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ROOM ACOUSTIC TREATMENT AND DESIGN OF A RECORDING SETUP FOR MUSIC THERAPY

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ABSTRACT

Improvisational music performance was found to be a very effective method of assessing patients as a therapeutic approach. Instead of conducting a therapy session as a one-to-one verbal interaction, playing musical instruments in a group is incorporated as a less intense form of communication, which requires a specifically designed room. Such therapy is developed for adults within the autistic spectrum to help with social-emotional regulation in their daily life. A room with poor acoustics was assigned to organise the therapy. Some of the parameters defining the room behaviour were modified to accommodate the alternation between speech and live music. The changes done to the room concerned mostly the reverberation time. Considering the purpose of the room, two standards were employed as references: ISO 23591:2021 for quiet acoustic music and BB93 for carrying speech in a comfortable environment for people with special communication needs. The results obtained are presented alongside the recommended values of the standards. In addition, we present a multi-channel recording setup specifically designed to collect audio data during therapy sessions. The setup enables music signal analysis of the recorded data and is non-intrusive towards the course of a session as well as the patients' psychopathology.

Keywords: *acoustic treatment, multi-channel recording, music therapy*

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1. INTRODUCTION

Music is considered a non-verbal means of communication for human thoughts and emotions. It is able to transmit such underlying information from the creator and/or performer to the listener. In the therapeutic context, this could be exploited by the therapist to achieve a better understanding of the patient's emotions and even psychopathologies. This type of analysis is possible through musical improvisation between therapist and patient or a group of patients. Music therapy is meant to create a more relaxed environment than in verbally interactive types of therapies. In addition, music therapy can promote therapeutic objectives such as communication, learning mobilisation, expression, flexibility and other social-emotional skills depending on the patients' needs [1].

Long reverberation time in rooms where live music is played is generally desired. A well known example is from Leo Beranek [2] suggesting an ideal reverberation time between 2.0s and 2.3s for a concert hall for symphonic music. On the other hand, reverberation time in listening rooms has to be rather short, in the range of 0.3s to 0.7s. However, either of these values is far from fitting the given purpose of the room. The more recent standard on acoustic quality criteria for music rehearsal rooms and spaces [3] (ISO 23591:2021) is a better approximation of the room used for music therapy. In the first part of this paper, we describe the acoustic treatment of a specific room designated for music therapy.

Despite music therapy being employed for more than 200 years [4], little research has aimed at collecting and analysing quantitative data. Several tools have been developed to aid the therapist in analysing the performance of a patient. One of the first publications on the subject from Hunt [5] is presenting a set of electronic instruments which transmit and collect MIDI data to a computer. The main purpose was to collect the data and offer the possibility of later analysis. The advantage of having MIDI format data is that some features can be extracted to a very accurate extent. For example, in more recent algorithms the beat can be tracked and even more relevantly, small deviations from the expected beats can be measured [6]. This already proved to be valuable information in diagnosing people with borderline personality disorder [7]. Despite the advantage of MIDI type of data, acoustics instruments are still widely used in music therapy or even non-conventional instruments, for example boom-whackers [8]. The music created by the patients is improvised, but the patients most often do not have any musical theory knowledge or performance skills. The improvisations are different in content than what could be expected from professional musicians. Therefore, extracting musical features can be helpful even for trained musicians and therapists.

Several algorithms [9–11] are now designed for the therapy context, in which music does not follow conventional structures related to composition. Despite MIDI data making feature extraction easier, only acoustic instruments were considered in the specific music therapy project we are concerned with in this paper. The reason for this choice is mostly related to the practicality of using existing gear. However, the use of acoustic instruments are an essential part of other goals which are beyond the purpose of this paper. While no algorithms are presented in this paper, the explanations given above are to inform on previous approaches taken in analysing music therapy samples, and to motivate the decisions taken regarding the recording setup. We therefore aim to collect multi-channel audio recordings during therapy sessions. To this end, a recording setup needs to be defined.

A final consideration in designing the measurement set-up is related to the population involved in the research. The patients taking part in the therapy sessions are adults within the autistic spectrum with moderate to high IQ. The psychopathology studies on autism spectrum disorder (ASD) [12] tell that the patients are sensitive to certain environments which moulded the entire approach taken to record and analyse the music performed. Loud and uncomfortable environments create extra discomfort for the patients and thus, affect the measurements and reduce the benefits of the therapy. Likewise, invasive recording equipment is to be avoided due to the pressure it may create towards the patients. In general, therapy should aim at a comfortable environment, even more so in this case.

