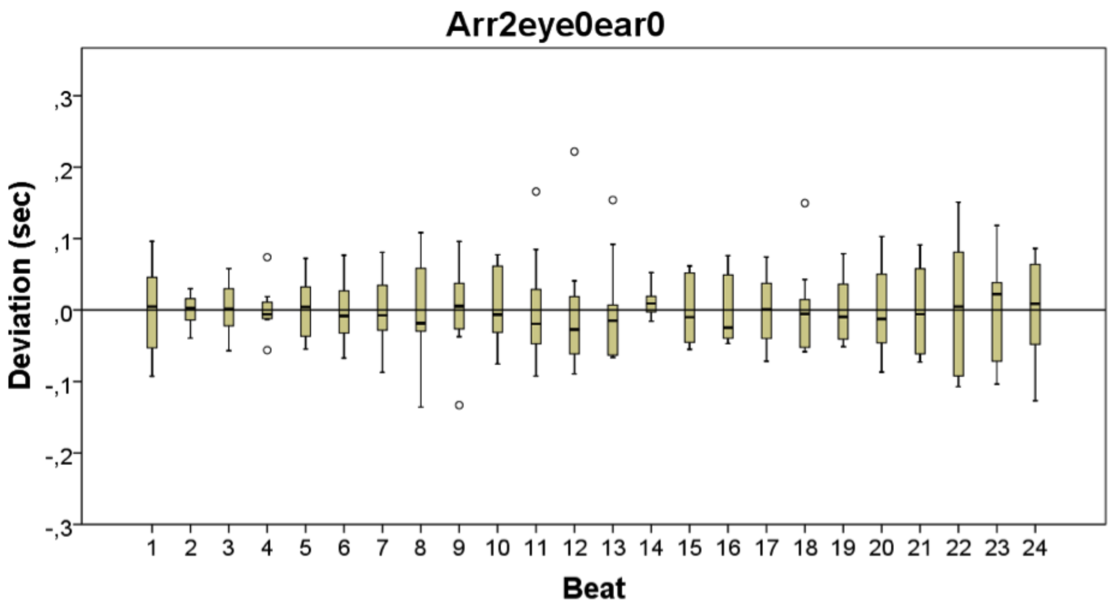

Figure 4.11: Arr2eye0ear0: Can not see, can not hear.

It is interesting that arr2eye0ear1 is so much better synchronised than arr2eye1ear0. The deviation for the whole piece is 34 milliseconds for arr2eye0ear1 and 46 millisecond for arr2eye1ear0. In eye0ear1, just hearing, the orchestra is started by clicks. The metronome clicks arrive later to the musicians on the left side on stage than to the orchestra members next to the loud speaker on the right side. So it would be harder to synchronise, but the musicians compensating for this some how. They differ in the first notes but the timing become better and better as the piece continues. This is more discussed in section 4.5. In arr2 even eye1ear1 is over the limit of synchronisation. The orchestra has a problem with synchronisation in this seating arrangement. It could be that they are missing the instruments that normally sits in the middle of the stage binding the two queues together. Try-out arr2eye1ear1 have so large deviations so it can be detected but it is still smaller than when removing one or two senses in arr2. Compare figure 4.10 and 4.11 to the other box plots for arr2.

Figure 4.12: Picture from recording session (Karl Tillberg 2016).

The deviations in arr3, seen in figure 4.13 and 4.14, differ from the other seating arrangements. The difference between eye1ear0 and eye0ear1 is smaller, it can be detected but not as much. The difference between the boxes in figure 4.4 and 4.5 are much larger. When sitting close together timing is not as affected when removing one sense. The advantage of sitting close together is also demonstrated further down in section 4.3.2 where the result of the Wilcoxon test with questionnaire data.

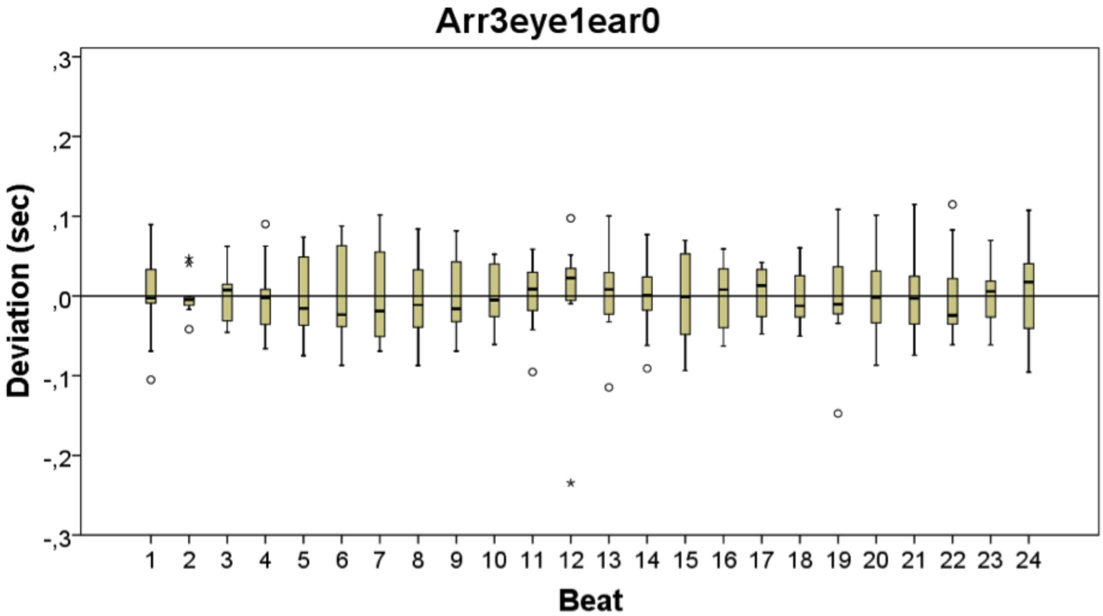

Figure 4.13: Arr3eye1ear0: Deviation around the mean value of onset times in each beat.

