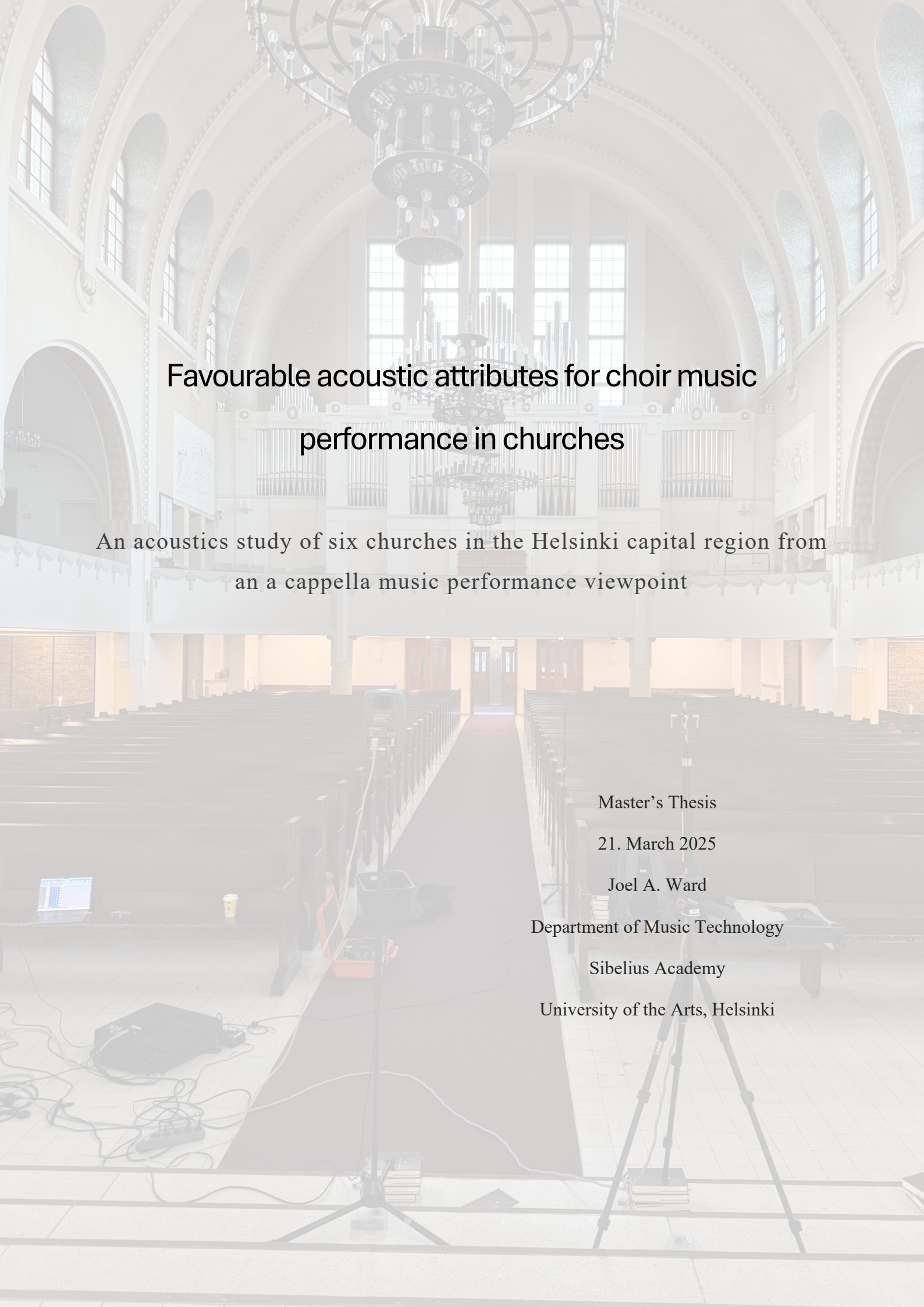

Favourable acoustic attributes for choir music performance in churches

An acoustics study of six churches in the Helsinki capital region from an a cappella music performance viewpoint

Master's Thesis

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Abstract

This thesis aims to identify what acoustic values and parameters are complimentary for ease in choral and a cappella music performance in churches. To determine the acoustic requirements that make performing choral music in churches either easy or difficult, first a survey was presented to both amateur and professional choir singers and choir conductors in Finland on the topic of easy and difficult church acoustics (Spring, 2024). Respondents were asked to pick three churches from two categories: three churches where it is easy to sing choral music in, and three churches where it is difficult to sing choral music in. Respondents were also asked to explain what acoustic aspects are valuable for easy choral music performance. The churches were presented as two multiple selection lists, and were limited to churches located Helsinki capital region. Based on the responses, the top three churches from both respective categories were chosen for acoustic research. While most acoustic location research is based on the listeners perspective, in this research we concentrate on the performers perspective, so the main measurements were taken from the most common performance location by using a GRAS type 50 VI-1 vector intensity probe, with secondary measurements from arbitrary locations around the space with general omnidirectional microphones. The measurements were then analysed in MATLAB, and the data is provided as objective parameters *G, C,* EDT & T_{20}, as well as spatio-temporal plots.

Tämän tutkimuksen tavoitteena on löytää ja esittää syitä kuoro- ja yhtyelaulumusiikin esittämisen helppoudelle ja vaikeudelle erilaisissa kirkoissa. Suomessa toimiville kuorolaulajille ja kuoronjohtajille esitettiin kyselytutkimus koskien kuoromusiikin esittämisen helppoutta ja vaikeutta erilaisissa kirkkosaleissa (kevät, 2024). Kyselyssä pyydettiin sekä valitsemaan monivalintalistasta kolme kirkkoa joissa kuoromusiikin esittäminen on subjektiivisesti tuntunut helpolta ja kolme kirkkoa jossa em. tuntuu vaikealta, että omin sanoin kertomaan helppojen ja vaikeiden akustisten ominaisuuksien piirteitä kuoromusiikin esittämiselle. Kyselyssä mainitut kirkot rajattiin pääkaupunkiseudulla sijaitseviin kirkkoihin ja muihin kirkkotiloihin (pl. seurakuntasalit, kryptat ym.). Kyselytutkimuksen perusteella kummastakin kategoriasta valittiin kolme eniten mainittua kirkkoa (yht. kuusi kirkkoa), joissa suoritettiin akustiikan mittausta kunkin kirkon tavanomaisimmalta esiintymispaikalta tutkimuksen luonteen mukaan. Mittaukset analysoitiin MATLAB-ohjelmassa, ja tulokset esitetään objektiivisilla parametreillä *G, C,* EDT & T_{20}, sekä spatio-temporaalisina graafeina.

Keywords

choral performance; church acoustics; performance acoustics; classical singing; choir music; acoustic measurement; a cappella

Thesis checked for plagiarism

15.5.2025

For Dad,

Your angelic radiance guides us all in the shadows of these troublesome times.

Table of contents

1. Introduction

The majority of vocal ensemble and choral performances in Finland are given in churches. From a total of 305 choral, vocal ensemble or other a cappella[1] concerts reported to *The Finnish Amateur Musicians' Association* SULASOL by its 282 member choirs in 2024, 195 (about 70%) were held in some kind of church space (SULASOL 2024). While it is important to note that not all SULASOL member choirs report their concerts to the organisation, we can quite safely assume that most member and non-member choirs and other a cappella ensembles alike follow suite in organising choral concerts in church acoustics on a regular basis. Churches are also generally more affordable to rent for concerts than dedicated concert venues and will even sometimes waive the rental fee if the compensation for a concert reservation is covered with e.g. a service performance. These types of agreements make churches a lucrative choice for especially amateur choirs who might rely wholly on member subscription fees for organising and promoting concerts, and thus don't have the means to reserve a dedicated concert hall or other type of performance venue for regular concerts.

Additionally, a significant amount of non-performing choral activity is organised within parishes. A cappella music has strong ties to the Evangelical Lutheran church in Finland, with almost every parish involving some activity related to amateur choral singing for all ages in their recreational activities. The union for Finnish church musicians reports 462[2] parish choirs in Finland in 2024 (Suomen Kirkkomusiikkiliitto ry 2024). It is rather safe to assume that parish choirs will rehearse and/or perform in a church space, be it a dedicated concert performance or a service performance.

[1] A cappella = sung by a group of people without any musical instruments
https://dictionary.cambridge.org/dictionary/english/a-cappella

[2] Reported music group organisations. The number might not represent the exact amount of singing ensembles. The list is also not fully exhaustive of all parish choirs in Finland, but rather gives a rough estimate of the situation.

Throughout history, churches and other secular spaces have been built and designed with high emphasis placed on the acoustic aspects of the space. Acoustic clarity or acoustic comfort is regarded as great importance when designing or maintaining a church space due to the nature of the usage of the space, as a significant portion of a typical church service is conducted by chanting (Kit, Phua Sai and Nazli Che Din 2023). Singing has kept a major role in Christian liturgy of many disciplines throughout its existence, whether performed by the priests and other holders of secular position who by the rules of the Church were allowed to sing the chants, or by the whole parish attending the service later in time, when e.g. reformation allowed common service attendees to join in the chant and to sing psalms together (Bertoglio 2017). It is also not insignificant that many staple standards of European traditional choral music since the 15th century (e.g. the whole repertoire of *J.S. Bach*, probably the most widely recognised name of this category) are based on secular texts and have been composed to be performed in church acoustics either a cappella or together with a pipe organ (Bagenal 1930).

If approximately 65% of choral concerts in Finland are given in some type of church space and recognising the importance of church acoustics in Western classical music in general, it is interesting to research the acoustic elements and acoustic behaviour of the spaces choral musicians perform in, focusing especially on the performance areas of churches themselves versus measuring church halls as a whole.

While lots of acoustic research has been conducted in churches (Girón, Álvarez-Morales and Zamarreño 2017), only a handful address the performers' perspective at all. Acoustic research and acoustic measurements of performance venues of many types tend to focus on the listeners perspective, with measurements taken from the seats or stalls of a performance venue rather than from stage. Generatively, the main goal of these studies is to identify the acoustic factors that make a space pleasant or unpleasant—or, put simply, good or bad—for listeners. However, they often overlook the acoustic elements affecting the musicians on stage, which could significantly impact the performance, either positively or negatively, as perceived by the audience.

1.1 Defining “good acoustics”

While it’s generally impossible and non-interesting to attempt to define absolute values for good and bad acoustic environments, we can divide the subject into several smaller

sections by requirement of the space in question and focus on what acoustic values are important in these individual settings. For this, we need some common parameters to discuss upon.

In their book *The Science of Sound*, Rossing, Moore and Wheeler divide the criteria for "good acoustics" into six sections as follows (quoted directly):

1. Adequate loudness. *Everyone must be able to hear the speaker of performer. The room should not be too large or have excessive absorption.*
2. Uniformity. *Listeners in all parts of the room should hear as nearly the same sound as possible. There must be a sufficient number of sound diffusing surfaces to avoid "dead" spots. All sections of an orchestra should blend together in a balanced way.*
3. Clarity. *There must be sufficient absorbing surfaces that the reverberant sound does not mask the following sound.*
4. Reverberance, or liveness. *The listener should feel bathed in sound from all sides, but at the same time be able to localize the sound source. Clarity and liveness may be partly contradictory.*
5. Freedom from echoes. *Reflected sound should arrive early enough to reinforce the direct sound but not be perceived as a separate echo.*
6. Low level of background noise. *The noise from heating and ventilating systems and from external sources should be kept very low.*

   (Rossing, Moore and Wheeler, The Science of Sound, 3rd edition, 534-535)

Research by Barron and Reichardt et al. has emphasized the importance of lateral reflections. Lateral reflections from side walls arriving between 35ms and 80ms from the direct sound add to the sense of spaciousness, while vertical reflections of the same length add more to the perceived early sound (Rossing, Moore and Wheeler, The Science of Sound, 3rd edition 2002).

In chapter 23.12 of *The Science of Sound*, the authors touch on applying these principles of good acoustics for churches. While most churches and other rooms of worship are not primarily used for music performance, they share the same acoustic requirements as those of e.g. concert halls[3] (Rossing, Moore and Wheeler, The Science of Sound, 3rd edition

[3] (Rossing, Moore and Wheeler, The Science of Sound, 3rd edition, 535-538)

2002). We have already learned from Section 1 of this thesis that early European churches and cathedrals were built in a way that reinforce the human voice naturally so that the whole congregation present could easily hear the voice of the speaker. The counter product of this type of design is, that while the reader's or preacher's voice is loud, it would be "boomy" or "muddy" especially at the back rows of the congregation. This implies low clarity and high reverberance, which would be found in cathedrals built mainly of stone and lumber, with lots of flat surfaces. This meant that liturgists would have to adapt their voices in a way that everyone present would understand the message. High background noise like rumble caused by a storm and leaky windows would make this task even harder. Especially in Northern Europe, the pulpit for the preacher was placed in an adequate place through trial and error to achieve the best possible clarity in the church. This could be further aided using a canopy, placed behind the speaker to create a reflective surface that feeds the sound forwards towards the congregation. The implementation of electronic sound reinforcement for the speakers allows some rest for the speaker's vocal cords and diaphragm, but also for more creative architectural decisions that can implement adequate clarity for the liturgist while also maintaining amplification for the whole congregation. Architects who are designing a rather small church in a noisy environment like a main road or a busy street should consult a qualified acoustician during the planning of the layout and design.

The notion of "good acoustics" for music performance in particular is not as straight forward as one might assume. It is often accepted that any church will suffice for any type of classical music mostly because "that's just how it should be" probably due to subjective experiences of how sound "blooms" in big, luscious halls. This doesn't necessarily hold truth, especially when considering how modern architecture and the use of sound reinforcement in churches has mitigated the value of designing a church with proper acoustics.

While it is naturally important to benefit from acoustical amplification (see strength in Section 4.1) that a church, similarly to a purpose-designed concert hall can provide, a lot of detail can be lost in reverberation. For example, while lush choral music with long phrases and sparse rhythm clearly benefits from long reverberation times, orchestral music with faster tempi and accentuation like pizzicatos in the strings and complex changes in the percussion parts get buried very quickly in high reverberation times (Howard and Angus 2006). Thus, rather than trying to define absolute values for good and bad acoustics, it's more interesting to discuss what acoustic values benefit certain types of music, especially when considering acoustic and generally non-amplified music performance.

In this thesis we are interested especially in perceived good acoustics for choral music performance from the performers' perspective, so understanding how different reverberation times and other acoustical elements can either make or break a performance is important. The previously quoted six parameters from section 23.7 of (Rossing, Moore and Wheeler, The Science of Sound, 3rd edition 2002), while not directly implied, also play a big role in the following sections of this thesis, even though they present principles for good acoustics from the listeners point of view.

2. Research questions and methods

2.1 Thought process leading to question

While professional and amateur singers and musicians alike understand that different types of performance spaces feel different to sing/perform in, it is usually unclear to the untrained eye or ear to establish the reasons and factors that cause either a good or a bad acoustic experience. Why is an arbitrary venue *A* better to sing in than venue *B*? Why does standing in the last row feel better than standing in the middle of the group, or in the first row? What does the conductor hear (and not hear), and how does that affect the way they might navigate the singers through a potentially technically demanding piece of music?

The above and many other questions are quite often discussed between singers and conductors. Experienced ensemble singers remember what it felt like singing in venue *A* and *B* and might thus prepare their performance to suit the space accordingly. Choir conductors are also able to rehearse and prepare musical gestures based on knowing what the performance acoustic is or what it might resemble, especially if rehearsing the singers occurs in a completely differently behaving acoustic space (Trinīte 2023).

In the introduction of (Fischinger, Frieler and Louhivuori 2015), the authors write:

"Taking into account the important role of acoustics for music performances, it is surprising that not much research has been done in this area from the musicians' point of view as compared to the listener's perspective which is a crucial factor in designing concert halls. Clearly, it would be beneficial for musicians to understand the effect of room acoustical features on their performance and how best to adjust tempo, phrasing, dynamics, and other musical parameters with respect to a given venue's acoustical environment."

2.2 Research question and methods

This thesis aims to inherently answer the sole question: What acoustic properties make a church either easy or difficult to perform choir music (accompanied and a cappella) in. The terms “easy” and “difficult” are chosen as opposed to the obvious “good” and “bad”, as this thesis doesn’t necessarily want to dwell into preferable acoustic properties of a church space as a whole but rather focus on what acoustic phenomena happen in the performance position that create either a desired or an undesired performance environment for choral music. For simplicity, we’ll assume that the most usual position for choral music performance in a church space is in the front-middle, or just in front of the altar area. Further arguments for this decision are presented in Section 4.

The scope of churches chosen for this research was determined by a quantitative questionnaire presented to amateur and professional choir singers and choir conductors in the Helsinki capital region. Survey respondents were asked to pick three (3) churches from two (2) categories. Based on the survey, a total of six churches in the Helsinki capital region were chosen for acoustic research. The survey results are presented and discussed in Section 3 of this work.

The acoustics measurements (Section 4) that followed were conducted in co-operation with Aalto University Acoustics Laboratory, and especially Prof. Tapio Lokki. The measuring and analysis methods in this thesis lean heavily on Prof. Lokki’s and his colleagues’ expertise, see e.g. (Lokki and Kuusinen 2021), (Tervo, et al. 2013) & (Pätynen, Tervo and Lokki 2013). Common parameters for acoustic measurements Strength G, early to late sound index (or Clarity) C_{50} *&* C_{80}*,* Early Decay Time EDT and Reverberation Time T_{20} will be used to aim to assess the general similarities and dissimilarities between the churches in the “easy” and “difficult” categories, while also interpreting spatio-temporal SDM[4]-pictures taken from four different receiving points with two different source points. The specific measurement and analysis methods used in the research of this thesis are further explained and discussed in Section 4.

[4] SDM = Spatial Decomposition Method, as presented by (Tervo, et al. 2013), further explained in Section 4.

2.3 Previous research and observations

Much research has been conducted about choral music performance acoustics, and how different reverberation times and early reflection parameters can affect the performance. The most notable contributor for choir acoustics research is probably Prof. Sten Ternström of the Stockholm Music Acoustics Group. Prof. Ternström was the person to first introduce the term "choir acoustics" and is regarded to be the pioneer in serious discussion of choral music performance in different acoustic spaces (Trinīte 2023). The author of this thesis also offers some personal insight and observations[5]. We will concentrate on a few topics that are interesting for this thesis.

In 1965, Marshall and Meyer conducted a study about small vocal ensembles in different acoustic spaces by placing a vocal quartet in a hemi-anechoic chamber[6] and altering the acoustic values of the room with speakers (Marshall and Meyer 1985). It was found that singers preferred higher reverberance loudness, while the reverberation time was of little significance. Also, vertical first reflections were not appreciated as much as lateral early reflections when the perceived levels of the early reflections were high (Ternström 2003). Specifically, early reflections arriving within 15-35 ms were perceived as helpful, while 40 ms early reflections were considered as particularly disruptive (Ternström 2003). The values correspond to lateral reflective surfaces of approx. 2.5 - 6 meters for preferred reflections, while any further surfaces caused disliked harmony. Sound diffusion was not a significant factor in this study.

Tonkinson (Tonkinson 1994) conducted a study about the Lombard effect within choir singers. The Lombard effect is a tendency to raise one's own voice when producing sound in an already loud environment, e.g. a choir setting in a small and highly reverberant space, to hear oneself better. The study was conducted by recording individual singers reciting a piece while listening to audio through headphones that were increasing in volume.

[5] The author of this thesis is a professionally trained singer and a professional choir musician, who performs regularly with the Helsinki Chamber Choir, one of the leading chamber choirs in the Nordics.

[6] A hemi-anechoic chamber is a space with no other reflective surface than the floor, the material of which can be varied to replicate different conditions for acoustic measurement of e.g. loud machinery. https://www.iacacoustics.global/news/the-difference-between-hemi-anechoic-chambers-and-fully-anechoic-chambers/

Amateur singers might not be able to adjust to the Lombard effect accordingly and will unintentionally start adjusting their own vocal production to potentially harmful extents, while professional singers with a trained voice are better equipped in approaching these types of situations where one can't necessarily hear their own voice in a loud environment. In situations where instincts call for singing louder to compensate for growing ambient volume levels, it is imperative for a singer to refrain from adjusting their own voice production to unnecessary levels to ensure that the blend of voices in the choir isn't affected substantially and to avoid potential harm to the vocal cords.[7]

Tonkinson found that both amateur and professional singers alike were able to resist the Lombard effect when given specific instructions to try to avoid singing louder when the volume around them increased (Tonkinson 1994).

