Automized Optimization of Stage Monitor Hearing

Moving the monitor hearing sweet spot in real time
– a solution for the moving musicians on stage?

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Abstract

A novel stage monitor hearing model has been developed to evaluate the idea of a system that moves the stage monitor hearing according to the positions of the live performing musician. The aim of the study was to answer to what extent is such a system useful during live music performances. The system model is programmed using Pure Data and adjusts the different sound mixes for each monitor on the stage so that the location of the spot of the ideal stage sound corresponds to the positions of the musicians. The positions of the musicians are obtained by using a Motion Capture camera system together with software to communicate with Pure Data. During the study interviews and user tests were performed with performing musicians and sound engineers. The results indicate that the musician's performance is improved and previous limitations caused by a restricted monitor hearing sweet spot are reduced. The extent of the usability of such a system within the rock and pop genres is believed to increase with the overall sound level and complexity of the genre performed, and it is also associated with the musician's own musical preferences. A set of model simplifications was however made to the system that would need to be taken into consideration for implementation in an actual live concert performance.

Acknowledgements

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Finally, we would like to thank everyone who participated in our interviews and user tests.

Thank you, you rock!

Jimmie Paloranta & Ida Renström
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Content

1 Introduction

When musicians are performing live on stage, the sound from the speakers directed at the audience is often too loud for the musicians to be able to distinguish the different instruments and hear themselves. In order to improve the stage sound, a set of monitor speakers are arranged facing the performers on the stage. The mix coming from the monitor speakers are often individually adapted to each musician (Mellor, 2005). For example, a guitarist might want to hear more from the bass and drums while a violinist might want to hear more from the melody playing instruments, like the keyboard. However, this ideal stage sound is adjusted for a particular spot on stage, and if the musicians move away from their individual spot their monitor hearing will be impaired. This limits the possibility for the musicians to move around during performance while maintaining their ideal monitor hearing.

Using in-ear monitoring is one solution to the problem, since the musicians mix is sent directly in to the ears through earpieces. However, some musicians feel that in-ear monitoring reduces the live experience and isolates them from the rest of the musicians and the audience (Harrison, 2004). Therefore in the current study an alternative solution for the monitor hearing problem is proposed.

Florencio *et al.* (2011) claim in the paper *An interactive 3-D audio system with loudspeakers* that the research concerning realistic audio is lagging behind compared to other multimedia areas, for example networking and improved image quality.

1.1 Idea

The study consists of two parts. The first part was to design a system that uses the information of the variable positions of the moving musicians on stage in order to place out the individual stage sound for each musician in real time. This way, the musicians are able to move around on stage without sacrificing their preferred monitor hearing. The second part was to evaluate the concept for live music performances. The system, programmed using Pure Data[1], adjusts the different sound mixes for each monitor on the stage so that the location of the spot of the ideal stage sound corresponds to the positions of the musicians. The positions of the musicians are obtained by using a Motion Capture camera system and software to communicate with Pure Data.

1.2 Problem formulation

The main question of the study was:

> *During live music performances, to what extent is a system that adapts the monitor hearing according to the positions of the musicians on stage useful?*

To be able to answer the main question, some additional questions were formulated:

[1] Puredata.info

- Is there a need for a monitor hearing system that takes the possibility to move around on stage into account?
- How much does the monitor hearing affect the musical performance?
- Would the musical performance be improved by using such a system?
- How should such a system be designed?

1.3 Delimitations and clarifications

Presented below is the purpose and delimitations of the study and musical clarifications and target group are defined.

1.3.1 The study

The aim of the study was to evaluate the idea of a system that moves the monitor hearing according to the positions of the musicians, and not to design a complete system that can do this in actual concert situations. This included evaluating the experience of musical performance using the system compared to performing without using the system.

1.3.2 The musical instruments and musical genre

For this study only two playing musicians were included for position tracking. The instruments for which the sound mixes were designed are the electric violin and the electric guitar, with the reason being that they require different sound mixes from their respective monitors. Furthermore, the authors play these two instruments and had thus the opportunity to test the system continuously during development. A backing track was used to simulate the other instruments in the intended band, including drums, bass and keyboards. These simulated backing musicians were assumed to remain in one fixed position during performance. The study mainly address the rock and pop genres, which are similar in terms of sound levels, equipment on stage and demands from the acoustics of the concert hall (Adelman-Larsen et al., 2007).

1.3.3 The simulated concert environment

The stage that was simulated compares to a small indoor venue with an audience capacity of about 500 persons. A top view sketch of the stage is shown in Figure 1. A more detailed description of the simulated stage of the current study can be found in Chapter 3.2.1. A set of model simplifications that should be considered when evaluating the system were made and these are described in Chapter 3.2.3.

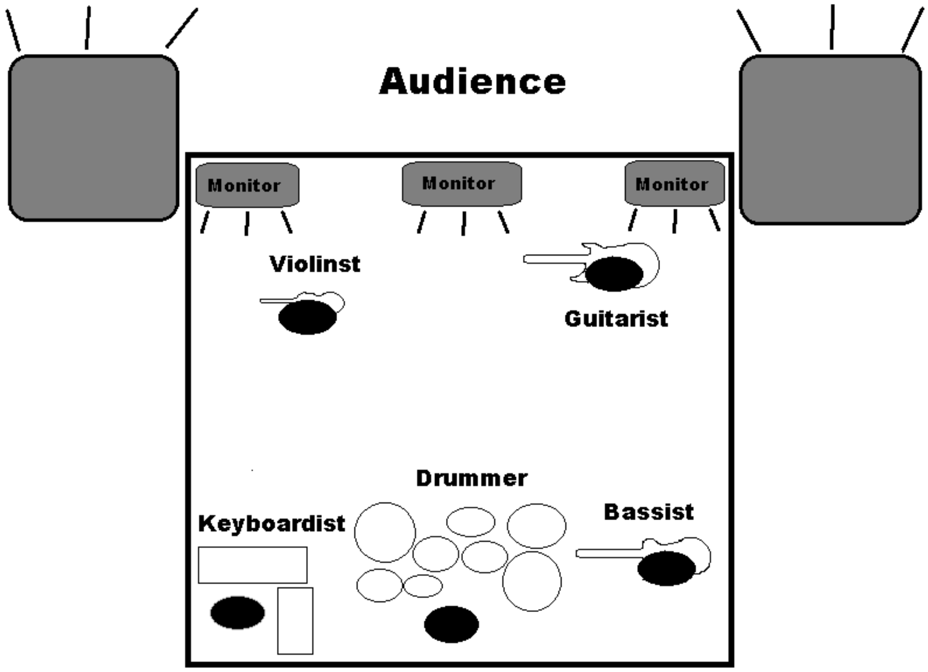

Figure 1. A general stage plan from above with keyboardist, drummer and bassist positioned in the rear part of the stage and violinist and guitarist in the front part of the stage. Monitors facing the performers providing the sound on stage and speakers facing the audience providing the sound to the audience.