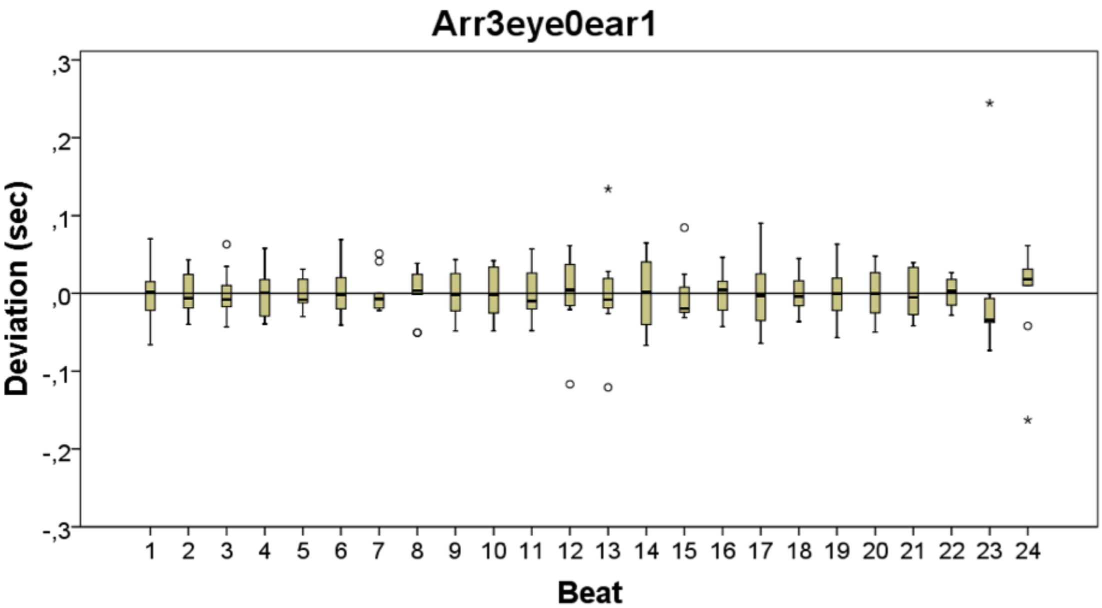

Figure 4.14: Arr3eye0ear1: Deviation around the mean value of onset times in each beat.

4.3.2 Result Questionnaire

The answers from the questionnaires are treated with statistical techniques explained in the Method section 3.6. Comparing the median and mean of the answers shows that the musicians find the most difficult settings to play in synchrony are when playing try-outs with eye0ear0. In figure 4.7 every try-out is sorted from the most difficult in the top down to the least difficult. The least difficult to play in synchrony is eye1ear1. The try-outs in the middle are eye1ear0 and eye0ear1, where one sense is taken away. This mirrors the result from the other analyses above.

Table 4.7: Try-outs sorted from most difficult to least.

Most difficult	N		Mean	Median	Mode	Std.D	Min	Max
	Valid	Missing						
arr1eye0ear0dir	21	0	5.71	6	6	1.10	1	6
arr1eye0ear0click	21	0	5.33	5	6	0.79	3	6
arr2eye0ear0click	21	0	4.47	5	5	1.40	2	6
arr3eye0ear0dir	21	0	4.33	5	6	1.55	2	6
arr2eye0ear0dir	20	1	4.15	4.5	5	1.34	2	6
arr3eye0ear0click	20	1	4.05	4	4	1.46	1	6
arr1eye1ear0click	21	0	3.14	3	3	1.35	3	6
arr1eye1ear0dir	21	0	3.04	3	4	1.24	1	5
arr2eye1ear0dir	21	0	2.61	3	2	1.02	1	4
arr3eye0ear1click	20	1	2.4	2	2	1.31	1	6
arr2eye0ear1dir	21	0	2.33	2	3	0.96	1	4
arr1eye0ear1click	21	0	2.28	2	1	1.27	1	5
arr2eye1ear0click	21	0	2.19	2	2	0.92	1	4
arr3eye1ear0dir	21	0	2.04	2	2	0.58	1	3
arr1eye0ear1dir	21	0	2.05	2	2	0.80	1	4
arr3eye1ear0click	21	0	1.90	2	2	0.77	1	3
arr2eye0ear1click	21	0	1.80	2	2	0.67	1	3
arr3eye0ear1dir	21	0	1.80	2	2	0.81	1	4
arr1eye1ear1click	21	0	1.57	1	1	0.97	1	5
arr2eye1ear1click	21	0	1.33	1	1	0.57	1	3
arr3eye1ear1dir	21	0	1.23	1	1	0.88	1	5
arr1eye1ear1dir	21	0	1.19	1	1	0.51	1	3
arr2eye1ear1dir	21	0	1.14	1	1	0.47	1	3
arr3eye1ear1click	21	0	1.04	1	1	0.21	1	2

The musicians find the level of difficulty very different when playing with eye1ear0 than when playing with eye0ear1, even when sitting in the same way. The Significance level for both arr1 and arr2 in the output from the Wilcoxon Signed Ranks Test are below 0.05 meaning that there is a significant difference between the try-outs in the pair, eye1ear0 and eye0ear1. Arr2 have a ten times lower Significance level than arr1 so there it differ the most.

Wilcoxon Signed Ranks Test				
Ranks				
		N	Mean Rank	Sum of Ranks
arr1eye0ear1click - arr1eye1ear0dir	Negative Ranks	13[a]	9,50	123,50
	Positive Ranks	4[b]	7,38	29,50
	Ties	4[c]		
	Total	21		
arr2eye0ear1click - arr2eye1ear0dir	Negative Ranks	13[d]	7,69	100,00
	Positive Ranks	1[e]	5,00	5,00
	Ties	7[f]		
	Total	21		
arr3eye0ear1click - arr3eye1ear0dir	Negative Ranks	5[g]	5,50	27,50
	Positive Ranks	7[h]	7,21	50,50
	Ties	8[i]		
	Total	20		

Test Statistics[a]			
	arr1eye0ear1click - arr1eye1ear0dir	arr2eye0ear1click - arr2eye1ear0dir	arr3eye0ear1click - arr3eye1ear0dir
Z	-2,285[b]	-3,090[b]	-,933[c]
Significance level	,022	,002	,351

a. Wilcoxon Signed Ranks Test
b. Based on positive ranks.
c. Based on negative ranks.

Figure 4.15: Output from Wilcoxon Signed Rank test. The Significance level is discussed in this section.