In 2015, Fischinger, Fieler and Louhivuori published an article addressing the influence of room acoustics on choir singing (Fischinger, Frieler and Louhivuori 2015). A multitrack recording of a 23 piece mixed choir was taken in a professional recording studio with individually miked choir singers, while each singers all wore open-back headsets that were used to simulate different room acoustics with three virtual room sizes named AC1, AC2 and AC3[8] (Fischinger, Frieler and Louhivuori 2015). The piece chosen was a motet called *Locus Iste* by Anton Bruckner (1824-1896), which is a composition for SATB[9] chorus with an original tempo marking of allegro moderato[10]. In this experiment, the motet was performed in a medium slow tempo of approximately ♩ = 80, which is rather much slower than the andante moderato marking found in the original manuscript of the composition.

Fischinger, et al. found, that while intonation of the musicians wasn't substantially affected when changing the virtual room sizes, there were drastic changes in the time domain. As the virtual room sizes were increased, the tempo of the piece used in the experiment

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[7] The author of this thesis has succumbed to falling for the Lombard effect himself, especially at an earlier stage in their professional singing career. This phenomenon is often discussed thoroughly between professional singers and choir conductors alike. Choir conductors very often ask for singers to not adjust their voice levels in a highly reverberant space.

[8] AC1 = reverb effect bypassed (dry studio environment)
AC2 = "Concertgebouw", RT = 1.77 s
AC3 = "Spanish Cathedral", RT = 4.79 s

[9] SATB = Soprano, Alto, Tenor, Bass – a regular abbreviation to explain a basic mixed choir part arrangement

[10] "Moderately fast" or "fast but not too fast", approximately ♩ = 120

tended to slow down and that timing was less precise. This finding is accordance with results from similar experiments conducted by (Kalkandjiev and Weinzierl 2015) and (Ueno, Kawai and Kato 2010).

One interesting finding was that out of the three different virtual room sizes used, out of which AC2 and AC3 were simulated and one, AC1, was completely dry, the medium sized room or AC2 was subjectively enjoyed the most, according to the singers. It was observed that the singers would constantly sing louder in the medium reverberation environment AC2. This may be a combination of cognitive and emotional effects (Fischinger, Frieler and Louhivuori 2015).

Fischinger, et al. discuss, that personal uncertainty of one's own singing voice is easier to perceive in a dry environment (AC1), which may lead to loss of usage of proper singing technique especially with amateur choral singers who are not used to hearing their own voice so intimately[11]. Also, similarly but on the other end of the spectrum, the high reverberation time of AC3 can be perceived as louder and noisier, which might have resulted in singers singing more softly due to not being certain of their own voice and/or the timbre or relative pitch that they were producing (Fischinger, Frieler and Louhivuori 2015). Interestingly, this somewhat contradicts with the Tomkinson's (Tonkinson 1994) research and findings regarding the Lombard effect in choral singing.

In 2020 Luizard, et al. studied classical singers interpreting familiar pieces of music (e.g. arias from Mozart, Puccini, Verdi, Bach) in varying tempi in different types of environments and how the changes in acoustics influence the performances and interpretations. Luizard, et al. found, that while the differences in acoustics didn't change the musical performance in terms of tempo or volume, each professional singer adapted their technique to the specific space to be able to perform the piece consistently. This suggests that professionally trained singers are able to give consistent, thoroughly rehearsed performance in very differing acoustics without much alteration of interpretation (Luizard, Steffens and Weinzierl 2020).

[11] The author of this thesis has observed this type of behavior when recording a classical chamber choir in a dry studio setting with close mics. Singers with classically trained voices are most often used to sing in a somewhat reverberant and/or ringing environment, which professional singers use to their advantage to project their sound further into the space. The lack of excitation of the space in a dry room, e.g. a studio, will often require adaptation of technique especially when blending with other voices is important.

3. Survey for choir singers and conductors

3.1 Scope of survey

To assess the scope of churches in Helsinki for the acoustic measurement research in Section 4, a mixed survey was conducted among amateur and professional choir singers and choir conductors in the Helsinki capital region. The questionnaire consisted of both multiple choice and open answer options, preceded by a short preliminary section to gather general information of the respondent's activity and situation in the choral music environment.[12]

Section 2 presented two exhaustive lists of churches or church-adjacent spaces in the Helsinki capital region. From the first list, respondents were asked to choose three (3) churches that they subjectively feel are "easy"[13] to perform choir music in. The contrary was asked from the second list with the adjectives "hard" or "difficult"[14]. Respondents were also asked to explain with their own words and knowledge an easy or a hard acoustical space to sing in based on their own experience. Both lists were followed by an optional field for further remarks and arguments for their choice.

The survey was conducted on Google Forms, and it was distributed via different choir music and singing related channels on social media platforms, e.g. Facebook and WhatsApp. The survey was also spread to the member choirs of Kausikonserttikuorot ry., a Finnish

[12] General questions:
- Are you a choir a) singer, b) conductor or c) both?
- Are you a a) soprano, b) alto, c) tenor or b) bass? (multiple choice allowed)
- Do you currently sing in a choir? a) yes, b) no, c) on hiatus
- What choir or choirs do you sing in at the moment? (open answer)
- How long have you sung in a choir? a) <1 year, b) 1-2 years, c) 2-5 years, d) >5 years
- Are you a professionally trained musician?

[13] Finnish: *helppo*
[14] Finnish: *vaikea*

organisation to promote choir concerts. Some specifically interesting choirs and vocal ensemble groups were approached directly with email. A few individual singers were asked to join the survey over rehearsal breaks.

The survey was given in Finnish over approximately three months in Spring 2024. The full blank survey is presented in Appendix I.

3.2 Results

3.2.1 Section 1 – Metadata

The survey was answered by 47 people, out of which 42 (89.4%) were exclusively singers and 5 (10.6%) both singers and conductors. None of the respondents chose option "[only] conductor".

Forty respondents (85.1%) were active choir singers, while 3 (6.4%) did not currently sing in a choir at the time of answering to the survey. Four respondents (8.5 %) claimed to be on hiatus from choir singing activities.

Out of the multiple-choice question gathering the part or parts respondents sing in a choir, tenor was the leading voice group within the respondents at 17 answers (36.2%). Soprano and alto were equal at 13 answers each (27.7% ea.), while bass amounted to 11 answers (23.4%). By taking a closer look into individual answers, seven respondents picked more than one option from this question, suggesting that they often switch parts.

An overwhelming majority of 44 respondents (93.6%) claim to have sung in choirs for over five years. 3 respondents (6.4%) have sung in choirs from 2 to 5 years at the time of the survey. No respondents chose the first two options of <1 year or 1-2 years.

Ten respondents (21.3%) are professionally educated musicians, 36 respondents (76.6%) do not have professional education in music. One respondent (2.1%) chose to explain some details of their music education history and occupation as a professional singer.

Respondents were encouraged to mention what choirs they either sing in currently or have sung in the past. A total of 55 different choirs or vocal ensembles were mentioned. Some of the choirs mentioned do not operate either often or at all in the Helsinki capital region (◊), and some choirs and vocal ensembles mentioned are no longer in active operation (†).

Addictio	Klemetti-opiston kamarikuoro ◊	Suomalainen kamarikuoro
Akademen	Krysostomos	Suomen kansallisoopperan kuoro
Audite	KYN	Suomen Nuorisokuoro
Bach Collegium Helsinki	Laulu-Miehet	Talla †
Cantores Minores	Lumen Valo	Tapiolan kamarikuoro
EMO Ensemble	Lyran	Tapiolan kuoro
Eteläsuomalaisen osakunnan laulajat	Muntra Musikanter	Unreality
Euga ◊	Musica	Utopia
FluoCanto	Naskalit ◊	Uusimaa-kuoro †
Freija	Olaus Petrikören	Valkia
Hämäläisen osakunnan kuoro	Polyteknikkojen kuoro	Vantaan kamarikuoro
Helsingin Filharmoninen kuoro	Psaldo	Värinä
Helsingin kamarikuoro	Radion Kamarikuoro †	Versio
Helsingin Laulu	Ruamjai ◊	Viipurilaisen osakunnan kuoro
Jubilate	Savolaisen osakunnan kuoro	Vires ensemble
Kaamos	Sibelius-Akatemian vokaaliyhtye VOKIS	Vokaaliyhtye Uoma
Kaari	Somnium Ensemble	Vox Aurea
Kampin laulu	Spira Ensemble	Ylioppilaskunnan Laulajat
Kauppakorkeakoulun Ylioppilaskunnan Laulajat		

Table 1. All choirs or vocal ensembles mentioned in the survey

3.2.2 Section 2 – Open answers and church choices

In the second section, respondents chose three churches from two categories: easy and difficult. Before selecting the churches, respondents were asked to describe what they feel is necessary for either an easy or a difficult environment to sing in. The responses are presented in Appendix III.

For the “easy” category, the most mentioned aspect was that it is important to hear the other singers as well as one’s own voice in order to balance the ensemble sound. A

sufficiently long (but not too long) reverberation time was appreciated while also appreciating clear articulation of fast rhythms.

"In easy acoustics, you can clearly hear the other singers/parts, but you can also hear your own voice, and singing feels effortless, with the sound carrying well. Easy acoustics are not too dry, but there should also not be too much reverb."[15]

"Easy acoustics: good stage audibility (i.e., being able to hear what the other end / front row is singing); but at the same time the back row doesn't come through too loud (– –). Additionally, the hall should have a suitable amount of reverb that isn't too harsh or 'stone-like' (of course, the appropriate reverb depends quite a bit on the pieces being performed), which also helps with breathing."[16]

"Easy: A sufficiently reverberant and absolutely quiet space that inspires the tuning of ringing intervals such as seconds, where the sound image allows individual parts to stand out in the chords. However, the reverb should not create a deep-space effect that disrupts the sense of rhythm."[17]

A total of 29 different churches or church spaces were either chosen from the provided multiple selection list or added in as the option "other". The top three churches that were considered easy to sing in were Kallion kirkko (20), Paavalinkirkko (17) and Olaus Petrin kirkko (11). It is noteworthy that the top two churches received significantly higher ratings than the rest.

[15] Original quote in Finnish: "Helpossa akustiikassa kuulee hyvin muut laulajat/stemmat mutta kuulee myös oman äänensä ja laulaminen tuntuu vaivattomalta, ääni kantaa. Helppo akustiikka ei ole liian kuiva mutta siinä ei saa olla myöskään liikaa jälkikaikua."

[16] Original quote in Finnish: "Helppo akustiikka: hyvä lavakuuluvuus (eli kuulee myös mitä toinen pää / eturivi) laulaa; mutta toisaalta taaempi rivi ei tule liian kovaa (esim. ns. jenkkityyppiset kuorolavat joissa takasein buustaa takarivin ääntä aivan älyttömästi). Myös salin sopiva kaiku joka ei liian kivinen (toki sopiva kaiku riippuu aikapaljon esitettävistä biiseistä), helpottaa hengityksiä.

[17] Original quote in Finnish: Helppo: Tarpeeksi kaikuisa ja absoluuttisen hiljainen tila mikä innoittaa soivien sekuntien virittämiseen, kun kuulokuvasta erottuu myös oma stemma soinnuissa. Kaiussa ei kuitenkaan synny rytmitajua sotkevaa syvän tilan vaikutelmaa.

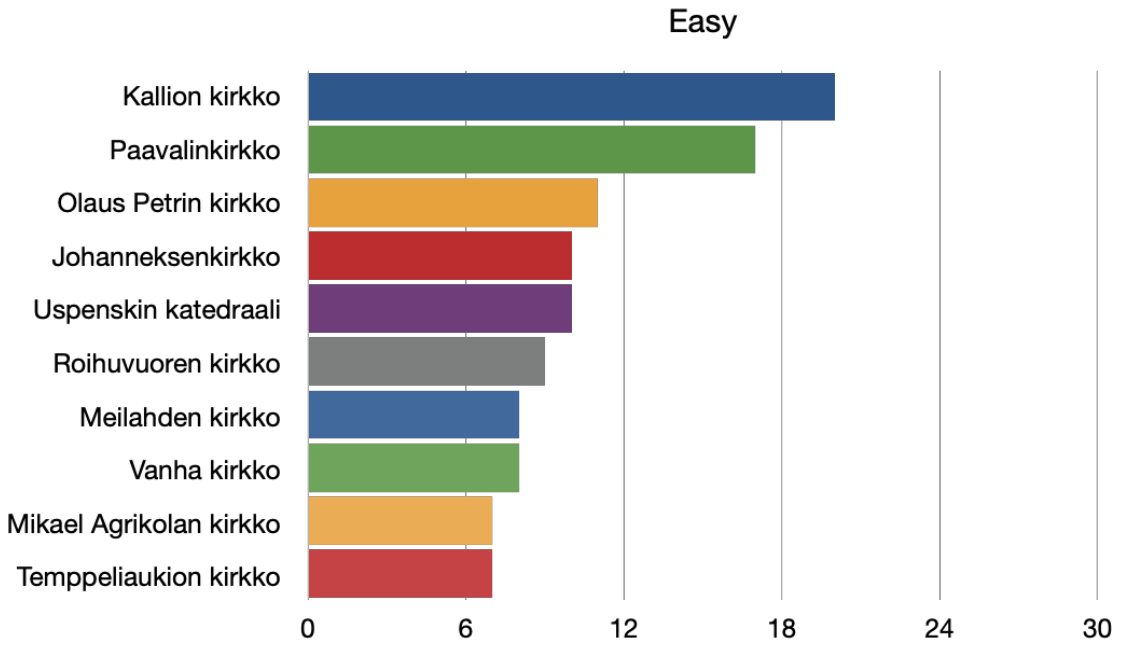


Figure 1. Top 10 responses in the "easy" category

A common occurrence in the descriptions was that a difficult acoustic space limits the amount of the comprehensive ensemble sound that one singer can perceive. A difficult acoustic space was described with adjectives like “dry” and “non-reverberant”. Many respondents also wrote that they start feeling a tendency to push their voice in a difficult acoustic environment due to not being able to hear others clearly.[18] Very long reverberation times were also not appreciated.

“In very challenging acoustics, it is like singing into a bag: you might not even hear your own voice, let alone the other parts. There is either no reverb at all, or there is too much and it muddles everything.”[19]

“From a singer's perspective, difficult acoustics are those where the auditory feedback provides a very incomplete response of the choir's overall sound and one's own singing. For example, you might

[18] i.e. the Lombard effect, (Tonkinson 1994)

[19] Original quote in Finnish: ”Hyvin vaikeassa akustiikassa "on kuin pussiin laulaisi": omaakaan ääntä ei välttämättä kuule, muista stemmoista puhumattakaan. Kaikua ei ole ollenkaan, tai se puurouttaa kaiken.”

hear only yourself and a few nearby singers, or barely hear yourself at all, making it hard to reflect on your own singing in relation to the choir's overall sound."[20]

"In difficult acoustics, you can't hear others well or you only hear a few individual singers other than yourself. [In difficult spaces] the acoustics are 'dry', with the sound fading quickly – – difficult acoustics can also have very long reverb, which easily muddles articulation and forces the tempo to slow down significantly."[21]

Thirty nine churches or church spaces were selected from the difficult acoustics category list or added as the option "other". The most disliked churches for choir performance acoustics were Temppeliaukion kirkko (24), Helsingin Tuomiokirkko (20) and Tapiolan kirkko (9). Similarly to the previous category, the top two churches received higher scores than the subsequent third and rest.

[20] Original quote in Finnish: Laulajan kannalta vaikea akustiikka on sellainen, jossa laulajalle tuleva kuulokuva tuo hyvin vajavaisen vasteen koko kuoron soinnista ja toisaalta omasta laulusta, esim. kuulee vain itsensä ja muutaman vierustoverin tai ei kuule itseään juuri lainkaan ja sitä kautta on hankalaa reflektoida omaa laulamaista suhteessa kuulemaansa koko kuoron sointiin.

[21] Original quote in Finnish: "Vaikeassa akustiikassa ei kuule muita hyvin tai kuulee vain joitakin yksittäisiä laulajia. Akustiikka on "kuiva", äänen sointi sammuu nopeasti. Toisaalta vaikeassa akustiikassa voi olla myös todella pitkä kaiku, joka helposti puurouttaa artikulaation ja tempoa joutuu hidastamaan paljon."

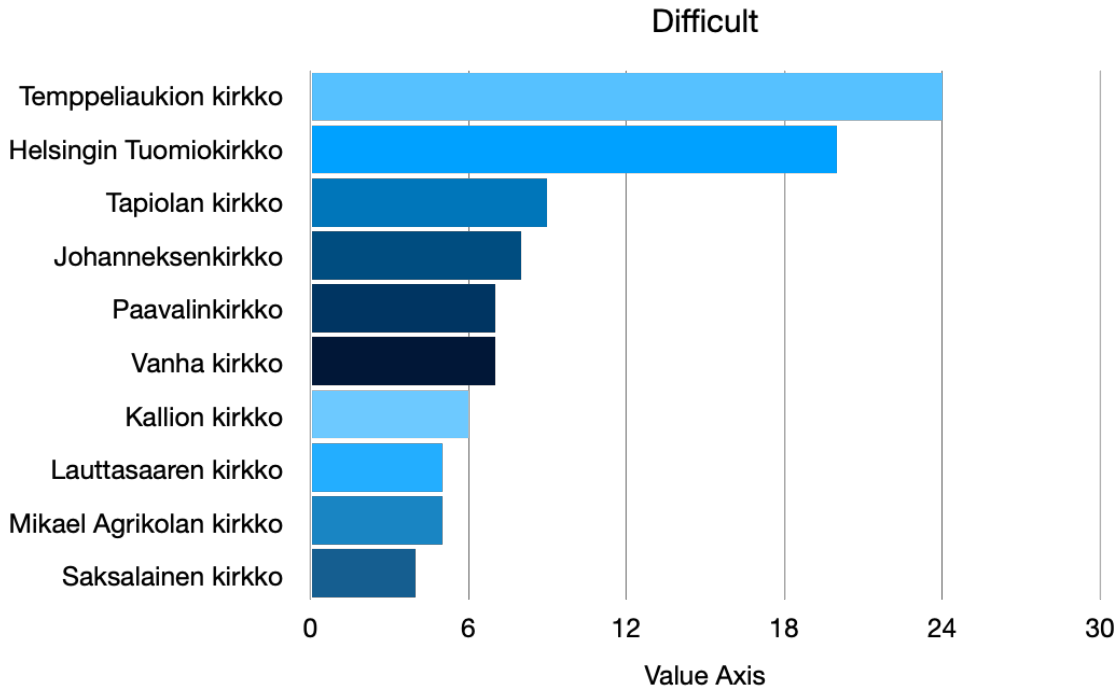


Figure 2. Top 10 responses in the "difficult" category

Figures 1 & 2 present only the top 10 picks in each respective category or churches or church spaces. The full list of churches picked and their popularity in the survey is presented in Appendix II.

3.3 Survey summary and discussion

The survey reached a delightful number of singers and conductors based mainly in the capital region of Finland, with a few responses coming from outside the main scope but that still provided valuable insight. The list of choirs mentioned depicts a wonderful and vibrant choral scene around Helsinki, with almost all respondents having over five years of experience in singing in choirs. Many respondents shared excellent insights about singing in differing acoustic spaces, and almost all the open question answers were coherent with each other, proving that experienced choir singers have a good and comprehensive understanding on what acoustic characters are helpful for choir singing at least on a general level without needing to know a lot about the technical side of acoustics

Based on a rough glance of what choirs or other vocal ensembles respondents sing or have sung in, bigger groups like Ylioppilaskunnan Laulajat and Cantores Minores and other large-format choirs got the greatest number of mentions. This would explain the popularity of

the larger churches versus smaller churches in the responses. Naturally, larger performance spaces are also more equipped to accommodate higher audience volumes.

None of the respondents chose option "[only] choir conductor", which can mean that, in a general sense, choir conductors are also singers in some setting or another. Having first-hand experience of singing in different types of acoustics may help the choir conductor in conducting their group in said acoustics, as they know personally how the space works from a singing perspective. Excellent choir conductors who don't have trained voices or any singing experience will engage in dialogue with the singers they are leading to make sure that everything is alright.

It is also worth mentioning that the survey didn't ask the respondents to specify the specific performance situations in the churches of their choosing. This was a deliberate choice when constructing the survey, as different points of possible performance locations and/or setups might vary greatly depending on the church, and the time it would take to change measurement setups multiple times in one church, if even possible due to time and budget constraints would have become overwhelming for the scope of this masters' thesis. Thus, it was decided that the following acoustic measurements would be taken from the usual performance locations of any given church, while understanding that e.g. singing from the gallery[22] might feel very different and might provide very different results. Future research on this topic might want to incorporate measurements from different performance locations in church spaces.

The measurements would also be taken when the churches are empty from audience, which naturally provide somewhat different results compared to when the stalls are filled with people (Desarnalulds, Carvalho and Monay 2002). This compromise is quite common when taking acoustic measurements of performance spaces, as while simulating an accurate performance environment would produce the most accurate results, gathering a sufficiently large amount of people to fill up an audience and have everyone sit still and nigh on completely quiet would create more problems than it would provide help. Similarly, the measurements would be taken without the presence of a choir of people on the stage, which is also an aspect to consider when interpreting the measurement results that are presented in Section 4.3 and 4.4.