2 Theory

2.1 Perception of sound

In Ternström's book *Ljud som informationsbärare* (2010) he gives the following description of the meaning of sound: "The word sound actually has two different meanings: a physical, namely pressure variations, and a perceptual, namely the sensation of pressure variations that are mediated by the sense of hearing". The physical form of sound can be objectively measured by, as mentioned, its pressure variations, but also its intensity or its energy. The human body however, does not simply take these physical stimuli and linearly maps them into the perceptual world. Measuring the subjective experience of sound is much more complex as the relation between stimuli and perception is complicated by nonlinearities and interactions, and bounded by the limitations of our sensory and cognitive capability (Buxton et al., 1994a). The human ear can only perceive sounds in the frequency range 20 Hz to 20 kHz and the upper limit of sound pressure level lies around 120-130 dB (the lower limit for normal hearing persons lies at 4.2 dB at 1 kHz, Ternström, 2010). The ear is also extra sensitive at certain frequencies and can perceive sound pressure levels differently depending on frequency. This is shown in the "*Fletcher-Munson" curves* in Figure 2, where the hearing area has been divided into different contours where the ear perceives sine wave tones of different frequencies as equally loud (Ternström, 2010).

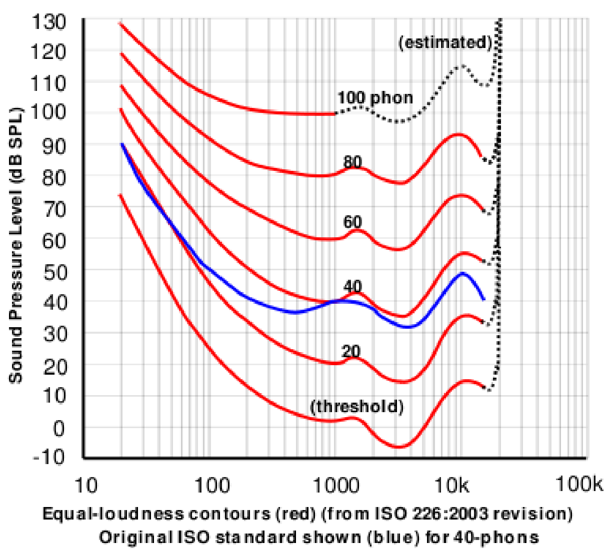

Figure 2. Fletcher-Munson curves (Wikipedia, 2012a).

Through these curves one can tell that a sound is perceived as twice as loud if the loudness level is increased with 9 Phon, which at most part of the hearing area corresponds to 9 dB (Ternström, 2010). Sound perception is also affected by the duration and distance of a sound. For sounds shorter than about a second, loudness increases with duration, while for sounds longer than a second, loudness remains constant (Buxton et al., 1994). Sound intensity decreases with distance to the source, obeying the inverse square law. The law is explained in Figure 3. The inverse square law is however, like most laws, only accurate in idealized situations, in this case in free field conditions.

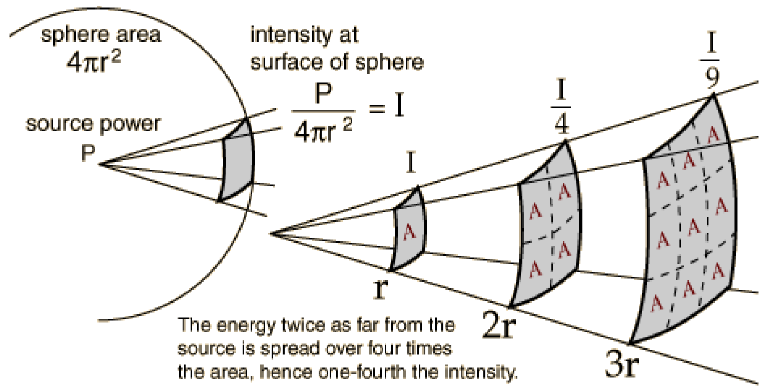

Figure 3. The inverse square law (Nave, 2012).

2.2 Stage monitoring and PA-system

Stage monitoring can be divided into two parts, monitoring the sound on-stage and monitoring the sound off-stage (ergo, the sound which the audience hear). Both of these tasks are managed by the sound engineer(s) who provides the best possible sound to the audience while monitoring the sound on stage to make sure that musicians hear themselves and each other as good as possible (Wikipedia, 2012-05-11b).

In music concerts, a Public Address system (PA-system) is used as an electronic amplification system used to reinforce one or several sound sources. The components of a PA-system may differ depending on the situation, and in this study focus is on components concerning live musical performances. For live music concerts, two PA-systems are usually used, one "main" system and one "monitor" system. Each system consists of amplifiers, speakers, microphones and a mixing console. The mixing console consists of three main sections: channel inputs, master controls and audio level meters. The main system provides the sound for the audience and is also known as a "front-of-house" system (FOH), while the monitor system, also known as a "foldback" system, provides the sound to the performers on stage (Wikipedia, 2012-05-11c).

2.3 Spatial audio; the sweet spot and panning

For the musician, the position relative to the monitors is of great importance when pursuing good monitor hearing. This spot, where the supporting audio mix from the monitor(s) is ideal, is usually referred to as the sweet spot (Jang et al., 2008). A "moving sweet spot" could therefore be of value when pursuing automized optimization of stage monitor hearing. When representing two identical mono audio signals via two loudspeakers, a phantom center is produced between the speakers. The signal can also be panned between the two speakers by relatively varying the amplitudes for the speakers or/and by adding delay to one of the two audio signals. When moving from the center, away from the sweet spot, the sound will by the listener be perceived coming from the closest speaker. This is the so called Haas-effect and causes the sound to follow the listener to the nearest speaker when moving away from the center (Vickers, 2009).

2.4 Crosstalk cancellation

The goal of crosstalk cancellation is to send an audio signal from the right speaker to the right ear and from the left speaker to the left ear while eliminating the signal from the left speaker to the right ear and vice versa. Adding crosstalk cancellation to the audio signal allows binaural recordings to be played back via loudspeakers instead of headphones (Choueiri, 2008).

2.5 Audio feedback

When using on stage monitors the signals from the monitors can be picked up by the microphones and create unwanted feedback (Adelman-Larsen et al., 2007). When a sound loop occurs between an audio input and an audio output, the input signal is amplified and passed out of the loudspeaker. The sound from the loudspeaker can then be received by the audio input again, amplified further, and then passed out through the loudspeaker again. Most audio feedback results in a high-pitched squealing noise (Wikipedia, 2012-05-11d).

2.6 Moving the sweet spot

There are several studies where the goal is to move the sweet spot in real time according to the listener's position. In a study carried out by Florencios *et al.* (2011) a webcam-based head tracker was used to track the position and orientation of the human head and used the information combined with room modeling to create a binaural synthesis and crosstalk cancellation process. The results of the study showed that the proposed 3D-system improved the users' perception and localization ability.