Eye1ear0 is often above eye0ear1 they have the same setting in the list in table 4.7, meaning that synchronisation is more difficult with eye1ear0 than eye0ear1. The big difference in the musicians' subjective opinions of the difficulties of eye1ear0/eye0ear1 could be affected by them having the hypothesis that eye1ear0 will be the most difficult. This hypothesis is demonstrated over and over again when talking to different people before the test, both participants and others. For arr3 there is no significant difference. The Significance level is above 0.05 by far. This is when sitting closest to each other which again seems to make synchronisation easier.

The answers from the musicians show how big differences there are when playing with only sight or with only hearing. To test the reliability of the try-outs in the structural test is the coefficient Cronbach's Alpha declared for two sets of try-outs. The sets are shown in table 4.8 and 4.9. This is to see if some settings differ from the others. The first set are the three try-outs with eye1ear0, and the other with eye0ear1. For all three seating arrangements. Cronbach's Alpha when item deleted take away one try-out at a time in the set and gives a value of the correlations within the try-outs left. The three parts are combined to a Cronbach's alpha for the whole set. Both sets have 0.6-0.7 and that is an estimation of how good reliability the try-out have. A number above 0.5 indicates a good reliability, as told in section

3.6. They measure the same things in the try-outs in every set. Even when having different seating arrangement the structural test and questionnaire in this thesis can tell how well only sight compared to only hearing is.

Table 4.8: Cronbach's Alpha for eye1ear0.

Try-out deleted	Cronbach's Alpha when one try-out deleted
arr1eye1ear0dir	0.557
arr2eye1ear0dir	0.187
arr3eye1ear0dir	0.680
Whole group	0.620

If arr2 in the set for eye1ear0 is deleted the value fall down to 0.187, see table 4.8. This indicates the big difference there is between sitting far apart as in arr1 and very close as in arr3, when having just sight. Arr2, where the spacing is somewhere in between, is needed to make this group correlate well. Testing all parameters in all three seating arrangement are good for the results. For eye0ear1 the values are more even, not depending on which is deleted. Cronbach's Alpha show that even if there are differences in the results from different settings they do indicate the same thing and correlate well to each other.

Table 4.9: Cronbach's Alpha for eye0ear1.

Try-out deleted	Cronbach's Alpha when one try-out deleted
arr1eye0ear1click	0.568
arr2eye0ear1click	0.502
arr3eye0ear1click	0.626
Whole group	0.653

4.4 Lidar vs Mozart

After recording all combinations of settings with the Lidar piece some of the try-outs are recorded with the Mozart piece. These try-outs are analysed by listening and questionnaire. The answers from the questionnaire are treated with the Mann-Whitney U Test. The output is seen in figure 4.16. In this test the try-outs where Mozart is played are compared to the try-outs Lidar is played. The Mean Rank in the third column shows how difficult the musicians find synchronisation in the different try-outs playing the different pieces of music. When having no hearing as in eye1ear0 they find it more difficult to play. In Mozart they think it is even more difficult than in Lidar. Mozart has a higher Mean Rank than Lidar and is therefor considered more difficult by the musicians. The try-out eye1ear1 have almost the same Mean Rank for both pieces. These musicians are well trained so playing any of these pieces with both sight and hearing at the same time is no problem for them. The Mann-Whitney U Test displays if there are statistically significant differences between synchronising playing Mozart and synchronising playing Lidar. The value in the bottom row, Significance level, is the conclusion. Eye1ear0 and eye0ear0 have Significance levels less than 0.05 meaning that there is a statistically significant difference when comparing the level of difficulty when playing the two pieces. As been said earlier the Mean Ranks for Mozart are higher so that piece is considered more difficult to play with good timing. Whereas eye1ear1 and eye0ear1 have significance levels above 0.05 meaning that there is no significant difference in difficultly when playing Mozart or Lidar in those try-outs according to the musicians directly after each try-out.

Mann-Whitney Test

Ranks

Stycke		N	Mean Rank	Sum of Ranks
eye1ear0	Lidar	21	12,43	261,00
	Mozart	29	34,97	1014,00
	Total	50		
eye0ear0	Lidar	21	18,67	392,00
	Mozart	29	30,45	883,00
	Total	50		
eye1ear1	Lidar	21	24,00	504,00
	Mozart	29	26,59	771,00
	Total	50		
eye0ear1	Lidar	21	23,05	484,00
	Mozart	29	27,28	791,00
	Total	50		

Test Statistics[a]

	eye1ear0	eye0ear0	eye1ear1	eye0ear1
Mann-Whitney U	30,000	161,000	273,000	253,000
Wilcoxon W	261,000	392,000	504,000	484,000
Z	-5,547	-3,095	-,972	-1,069
Significance level	,000	,002	,331	,285

Figure 4.16: Output from the Mann Whitney U Test comparing the try-out playing Lidar and Mozart.

The summary of all answers from the questionnaire playing Mozart is seen in table 4.10. They are sorted with the try-out considered most difficult in the top down to the least difficult. Eye0ear0 is of course considered most difficult, which is understandable, but a surprising notice when listening to this try-out with Mozart is that it sounds very well and more synchronised than many other of the try-outs. This indicates that in Mozart the musicians have a common inner pulse that they could rely on because it was synchronised with others. This piece of music was rehearsed more than the Lidar piece which helps them to have time to create this common pulse. Mozart was an experienced composer who knew how to write music to come to its best and also the musicians play this kind of music a lot. The Lidar piece is much more simple in its structure and tone choice but have deliberately been composed with some difficulties as pauses for everybody and then a synchronised start at the same time. This piece of Mozart has more long lines and a natural melody that may be easier to play just following the internal pulse. Both pieces are found in appendix A.

Table 4.10: Most difficult Mozart

Try-out	Mean	Median	Mode	Std. Deviation	Min	Max
eye0ear0dir	5.59	6	6	0.733	3	6
eye1ear0dir	3.55	4	4	1.088	2	6
eye0ear1dir	2.10	2	1	0.976	1	4
eye1ear1dir	1.24	1	1	0.511	1	3

4.5 Relation between different instrument groups

In the following figure 4.17, showing arr1eye1ear0 again, every recorded instrument can be followed ta see who plays the different onsets.