[22] The organ gallery is a very common singing location for services, but not so much for traditional concert performances, unless the performance utilises an organ that is situated far away from the front of the church. Sometimes, choirs will choose to perform certain pieces from e.g. J. S. Bach from the gallery, as was the convention in the composers' own time (Bagenal 1930).

4. Acoustic measurements of six churches

4.1 Parameters

The aim of this research is to determine general acoustic qualities of one performance situation in six churches, which are chosen based on the answers from the survey that was presented in Section 3. Descriptions for each parameter with adjacent equations are presented below, with further figures from Thomas D. Rossing's *Springer handbook of acoustics*.

Strength G is the measurement for what could be called "loudness" or "gain" of the measured space. A common interpretation of G is the ratio between total energy and direct sound energy from a fixed distance (10 m) from an impulse response recording:

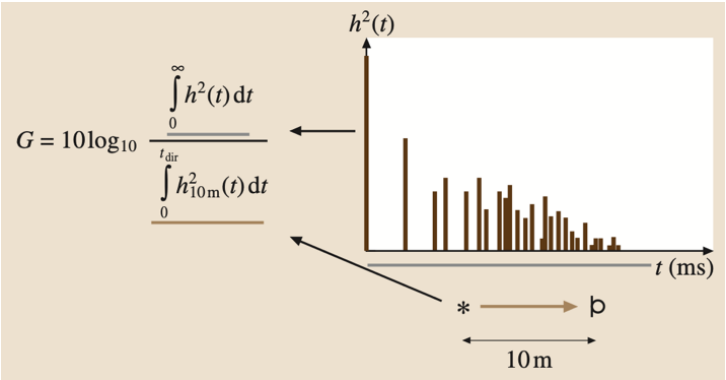


Figure 3. The definition of strength G: the total energy in the impulse response measured relative to the direct sound level at 10 m distance from the source (Rossing, Springer handbook of acoustics 2007)

Clarity describes the difference between detail and diffusion. In a nutshell, clarity can be interpreted as a counter to reverberance, as higher reverberance usually coincides with lower clarity. For example, let's imagine someone talking in a reverberant space. Higher values of clarity will make understanding the speaker a lot easier. Beranek writes, that

mathematically clarity is “The ratio between early and late energy in the impulse response” (Beranek 1986). For this, we get *C*:

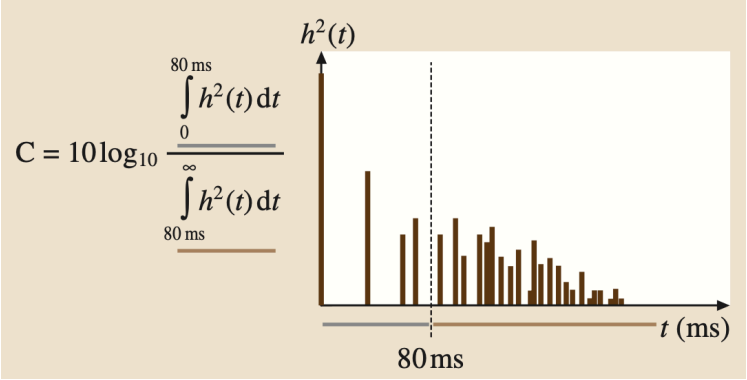


Figure 4. The definition of C: The ratio between early and late energy in the impulse response (Rossing, Springer handbook of acoustics 2007)

Early Decay Time EDT and Reverberation Time *T* are the most common suspects of any modern-day acoustic research. While EDT and *T* graphs usually look very similar, EDT is widely considered to be more reflecting of subjective reverberance impressions when music or musical elements are being discussed (Pätynen, Tervo and Lokki 2013). *T* is still arguably the most cited acoustic parameter despite being among the oldest (invented more than 100 years ago by W. C. Sabine), which is why it is presented here together with the more modern EDT.

T is defined by how long it takes for a sound source to decay by 60 dB in a space, after a continuous excitation has been turned off. In practice, only 30 dB of range is used for measuring *T*, as we will quite often hit background noise after that. The measurement range starts when the continuous sound has dropped by 5 dB, giving us an effective window of –5 dB and –35 dB for the measurement. Because of the bad SNR[23] that usually is an issue with T_{60}, commonly T_{30} or T_{20} are used instead, where T_{30} is the measured from –5 dB to –35 dB and then multiplied by two, and T_{20} is –5 dB to –25 dB multiplied by three.

As mentioned, EDT is a much more effective way of measuring perceived reverberance during music. EDT also measures the rate of decay like *T* above, but only between the interval of 0 dB and –10 dB, which allows us to probe into shorter windows of sound, as *T* requires a 5 dB decrease in level before the measurement begins. The measured

[23] Signal-to-noise ratio

decay value between 0 dB and –10 dB is multiplied by six, in the same fashion as T_{30} and T_{20}, to match T in time.

EDT values are often found to vary in different positions of the measured space, which makes it a better tool when comparing performance situations against each other, as T will more likely just present overall reverberance of the space and not the specific performance location.

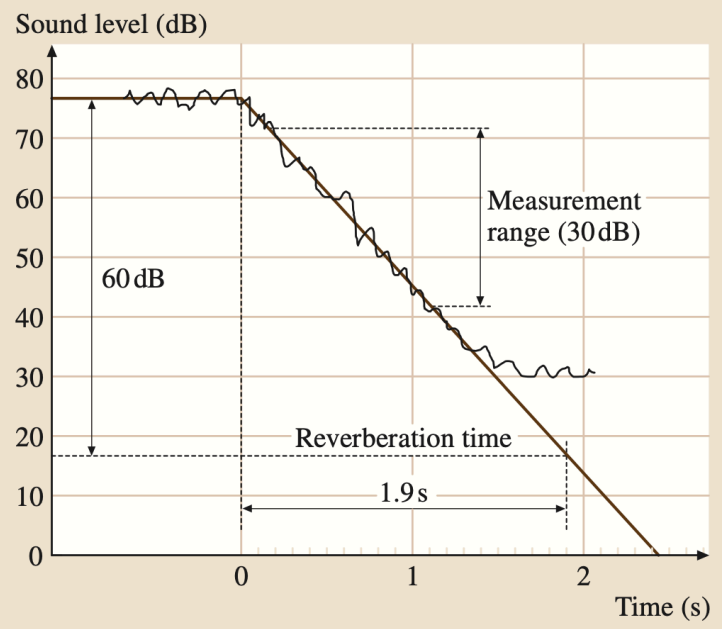


Figure 5. The definition of reverberation time (Rossing, Springer handbook of acoustics 2007)

We will use these parameters to a) compare the six churches against each and to b) attempt to determine what general acoustical qualities have tendencies to make a church space either easy or difficult to perform a cappella music in. Please see (Beranek 1986) or (Rossing 2007) for detailed formulas and more in-depth explanations for each of the mentioned parameters.

We also analyse and interpret lateral spatiotemporal responses or SDM's (Pätynen, Tervo and Lokki 2013) from different positions of an arbitrary but approximated standard setup for a choir performance situation. Vertical spatiotemporal responses are available in Appendix IV.

4.2 Methods and apparatus

All churches were measured from the front of the church in front of the altar, which is the typical concert performance spot in all the six churches. For these measurements, 4 seconds of logarithmic swept sinusoid excitation from 10 Hz to 24 kHz with 7 seconds of silence afterwards was played from two sources S1 and S2. A single Genelec 8030 speaker at ~180 cm from the ground, measured from the tweeter, was used for both source positions. S1 was located at the approximate location of where the middle of the first row would be, facing directly at the conductor. S2 was situated two meters left from S1, angled slightly to face the conductor and to simulate how a choir would traditionally form arched rows to achieve both visibility and audibility of each other and the conductor. A simple map with relative positions of sources S1 and S2 and receivers R1-R4 is presented in Figure 6. positions and dimensions of S1,2 & R1,2,3,4.

The responses from both source positions were measured by a six channel GRAS type 50 VI-1 vector intensity probe[24] in four receiving locations (R), also at ~180 cm from the ground when measured from the front-facing capsule X1. The vector intensity probe, or just probe for short, has three co-centric and phase-matched pairs of GRAS 40AI sound-intensity microphones in orthogonal directions with spacing of 100 mm between capsules. The capsules are amplified through dedicated GRAS 26AA 1/4-inch preamplifiers built-in to the handle of the microphone, which are powered by e.g. a suitable power module via a 24-pin LEMO output socket. From the power module, which in this case was the GRAS 12AC 6-channel box, line-level signal was fed into an RME UFX III audio interface, controlled by TotalMix over USB.[25] The responses were recorded into Pro Tools running at a sampling rate of 192 kHz and a depth of 32 bit. The sinusoid excitation sweeps were also played from the same Pro Tools session for every S and R locations by selecting the sweep file length for the recording duration, which assured that all response captures were the same length with synchronised start and end points.

The probe was angled the same way in all R's, so that the SDM graphs could be accurately and easily compared against each other. There might've been arguments for angling the probe to mimic the arching of singers in a typical performance setting, but it was decided to keep capsule X1 facing towards the audience for easier comparison later. This also

[24] https://www.grasacoustics.com/products/special-microphone/intensity-probes/product/272-50vi-1

[25] Using a software-controlled audio interface helped make sure that all important levels remained the same for each setup by always loading the same template for the UFX. RME's TotalMix software makes this an exceptionally easy task.

applies to R4 which was considered the choir conductors location. Usually, the conductor would be facing towards the choir in a performance setting, but as the probe doesn't incorporate any sort of head-modelling like e.g. binaural heads such as the Neumann KU100, we can safely compare the results with this positioning.

In addition to the probe responses from four R's, two generic omnidirectional microphones (Line-Audio OM1) in random spots were recorded to create a general picture of the acoustic properties of the church halls. The locations for these microphones weren't documented or in any way replicated between the churches, as their sole purpose was to produce some extra data for cross-referencing the responses from the performance situation together with a bigger picture of the church hall. The locations of these microphones were altered between every sweep, sometimes located rather near to the performance situation and other times very far in the middle or the rear end of the church space.

For the rest of this thesis, we will discuss the churches with slightly abbreviated[26] names, as presented in the objective parameter graphs and SDM plots.

[26] Paavalinkirkko (Paavali church) = Paavali
Kallion kirkko (Kallio church) = Kallio
Olaus Petrin kirkko (Olaus Petri church) = Olaus Petri
Temppeliaukion kirkko (Temppeliaukio church, aka. "Rock Church") = Temppeliaukio
Tapiolan kirkko (Tapiola church) = Tapiola
Helsingin Tuomiokirkko (Helsinki Cathedral) = HKI Tuomio

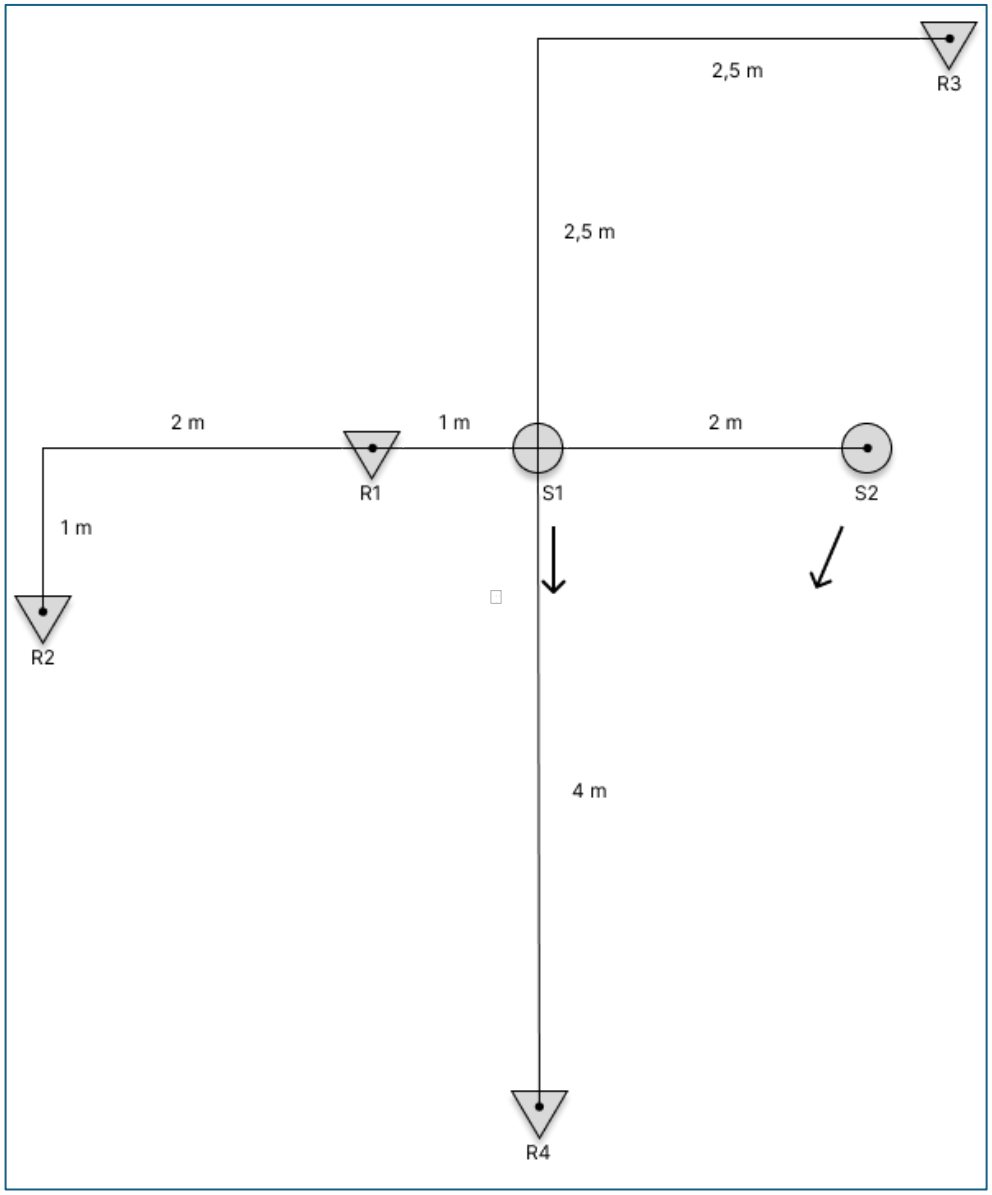


Figure 6. positions and dimensions of S1,2 & R1,2,3,4

Every individual recording from both the 6 probe channels and the extra 2 omnidirectional microphones were exported out of Pro Tools as 192 kHz, 24-bit WAV files, which were sent to Prof. Tapio Lokki at Aalto university for analysis. Prof. Lokki suggested that he would conduct the analysis with MATLAB script templates that had already been used for e.g. (Pätynen, Tervo and Lokki 2013) and due to the substantial amount of time it would take for someone who has next to none experience of MATLAB and it's workflow beforehand to first go through the learning curve to comprehensively understand what they're doing and formulating the scripts themselves. The scripts were used for analysing and creating the graphs for all the acoustic parameters presented in Section 4.1.

4.3 Results – objective parameters (probe)

First, one omnidirectional microphone from the probe measurements were selected for the analysis of the room acoustical parameters. Note, that the measurement are done with relatively close source and receivers, however, they nicely correspond to the situation between the singers in a choir. In other words, they describe the acoustical conditions on stage, sometimes also called as “platform parameters” in acoustic literature.

4.3.1 Strength

This graph has been constructed without an exact reference value for *G*, meaning that the values for *G* don’t represent specific amounts of strength for each church. In other words, the absolute values might be different than in standard *G* measurement, and this graph should only be used to compare the relative differences in strength of the six churches discussed in this research.

The values in strength *G* in all churches follow the same trends. After a very shallow rise to 250 Hz, *G* plummets massively. Olaus Petri provides more and Temppeliaukio generally less strength than the other four churches. Paavali, Kallio, HKI Tuomio and Tapiola are very closely like one another.

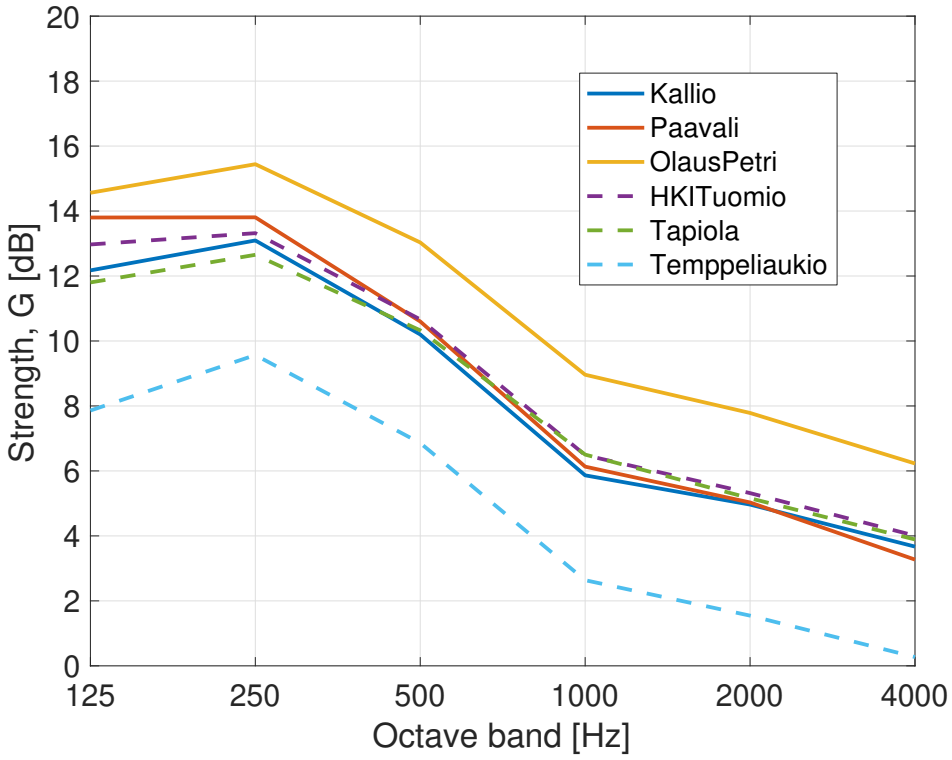


Figure 7. Strength G (probe)

4.3.2 Clarity

The graphs for early-to-late sound indexes C_{50} and C_{80} present quite differing trends in clarity between the easy and difficult churches. It appears that both C_{50} and C_{80} are higher in the difficult churches, which is an interesting finding. Especially in the 250 Hz region, clarity seems to be extremely high in both Temppeliaukio and Tapiola. The results between C_{50} and C_{80} readings from the probe mirror one another quite closely, with the obviously higher values on the C_{80} dB scale due to a longer window of early energy versus late energy.