The purpose of this research is to improve on group therapy by collecting and analysing quantitative data, given the constraints described above. Here is presented only the setup designed to achieve that goal, divided into two main topics. In Section 2, the acoustics of the room where further measurements will be taken, is extensively discussed. The approach taken in collecting the audio data is described in detail in Section 3. A conclusion is formulated in Section 4.

2. ROOM ACOUSTIC TREATMENT

From the beginning, the room designated had poor acoustics, mainly referring to long reverberation times. This was already found inappropriate from the therapists' point of view and the mitigation is presented below. Apart from the therapists' opinions, the population involved in the research was taken into consideration and the room was designed for the specific situation.

In this section is described the method used to measure the reverberation time of the room before and after acoustic treatment was installed (Subsection 2.1), how the target reverberation time was defined (Subsection 2.2) and the acoustic treatment necessary to achieve it (Subsection 2.3). The values of the reverberation time measures are shown per octave band.

2.1 Reverberation time measurements

In order to assess the room acoustics in its initial state, acoustic predictions and measurements were done. The predictions were done using available absorption coefficients for different surfaces of the room. To calculate a predicted value for the reverberation time the Norris-Eyring equation [13] was used,

$$T_{60} = \frac{-0.161V}{S\ln(1-\alpha)} \tag{1}$$

which resulted in more accurate predictions that Sabine's equation,

$$T_{60} = \frac{-0.161V}{S\alpha} \tag{2}$$

Moreover, the measured reverberation time after the acoustic panels were installed, was almost identical to the predicted response after the addition of absorption.

When taking the acoustic measurements, the ISO 3382-2 standard [3] was followed with an engineering level precision (six source-microphone combinations). To excite the room, an exponential sine sweep (ESS) was played through a loudspeaker (Genelec 8030) with frequencies from 45 Hz to 20 kHz for 10 seconds, two cycles with five seconds of silence in between [14]. The two loudspeaker positions were near two corners of the room. The sound source used was directional with a flat frequency response in the range of interest. According to ISO 3382-2:2008, the source should be as omnidirectional as possible, however, for engineering precision measurements there are no strict requirements ([3] section 4.2.1 Sound source) . In order to have a more omnidirectional source, the loudspeakers were placed facing the corner at angles different from 45 degrees (to avoid any symmetry in sound propagation). In this case, the sound received at the microphone is indirect.

An omnidirectional microphone (DPA 4060) was used to record the sweep played back through the loudspeaker. The six microphone positions were chosen following the ISO 3382-2, with a height of 1.2 m, at least 1 m away from any wall or surface, and spatially distributed around the room in order to cover the entire room. For calculations, the Aurora plugins were used [15]. The exponential sine sweep was created in Adobe Audition with the Aurora plugins automatically generating the inverse filter of the sweep. That filter can then be convolved with the recorded audio file to obtain the impulse response. For details of the processing involved the reader can refer to [14,16–18]. Also using the Aurora plugins, the acoustic parameters were calculated and the data was exported for analysis.

The same approach was taken for measurements of the room untreated and after treatment. The same equipment and measurement positions were kept for both series of measurements.

2.2 Room Description and Target Reverberation Time

Based on the purpose of the room, no standard defines any acoustic parameters for the particular case of having live music and therapy combined. Therefore, two relevant documents were used as guidance. First, knowing that live music will be played in the room, the ISO 23591:2021 [19] was used to define the lower and upper octave-band limits of the reverberation time in the room. According to the standard, there are three categories of live music that can be played: quiet/loud acoustic and amplified music. The parameters for the categories are based on the type of instruments, the volume of the room and the number of people playing. For the research presented here, the therapy is to be performed as a group, with no more than four patients and two therapists playing different acoustic instruments together. Thus, the room belongs to the quiet acoustic music category.

As mentioned before, the population taking part in the research are adults with high compensating autism and the purpose of the research is therapeutic. Clearly, speech has to be accommodated and remain intelligible. The second document used as guidance was the Building Bulletin 93 (BB93) [20] which presents values for acoustical parameters in schools, including spaces dedicated to students with special hearing or communication needs. An ordinary refurbished classroom should have less than or equal to 1 s of reverberation time in all mid-frequency one-third octave bands. Similarly, for a classroom intended for students with special communication needs, the reverberation time should be less than or equal to 0.4 s.