A study made by Merchel and Groth (2010) resulted in the application "Sweetspotter". The listener's position is tracked using a camera and a face recognition algorithm, and delay and level of the sound are adjusted according to the position. A screen shot of Sweetspotter is shown in Figure 4. The results of the study indicated that this application improved the localization over the listening area.

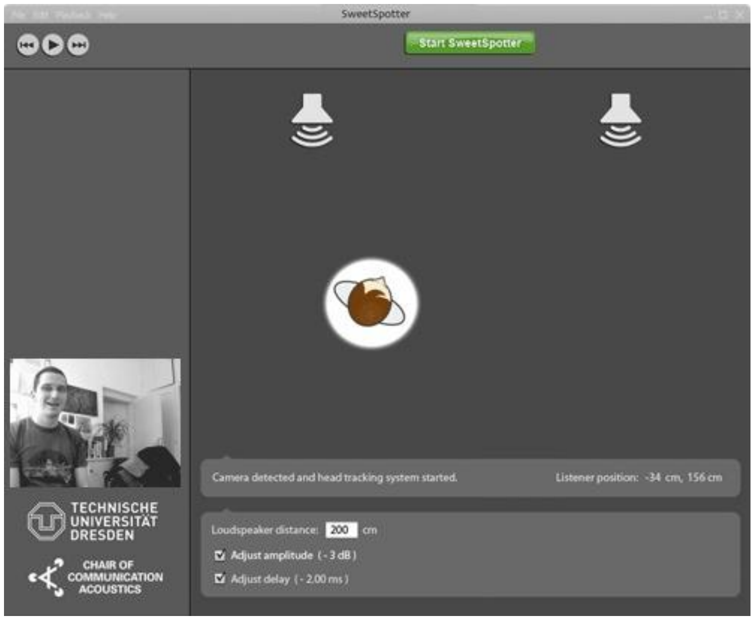

Figure 4. The Sweetspotter application where we can see the listener's position in relation to left and right speakers. The view of the camera is shown in the bottom left corner (Merchel, 2012-05.15).

2.7 Automatic monitor mixing

Reiss and Terrel presented in their paper *Automatic Monitor Mixing for Live Musical Performance* (2009) an automatic monitor mixing model that simultaneously consider listener requirements, maximum and minimum allowable sound pressure level on stage and preventing of acoustic feedback. The study showed that the additional constraints, in particular the prevention of audio feedback, make it more difficult to get an ideal mix. It was also shown that the position of sources and monitor loudspeakers can be included in the optimization algorithm to improve stage setup.

2.8 Musical performance depending on audio perspective

Cooperstock *et al.* (2011) made a study concerning the quality of musical performance depending on the musicians' audio mix. The performers of a large jazz band performed with two different audio mixes and a comparison in performance was made. The first mix sounded like when the performer was placed in his or her regular place in the band where only the nearest instruments could be heard. The other mix consisted of all the other instruments in the band, thus the kind of audio mix that the audience would hear. The conclusion of the study was that the choice of audio perspective makes a significant difference in some musicians' performances. Related to the current study we can notice the importance of getting the best audio support from the surrounding ensemble to perform at your best.

3 Methodology

3.1 Interviews

During the study interviews were performed with musicians and sound engineers to get a general opinion of stage monitor hearing and the ability to move around on stage during live performances.

3.1.1 Interviews with sound engineers

Two persons (S1, S2), both males in the ages 20-30, that have worked as sound engineers (although it is not their current profession) were interviewed in order to get their thoughts on stage monitoring and live mixing, and how the system of the current study should be designed. S1 had done over 100 shows as a sound engineer and is currently working as a music producer. S2 had done 30-40 shows as a sound engineer, studied music production for a year, worked as an audio technician for two years and is currently studying media technology at KTH. Both S1 and S2 were also interviewed as performing musicians, as noted below.

3.1.2 Interviews with performing musicians

Eight musicians (S1, S2, S3, S4, S5, S6, S7, S8), all males in the ages 20-30, were interviewed to have their thoughts about stage monitoring hearing, how it affects their musical performance and if a system of the current study could be of interest to them. All the musicians had the guitar as their main instrument and had been playing for 5-18 years. Their musical styles ranged from jazz and punk to metal and melodic rock. Unfortunately no violinists were able to participate in the interviews. S1, S2 and S3 had played over 100 shows, S4 and S7 had played 40-50 shows and the remaining musicians had played between 10-20 shows. S1, S2 and S3 were also the ones who had played on the biggest venues, including Sweden Rock Festival and Debaser Medis, while the rest had mainly played smaller venues like pubs and school gymnasiums. All the musicians are currently studying media technology at KTH except S1 and S3. S1 is as earlier mentioned working as a music producer, and S3 is a professional musician in a melodic rock band.

3.2 Automized optimization of monitor hearing system

Developing an automized optimization of stage monitor hearing system was necessary for the study. The system consists of two components, one motion tracking system and one program that controls and distributes the sound. The motion capture tracking system was already available and the sound mixing part was developed using Pure Data.

3.2.1 The test environment

The environment where the user tests were performed was in lecture a room with concrete walls and tables with computers and other equipment along the sides (see Figure 5).

Figure 5. The room for tests and experiments.

The room acoustics was far from ideal as the sound was reflected in different directions by the surfaces of the walls, floor, ceiling and furniture. This creates additional sound sources that contribute to the overall intensity but at other locations than the original sound sources (Buxton et al., 1994c). The area of the room is approximately 5 x 7 m. The walkable area is about 4 x 7 m and simulated the part of the stage dedicated to the guitarist and the violinist. By adding an imagined additional rear stage, where the drummer, the bassist and the keyboardist were positioned, we got a simulated full sized stage (see Figure 1) with an approximate area of 7 x 7 m. Along the long side of the room, three monitor hearing speakers (Genelec) were placed out with equal distance between them. The speakers on the sides produced the signal from channel 1 respectively channel 2 and the center speaker produced the channel 3 signal. The three speakers produced the musicians' sound mixes and functioned as the monitor hearing speakers. Also, two rear stereo speakers (Genelec) were placed out along the opposite side of the room, producing the simulated acoustic sound from the drums, via channel 4 and 5. Figure 6 shows an overview of the room and an imagined rear stage for the drummer, keyboardist and bassist. The dots in the figure represent the eight cameras used for the Motion Capture camera system.