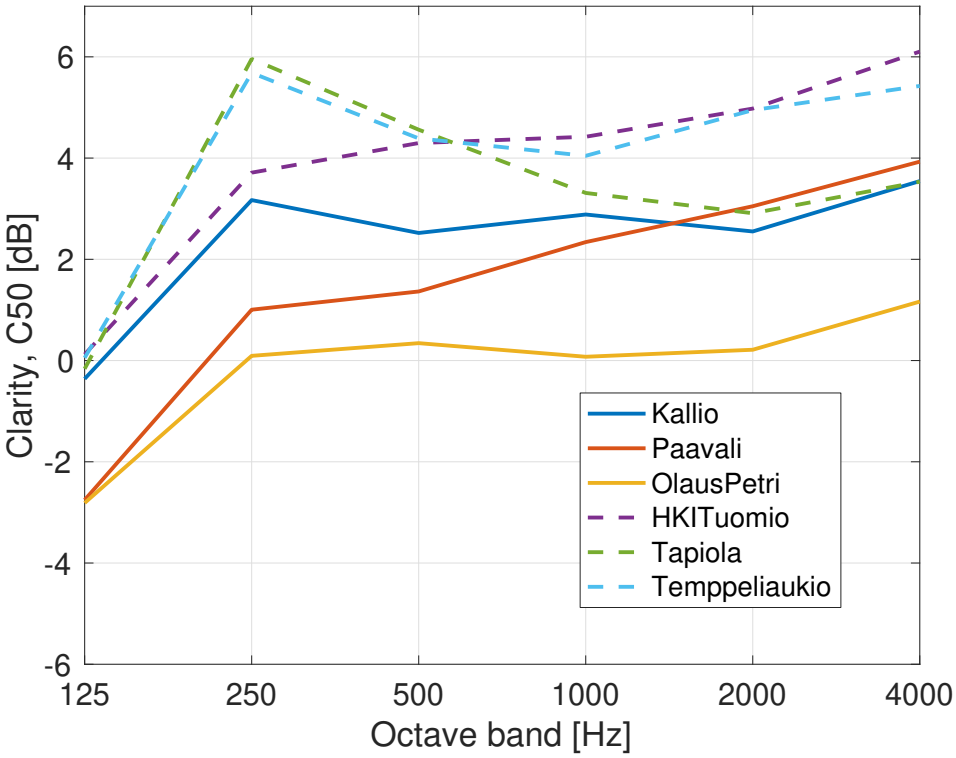


Figure 8. Clarity C_{50} (probe)

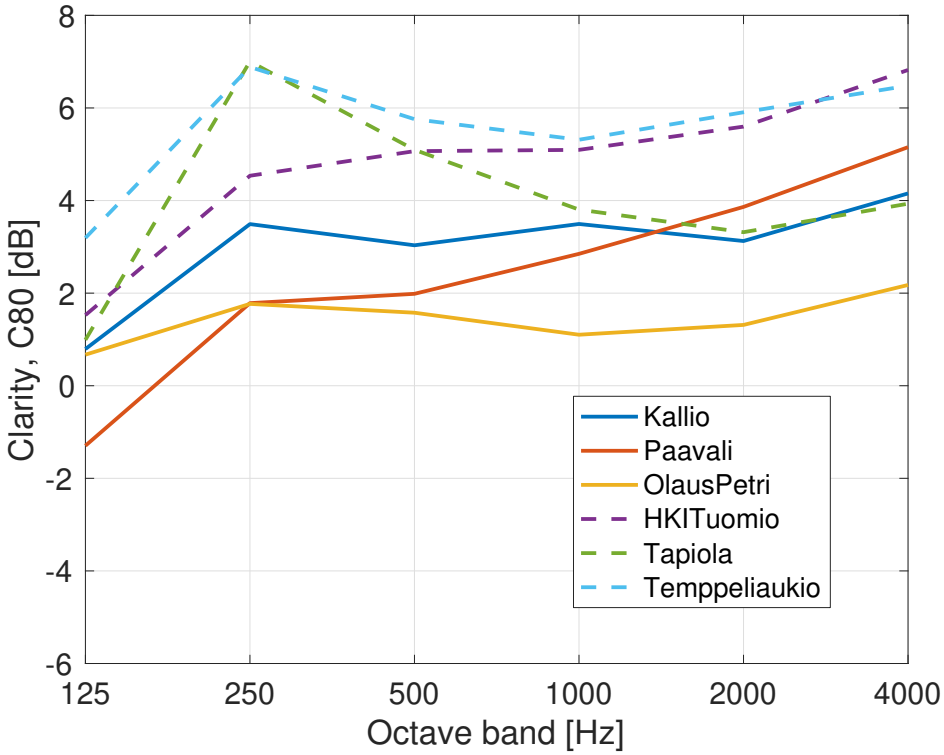


Figure 9. Clarity C_{80} (probe)

4.3.3 Early Decay Time

The Early Decay Time graph shows presents differing scenarios for all churches. Generally, the easy churches have a higher EDT overall than the difficult churches. Tapiola has a steep dip in the 250 Hz area. Temppeliaukio produces the lowest EDT values out of all six, and Paavali the highest. Notably, EDT in the lower bands is substantially higher in Paavali compared to the other five.

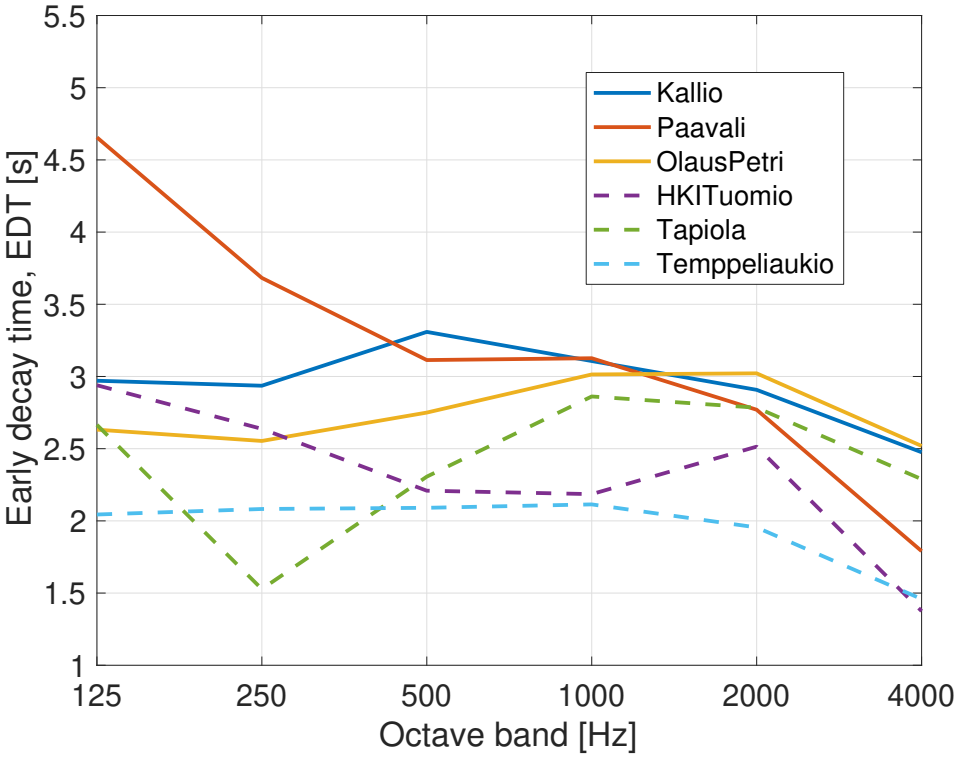


Figure 10. Early Decay Time EDT (probe)

4.3.4 Reverberation Time

While EDT and T_{20} graphs usually look very similar[27], the differences between EDT and T_{20} in this research prove to be surprisingly different. Granted, some similar trends can be distinguished from both graphs, but e.g. the reverberation time at 125 Hz is surprisingly longer in Temppeliaukio than what the EDT graph might suggest. Reverberation time then drops down to ~ 2.3 seconds at 250 Hz. All other churches have higher values in T_{20} than EDT other than Temppeliaukio, which seems to match T_{20} and EDT remarkably at and after 250 Hz.

It is also interesting that Olaus Petri produces a very flat reverberation time response all the way up to 2 kHz.

[27] Note that in the graph for EDT, the y axis is ranges from 1 to 5.5, whereas in the graph for T20 the y axis reaches 6.5

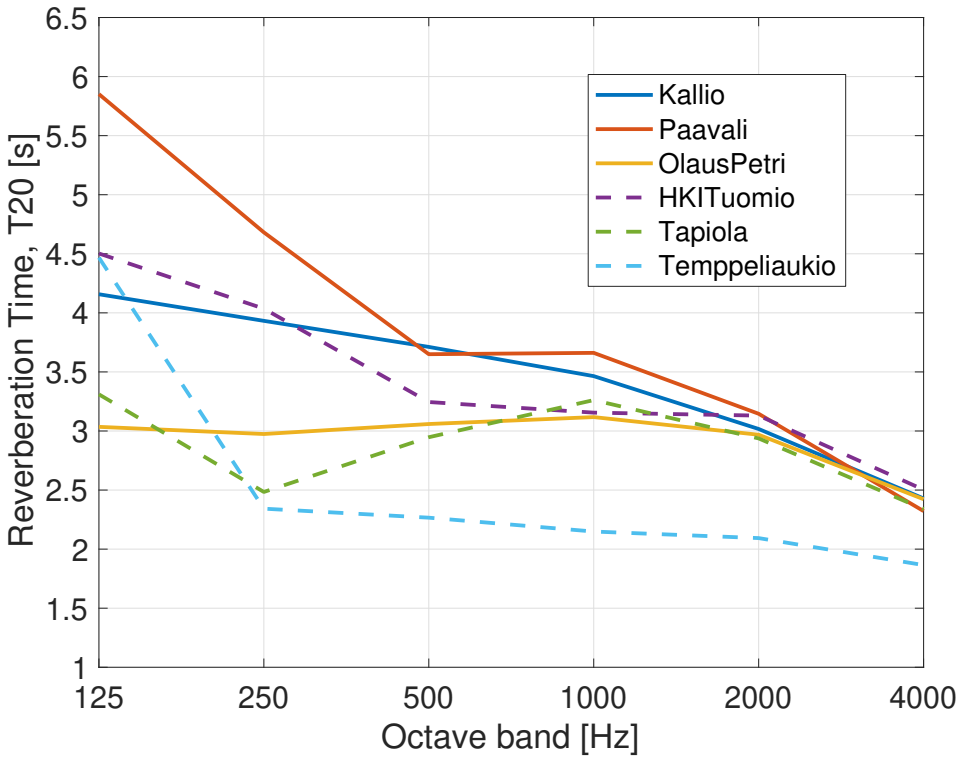


Figure 11. Reverberation Time T_{20} (probe)

4.4 Results – objective parameters (additional omnidirectional microphones)

The two Line-Audio OM1 omnidirectional microphones that were placed in semi-random positions on a larger plane in the church hall, moved to new positions between each sweep, produced some differing results than what the probe measurements imply. In other words, these measurements tell more on the acoustics that the audience perceives, while the probe measurements were from the choir perspective. While the general trends are similar between the probe and the extra measurements, there are a few differences that can be observed.

The following graphs are an analysis of all the measurements from both microphones combined and the measurement positions weren't documented in any way, so the results should be considered purely as some general acoustic perspective between the six churches.

As this isn't in the direct scope of the research but rather considered a nice-to-have addition, these results are provided only as reference without further analysis in this section.

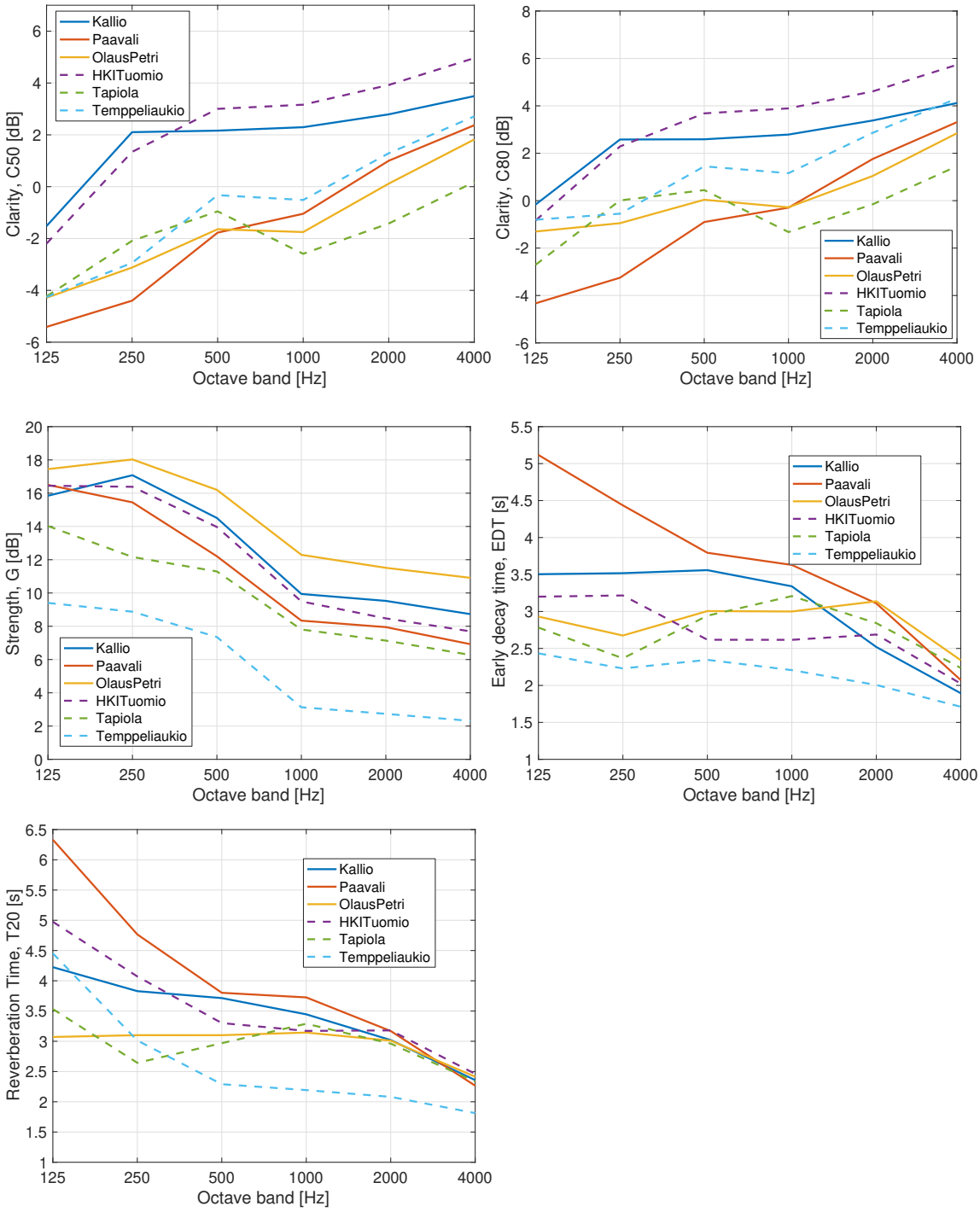


Figure 12. Extra omni mics

4.5 Results – SDM (probe)

4.5.1 Explaining SDM plots

One of the major benefits of using a microphone array is that it allows us to plot spatiotemporal plots by measuring the cumulative sound energy over time and space. The method determines the direction of sound energy incidence for each discrete moment in time, using very short time windows for analysis (Pätynen, Tervo and Lokki 2013).

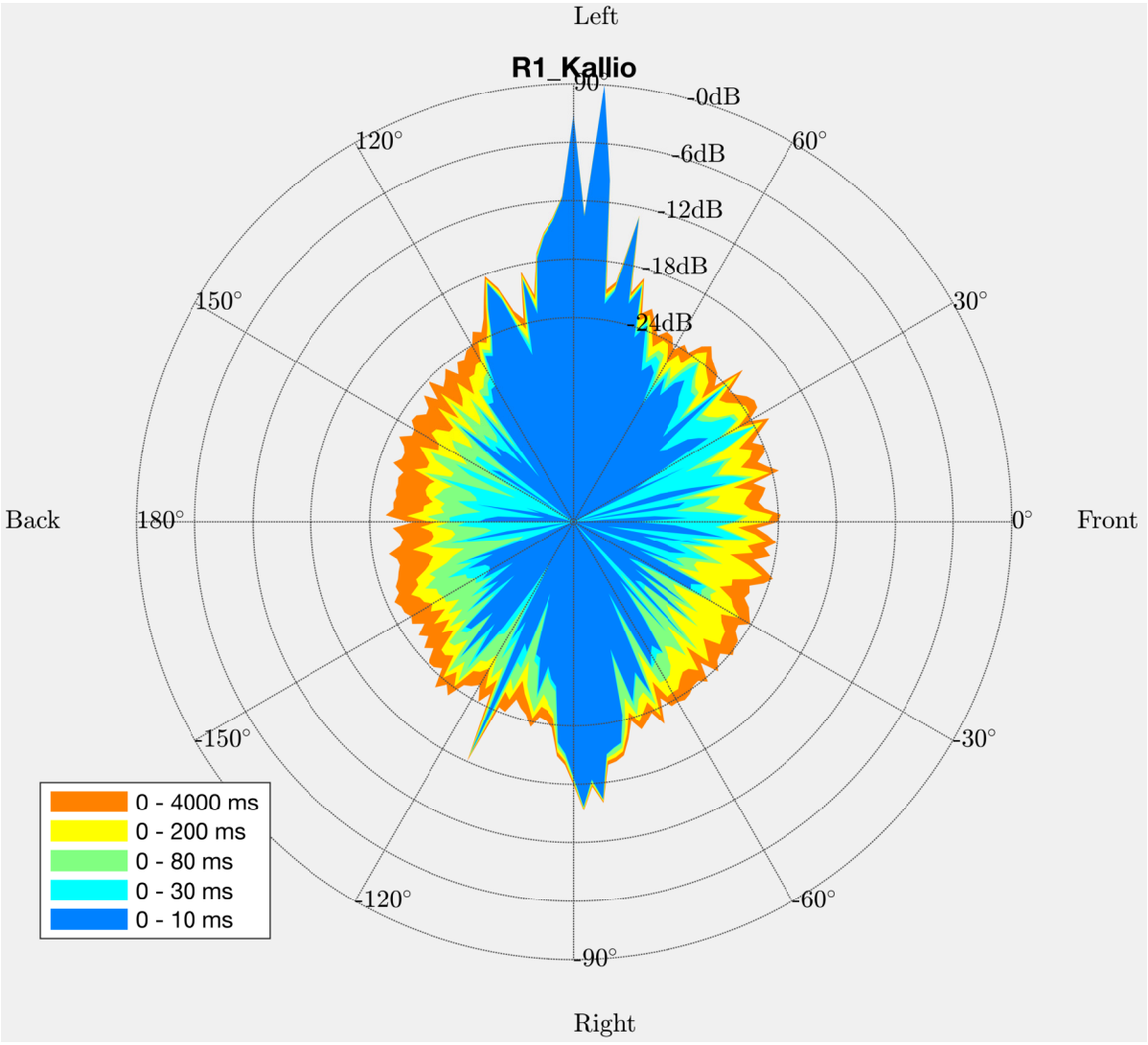


Figure 13. Example of an SDM plot. Different time-windows are presented as discrete colours.

Interpreting the spatiotemporal plots happens by observing the amount of each colour area on an azimuth (lateral) plain. From 0-10 ms (dark blue), we only receive direct sound, with some first reflections from the floor, after which we can observe how the sound energy

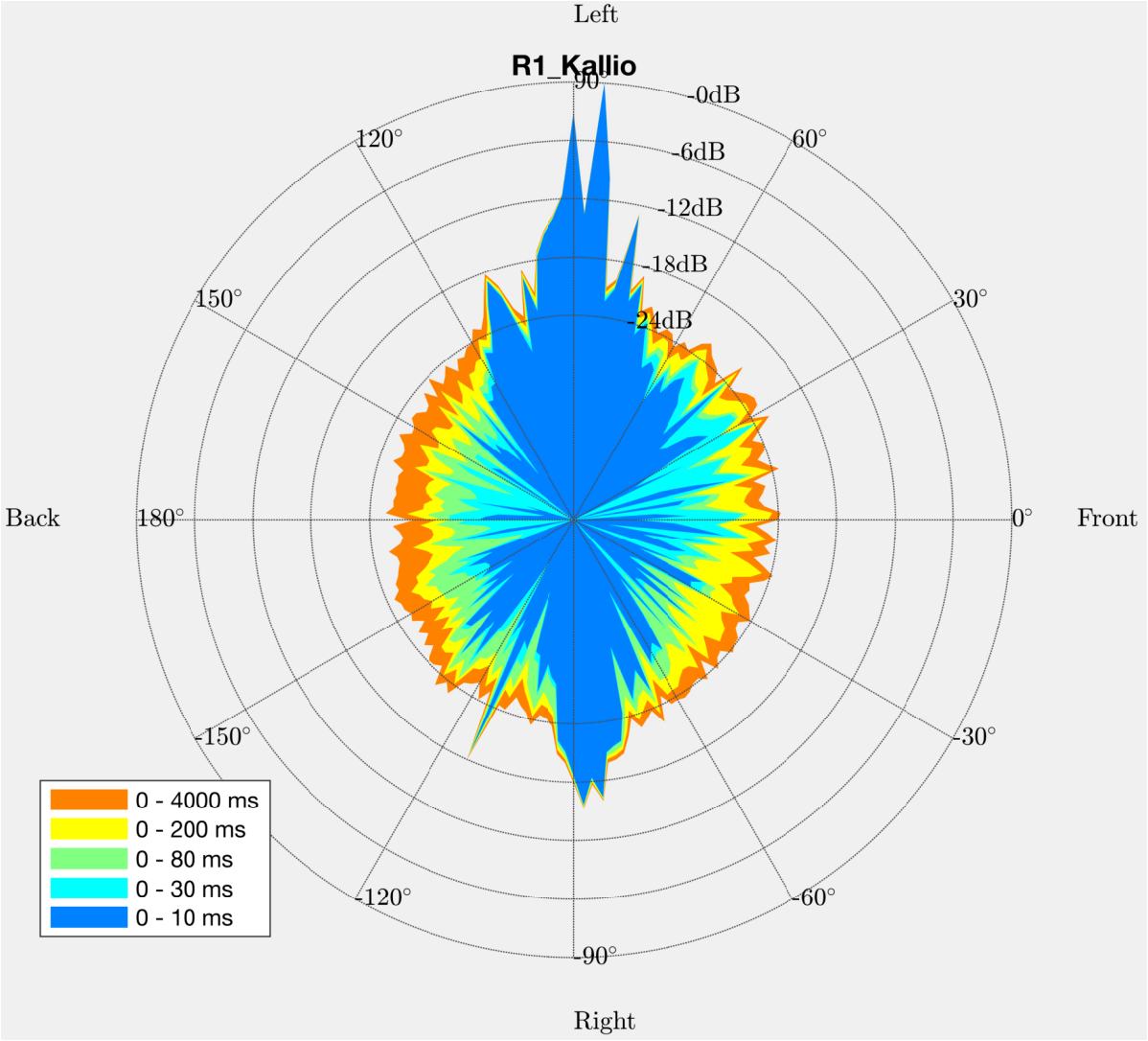
dissipates. Because the front-facing capsule X1 was kept facing the audience for all R's, the direct sounds will appear in different locations for each R. Left (or 90°) is always up. When approaching longer windows, the aural response starts to even out into a more cohesive sphere, as reflections from lateral surfaces and the ceiling arrive, furthermore augmented with diffused reverberation. For further in-detail information about the measurement and analysis techniques used for creating spatiotemporal plots presented in this thesis, please see (Pätynen, Tervo and Lokki 2013).