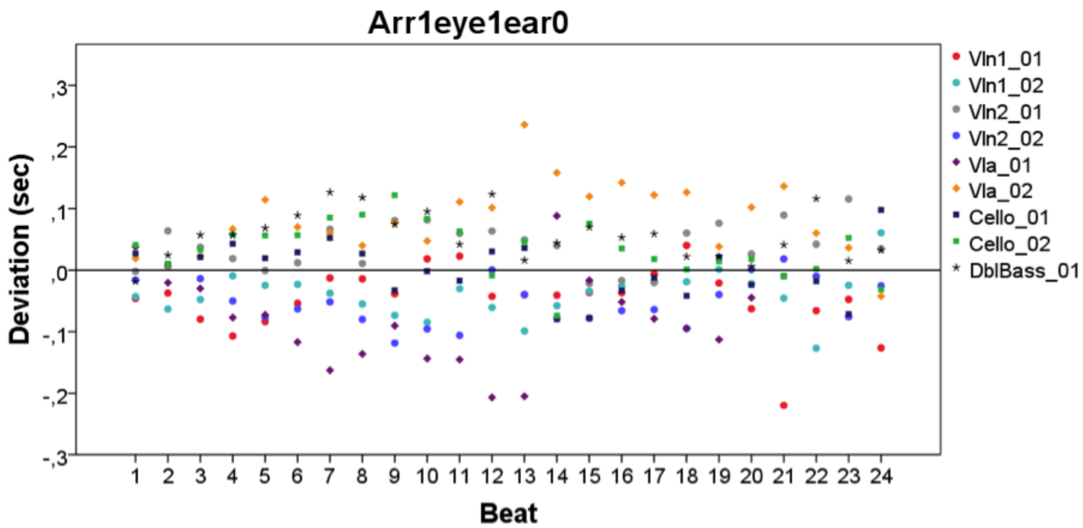

Figure 4.17: Arr1eye1ear0 again.

It is possible to see whether the same person differs in the same way throughout the piece. The onset deviations from the different instruments vary in every beat but a few things are clear in this try-out. The majority of the red dots, marking the concert master from the first violin, is below the middle line, meaning that they are ahead of the beat. This is also found when listening to recordings. The concert master do always have a leading role in an orchestra, with and without conductor. No instructions whether to be the leading part or not where given to the first violins, but this is so normal to them so even in this test they tend to lead.

Vla 02 with yellow dots seem to be around 100 ms after most of the time. It depends on the person playing that viola. The other viola player, vla 01, do often play one of the first onsets in the orchestra. Figure 4.17 are showing the try-out where there is only sight and the orchestra is started by the conductor. In figure 4.18 are the try-outs where the orchestra is started by clicks from the side and sitting in arr2 analysed. In this setting are the double-basses nearest to the loudspeaker and hears the click before the sound has travelled over the stage to the musicians on the other side. The loudspeaker used to start the orchestra with clicks is standing behind the double basses on the right side. The musicians nearest to the loudspeaker hear the click first, in arr2 the double bass, and 34 milliseconds later the click has arrived to the other side of the orchestra in arr2, the viola. See reference distances in figure 4.2. The distance between the musicians on different sides in arr1 is the same distance as E in table 4.2. The first tone from four try-outs with click start are showed in figure 4.18.

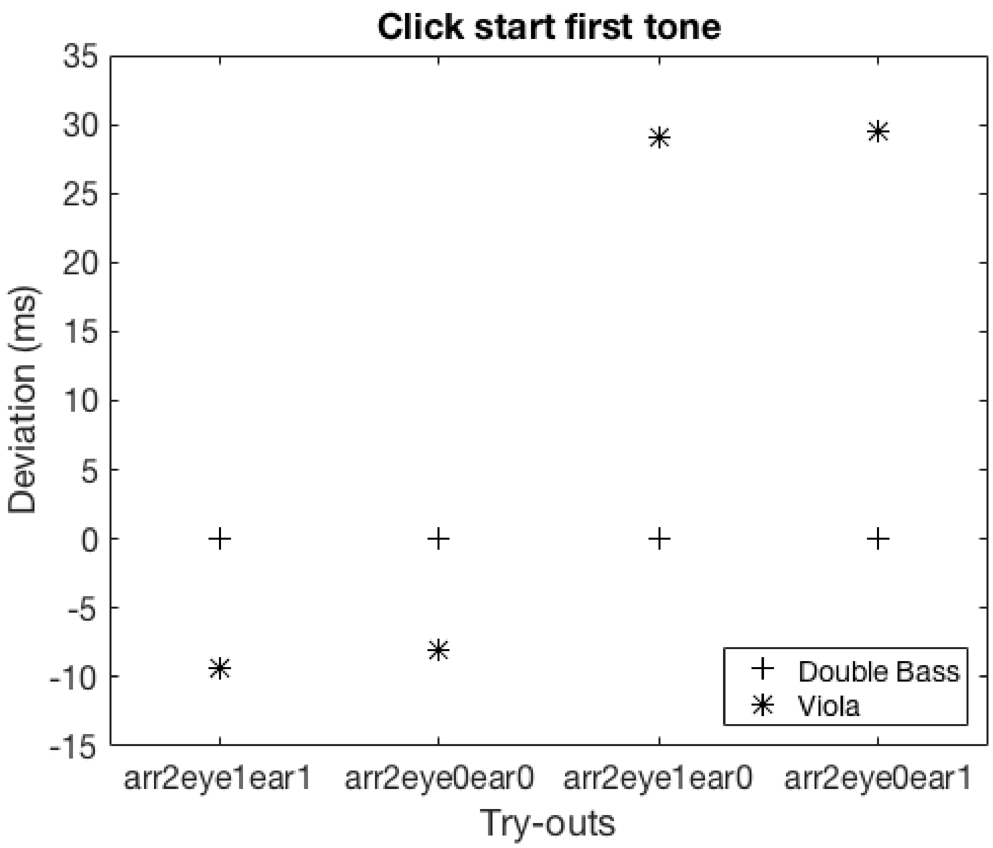

Figure 4.18: Violas onset of first tone relative to double bass when starting with click, sitting on different sides of the stage.

The plus signs mark the double bass' first tone in every try-out in the figure. The viola's first tone is related to the double bass and marked with stars. In two of the try-outs, eye1ear0 and eye0ear1, the viola plays her onset tone after the double bass. According to the hypothesis the viola would be starting the tone later than the double bass and that happens in eye1ear0 and eye0ear1 but not in the two other try-outs. When playing with both senses active, eye1ear1, the onset are almost at the same time. Ten milliseconds are too little to be noticed as a difference when listening. But when taking away one sense the musician on the other side of stage is playing 30 milliseconds later, showing again that both sight and hearing are important.