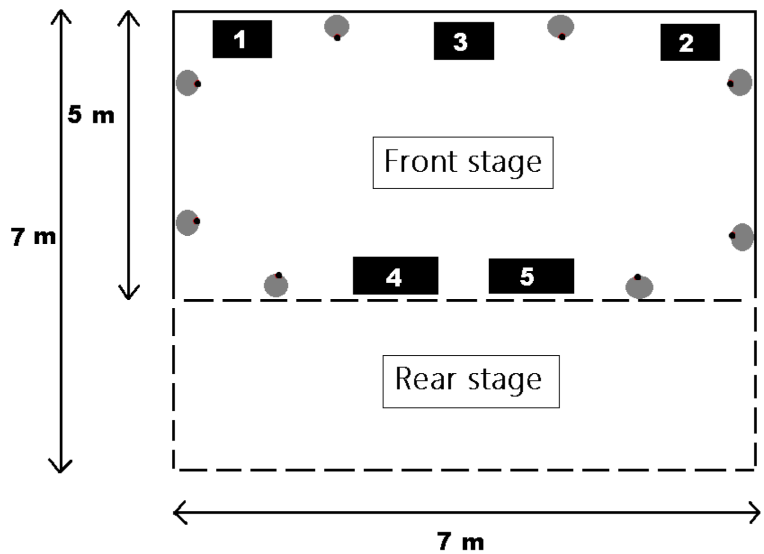

Figure 6. Stage overview. Black speakers numbered with their respective channel and circles representing eight motion capture cameras.

3.2.2 Tracking the musician

The x- and y-positions of the musicians were obtained using an Optitrack camera system from Natural Point, consisting of 8 infrared cameras. The camera input was processed with Tracking Tools software (see Figure 7) which sends Open Sound Control to Pure Data.

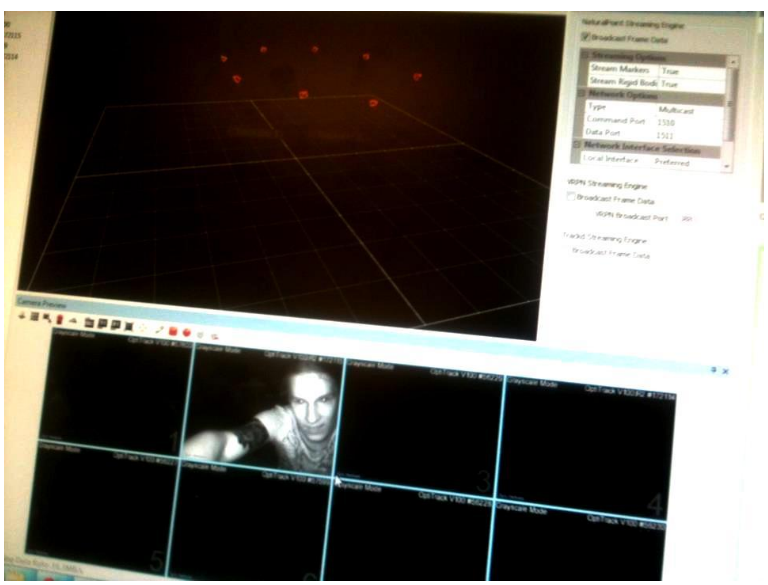

Figure 7. Tracking Tools on screen. The eight motion capture cameras are shown in the top window. The eight windows below represent the view of each camera.

Several different placements of the sensors on the musicians were discussed during development for optimal tracking. The sensors, small reflective marbles (Figure 9), have to be seen by at least three of the eight cameras in order to be recognized as a rigid object by Tracking Tools. Achieving this for the largest possible area proved to be a difficult task as the cameras have limited range and was not able to cover the whole room. We found the optimal tracking height to be in the waist-chest area and calibrated the system with the idea that the test users would have the sensors on both arms. With this calibration, the users were able to be tracked almost everywhere in the room except for in the corners. The tracking was also extra critical along the borders of the room, at times causing the users position to "get stuck". Figure 8 shows an approximate image over the area of the stage where the user could be tracked.

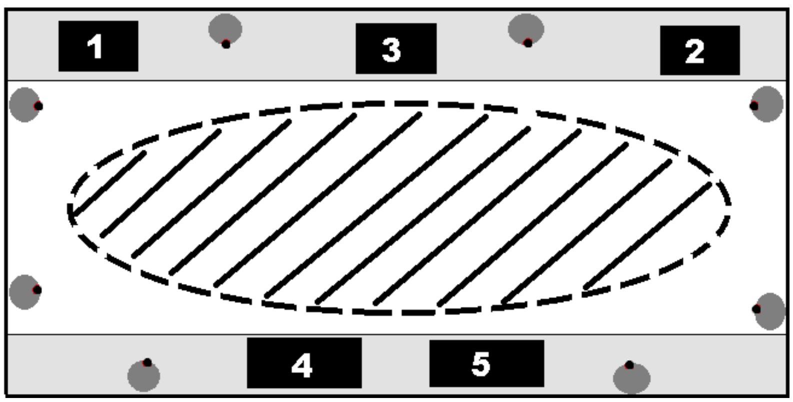

Figure 8. Approximate tracking area for the musicians.
Speakers 1,2,3,4 and 5 were placed on tables.

We eventually settled for placing the sensors on the head of the instruments (see Figure 9) so that extra equipment placed on the users could be avoided, and also to reduce the number of trackable bodies down to one per user instead of two (one per arm as we first intended).

Figure 9 Guitar and violin with tracking sensors. The reflective balls define the instruments as rigid bodies.

3.2.3 Model simplifications

Due to the non-linear nature of sound perception (Chapter 2.1) sound levels should ideally be worked with logarithmically (Thomas, 2012). The experiment room (Chapter 3.2.1) had low absorption, many surfaces, small measures and high playback levels. Due to this, we chose not to use laws and logarithmic formulas applicable to free field or idealized acoustic conditions to calculate sound levels, as they would not be valid in the testing environment. Instead, a linear relationship between the position of the musician and the level from the monitors was established that the authors believe gave a sufficiently good result. Sound perception and room acoustics should however be considered if one would want to exactly reproduce the sweet spot at any given position of the musician.

Rock concerts generally have a high sound level (compared to for example classical music concerts) generated through high-power PA systems (Adelman-Larsen et al., 2007). The front of house sound was not simulated during the user test, nor was audience noise. The only sound produced in the test was the sound coming from the musicians mixes through the monitors. Audience noise and the front of house sound should be considered in real practice.

During the experiments, no microphones were used since the two instruments were lined directly into the PA. In a real music performance however, one would probably use microphones for vocals, speech, acoustic instruments or to mic an amp, and the audio feedback (Chapter 2.5) would need to be taken in consideration.

3.2.4 Programming

The program controlling the outgoing sound via the monitors and communicating with the Motion Capture system was programmed using Pure Data. The program was designed to perform the basic work of a mixing console and an audio engineer, meaning that once the musicians have adjusted their individual sound levels in their respective monitors, the system will work autonomously, requiring no further adjustments. Figure 10 shows the main patch of the program, with the positions of the musicians, the master volume slider for both of the mixes, the backing track and algorithms for alternating the sound levels between the monitors as smoothly as possible.