It is necessary to mention that not one of the two documents presented is representative of the purpose of the room. The BB93 is specific to teaching activities, however, music played in such a low reverberation room becomes unpleasant. Therefore, parts of both documents were combined to define a desired target.

The room's dimensions are $8 \times 6.6 \times 5.4$ m giving a volume of approximately 285 m^3.The building is structurally old and some ceiling decorations had to be kept intact and visible, therefore no treatment of the ceiling was taken into consideration. One of the walls was mostly covered by a bookshelf closed with glass doors and had to remain the same. One of the adjacent walls encompassed two large windows with long heavy curtains, and no panels were to be placed on it either. Therefore, acoustic panels could be placed only on the other two adjacent walls. The floor was already carpeted and no changes were allowed. Any panels installed in the room had to be removable for future changes of acoustics in the room outside this research.

Based on the documents presented as guidance, the target was defined as such: the reverberation time measured after the acoustic treatment should be below the upper limit of ISO 23591:2021 and remain above the suggested values of BB93. There was no restriction to remain within the limits of the ISO 23591:2021.

The initial measurements were compared against the target, as shown in figure Fig. 2. The figure also shows the minimum and maximum values (vertical bars) of all the six positions measured as compared to the average (solid line). Based on this, the amount of absorption desired was calculated. Although the formula used to predict the reverberation time Eqn. (1) calculates T60, the measurements are used to calculate T20 because of the room's dimensions. A decay of 60 dB is not feasible for small volume. Another aspect was that the room had several parallel surfaces which can encourage standing waves. As mentioned before, one wall was mostly covered by a bookshelf closed with glazed doors which is a highly reflective material. Therefore, some diffusion was necessary.

2.3 Acoustic Treatment

Several designs were rendered to obtain the most suitable one for the purpose and encompassing all the constraints encountered. Three types of panels were found necessary to treat the room, out of which two types of absorption panels for low and mid-range frequencies, and one type of panel for diffusing the sound. The technical specifications of each of the panels can be found in [21–23]. The amount of absorption was calculated based on the given specifications, for all relevant octave band frequencies. It should be noted that the bass traps used are meant to be placed on walls rather than corners of the room and the specifications in the technical note are given for this situation.

Considering the different properties of the panels and the desired outcome of the room acoustics, the amount of panels and positioning of each was decided. The final product is shown in Fig. 1. The different types of panels were mixed on the surface of the walls to create a diffuse sound field in the room. The height of the first row of panels was chosen based on the fact that people are seated and the panels have to be at least as low as ear-height. Other considerations include regions where pressure build-up was favoured by the geometry of the room, compensation for lack of ceiling absorption panels, or fixed positions of instruments.

2.4 Measurement results

Measurements of the room acoustics were done after mounting the acoustic panels, keeping all variables the same as for the initial measurements. In Fig. 2 the results in octave bands from both measurements are shown. A reduction of the reverberation time T20 with an average of 0.35 s was obtained for all bands. When comparing the results of the final measurements to the target, it can be seen that the desired outcome was obtained. A small deviation is observed at the 125 Hz octave band, where the results are just above the maximum value desired. However, the measurements were done with only one person present in

Figure 1. Picture of acoustic panels' placement in the room.

the room. It is expected to have five more people during music therapy sessions which will have an impact on the reverberation time, lowering all values, however not drastically.

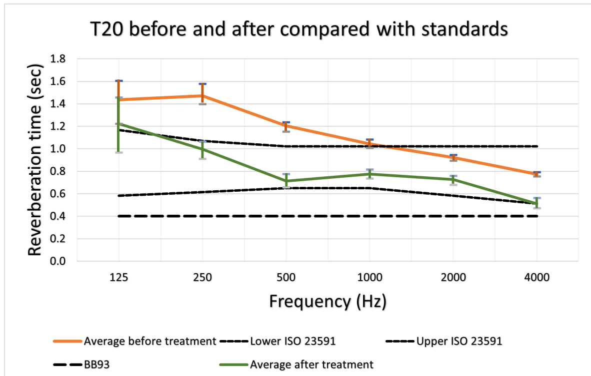

Figure 2. Measurements results. Solid lines - averages of measurement positions with minimum and maximum values per frequency band, dashed lines - upper and lower limits of the ISO 23591:2021 and BB93 values.