The very first tone of the Lidar piece is of interest because it would be that tone that is affected by the starting clicks. The first tones are delayed in reference to the musicians nearest to the loudspeaker, but after a few notes the musicians that lag have adjusted to the other orchestra members. This is noticed when listening to the recordings of the try-outs with click start. The musicians on the other side of the stage are compensating because they notice that they are delayed by the distance. If they would only synchronise to what they hear the whole orchestra would slow down. Musicians on the other side are late from the start and the sound from them is delayed when going back to the first side. But the internal pulse alerts the musicians that they are producing a ritardando and keep up the tempo, despite of what they hear.

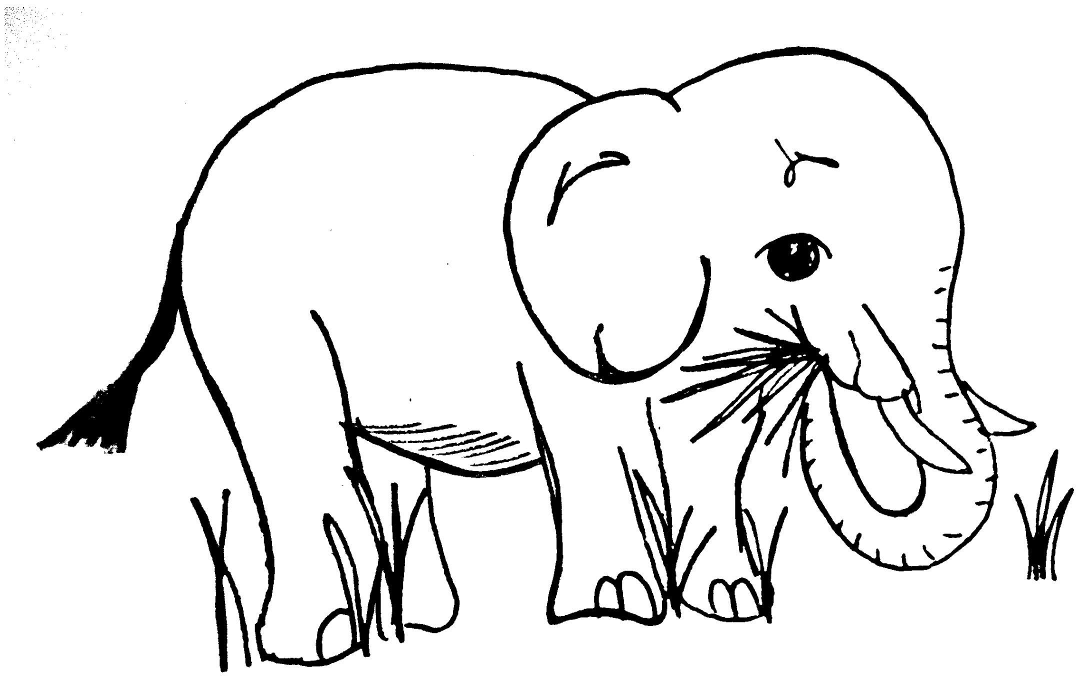

Figure 4.19: Elephant eating grass (Frida Bohman 2016).

5

Conclusion

All objectives from the introduction in section 1.1 have been investigated. A piece of music was especially composed by the author to test synchronisation an orchestra. The studies show larger deviations in synchronisation between musicians when playing with just sight than with just hearing. The conclusion is that both senses are needed to get the best timing. When comparing the try-outs in arr2, deviations shown in table 4.6 are larger when taking away either sight or hearing than when having both. The orchestra seating on stage is affecting the ability to synchronise the onsets of tones. Different seating arrangements are tested and the setup where the orchestra sits closest together improve timing in all settings.

When removing both sight and hearing, other cues are used to be able to play in synchrony. Vibrations from the double basses and cellos with endpins connected to the floor were more noticed by musicians in other sections in this case. The importance of the common inner pulse is noticed from the result in section 4.4. The orchestra play the second movement of Mozart piano concerto 23 surprisingly synchronised when having no sight and no hearing. The piece has a consistent rhythm and long lines which probably helps to create a common inner pulse in an orchestra. These are subjects that could be further investigated.

The gathered results indicates that many senses influence the ability to synchronise. Therefore, acoustic measurements alone cannot explain the features of the stage, at least not when it comes to playing synchronised.