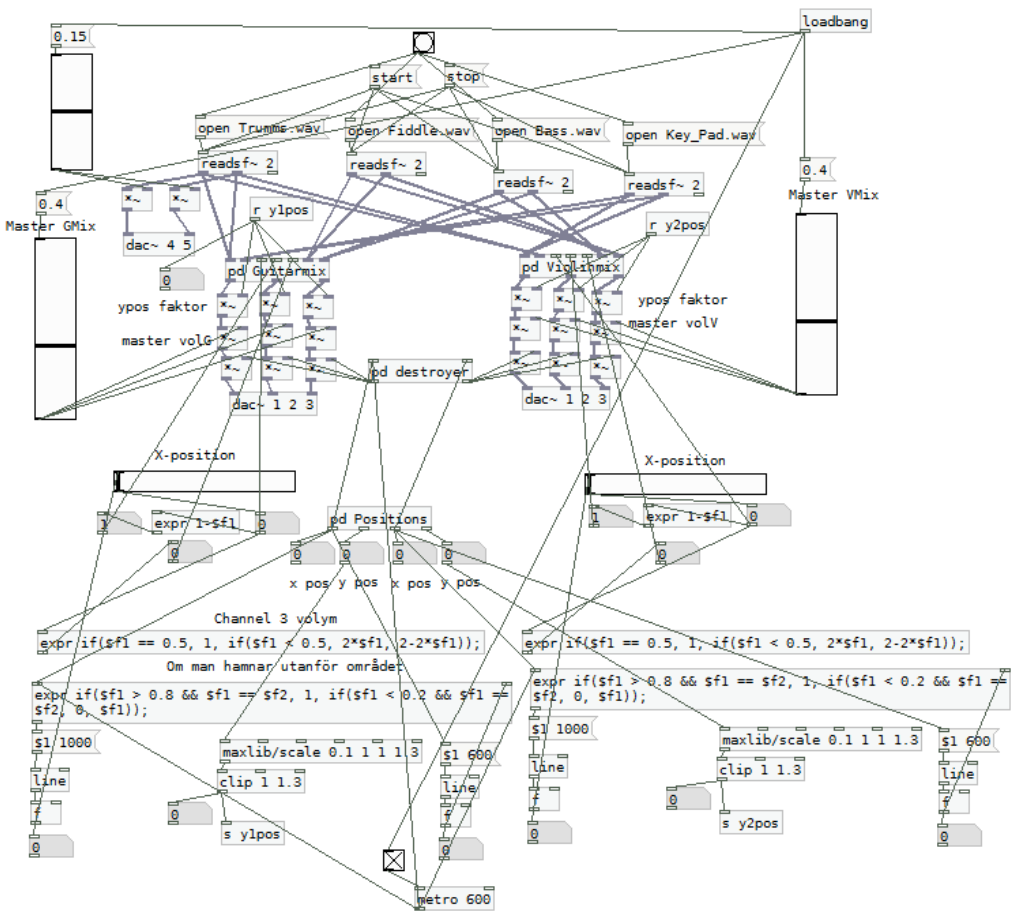

Figure 10. The main program in Pure Data that controls the monitor hearing signals.

3.2.4.1 The mixes

In the program, two separate patches control the outgoing audio mix for the guitarist and the violinist (see Figure 11 for an example of the guitar mix patch). The levels of all the instruments can be set according to the musicians' needs and the sound is sent to the three stage monitors (left, right and center). The patches use the information of the position of the musicians to alter the volume of the monitors in order to create the feeling that the sound follows the musicians. For example, if a musician would stand in front of the right monitor, it would send out 100% of the sound level while the left and the center monitors would send out 0%, and if a musician would stand in-between the right and the center monitor, they would both send out 50% of the sound level (creating the illusion of the sound coming from between the monitors) and the left monitor would send out 0%.

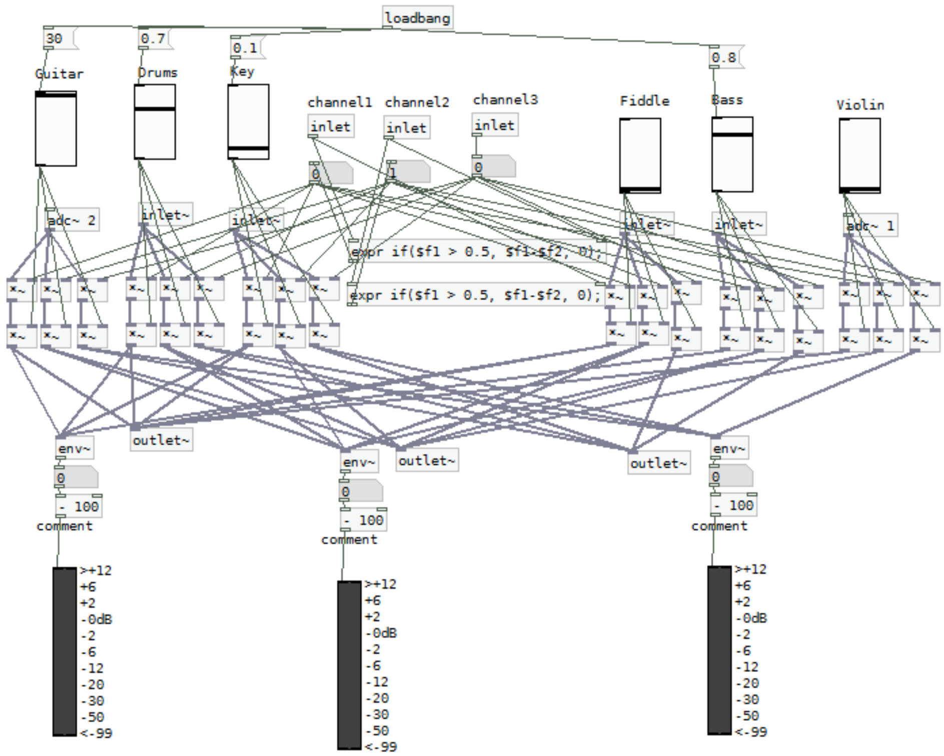

Figure 11. The Pure Data patch for the guitar mix, complete with channel input, master controls and audio level meters.

3.2.4.2 Sharing is caring - how to prevent audio mixes from interfering "too much"

When creating the system for two musicians, where all the monitors are shared, we knew that we would face the issue of both audio mixes being sent out from a monitor at the same time. When the musicians are on separate sides of the stage and just one monitor is shared (the center monitor), this would not be a problem. Each musician would also have their separate audio mix in one of the left or right monitors, the one closest to the musician, meaning that their own audio mix would be perceived to be closer than the co-musicians audio mix, and one could therefore easily ignore the other mix. However, when the musicians share two monitors (meaning that they stand on the same side of the stage), the co-musicians audio mix would interfere with the musicians own audio mix, making it difficult to distinguish the audio signal that the musicians would want and need to hear. In order to deal with this problem, we divided the stage area into two sections, one for each musician. The reason for this is that musicians usually have individual "territories" on stage where they have additional equipment that they need to play certain parts of a set or a song. For example, a guitarist often uses a pedal board for effects and boost during soloing, meaning that there will most likely be a playing position with e.g. a pedal board, restricting movement during use of these effects. The area where each musician's additional equipment is placed will be their "safe zone", meaning that once they are in that area, other musicians entering that area will receive a gradual lowering of their audio mix, depending on how close they are to the "owner" of the area.