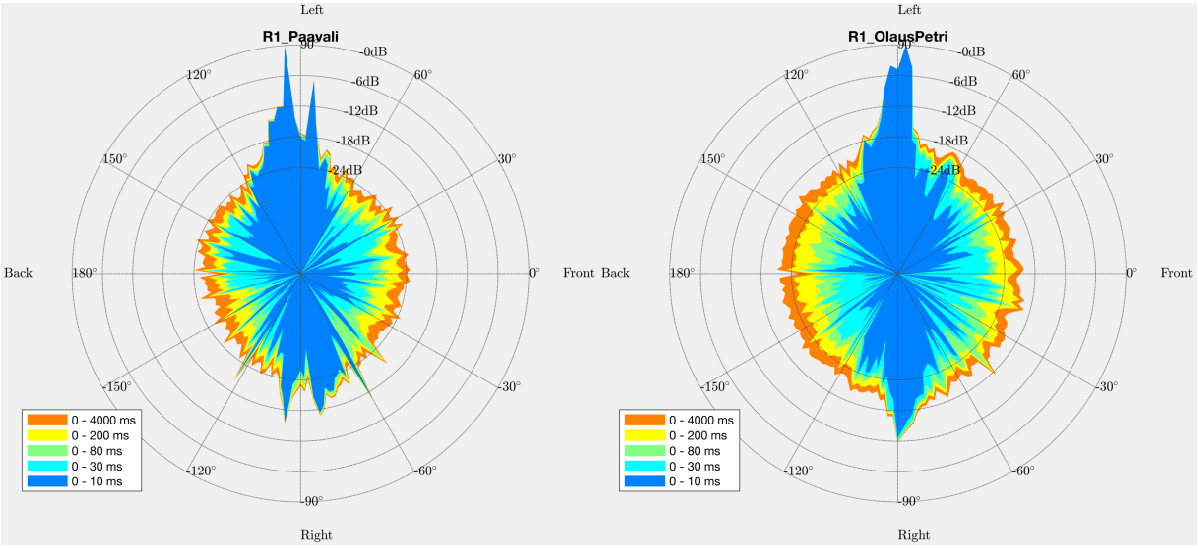
The plots in this thesis have both S1 and S2 overlayed in one plot for each receiving position R. This is why all plots have two distinct direct sound "spikes" (dark blue), one for each source S. Please refer to Figure 6. positions and dimensions of S1,2 & R1,2,3,4 for the locations and relative positions for S and R.

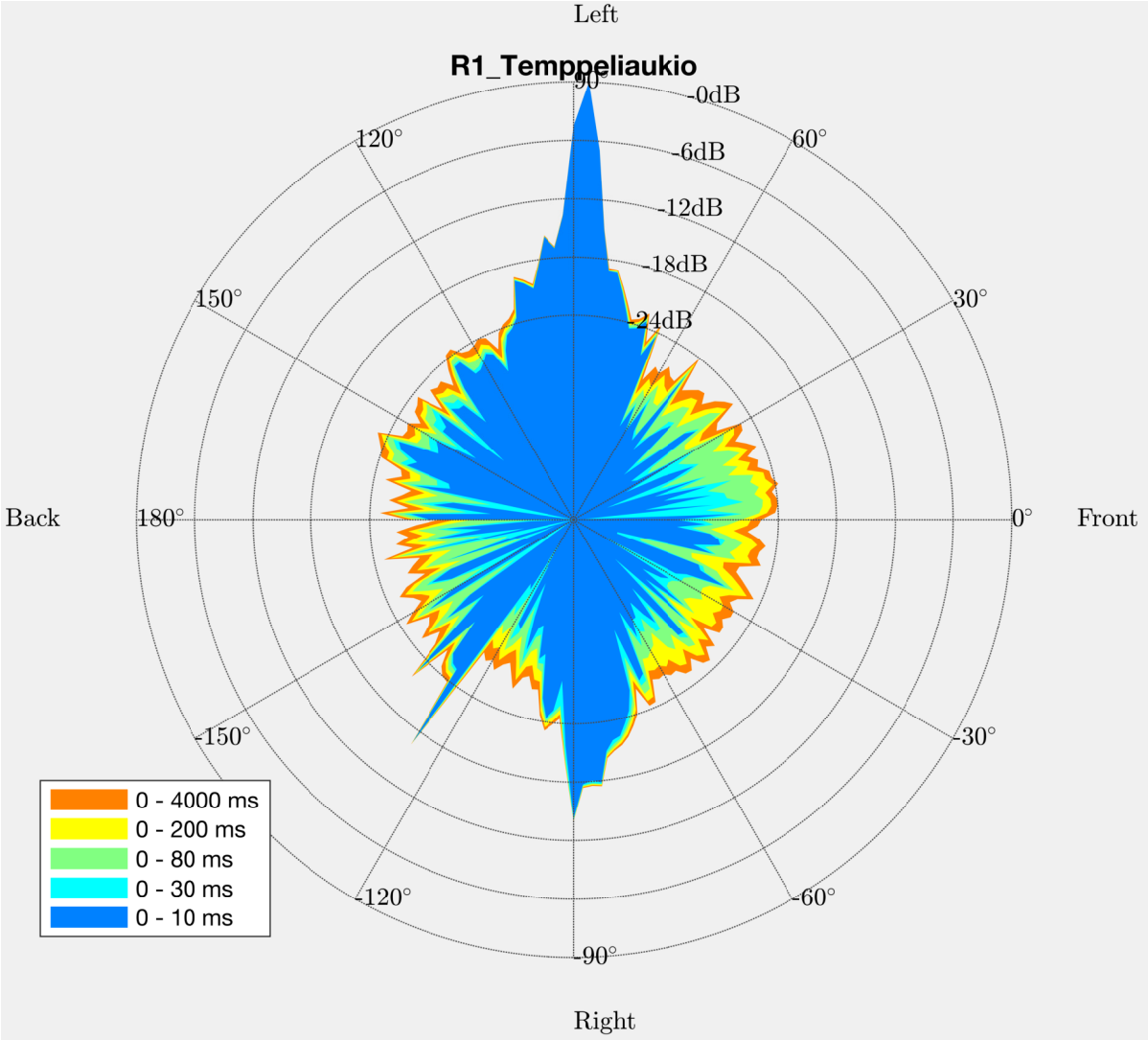
We will now observe all six different plots for each R position in the lateral plane. For clear presentation and saving space, the most favoured church Kallio and most disliked church Temppeliaukio will be zoomed in, with the two other churches from each category will be presented zoomed out. Vertical plots will be provided in Appendix IV.

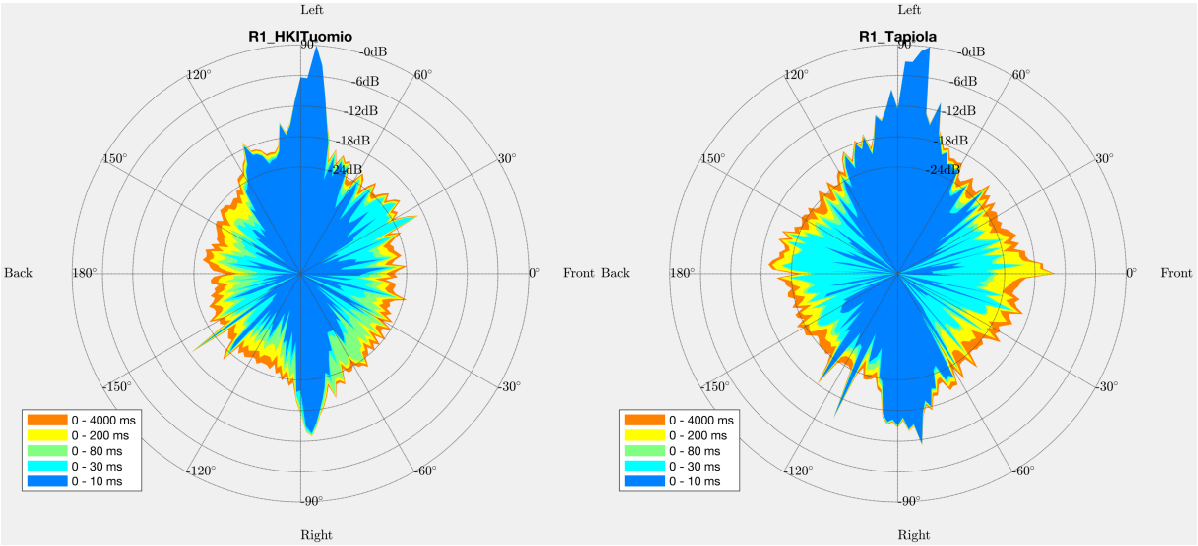
For the R4 plots, keep in mind that capsule X1 still points towards the audience, meaning that 0 – 10 ms will plot 180° to what a choir conductor would normally hear while facing the choir. One can imagine that the choir conductor is turned to face the audience in the R4 situations.

4.5.2 SDM plots – R1

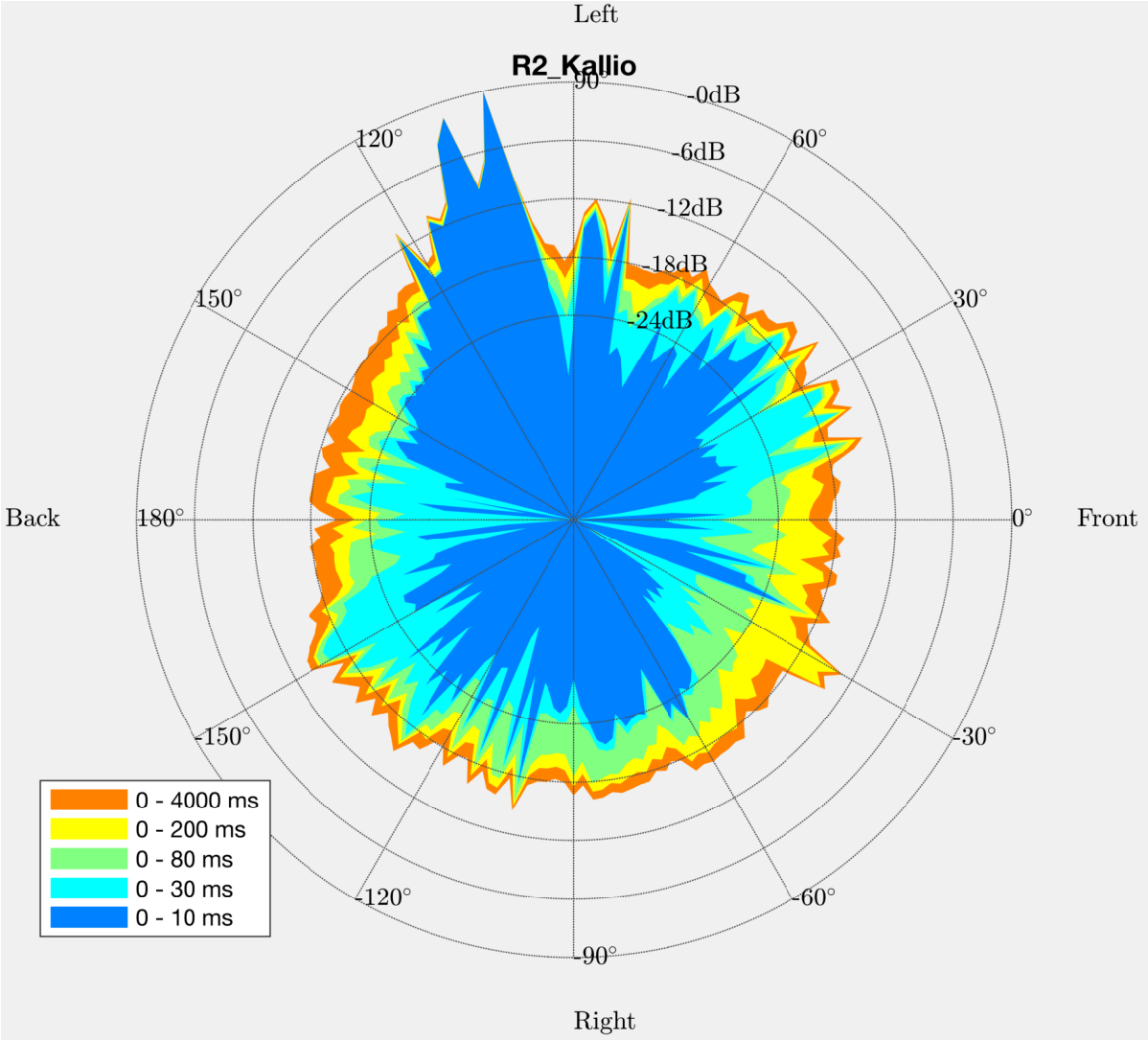


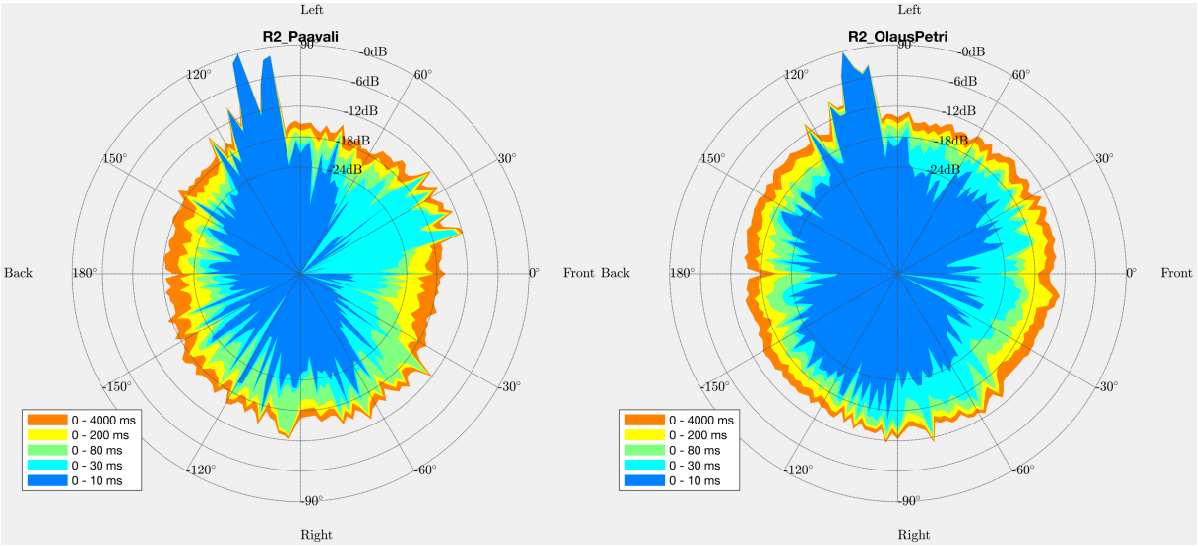


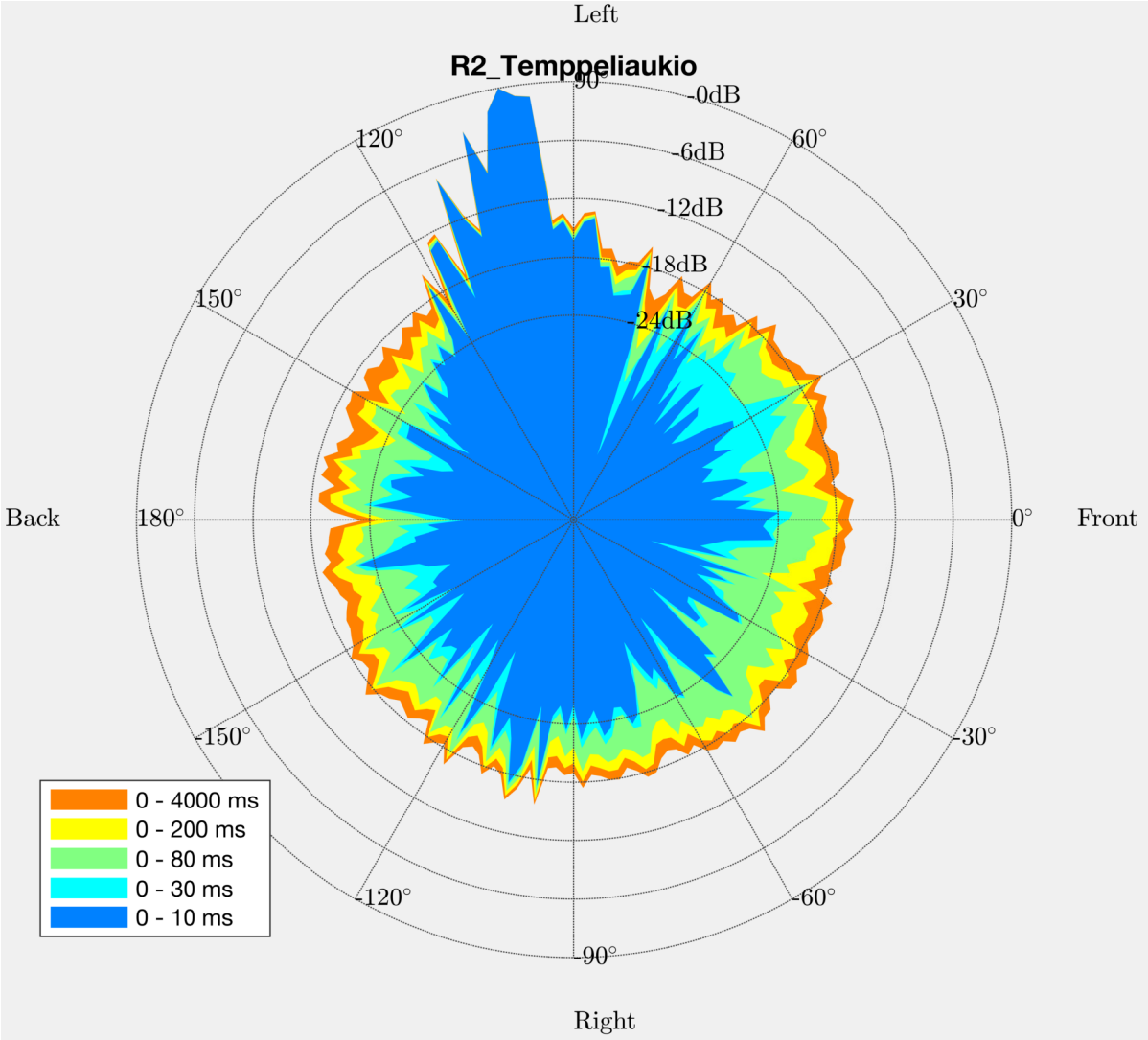

Left
R1_Temppeliaukio
90°
-0dB
120°
60°
-6dB
-12dB
-18dB
150°
-24dB
30°
Back
180°
0°
Front
-150°
-30°
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms
-120°
-60°
-90°
Right

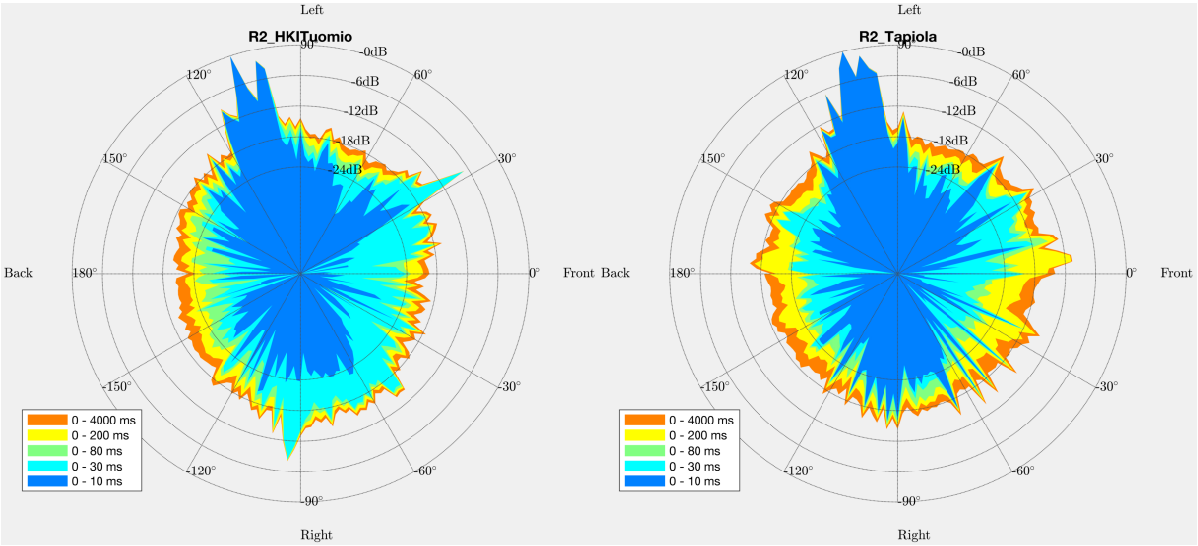

Left
R1_HKITuomio
Back
Front
Right
Left
R1_Tapiola
Back
Front
Right

4.5.3 SDM plots – R2






Left
R2_Temppeliaukio
90°
-0dB
120°
60°
-6dB
-12dB
-18dB
150°
-24dB
30°
Back
180°
0°
Front
-150°
-30°
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms
-120°
-60°
-90°
Right