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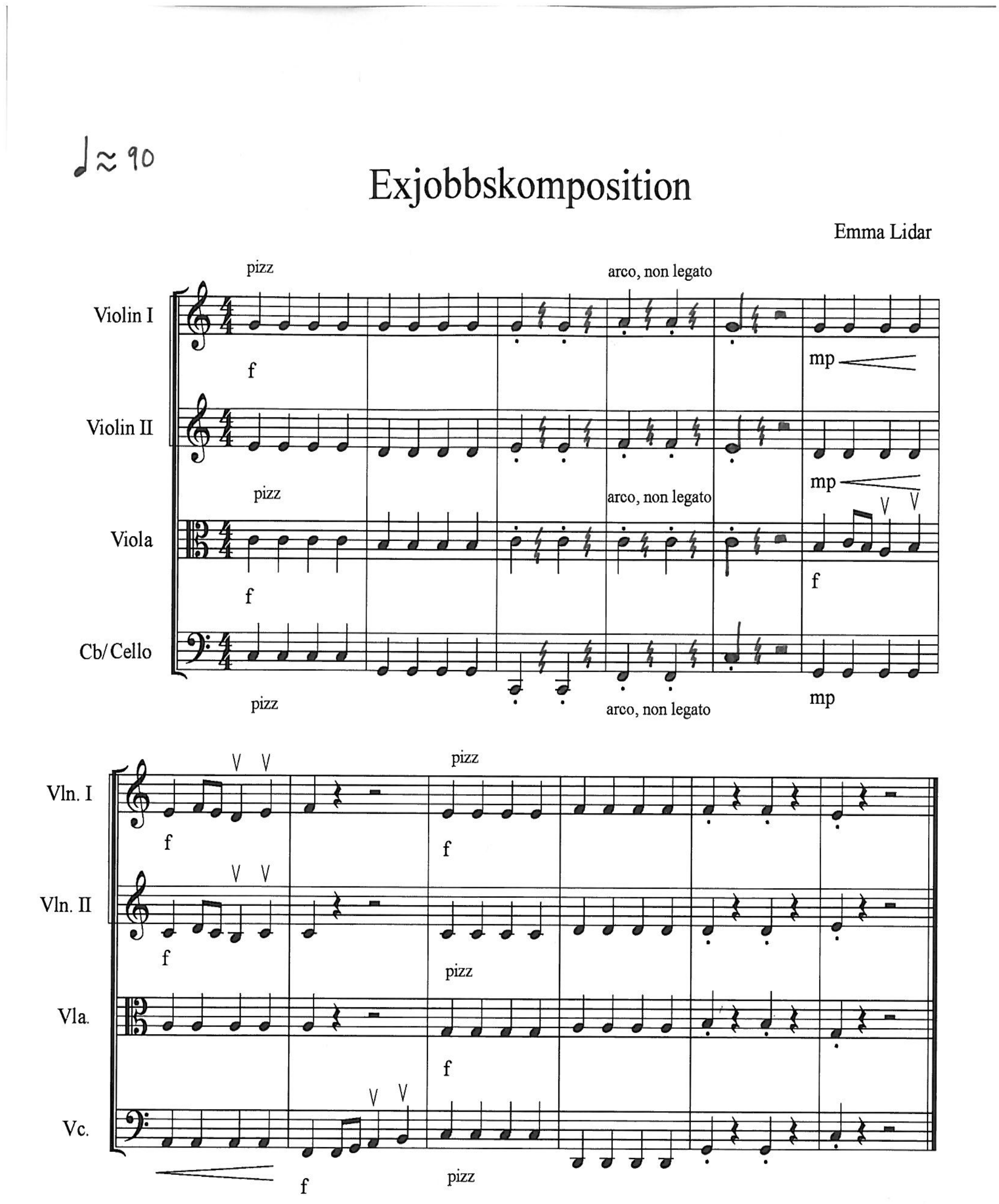