2.5 Background noise measurements

Another set of measurements was performed according to IEC 16032:2004 [24] to determine the background noise after the acoustic treatment was mounted. A Bruel &

Kjaer sound level meter type 2250 was used to measure A-weighted sound pressure level in octave bands for occupied and unoccupied conditions. The results were below 20 dBA in all octave bands for both cases. However, the noise is highly non-stationary mainly because the room is situated in a music school, thus, higher levels could be expected at different time instants.

3. RECORDING SETUP DESIGN

In this section we will briefly present the entire setup for recording group music therapy sessions. The focus is on the design and implementation that satisfy all requirements despite the constraints faced, and the equipment used and why. In this paper, there are no results presented in connection with the recording of the therapy sessions, only the setup proposed.

3.1 Therapy-specific Constraints

One of the most relevant aspects of group music therapy is that the participants, either patients or therapists, can see each other and so, they can visually communicate when playing different instruments. That implies that the group is sitting in a circle (see Fig. 3) and an obvious solution would be to place microphones in front of each patient. However, due to the psychopathology of the patients involved, the obvious solution is considered intrusive. The proposed alternative solution was a circular array placed at the centre of the setup.

Figure 3. Picture of circular setting prepared for group music therapy

Apart from the audio recordings, video content was also needed for further analysis and as reference for the therapists involved. The video camera needed to be able to capture micro-movements of each patient, such as facial expressions and other minimal body movements. Naturally, a 360 degrees camera was considered to be placed at the centre of the group.

One challenging aspect of improvisational music therapy is the unpredictability of events during each session. For example, the participants can choose any instrument available in the room and so can also change their position in the room. The video recording is therefore useful for tracking each patient. The information is necessary for identifying the patients and keeping track of their personal progress throughout the therapy process.

3.2 Hardware

The complete list of hardware used for recording the sessions is shown in Tab. 1, excluding any cabling. In the equipment list there are four types of microphones for different purposes. The ambisonic microphone was needed for creating a 360 degrees recording and the omnidirectional microphones were used in the microphone array (see section 3.3). The contact microphones were needed to record some instruments used by the participants as a reference for further post-processing connected to music analysis. The directional microphones (M88TG) are used as well for reference in locations that may need some coverage when participants change position in the room.

In Tab. 1 we also shown the analogue-to-digital (AD) converter and the sound card that are used to connect to a computer and record the audio with a software of choice. The direct injection (DI) boxes are included to balance the audio signals from the ambisonic microphone and from the video camera. As mentioned before, the camera is used to record the entire therapy session, with precise details of the patients' reactions and its position will be further described.

3.3 Array Design

A microphone array was designed for the specific problem considered here. Since the positioning of the participants is mainly circular, the array was designed in a circular configuration as well. To avoid interference with the line of sight of a seated person, the support holding the array of microphones was brought as close to the floor as possible, at a height of 43 cm.

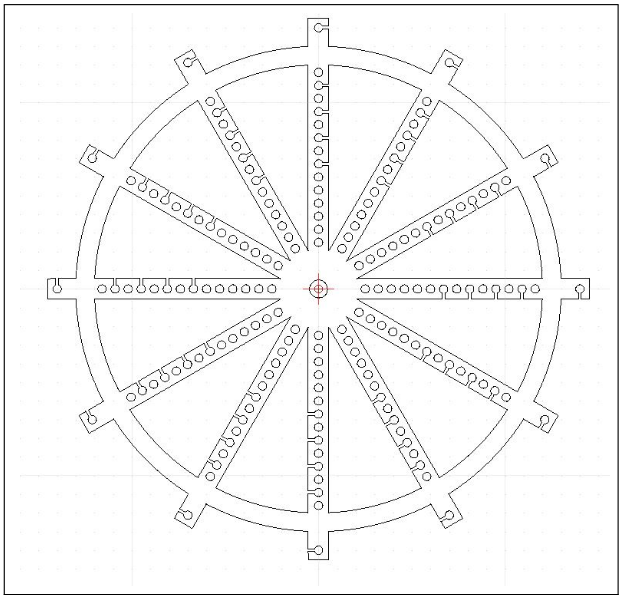

Figure 4. Drawing of the microphone array top plate.

The 12 microphones are held by the circular plate shown in Fig. 4, at the ends protruding outwards. The cavities on the plate are made mainly to diminish the possible reflections reaching the microphones, while the plate remains sturdy. The radius from the centre of the plate to the centre of the cavities holding the microphone capsules is 140 mm. The microphones are placed at 30 degrees, 72.5 mm apart from each other.