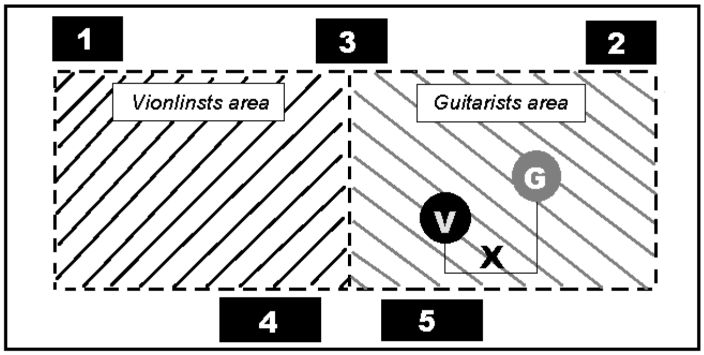

Figure 12. The violinist (V) and guitarist (G) placed in the guitarist's area at the same time. The sound level of the violinist's mix decreases as the distance X decreases.

In Figure 12, the violinist has entered the guitarist's area while the guitarist is still there. As the distance between the two musicians (marked "X" in the figure) decreases, the violinists audio mix from channel 2 and 3 will be lowered by a factor starting at 1.0 and going down to 0.4 when X = 0. This factor was determined through experimentation.

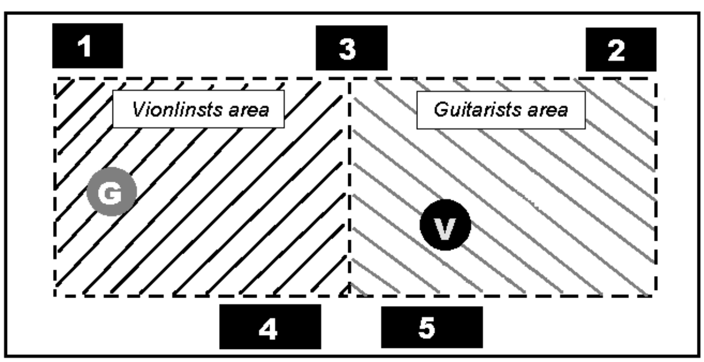

Figure 13. The violinist (V) placed in the guitarist (G) area and the guitarist placed in the violinist area.

In Figure 13, the guitarist has moved across to the violinist's area. Now the guitarist and the violinist receive no lowering of their audio mixes even though they are in the other musician's area.

3.2.4.3 Moving the sound through volume alterations

As explained in Chapter 3.2.4.1, the sound level in each channel is alternated according to the position of the musician in order to move the sound sideways (so called panning, Chapter 2.3). However, due to the

Haas-effect (Chapter 2.3), the location of the perceived sound does not always follow the musician as naturally and smoothly as desired. When standing between two speakers (in front of the phantom center) and moving closer to one of the speakers, the location sound will appear to “jump” to closest speaker (which will also be the loudest speaker due to panning, further increasing the effect of the jump). In order to reduce this effect we chose to not increase the volume of the closest speaker until the distance from the further speaker was about twice the distance from the closest speaker. The sound will still be perceived to come from the closest speaker, but the “jump” would not be that distinct.

We designed a function to keep the sound level at the same perceived level when moving towards and away from the speakers. Applying the inverse square law (Chapter 2.1) was however not an option due to the non-ideal environment of the room (Chapter 3.2.1), so instead we used interpolation. We measured the sound levels in front of the speakers and as far away from the speakers as possible with a sound level meter, and noted what factor the signal needed to be multiplied with in order to get the same result at both locations. We then modified that number according to our own perception until we felt we got a desirable result.

3.2.4.4 Moving outside of the tracking area

As explained in Chapter 3.2.2, the cameras cannot track the musician outside of the calibrated area, and the tracking was extra critical along the borders of the room. As the position of the musician at times could get stuck, although the musician were moving, we had to prevent the sound from suddenly “jumping” directly to the new position received by the system once the musician could be tracked again. This was achieved by adding a function to the program that continuously decreased or increased the value of the obtained positions over a certain amount of time, instead of suddenly “jumping” to a new position. Also, by looking at Figure 8 one can tell that the probability that the musician would walk out of the tracking area was greatest along the sides, while being closest to either the left or the right speaker (marked "1" and "2" in the figure). So whenever the position of a musician would not change for a limited amount of time, the program would automatically set the position of the musician to be in front of one of those speakers, as that would be the most likely scenario. This applied only to when the unchanged position was closest to either the left or the right speaker, and not the center (marked "3" in the figure), as the musicians would almost always be able to get tracked in the area closest to that speaker.

3.3 User tests

During the study user tests were performed with musicians to evaluate the designed automized optimization of monitor hearing system.

3.3.1 Test users

The musicians S2, S4, S5, S6, S7 and S8 that participated during interviews (Chapter 3.1.2) were also the musicians used for our users test. S1 and S3 could unfortunately not take part in the tests, nor any violinists. In Figure 14, one of the users can be seen testing the system with one of the authors (who played violin during all experiments).

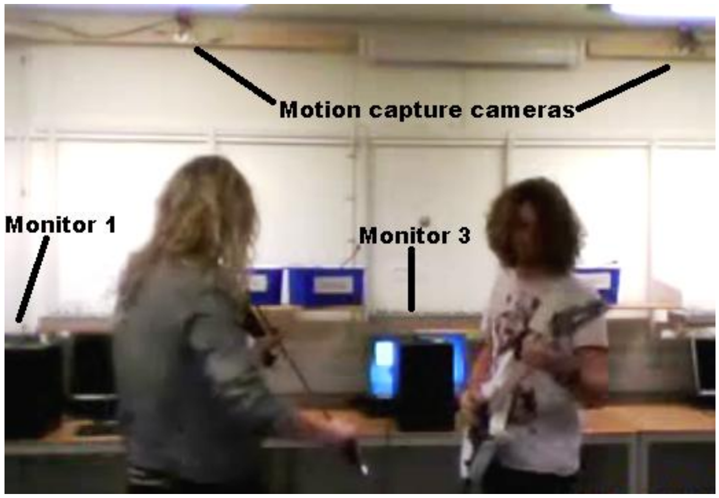

Figure 14. One of the guitarists testing out the system together with one of the authors. Monitor 2 is placed outside of the picture to the far right.

3.3.2 The backing track

The backing track simulated the drums, bass and keyboard and was musically backing up the guitarist and the violinist. All the instruments were recorded on separate tracks in order to set individual levels on all instruments for each musician's audio mix. The drums were recorded in stereo to give a more realistic sound through the two rear speakers.