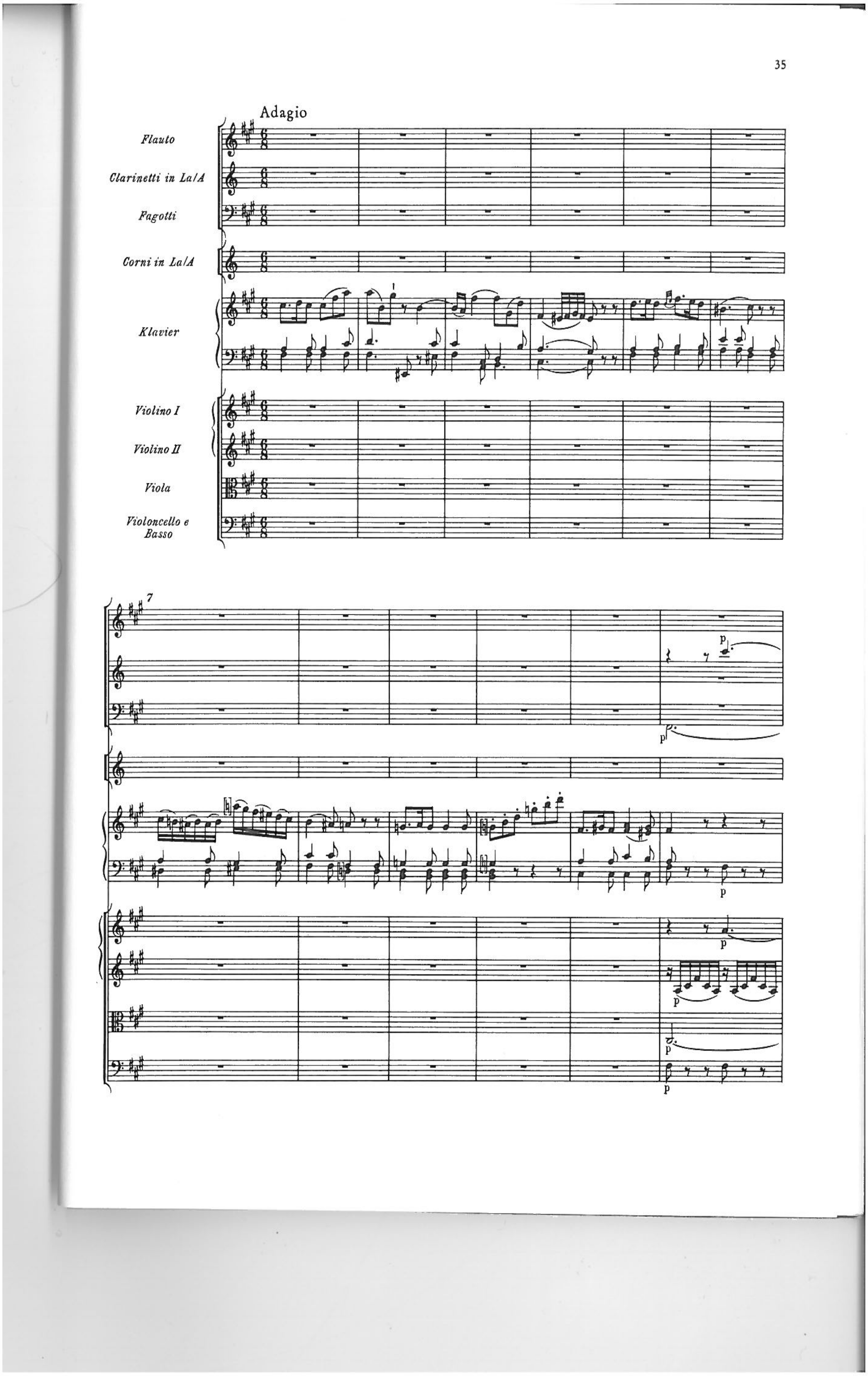
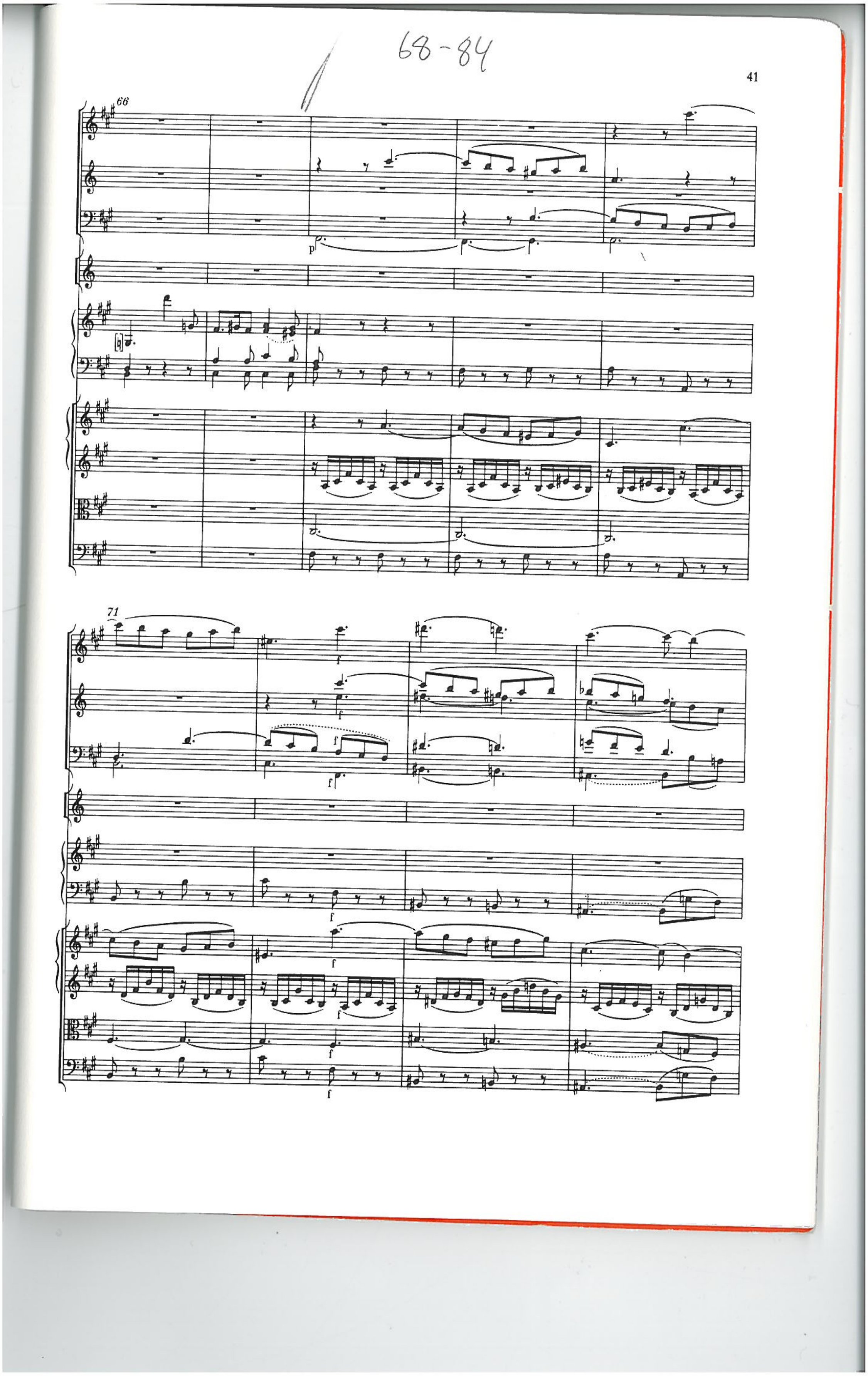
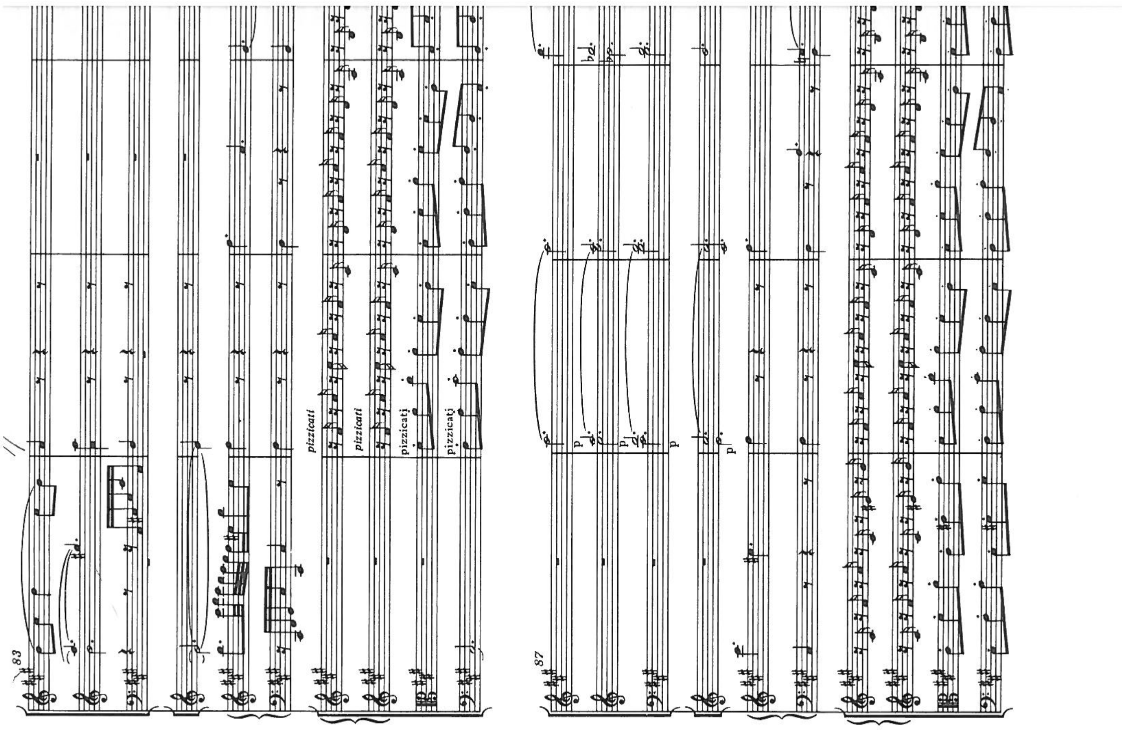
A