Left
R2_HKITuomio
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Front
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R2_Tapiola
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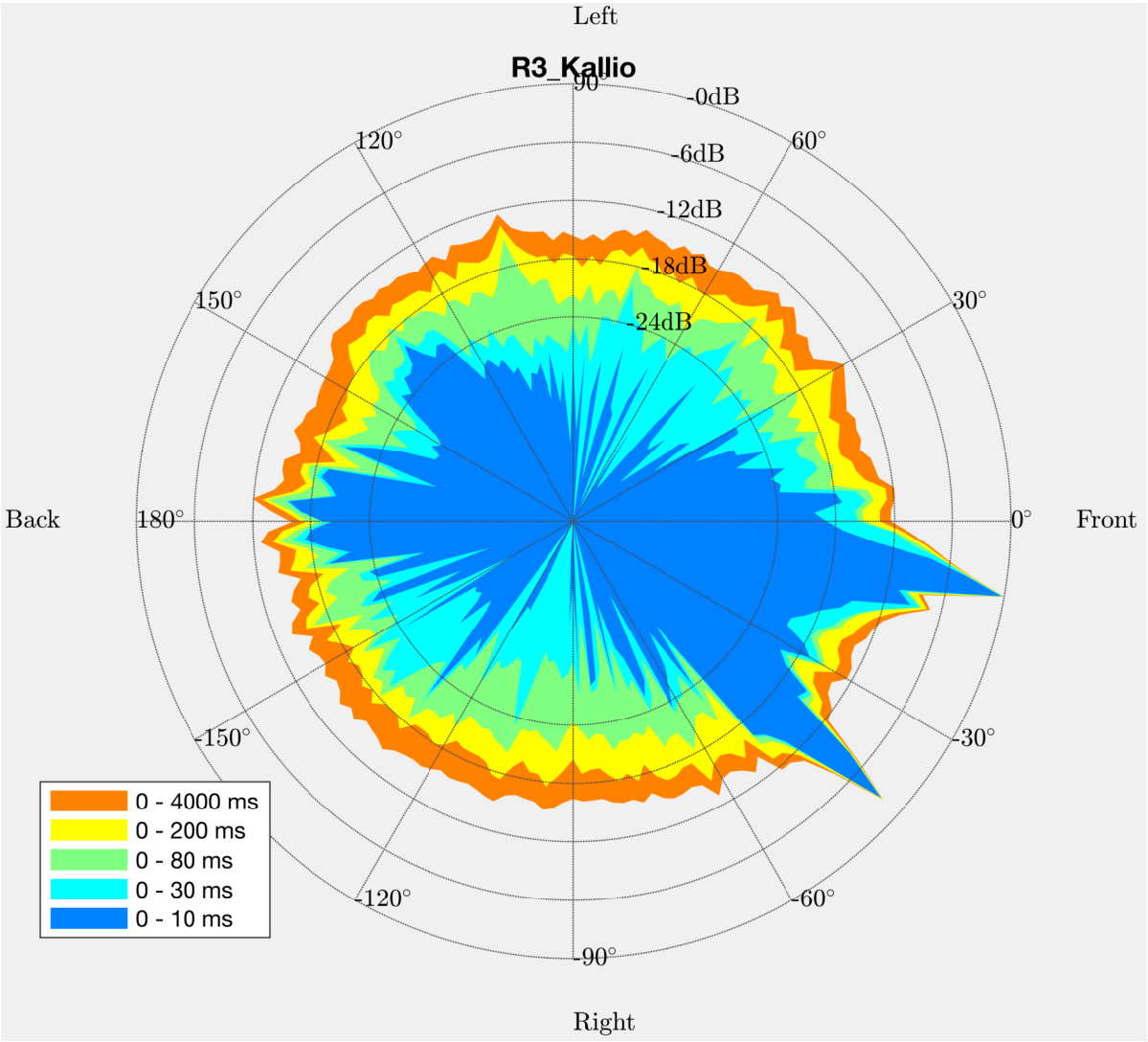
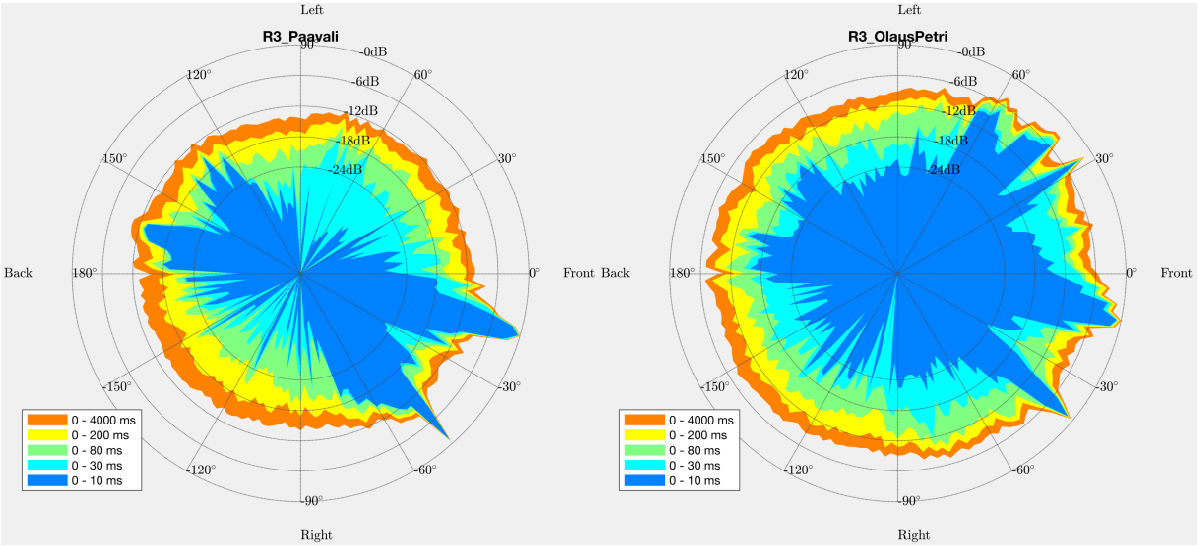
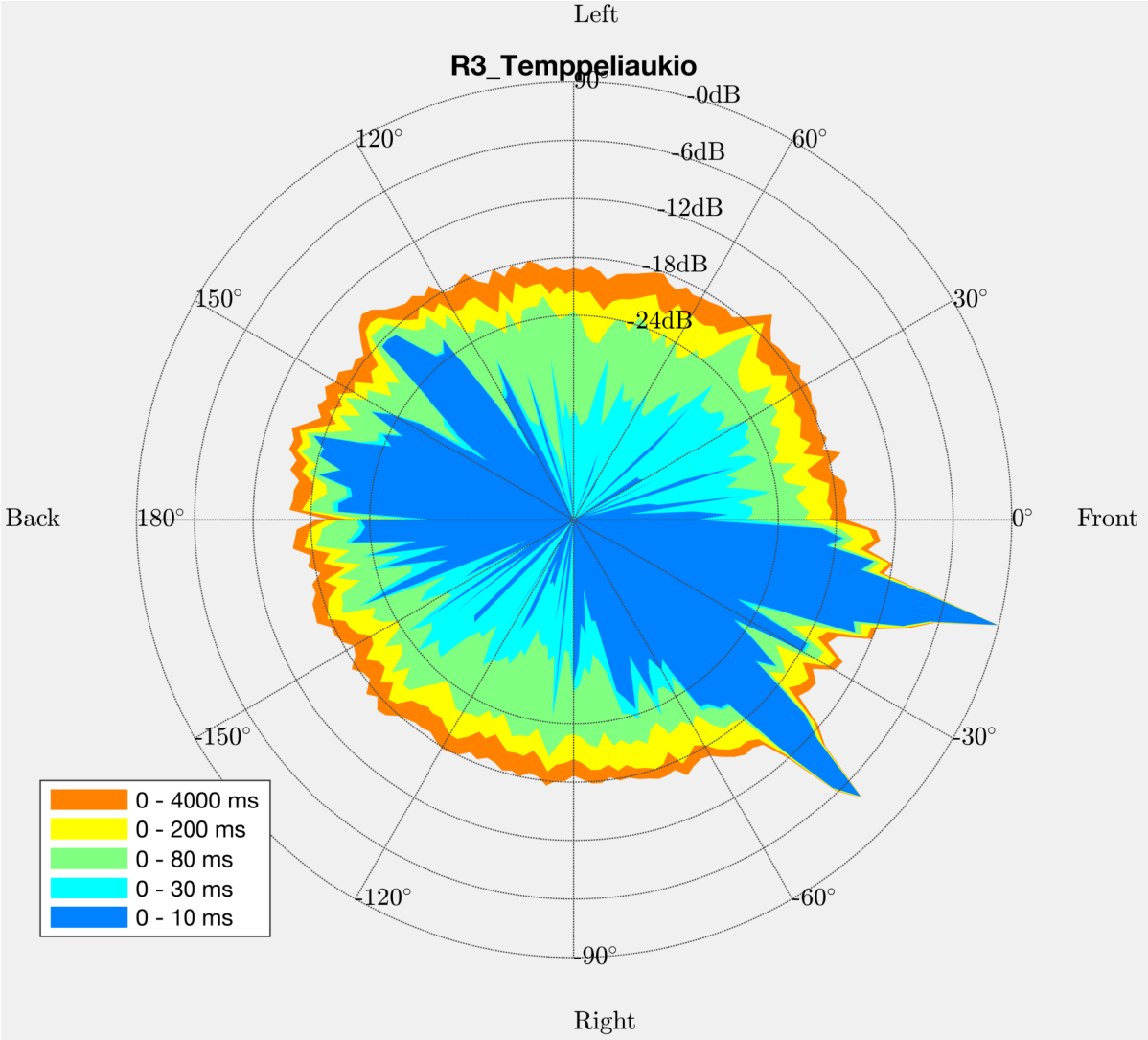
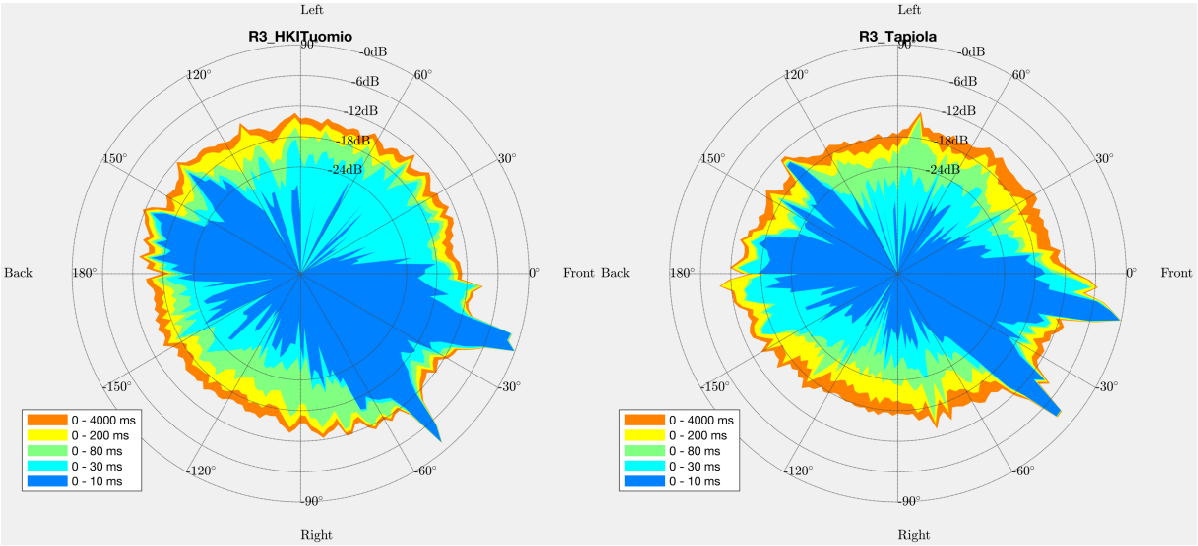
4.5.4 SDM plots – R3

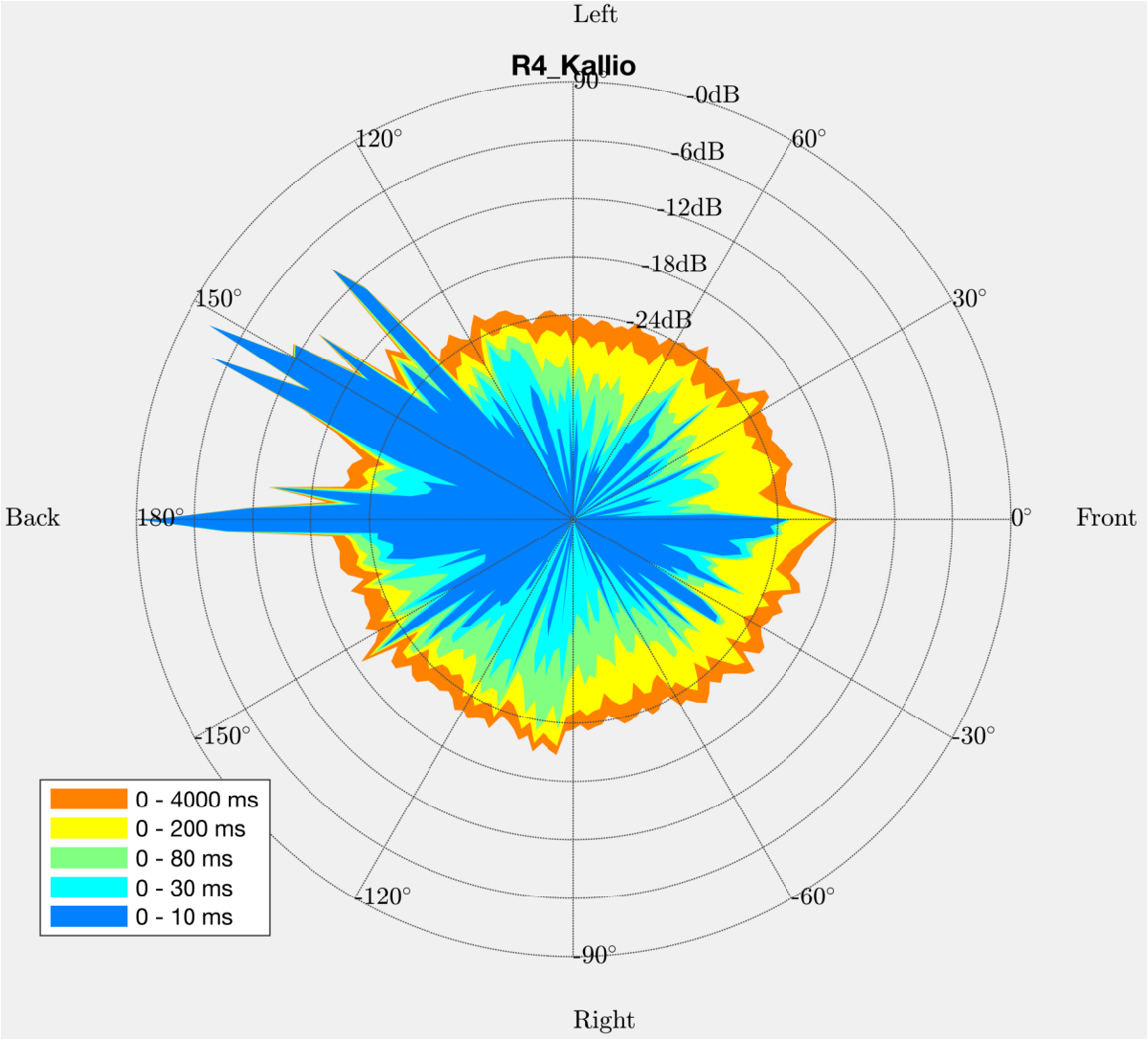


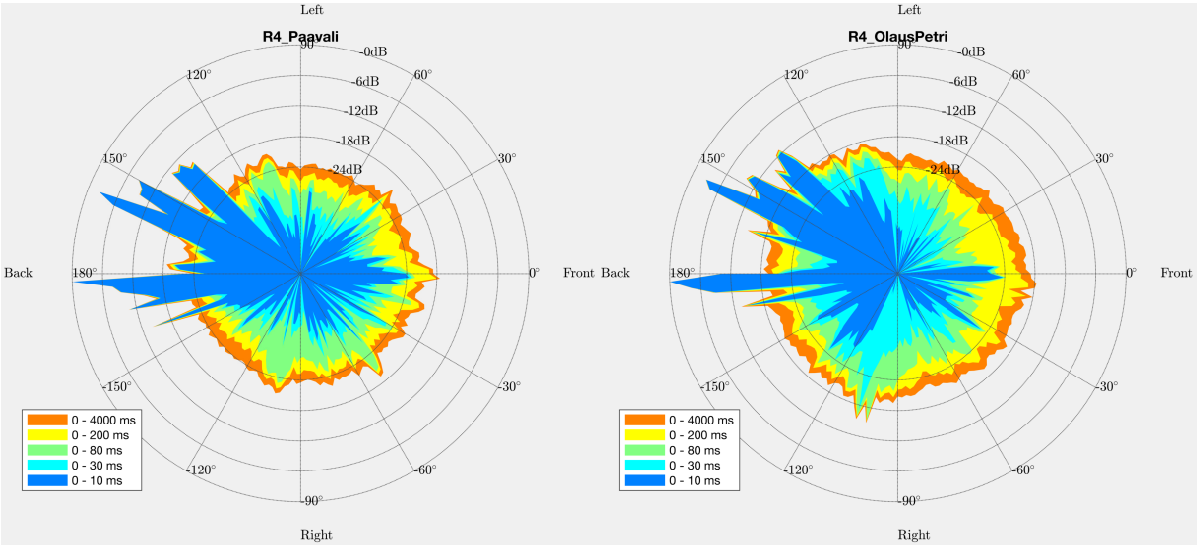


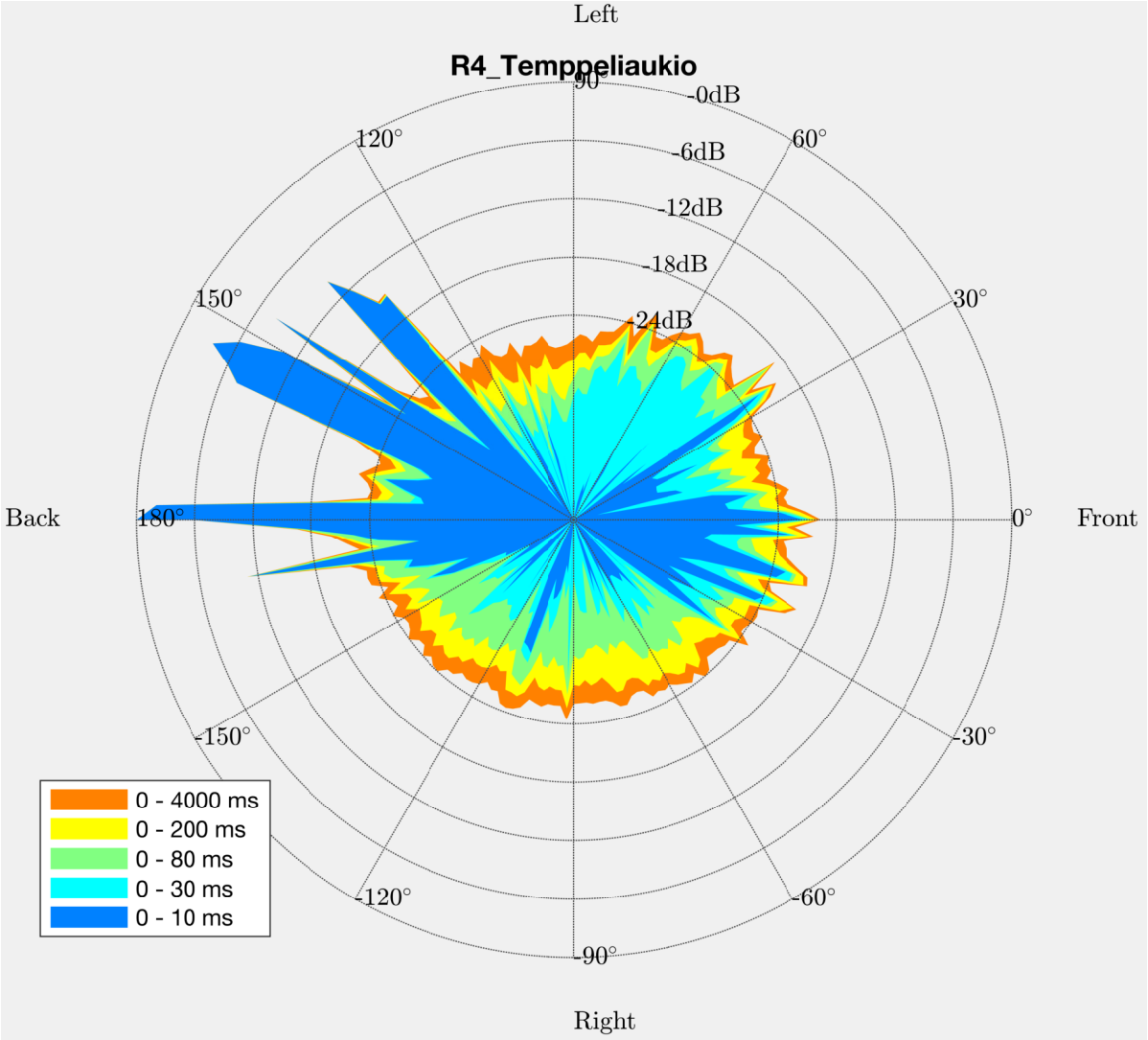

Left
R3_Temppeliaukio
90°
-0dB
120°
60°
-6dB
-12dB
-18dB
150°
30°
-24dB
Back
180°
0°
Front
-150°
-30°
-120°
-60°
-90°
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms
Right