3.3.3 User test implementation

The musicians prepared themselves by listening to the backing track and learn their part in the test song. First, the users would get a short explanation of how the system worked and its features. Then the sound levels of all the instruments were set in one of the monitors until they felt satisfied with their monitor hearing. Due to the environment not being a usual concert environment the users got to play along to the backing track together with one of the authors without the system being activated, in order to get a "feel" for the room, its acoustics and the lack of surrounding sounds (audience noise and FOH). The system was then turned on and the musicians got to play the song one more time, using the system. This would give the users the possibility to compare the performance experiences with and without the system under the same circumstances. After the test, the users would answer questions about their experience and their overall opinion of the system.

4. Results

4.1. Interviews

4.1.1 Stage monitoring and monitor hearing

One sound engineer, S1, expressed that controlling the stage monitor hearing is always a problem during live performances, especially with bands with tendency to move around a lot. S2 felt that the biggest problem during live performances is the communication difficulties between the sound engineer and the band, which makes it hard to do anything about the monitor hearing during a performance. S2 also mentioned that it is important that the volume of the on-stage sound cannot be too loud (S1 claimed that the monitors often were maxed in order to give a decent monitor hearing for bands that move around a lot), else it might spill in to the audience and blend with the FOH-sound, which can ruin the sound for the audience. S1 also mentioned issues with unwanted audio feedback from the stage monitors, which could be handled by eliminating certain frequencies of the sound through equalization, and by making sure that all microphones on stage were on stand-by when not being used by the musicians.

4.1.2 Monitor hearing and how it affects the live performance

All the musicians claimed they have had issues with monitor hearing during live performances, but how important it was varied from person to person. S1, S3, S5 and S8 felt it was really important to have good monitor hearing on stage, while S2 claimed he had gotten used to often having bad monitor hearing. However they all agreed on that bad monitor hearing impaired their performances. S6 and S7 said that they did not think about it too much when they knew the songs really well, although they both preferred to actually hear what they were playing in order to keep track on where they were in the song. S4 said it varied depending on what musical style he was playing. When playing jazz fusion he felt that monitor hearing was not an issue as the soundscape was quite clear and the overall sound level was not too high, but when playing metal, with the amps maxed, he needed to stand right in front of the monitor just to have a chance of hearing himself.

All the musicians except S2 and S8 felt that they would like to move around more on stage but that the monitor hearing at times prevented them from doing so. S8 however said that even though he did not necessarily want to move around more, he would like to have to option to do so, which he did not felt he had due to the monitor hearing and its locked sweet spot. Everyone were positive to the idea of having the monitor hearing sweet spot follow the musician and believed that it could improve their performance.

4.1.3 The need for improvements

All the musicians felt there was a need for further research and development in the stage monitor hearing field and that the current situation definitely could be improved. S3 said that an improvement of the monitor hearing would probably lead to him being able to focus more on the audience and enjoying himself on stage rather than concentrating on trying to hear what he was playing, an opinion that was shared among most of the musicians. Some mentioned in-ear as the best current solution for ideal monitor hearing, but at the same time expressed great dissatisfactions with the system. S1 claimed it was hard to get used to and felt unnatural, and that the timing in the band could be off due to delays in the earphones. S3 said that he lost feel and contact with the band and especially the audience, and S5 also mentioned that he felt isolated when using in-ears. S4 said that while he had not tried in-ears, he did not fancy the thought as he believed he would find them disturbing.

4.1.4 Performing with motion capture sensors

The general opinion among the musicians was that they would probably not want to run around with the sensors on their head during live performances, but if it could be integrated with the stage outfit while at the same time not be disturbing for the musician, it would definitely be worth considering in order to receive improved monitor hearing.

4.1.5 Compromising with your fellow band members

A compromise between band members who were using the system in order not to "ruin too much" for each other when standing in the same area seemed reasonable to all the musicians, although some were skeptical on how to successfully implement it. S4 said he would find it disturbing to have to compromise with another musician, but it would still feel like an upgrade from the current monitor hearing state. He also said that as long as the musicians agreed on when not to interact, for example during a solo, it would not be a problem. S3 claimed that planned choreography would be a necessity once your band starts playing the bigger venues anyway, so compromising over stage area in order to receive better monitor hearing would not be an issue to him. S1 gave the suggestion of dividing the stage into areas where each musician has its own "safe zone". There, the other musician's audio mix could be lowered to about 30% if they entered while the area was already occupied by its "owner".

4.2. User tests

The questions asked during users tests can be found in the appendix. During the test with S2, the violinist was limited to using only one string when playing, due to the other strings being damaged and not being able to get in tune. This might have had affect on the results of S2's test. Due to these technical problems, the tests with S1 and an additional musician had to be canceled. This was unfortunate as both S1 and the additional musician, together with S3, where the users who had most experience of live performances while moving around on stage, and would probably have given us valuable information.

4.2.1 Moving the ideal monitor hearing sweet spot

All the users felt that the sound followed them in a pleasant and natural way, both when moving collaterally and when moving closer to or further away from the speakers. S7 said that he felt surprised whenever he walked to a new position and noticed that "the sound was there" and S5 was astonished over how well the system could track him. S4 and S7 noticed a decrease in volume when they were positioned quite close to the edge of the stage between two of the monitors. S4 said it was understandable due to the angle and that the monitors should ideally be positioned further away from the edge of the stage. S5 noticed a small "jump" in the sound when moving between the speakers, but still felt the sound followed in a comfortable manner. S2, S4, S5, S6 and S8 said that they felt "more free" when using the system and S7 said that he could move around a lot more than usually. S8 said that when playing without the system he felt the urge to return to his monitor immediately, and S4 claimed he felt encouraged by the system to move around more.

4.2.2 Compromising with another musician

All the musicians liked the idea of individual "safe zones", and S2 said that "While having the monitor hearing following you is good, not being able to ruin for one another is *really* good". S4 liked the idea, but found it disturbing when sharing the stage area and monitors with another musician, as he felt it became difficult when entering the other musicians area and that the volume of his mix was lowered too much. S5 and S6 also mentioned that their volume was a little bit too low when entering the other musician's area, but still he felt the idea was good. S8 and S2 felt the mixes were balanced in a good way. S2 also said that level differences between the musicians mixes is something that the musicians could decide between themselves, but that it would be good to have some presets.

4.2.3 Placement of the sensors

Our users expressed no issues having the sensors on the instrument, but when asked about other placings most users believed they would probably receive a better sound if it was sent to their own head and not to the head of the instrument. S6 suggested an algorithm in the program, compensating for the distance between the head of the instrument and the musician's head. Still, everyone felt that they perceived the sound in a natural and comfortable way, and no one felt disturbed by the sensors. S2 said that the placement did not matter too much, as long as the monitor hearing follows you.

4.2.4 Future potential

All of the users believed a system like this could be of use during live performances, but mainly for big bands on big stages. S5 thought that there is no optimal monitor hearing solution at the moment so this system definitely had a need to fill, while S4 said it would depend on how practical the installation of such a system would be. Most users also mentioned the cost as a possible issue and that smaller bands would probably only be able to use a system like this if it was already installed at the venues where they perform.