Test pieces


♩≈ 90
Exjobbskomposition
Emma Lidar
pizz
arco, non legato
Violin I
Violin II
Viola
Cb/Cello
f
mp
Vln. I
Vln. II
Vla.
Vc.


35
Adagio
Flauto
Clarinetti in La/A
Fagotti
Corni in La/A
Klavier
Violino I
Violino II
Viola
Violoncello e Basso
7
p


68-84
41
66
71


83
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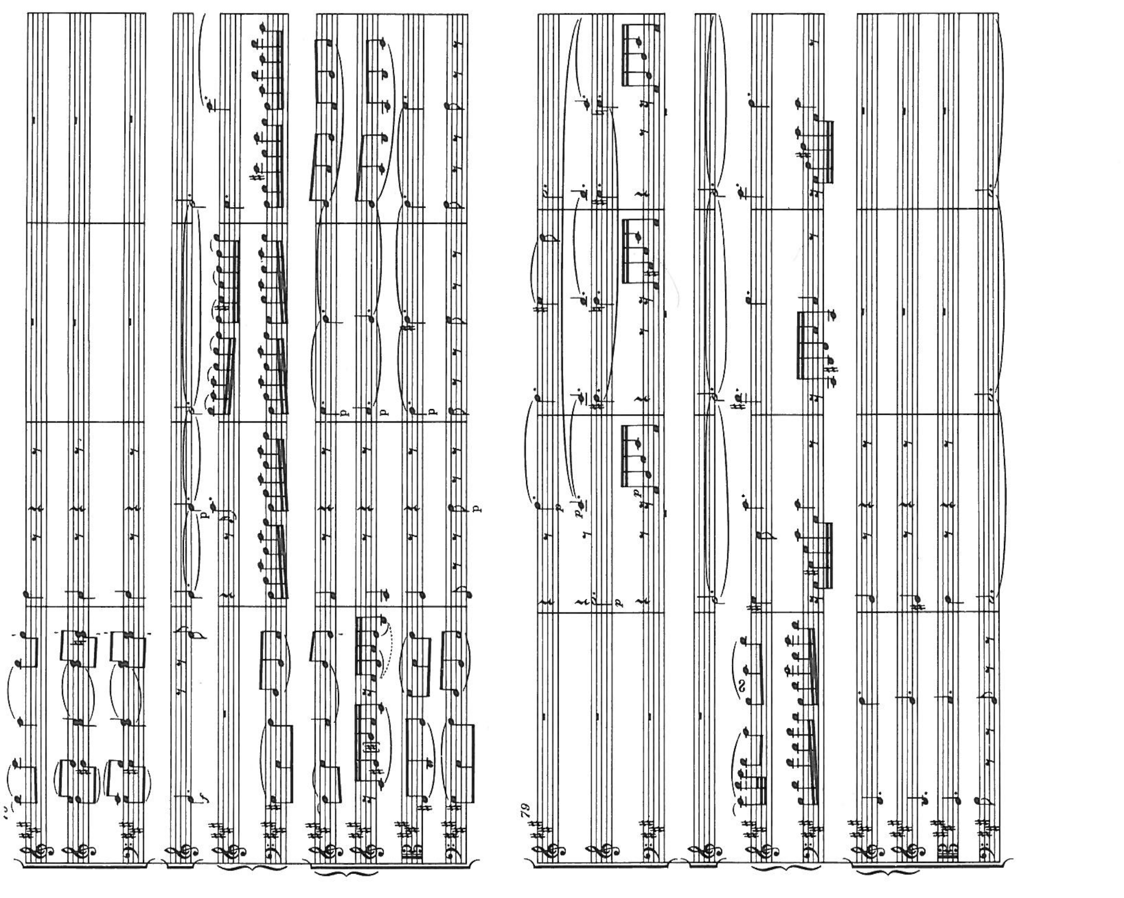
87


79

B

Questionnaires

Questionnaire 18 april 2016

Instrument:________________ Number:_______

How well is your playing today?

Bad	Medium	Good	Very good

How difficult was timing (playing synchronised together) in this situation? **1 is very easy and 6 is very difficult.**

Test 1	1	2	3	4	5	6
Test 2	1	2	3	4	5	6
Test 3	1	2	3	4	5	6
Test 4	1	2	3	4	5	6
Test 5	1	2	3	4	5	6
Test 6	1	2	3	4	5	6
Test 7	1	2	3	4	5	6
Test 8	1	2	3	4	5	6

Test 9	1	2	3	4	5	6
Test 10	1	2	3	4	5	6
Test 11	1	2	3	4	5	6
Test 12	1	2	3	4	5	6
Test 13	1	2	3	4	5	6
Test 14	1	2	3	4	5	6
Test 15	1	2	3	4	5	6
Test 16	1	2	3	4	5	6

Test 17	1	2	3	4	5	6
Test 18	1	2	3	4	5	6
Test 19	1	2	3	4	5	6
Test 20	1	2	3	4	5	6
Test 21	1	2	3	4	5	6
Test 22	1	2	3	4	5	6
Test 23	1	2	3	4	5	6
Test 24	1	2	3	4	5	6

Test 25	1	2	3	4	5	6
Test 26	1	2	3	4	5	6
Test 27	1	2	3	4	5	6
Test 28	1	2	3	4	5	6

Questionnaire 22 april 2016

Instrument:________________ Number:_______

How well is your playing today?

Bad	Medium	Good	Very good

How difficult was timing (playing synchronised together) in this situation? **1 is very easy and 6 is very difficult.**

Test 31	1	2	3	4	5	6
Test 32	1	2	3	4	5	6
Test 34	1	2	3	4	5	6
Test 35	1	2	3	4	5	6
Test 36	1	2	3	4	5	6
Test 37	1	2	3	4	5	6
Test 38	1	2	3	4	5	6
Simon1	1	2	3	4	5	6
Simon2	1	2	3	4	5	6
Simon3	1	2	3	4	5	6
Simon4	1	2	3	4	5	6
Simon5	1	2	3	4	5	6
Simon6	1	2	3	4	5	6
Simon7	1	2	3	4	5	6
Simon8	1	2	3	4	5	6

15:00	Instructions and Sound check				
15:10	Rehersal without sheet music				
15:20	31	eye1	ear0	dir	31eye1ear0dir
15:22	32	eye0	ear1	dir	32eye0ear1dir
15:24	34	eye1	ear1	dir	34eye1ear1dir
15:26	35	eye1	ear0	hel	35eye1ear0hel
15:28	36	eye1	ear1	in	36eye1ear1in
15:30	37	eye0	ear1	in	37eye0ear1in
15:32	38	eye1	ear0	in	38eye1ear0in
15:34		Simon	1		Simon1
15:37		Simon	2		Simon2
15:40		Simon	3		Simon3
15:43		Simon	4		Simon4
15:46		Simon	5		Simon5