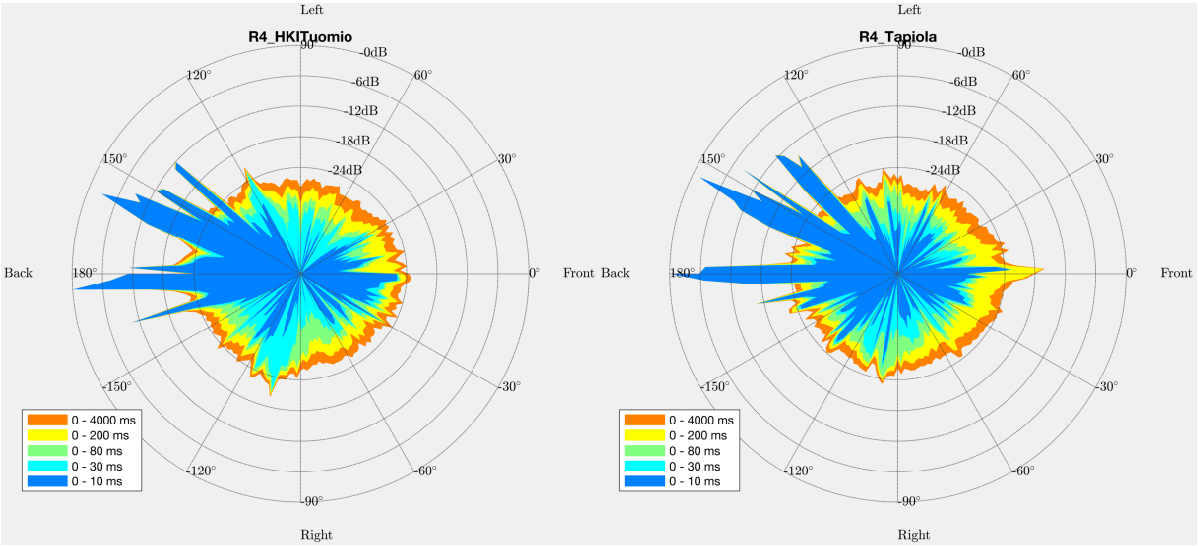

Left
R3_HKITuomio
Back
Front
Right
Left
R3_Tapiola
Back
Front
Right

4.5.5 SDM plots – R4






Left
R4_Temppeliaukio
90°
-0dB
120°
60°
-6dB
-12dB
-18dB
150°
30°
-24dB
Back
180°
0°
Front
-150°
-30°
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms
-120°
-60°
-90°
Right


Left
R4_HKITuomio
Back
Front
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Left
R4_Tapiola
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Front
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4.6 SDM Analysis

The receiving positions R1-3 were chosen to represent three different positions in a traditional two or three row choir singer arrangement, with R4 representing the conductor's perspective.

In R1, the imagined singers are placed close to each other, with one meter between R1 and S1 and three meters between R1 and S2, respectively. Thus the direct sound (especially between R1 and S1) are prominent, and dominate the sound field. In most situations, this is what the singer should be able to hear at the very least. What can be noted is that in the first three plots for the favoured churches, the sound energy arriving after the direct sound is rather round and cohesive, meaning that the singer experiences a much more balanced image of their acoustical surroundings. The amount of energy is also much higher (generally over –24 dB) than in the disliked churches (generally under –24 dB), which can be seen in the size of the overall energy when comparing the plots of the favoured and disliked churches. This means that the halls are giving more feedback to the singers about the sound. In the disliked churches the plots seem to be more jagged and uneven, with especially Temppeliaukio lacking in any amount of later energy after the direct sound. In Tapiola, there is a massive burst of relatively quick energy (0 – 30 ms) after the direct sound.

Generally, the yellow 80 – 200 ms areas in the plots seem to be larger in the favoured churches relative to the disliked churches, which directly decreases *clarity* but increases T_{20}. We have already discussed in previous sections the importance of feedback within 200 ms of direct sound, so this finding coincides with previous research. In Section 5 we will attempt to establish reasons for why there is higher feedback in the 80 – 200 ms range.

R2 was positioned to emulate the rough position of the last singer in the first row for a typical chamber choir sized group. Plots for R2 positions are surprisingly like one another. Early energy (0 – 10 ms & 0 – 30 ms) seems to be the most prominent sounds in these positions. The distance between R2 and S2 is also the furthest of any combination of R and S, which could explain the relatively high 0 – 30 ms energy bursts. 0 – 10 ms seems to be extremely dominant in Temppeliaukio R2 and Olaus Petri R2.

The R3 position is from the back row, where maybe a member of the tenor or bass section in a mixed choir might stand, effectively behind both S1 and S2. All other churches produce natural 0 – 10 ms responses, while back row singers in Olaus Petri will experience substantial early energy. In Temppeliaukio, the later energy seems to settle in the 0 – 80 ms window. The two source positions can be quite clearly established from the R3 plots,

excluding Olaus Petri which seems to have multiple very strong early reflections. One key takeaway from the R3 positions is that late energy (0 – 200 ms and even 0 – 4000 ms) is rounder and more cohesive in the favoured churches, while in the disliked churches late energy is either still dominated by high early energy (Tapiola), non-symmetrical (HKI Tuomio) or relatively weak in total energy (Temppeliaukio). Early energy (0 – 80 ms) doesn't seem to loom around for too long in the favoured churches, which can be observed from the rather equal sizes of the energy over time plots.

In the conductor's position R4, direct energy is very strong compared to later energy, but we can easily find resembling similarities from the R3 shapes of late energy. In the favoured churches, the conductor experiences an equal amount of later energy (0 – 200 ms and beyond) from all around the space. In the disliked churches the late energy is not symmetrical, and especially in Tapiola there seems to be a rather large spike of 0 – 200 ms energy coming presumably from the rear wall. All churches present some kind of later energy spikes from the surrounding lateral surfaces (e.g. 60° in Temppeliaukio, -110° in HKI Tuomio).

5. Discussion

Classically trained singers are used to singing in an environment that can amplify their own output in a natural way that simultaneously excites the singer with confidence and projects their voice favourably for the listeners. An adequately reverberant environment is thus more or less a non-negotiable requirement for classical singing, excluding some cases where the material demands a drier environment or a completely acoustically dead space altogether to accommodate e.g. contemporary pieces where vocal headset microphones and sound reinforcement is used[28]. Singing acoustically in a non-reverberant space usually feels unnatural and obscure, and if a singer doesn't know how to adjust their technique, prolonged periods of singing in a situation like this may produce extreme damage to the singers' vocal cords, as we discussed in Section 2.

There is a common saying among singers in Finland: "like singing into a sock", which in lay-man's terms means that "there is no reverb". These are usually performance spaces purpose-built for amplified music, like black boxes or other types of acoustically "dead" halls. Church spaces will generally not be this extreme, at least typically, but this doesn't mean that a church might not feel like "singing into a sock", especially when performing as a group where one can't necessarily rely on the space to provide enough acoustic feedback to maintain confidence. Arguably, professional singers won't be as negatively affected by dry acoustics than amateur singers due to the professional's ability to rely on their technique and adaptation skills.

[28] See for example Juhani Nuorvala's *FLASH FLASH - the two deaths of Andy Warhol*, where classically trained opera singers are equipped with headset microphones. The performance was given in a rather dry theatre, but sound reinforcement together with electronics and adequate competence in adjusting technique made it possible. https://www.youtube.com/watch?v=yVGEcVYoBW4

1 Paavalinkirkko

The top three churches in the favoured category are all long churches[29] by design, with distinctively flat front and back walls and an arched ceiling. Paavali (picture 1, above) and Olaus Petri (picture 3, below) both also have complete side walls with no side balconies, which are great for lateral reflections. The art-nouveau style Kallio (picture 2, below), while featuring side balconies, does also have distinctive side walls that are not that far apart each other, but it has quite a different front segment altogether. There is a flat wall right behind the altar that is beneficial for reflective energy, but while the back walls in Paavali and Olaus Petri extend all the way up to the ceiling, this wall in Kallio ends after a few meters, after which the space continues further forward. This slightly resembles a more middle to southern European catholic cathedral where the altar section extends very deep into the front. To keep the scope of this research narrow enough, we will not discuss the acoustical effect of this extension of space in detail, as the aforementioned back wall is more significant for the performers. If anything, the combination of a distinctive lateral reflection surface behind the singers combined with the open space that extends beyond said surface after a few meters of height might be beneficial in itself.

A notable feature of both Paavali and Kallio is also the deep, arch-vaulted windows on the side walls, which create surfaces that reflect sound back to the performers already before the rear wall. The closest vaults produce reflections already before 80 ms, after which there

[29] Finnish = Pitkäkirkko (literal translation is ”long church”, while there is no official name for the design in English).

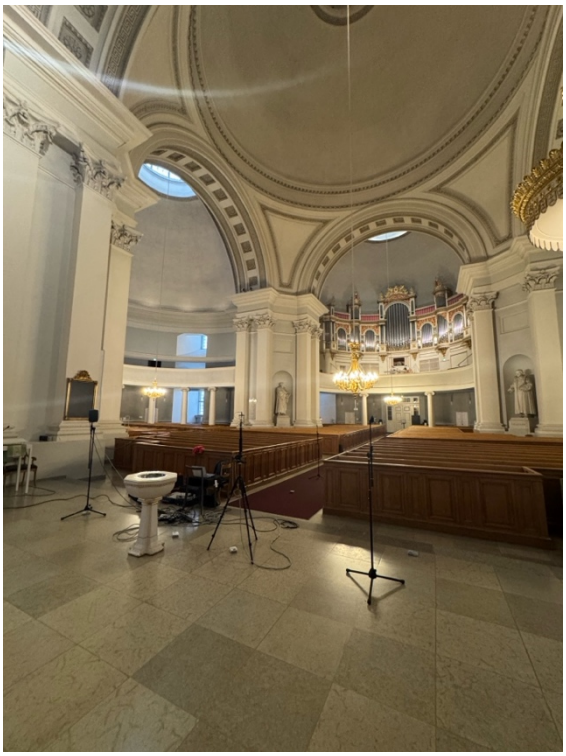
are periodical reflections within the preferred 80 – 200 ms window. The reflections from these surfaces can be seen in e.g. Kallio R2 in the vertical SDM plots found in Appendix IV. The effects of these reflective surfaces are probably most significant in Paavali, where the vaulted arches stretch all the way from the floor to the ceiling. Olaus Petri also features some vaulted windows, but the relatively small amount of them together with a relatively smaller footprint probably doesn't add to the reflections as significantly than in Kallio and Paavali, and the smaller size of Olaus Petri in general comparing to Kallio and Paavali lessens the need for such reflective surfaces, as the soundwaves are already very tightly packed together in Olaus Petri.

3 Kallion kirkko

2 Olaus Petrin kirkko

Not very surprisingly, the three most disliked churches are not long churches by design. They are extremely dissimilar to each other and generally represent plans that are not very common in Finland. HKI Tuomio (picture 5, below) is a neoclassical style, Greek cross plan cathedral with lots of arched walls and ceilings, which means that there are close to none direct lateral reflection points. These round and parabolic surfaces project the sound away from the performers. Tapiola (picture 4, below) could be considered as an exact opposite to HKI Tuomio, as it is designed with almost only 90° angles. It is almost a perfect cube, with lateral surfaces either extremely close to or very far from the singers. This kind of equal-surface layout is apt for very regular and predictable acoustic patterns, which may produce a difficult

environment for choral music performance as there might be very little sense of fullness due to far less “random” acoustic phenomena. In some instances, the extremely regular 90° surfaces may even produce flamming of sound, which can be extremely off-putting for performers. An audience in the hall should adequately aid this problem if it appears.



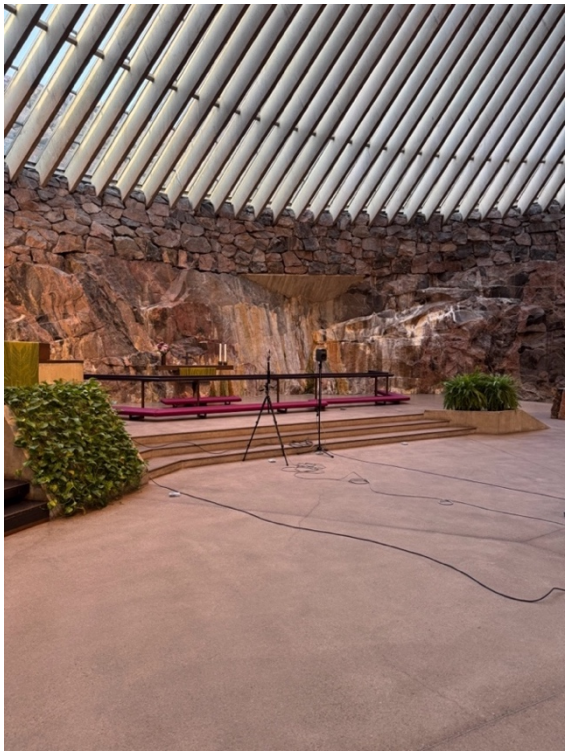
5 Helsingin Tuomiokirkko

4 Tapiolan kirkko

The least liked church for choir music performance, Temppeliaukio (picture 6, below), is a complete anomaly in traditional church architecture and thus definitely the most interesting subject of this research. The interior of the church is situated in an excavated bed of rock (hence it’s nickname “The Rock Church”), with a very distinctive domed ceiling made of copper wire windings and glass panes that are attached directly to the rock bed. An architectural design decision of the church hall was to create non-even walls in a circular form, with natural pieces of rock forming the inner wall. From an acoustical point of view, these infinitively uneven shapes in the wall create a very diffuse sound-field, as sound hitting the walls immediately ricochet in random directions. There are no flat surfaces in the hall other than the floor and a purpose-built flat wall behind choir raisers next to the organ, but these raisers are almost never used when a choir performs a cappella. The natural performance situation is in front of the altar. The usual explanation for this is that the audience enjoys an easier and a more aesthetically pleasing viewing experience of the singers when they are situated in front of the altar.

The three churches in this category also lack completely in the helpful reflective window arches that are present in Paavali and Kallio. As mentioned, Temppeliaukio and HKI Tuomio have close to none lateral surfaces for reflections, and Tapiola as a cube design only really provides meaningful feedback from the rear wall in one huge reflection burst, which is almost flam-like. This burst can be seen in the spatio-temporal plots quite clearly as well.

7 Temppeliaukion kirkko



6 Temppeliaukion kirkko

The complete lack of any lateral reflective surfaces together with the irregular shape of the space in general is probably why Temppeliaukio is widely considered to be a very pleasant venue to listen acoustic music in due to its very diffusive nature, while performance is a whole different matter altogether. From all spatio-temporal plots we can observe that the late sound energy is lacking compared to all other churches, further emphasized by especially the strength and reverberation time graphs, where Temppeliaukio performs the worst. If we were to put this very simply, it could be said that the space doesn't give anything substantial back to the performers from an acoustical point of view at least. The six laws of good acoustics from (Rossing, Moore and Wheeler, The Science of Sound, 3rd edition 2002) are probably met sufficiently for audience members (even though T_{20}, EDT and C are all relatively lower in value in the secondary omni-mic measurements), but not so much for performers. It would be interesting to know whether non-vocal musicians experience this the same way in e.g. a chamber orchestra setting.

It is worth noting that the values for clarity are generally higher in the disliked churches compared to the favoured churches. As we remember, the definition for clarity was the understandability of spoken word, by e.g. the priest giving a sermon. For choral music performance, high clarity seems to be a destructive trait, as higher clarity basically means less reverberation. If one was to evaluate a church space's compatibility for an a cappella performance, maybe one experiment would be to have another person read some text aloud from the performing end of the church while listening at the other end. If you're able to make out all the words without significant effort, that highly implies that the space you're in features good clarity. This could be beneficial if the aim is to find a space that is suitable for very precise contemporary music where exact rhythmical values are important. If, however, the repertoire consists of music from romantic composers like Brahms or Bruckner that have a natural ebb and flow of temporal values which might be dictated by both the conductor and the singers collaboratively and where the music is "allowed" to somewhat merge and blend into the reverberation, spaces with higher values in clarity should probably be avoided. The reverberation times of a specific space usually dictate the natural tempo for a piece, and professional musicians will either consciously or sub-consciously be aware of how the acoustics of the space they're performing in is either augmenting or diminishing the music and might adjust accordingly. In a drier environment, tempi will most likely be generally faster than in a highly reverberant venue (when discussing choir and ensemble singing specifically, as (Luizard, Steffens and Weinzierl 2020) found that different reverberation times don't affect solo singers when considering tempo).

Sufficiently high values in early decay time (EDT) seems to also be a contributing factor for ease in a cappella performance. In all three churches picked from the easy category, EDT is generally higher than in any of the churches from the difficult category. When looking at the graph for EDT in Figure 10, the eye immediately notices the substantially greater EDT values in the lower frequencies Paavali. This phenomenon is most likely and quite simply due to the relative size of the church compared to the others in the same category, and while Kallio is more or less in the same ballpark of volume, the lack of side balconies with extra seating in Paavali probably creates an excellent environment to low-frequency energy to linger in for a longer time before decaying, something that is also discussed in (Pätynen, Tervo and Lokki 2013). A solid fundamental spatial environment can be naturally seen as a benefit for a cappella performance, as the human voice can only go so far down into the very low frequencies. If the space can help with low-energy excitation without being overly obstructive (see Lombard effect, (Tonkinson 1994)), the bass section in a mixed choir probably doesn't need to work that hard.

6. Conclusions & future work

In this thesis, a survey was presented for Finnish choral singers based on the fundamental question: What churches in the Helsinki capital region are easy or hard to sing choral music in. Survey participants were asked to pick three churches that are "easy" to sing choral music in, and three churches that are "difficult" to sing choral music in. Respondents were provided a list of churches and church-adjacent performance spaces in the Helsinki capital region. Respondents were also asked to describe (to their best knowledge) the acoustical qualities of a church space that contribute to their selections. Based on the survey results, a total of six churches were chosen for acoustical research. The measurements were taken using logarithmic sinusoid sweep excitations from two source locations on the stage[30] produced by a Genelec 8030 speaker, and captured from four receiving locations (three on stage, one from the conductor's position) using a six-channel GRAS type 50 VI-1 vector intensity probe, with additional measurements taken with two generic omnidirectional microphones from around the church hall. The captured signals were analysed in MATLAB using scripts written by Prof. Tapio Lokki from Aalto University. The results were presented as objective parameters and spatiotemporal plots[31]. The results proved to be as expected, and similarities between the three spaces in their respective categories can be distinguished from both the objective parameters and SDM plots.

As a short recap, one can summarise that churches with higher values in clarity are not the most suitable spaces for choir music performance, while spaces with higher EDT and RT values support a cappella singing. Strength doesn't seem to be an important factor, although the most disliked church for a cappella performance (Temppeliaukio) produces significantly less strength than the other five churches in this research.