5. Discussion

In this section, the methods for the study and future potential of a fully developed system based on the designed model for this study are discussed. The limited scope of the study does not allow general conclusions to be drawn, although it can definitely serve as a basis for further work in this area. Also, the model simplifications made for the system (Chapter 3.2.3) will not be discussed from an implementation point of view as this was outside the scope. The simplifications possible affect on the results will however be briefly discussed in this chapter.

5.1 Results from interviews and user tests

5.1.1 The current view of monitor hearing

Based on the interviews, monitor hearing affects the performance of every musician, but the view of how important it is and to which degree it affects the performance varies between the subjects. Most of the subjects that moved around a lot on stage had expressed major concerns regarding the monitor hearing sweet spot, but even those who did not move around a lot claimed that the sweet spot restricted them in their performance. This leads us to believe that it is not necessarily how much the musician moves on stage that determines their need for better monitor hearing, but rather the musicians' personality and musical preferences. Apart from the personality of the performer we believe that the genre of music performed has a big impact on the musicians’ view of monitor hearing. This hypothesis is supported by the statement of one of the test users who claimed that when playing jazz fusion, the monitor hearing was not as important as when playing metal, due to the large differences in volume and intensity of the performances. Also, the only two persons who claimed that they did not give the monitor hearing that much thought during performance, as long as they knew their songs well, had primarily played punk rock. Punk rock is often defined by the simplicity of its music and to rather focus on the aggression of the sound, while a genre like metal (which most other of the musicians had experience performing) is more complex and technical (Chen, 2012). The simplicity of the songs might be the reason that users who primarily played punk rock often did not feel the need to hear themselves as well as the users who played death metal or melodic rock.

5.1.2 Using a system that changes the monitor hearing

The overall opinion of the system during the user tests was that the sound followed the musicians in a pleasant and natural way. It is hard to measure whether the musical performance that was played was actually improved or not by using the system, but as all the users claimed that they could hear themselves better with the system, we believe that an improvement of their playing was achieved. Most of the musicians also expressed an increased sense of freedom in their performance, which is positive in several ways. One being that the musician can interact with a larger part of the audience as the musician no longer feels locked on stage to the position of the monitor hearing sweet spot. For the same reason the musician can also interact more with the other musicians in the band, and due to the “sharing is caring” function

(Chapter 3.2.4.2) the possibility to ruin the monitor hearing for one another while doing this was reduced. All these factors contribute to the enjoyment of the performer and most likely lead to a better experience both for the musician and the audience.

5.1.3 Designing the system

One of the most important results of the user tests was that the users felt that the monitor hearing "followed" them around. The naturalness of the system was appreciated and when designing a corresponding monitor hearing system for actual live performances this is an important goal. The system model of the current study was designed for the test environment and a system able to be used in actual live performances would need to take the associated room acoustics in consideration to achieve this.

The sharing of monitors was considered a good solution and compromise in exchange for being able to walk over to the other side of the stage and play standing next to the other musician. However, the opinions on how much the sound level should decrease when entering the other musician's area differed between the users. According to one of the test users, the musicians should be able to choose from using a "preset" and adjust the levels themselves.

We believe that placing the sensors on the instrument worked well, and also the musicians were reluctant to put on any extra equipment while performing. Also, the difference between having the sensors on for example the head or the instrument was not believed to big enough to be of importance, and even though the sensors probably could be incorporated into the stage outfit, it would be easier and more convenient to incorporate them into the instruments.

5.2 Method criticism

5.2.1 Interviews

Of the eight people we interviewed, only two were professional musicians that had regular experience of performing at larger venues. As our target group for this system was musicians who moved around a lot on stage, it would have been optimal if all our subjects had performed on stages where they actually had had the possibility to do so. We also should have asked the musicians what genres of music they had performed as it probably affects their views and needs of monitor hearing. The current genres of the musicians were known beforehand by the authors, but not if the musicians had played several other genres or which genre they had performed the most.

5.2.2 User tests

A higher amount of user tests or/and musicians with more live performance experience and preferably with music as their profession would have been preferred to be able to reach general conclusions. The test environment was somewhat different from an actual live music concert environment, especially given that no FOH sound or audience noise was simulated during the user tests. This can have lead to a more positive result among the users as the lack of disturbing surrounding sounds makes it easier to hear the stage monitors. However, as the users got to play with and without the system, the differences in the experiences would still be similar and can therefore be applied to an actual live performance. Also, no microphones were used during the tests, eliminating feedback problems. Since in actual music performances feedback calls for adjustments between sound on stage and FOH levels, this would have to be considered when developing a future system.

5.3 Future works

As shown in the interviews with sound engineers and musicians, stage monitor hearing is a problem without a good solution that pleases everyone, and even though this study has highlighted some of the major issues and presented them with a solution in form of a system, there are still factors that have been overlooked (Chapter 3.2.3) that need to be researched and dealt with before an implementation of a system like this can be realized. When discussing the future potential of this system with the test users, most agreed on that it would be mostly bigger bands and bigger venues that would invest in such a system, so examining the opinion of those operators would be of great interest.

6. Conclusion

The study indicates that there is a need for a monitor hearing system that takes the possibility to move around on stage into account and that such a system would improve the performance of a moving musician. The system would also reduce the limitations that musicians experience due to the otherwise restricted monitor hearing sweet spot. The extent of the usability of such a system within the rock and pop genres increases with the overall sound level and complexity of the genre performed, and it is also associated with the musicians' own musical preferences.

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Appendix

Interview questions

Interview questions for musicians

- What is your musical background?
- How much are you thinking on your monitor hearing and how much does it affects yo during a performance?
- How much you move on stage when you are performing?
- Do you feel that the monitor hearing is preventing you from moving around more on stage?
- Would you like to move around more on stage?
- In your opinion, is there a need for research on improved monitor hearing when the musicians are moving on stage?
- If the monitor hearing would "follow you" when you are moving on stage, without using in-ear, i.e. with monitors, would it improve your performance?
- Would you be willing to compromise with your band colleagues on the monitor hearing on stage?

Interview questions for sound engineers

- What is the biggest challenge of controlling the monitor hearing for the musicians?
- What do you need to think about when setting the monitor hearing?
- In your opinion, there is need for research on improved monitor hearing when the musicians are moving on stage?
- If the monitor hearing would "follow the musicians," although they are moving, without using in-ear, i.e. with monitors, would it be a good thing for the musicians or would it cause difficulties for you as a sound engineer?

User tests questions

- Spontaneously, how did you experience the system?
- Did the sound follow you in a pleasant way?
- Did you notice any considerable volume alterations of the sound when moving in the x-respectively y-axis?
- How well did it work to share the system with another musician?

- How did you feel about the placement of the sensors?
- Did you feel that you could move around more than usual? Did you feel more free?
- Do you have any other opinions about the system and what could be improved?
- Do you think a system like this could be of use during real live performances?