The microphone cables were custom made to 15 cm from the capsule to the XLR adaptor so that the connection between the microphone and the cable reaching the AD converter is fixed on the support of the array (see Fig. 5). All the XLR connections rest on a lower circular plate, around 20 cm below the top one. The base of the support is fixed on three extendable pipes, similar to a tripod.

The main axle of the support extends above the top plate holding the microphone capsules. The reason for this was to mount the 360 video camera together with the ambisonic microphone on the same support. All the equipment was selected to be non-intrusive to prevent any negative impact on the therapy.

One set of measurements was done to assess the design of the array, following the IEC 60268-21:2018 [25]. The measurement purpose was to check if the top plate of the array has any impact on the microphone responses. For this, only one microphone was used. An ESS was

Figure 5. Picture of the microphone array support.

reproduced through a loudspeaker and recorded by the microphone (similar to Section 2.1). The Aurora plug-ins [15] were used as well. However, the microphone was placed on-axis 30 cm away from the loudspeaker to avoid reflections from the environment. The measurement was done for the microphone on a tripod without the array top plate (the reference), the microphone on the array including the top plate placed vertically and horizontally (regardless of the omnidirectional polar pattern of the microphone).

In Fig. 6 the frequency response obtained in all three cases is shown. Third-octave smoothing has been applied to the data presented for ease of reading the plot. It is clearly visible that there is no significant impact from the array top plate on the response of the microphone. At high frequencies there is a slight difference between the microphone being positioned in the supposed position on the disc and the other cases. However, the difference is less than 2 dB in a frequency range where it becomes perceptually negligible.

4. CONCLUSION

In this paper an approach was presented targeted at conducting and recording group music therapy sessions for psychological analysis. The paper was divided into two main topics, acoustics of the room and recording setup design with a non-intrusive approach.

The acoustics of the room were modified to accommodate the two-fold purpose of playing live music and carrying conversations. The reverberation time in the

Table 1. List of equipment chosen for the specific recording setup

Hardware	Amount	Brand
Ambisonic microphone	1	Zoom H3-VR
Directional microphone	2	Beyerdynamic M88TG
Omnidirectional microphones	12	DPA 5060
Contact microphones	5	Schertler Dyn-Uni
12-channel analog-to-digital converters	2	RME12mic
Soundcard	1	RME Digiface
DI Box	2	Behringer
Video camera	1	Insta 360

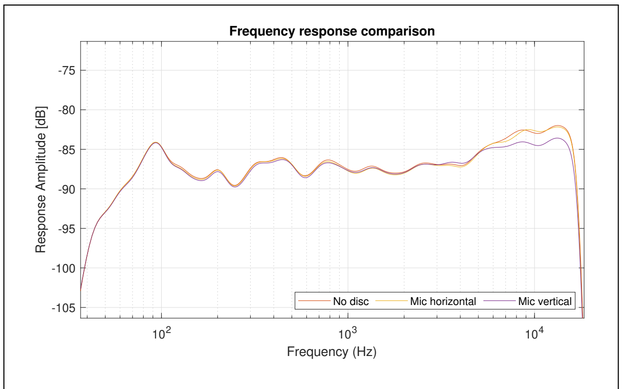

Figure 6. Frequency response comparison for the effect of the array top plate.

room was lowered to fit in between the upper limit of ISO 23591:2021 and above the BB93 limit for students with special hearing and communication needs. The methods for achieving the desired response and the final results are presented. Informal subjective feedback from professors and students in music therapy has suggested that a balance between playing live music and talking in the room was achieved.

For the recording setup, therapy-specific constraints were taken into consideration for the design of the entire method of collecting the necessary data. The main part of the setup was the design of the microphone array which was briefly presented, alongside two measurements done to verify the quality of the built array. Other elements of the recording setup were also mentioned to inform the entire method used.

The room acoustics and the recording methodology presented here are a proposed approach for the context of group music therapy. The achieved goal was to create a comfortable environment for the participants while allowing for collecting quantitative data to do further analysis. For the given population involved in the research, the lower limit was chosen according to the BB93 section on rooms for students with special hearing or communication needs. However, for non-sensitive therapy patients, the reverberation time values could follow the ISO 23591:2021 standard which would be at least a valid guide to designing the acoustics of such rooms.

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