While the discrete lateral reflection times for all churches weren't analysed, we can gather from studying the design and layout of each measure church space that sufficient

[30] The usual performance locations for choirs in the church, usually in front of the altar.
[31] Measuring the intensity of sound energy over time.

reflective surfaces on the sides provide substantial help to the singers. In all three of the favoured churches, lateral surfaces can be found from the sides of the performance situation at a relatively shorter distance when compared to the length of the space, while in all three disliked church spaces the direct reflective surfaces are either too close and/or too far to produce helpful reflections in an appropriate window (e.g. Tapiola), or they are completely non-existent altogether in favour of parabolic (HKI Tuomio) or extraordinarily uneven and unpredictable (Temppeliaukio) surfaces. The roofs of the favoured churches are arched, which probably helps with mitigating the effect of discrete direct reflections from above that might arrive too late to be helpful for the singers.

6.1 Future work

One of the main scopes of this research was to investigate whether the question of distinguishing acoustical properties of different types of church spaces that are commonly used for choral and other a cappella music performance is interesting to study. Based on the reception of the initial survey and other discussions about the subject in general between the author and colleagues in the choral scene, the subject has gathered lots of attention.

To keep the scope acceptable in size for a master's dissertation, the amount of measurement points in each church were kept at a relatively low amount. In further research on the subject, more source and receiving positions should be used, and the effect of human bodies should also be considered when performing measurements as the signals for this research were excited in completely empty spaces, save one or two humans present. It would be interesting to measure the acoustic properties of a performance situation with a whole ensemble of singers and a full audience, but that would naturally produce large costs and would require very strict behaviour from each participant to assure that the measurements wouldn't fail due to noise.

The apparatus for further research should also be slightly upgraded. The Genelec 8030 speaker was chosen for inventory purposes, while e.g. a Genelec 8341 model could be more accurate in replicating sound radiating from a human head and body, as it is more omni-like in the low and low-mid range than the 8030. Multiple speakers could also be used to study how the acoustical situation changes when several measurement signals are produced simultaneously, as to represent a larger number of singers producing sound together.

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Thank you to all my dear friends and colleagues in the choir music scene who have extended sincere interest in this subject, and with who I have been able to discuss ideas and theories that culminated in finalising this research. I hope that this research provides some answers to our common questions and thoughts on the theme!

My heart goes out to my family: my dear partner Emmi Vesterinen, my mother Laura Heikinheimo and my sister Emma Ward, who have all been such wonderful and lovely in supporting and helping me during the research and writing process of this thesis.

Most of all, thank you Dad in the sun. Feeling you shine down on me even through the gloomy and bleak days through the clouds gave me unmatched strength. I know that I've made you proud. Love you, Dad!

Appendix I – Blank questionnaire

Pääkaupunkiseudun kirkkojen akustisten ominaisuuksien tutkimus kuoromusiikkin esittämisen näkökulmasta tarkasteltuna

Osana Joel Wardin Sibelius-Akatemian Musiikkiteknologian aineryhmän gradua suoritetaan kysely koskien erityisesti kuoro- ja yhtyelaulun helppoutta ja vaikeutta suomalaisissa kirkkoakustiikoissa. Suurin osa suomalaisista kuorokonserteista järjestetään kirkoissa, ja tämän kyselyn aiheena on kartoittaa eritoten esiintyjien (laulajien ja johtajien) kokemuksia **helpoista** ja **vaikeista** kirkkoakustiikoista, laulullisesta ja yhteismusisoinnillisesta näkökulmasta katsoen. Tämän kyselyn perusteella valitsemme kirkkoja, joissa pyritään suorittamaan akustisia mittauksia myöhemmin vuonna 2024. Tutkimuksen luonteen takia mittaukset painottuvat lähtökohtaisesti pääkaupunkiseudun kirkkoihin.

Kyselyn tavoitteena ei ole arvottaa kirkkoja tai seurakuntia parhaista huonoimpaan. Tutkimuksessa käsitellään vain akustisia ominaisuuksia. Vastaathan siis puhtaasti laulamisen näkökulmasta, etkä arvota esimerkiksi oman seurakuntasi kirkkoa/kirkkoja tai muuten vain lempikirkkoasi jonkin muun asian perusteella korkeammalle.

Muistathan, että kyselyssä ei kartoiteta yleisön näkökulmasta hyviä kirkkoakustiikkoja, vaan ainoastaan esiintyjien kannalta **helppo**- tai **vaikealauluisia** kirkkotiloja.

Oletetaan kuitenkin, että kyseessä on esiintyminen, ja että paikalla on yleisöä.

* Indicates required question

1. Oletko laulaja vai johtaja, vai molempia? *

Mark only one oval.

- ◯ Laulaja
- ◯ Johtaja
- ◯ Molempia
- ◯ Other: _____

2. Mitä stemmaa/stemmoja laulat?

Check all that apply.

- [ ] Sopraano
- [ ] Altto
- [ ] Tenori
- [ ] Basso
- [ ] Other: _____

3. Laulatko tällä hetkellä jossakin kuorossa? *

Mark only one oval.

- ◯ Kyllä
- ◯ En
- ◯ Olen tauolla

4. Missä kuorossa tai kuoroissa laulat/olet laulanut?

_____

_____

_____

_____

_____

5. Kuinka kauan olet laulanut kuorossa? *

Mark only one oval.

- ◯ Alle vuoden
- ◯ 1-2 vuotta
- ◯ 2-5 vuotta
- ◯ 5+ vuotta

6. Onko sinulla ammattimuusikon koulutusta?

Mark only one oval.

- ◯ Kyllä
- ◯ Ei
- ◯ Other: _____

Alle on listattu kattavasti pääkaupunkiseudun kirkkoja ja kappeleita. Mikäli listasta uupuu jokin vaihtoehto jonka haluaisit mainita, lisää se "Other" kohtaan.

Valitse molemmasta listasta kolme (3) vaihtoehtoa. Ensimmäisessä listassa pyydetään kolme kuoromusiikin esittäjän näkökulmasta **helpointa** kirkkoakustiikkaa, ja toisessa listassa kolme **vaikeinta** akustiikkaa kuoromusiikin esittämiselle.

Oletetaan, että kyseessä on esiintyminen, ja että yleisöä on paikalla.

7. Kerro ensin muutamalla sanalla tai lauseella, miten itse määrittelisit helpon ja vaikean akustiikan. Voit joko kirjoittaa kokonaisia lauseita, tai mainita vain muutamilla yksittäisillä sanoilla mitkä asiat tarvitaan helppoon ja mitkä vaikeaan esiintymiseen. *

_____

_____

_____

_____

_____

8. Valitse mielestäsi kolme laulajalle **helpointa** kirkkoa kuoromusiikin esittämiselle *

Check all that apply.

- [ ] Alppilan kirkko
- [ ] Espoon tuomiokirkko
- [ ] Espoonlahden kirkko
- [ ] Hakavuoren kirkko
- [ ] Hakunilan kirkko
- [ ] Hämeenkylän kirkko
- [ ] Helsingin Diakonissalaitoksen kirkko
- [ ] Helsingin Tuomiokirkko
- [ ] Herttoniemen kirkko
- [ ] Helsinging pyhän Eliaan kirkko
- [ ] Honkanummen kappeli
- [ ] Huopalahden kirkko
- [ ] Hyvän Paimenen kirkko
- [ ] Johanneksenkirkko
- [ ] Kaivokselan kirkko
- [ ] Kallion kirkko
- [ ] Kannelmäen kirkko
- [ ] Käpylän kirkko
- [ ] Karunan vanha kirkko
- [ ] Kauklahden kappeli
- [ ] Kellonummen kappeli
- [ ] Kivistön kirkko
- [ ] Konalan kirkko
- [ ] Korson kirkko
- [ ] Koskelan kirkko
- [ ] Kristuskyrkan
- [ ] Kulosaaren kirkko
- [ ] Laajasalon kirkko
- [ ] Lähetyskirkko
- [ ] Länsimäen kirkko
- [ ] Lauttasaaren kirkko
- [ ] Leppävaaran kirkko
- [ ] Luther-kirkko
- [ ] Malmin kirkko
- [ ] Matasaaren kappeli
- [ ] Matinkappeli

- [ ] Matteuksenkirkko
- [ ] Maunulan kirkko
- [ ] Meilahden kirkko
- [ ] Mikael Agricolan kirkko
- [ ] Mikaelinkirkko
- [ ] Munkkiniemen kirkko
- [ ] Myllypuron kirkko
- [ ] Myyrmäen kirkko
- [ ] Olarin kirkko
- [ ] Olaus Petrin kirkko
- [ ] Otaniemen kappeli
- [ ] Oulunkylän kirkko
- [ ] Oulunkylän puukirkko
- [ ] Paavalinkirkko
- [ ] Pappilan kotikirkko
- [ ] Perkkaan kappeli
- [ ] Pihlajamäen kirkko
- [ ] Pitäjänmäen kirkko
- [ ] Puistolan kirkko
- [ ] Pyhän Annan lastenkirkko
- [ ] Pyhän Henrikin katedraali
- [ ] Pyhän Kolminaisuuden kirkko
- [ ] Pyhän Laurin kappeli
- [ ] Pyhän Marian kirkko
- [ ] Pyhän Nikolauksen kirkko
- [ ] Rekolan kirkko
- [ ] Roihuvuoren kirkko
- [ ] Ruskeasannan kappeli
- [ ] Saalem-temppeli
- [ ] Saksalainen kirkko
- [ ] Seutulan kappeli
- [ ] Soukan kappeli
- [ ] St. Jacobs kyrka
- [ ] Suomenlinnan kirkko
- [ ] Suvelan kappeli
- [ ] Tammisalon kirkko
- [ ] Tapanilan kirkko
- [ ] Tapiolan kirkko
- [ ] Tapiolan ortodoksinen kirkko
- [ ] Temppeliaukion kirkko

- [ ] Tikkurilan kirkko
- [ ] Tikkurilan ortodoksinen kirkko
- [ ] Tikkurilan vanha kirkko
- [ ] Töölön kirkko
- [ ] Tuomaankirkko
- [ ] Uspenskin katedraali
- [ ] Vaaralan kappeli
- [ ] Vanha kirkko
- [ ] Vantaan Pyhän Laurin kirkko
- [ ] Vartiokylän kirkko
- [ ] Viikin kirkko
- [ ] Vuosaaren kirkko
- [ ] Vuosaaren merimieskirkko
- [ ] Östersundomin kirkko
- [ ] Other: _____

9. Perustele halutessasi vastaustasi (**helpoimmat**)

_____

_____

_____

_____

_____

10. Valitse mielestäsi kolme laulajalle **vaikeinta** kirkkoa kuoromusiikin esittämiselle *

Check all that apply.

- [ ] Alppilan kirkko
- [ ] Espoon tuomiokirkko
- [ ] Espoonlahden kirkko
- [ ] Hakavuoren kirkko
- [ ] Hakunilan kirkko
- [ ] Hämeenkylän kirkko
- [ ] Helsingin Diakonissalaitoksen kirkko
- [ ] Helsingin Tuomiokirkko
- [ ] Herttoniemen kirkko
- [ ] Helsingin pyhän Eliaan kirkko
- [ ] Honkanummen kappeli
- [ ] Huopalahden kirkko
- [ ] Hyvän Paimenen kirkko
- [ ] Johanneksenkirkko
- [ ] Kaivokselan kirkko
- [ ] Kallion kirkko
- [ ] Kannelmäen kirkko
- [ ] Käpylän kirkko
- [ ] Karunan vanha kirkko
- [ ] Kauklahden kappeli
- [ ] Kellonummen kappeli
- [ ] Kivistön kirkko
- [ ] Konalan kirkko
- [ ] Korson kirkko
- [ ] Koskelan kirkko
- [ ] Kristuskyrkan
- [ ] Kulosaaren kirkko
- [ ] Laajasalon kirkko
- [ ] Lähetyskirkko
- [ ] Länsimäen kirkko
- [ ] Lauttasaaren kirkko
- [ ] Leppävaaran kirkko
- [ ] Luther-kirkko
- [ ] Malmin kirkko
- [ ] Matasaaren kappeli
- [ ] Matinkappeli

- [ ] Matteuksenkirkko
- [ ] Maunulan kirkko
- [ ] Meilahden kirkko
- [ ] Mikael Agricolan kirkko
- [ ] Mikaelinkirkko
- [ ] Munkkiniemen kirkko
- [ ] Myllypuron kirkko
- [ ] Myyrmäen kirkko
- [ ] Olarin kirkko
- [ ] Olaus Petrin kirkko
- [ ] Otaniemen kappeli
- [ ] Oulunkylän kirkko
- [ ] Oulunkylän puukirkko
- [ ] Paavalinkirkko
- [ ] Pappilan kotikirkko
- [ ] Perkkaan kappeli
- [ ] Pihlajamäen kirkko
- [ ] Pitäjänmäen kirkko
- [ ] Puistolan kirkko
- [ ] Pyhän Annan lastenkirkko
- [ ] Pyhän Henrikin katedraali
- [ ] Pyhän Kolminaisuuden kirkko
- [ ] Pyhän Laurin kappeli
- [ ] Pyhän Marian kirkko
- [ ] Pyhän Nikolauksen kirkko
- [ ] Rekolan kirkko
- [ ] Roihuvuoren kirkko
- [ ] Ruskeasannan kappeli
- [ ] Saalem-temppeli
- [ ] Saksalainen kirkko
- [ ] Seutulan kappeli
- [ ] Soukan kappeli
- [ ] St. Jacobs kyrka
- [ ] Suomenlinnan kirkko
- [ ] Suvelan kappeli
- [ ] Tammisalon kirkko
- [ ] Tapanilan kirkko
- [ ] Tapiolan kirkko
- [ ] Tapiolan ortodoksinen kirkko
- [ ] Temppeliaukion kirkko

- [ ] Tikkurilan kirkko
- [ ] Tikkurilan ortodoksinen kirkko
- [ ] Tikkurilan vanha kirkko
- [ ] Töölön kirkko
- [ ] Tuomaankirkko
- [ ] Uspenskin katedraali
- [ ] Vaaralan kappeli
- [ ] Vanha kirkko
- [ ] Vantaan Pyhän Laurin kirkko
- [ ] Vartiokylän kirkko
- [ ] Viikin kirkko
- [ ] Vuosaaren kirkko
- [ ] Vuosaaren merimieskirkko
- [ ] Östersundomin kirkko
- [ ] Other: _____

11. Perustele halutessasi vastaustasi (**vaikeimmat**)

12. Kerro tähän halutessasi muita mieleen tulleita ajatuksia koskien esiintymistä kirkkotiloissa.

    Onko esimerkiksi jokin kirkko hyvä jonkun tietyn aikakauden tyyppiselle musiikille, mutta täysin väärä toiselle? Miten yleisön läsnäolo muuttaa esiintymisakustiikkaa verrattuna kenraaliharjoitukseen tms.?

Appendix II – Survey church results

Easy (L) – Difficult (R)

Kallion kirkko	20		Temppeliaukion kirkko	24
Paavalinkirkko	17		Hesingin Tuomiokirkko	20
Olaus Petrin kirkko	11		Tapiolan kirkko	9
Johanneksenkirkko	10		Johanneksenkirkko	8
Uspenskin katedraali	10		Paavalinkirkko	7
Roihuvuoren kirkko	9		Vanha kirkko	7
Meilahden kirkko	8		Kallion kirkko	6
Vanha kirkko	8		Lauttasaaren kirkko	5
Mikael Agrikolan kirkko	7		Mikael Agrikolan kirkko	5
Temppeliaukion kirkko	7		Saksalainen kirkko	4
Saksalainen kirkko	6		EMPTY	4
Suomenlinnan kirkko	5		Espoon tuomiokirkko	3
Töölön kirkko	4		St. Jacobs kyrka	3
Käpylän kirkko	2		Suomenlinnan kirkko	3
Lauttasaaren kirkko	2		Töölön kirkko	3
Oulunkylän kirkko	2		Uspenskin katedraali	3
Tapiolan kirkko	2		Kannelmäen kirkko	2
Alppilan kirkko	1		Munkkiniemen kirkko	2
Espoon tuomiokirkko	1		Vantaan Pyhän Laurin kirkko	2
Hyvän paimenen kirkko	1		Östersundomin kirkko	2
Leppävaaran kirkko	1		Honkanummen kappeli	1
Matteuksenkirkko	1		Käpylän kirkko	1
Olarin kirkko	1		Karunan vanha kirkko	1
Otaniemen kappeli	1		Kauklahden kappeli	1
Pyhän Henrikin katedraali	1		Korson kirkko	1
Vantaan Pyhän Laurin kirkko	1		Matasaaren kappeli	1
Hietaniemen vanha kappeli	1		Matinkappeli	1
Riihimäen varuskuntakirkko	1		Maunulankirkko	1
Pyhän Sydämen kappeli	1		Meilahden kirkko	1
			Myllypuron kirkko	1
			Olarin kirkko	1
			Otaniemen kappeli	1
			Oulunkylän kirkko	1
			Oulunkylän puukirkko	1
			Pyhän kolminaisuuden kirkko	1
			Roihuvuoren kirkko	1
			Tikkurilan kirkko	1
			Munkkivuoren kirkko	1
			Turun Tuomiokirkko	1

Appendix III – Survey open question answers

Answers for determining acoustic factors for “easy” or “hard” singing

Hyvä kaiku, helppo kuunnella muita
Helppo akustiikka laulajan puolesta on sellainen, jossa lavalla kuulee muut stemmat hyvin. Vaikea esiintymisakustiikka puolestaan on esimerkiksi liian kaikuisa kirkko, jolloin esiintyjän on keskityttävä tehdäkseen esityksestä kuulijalle akustiikan puitteissa mahdollisimman selkeää jotta sanoista saa selvää
kimpoilevan kaikuva on haastava, myös jos on kahdessa tasossa ja kuoro on jaettu rakenteiden alle. Myös urkujen etäisyys alttarista vaikuttaa.
Kuulee hyvin
Hyvässä akustiikassa on helppo laulaa, tila soi ja kuulee muiden stemmojen laulua hyvin
Kuuluvuus lavalla stemmojen välillä pitää olla hyvä, sopiva kaiku (ei liian pitkä tai puuroutuva, mutta toisaalta sointia kannatteleva). Alla olevaan kysymykseen vaikuttaa merkittävästi se, paljonko on yleisöä. Vastaan näihin sillä oletuksella että kyseinen kirkko on liki täynnä.
Helppoon akustiikkaan tarvitaan sopiva määrä sopivan kestoista kaikua. Kirkko ei saa olla liian eikä liian pieni. Kaikki tietenkin riippuu myös kuoron koosta. Itselläni on kokemusta erikokoisista ryhmistä, mutta nyt vastaan ison kuoron näkökulmasta. Kaiku antaa ikään kuin palautetta masta äänestä, mutta myös kuvan koko kuoron soinnista. Itse pidän esittäjä suurista kaiuista, vaikka siinä on haasteensa ja esim. yleisö ei saa välttämättä sanoista selvää. En ole laulanut läheskään kaikissa alla mainituissa kirkoissa.
Kuulen muitakin laulajia, kuin itseni tai vieressä laulavan. Esiintymistilan pinnasta kaikuvan äänen viive on vähäinen/ kohtuullinen: tämä on sitä tärkeämpi, mitä nopeatempoisempi esitettävä musiikki on, tai mitä enemmän tulee kiinnittää huomiota artikulaatioon (staccatot, konsonantteja runsaasti sisältävät sanat) Myös hiljaa lauletuissa kohdissa laulajan on mahdollista muodostaa palaute soinnista (kaiku). Dynamiikan vaihtelut eri stemmojen välillä eivät aikaansaa tilannetta, jossa jokin stemma jäisi tilasta johtuen kokonaan kuulumatta (ts. Mitkä säveltaajuudet soivat missäkin tilassa ja voimakkuudessa parhaiten)

Akustiikkaan oleellisesti liittyvä seikka on, miten tilassa olevat esiintyjät voivat sijoittua (esiintymislavan fyysinen ulottuvuus, etenkin suurilla kokoonpanoilla); ns. ”Kuorokaari”; onko toteutettavissa, vai tuleeko kyseeseen jokin muu tasapainottava keino, esim. Eri stemmoja laulavien sijoittaminen sekoittaminen kokoonpanoon.
Ääni täyttää tilan kauniisti ja vaivattomasti, itsensä ja muut kuulee hyvin, ei kuitenkaan esim puuroudu liian kaiun takia
Vaikea sellainen missä muita stremmoja ei oikein tahdo kuulla, tai tulle tunne siitä että laulaa ”yksin” omassa kuplassaan.
Esittämäni musiikki tarvitsee tilan tunteen eikä lyhyehkö kaikukaan ole haitaksi. Asian kääntöpuoli on, että tällöin nopea musiikki ja tekstin selkeys kärsivät. Helpoimpia laulamisen kannalta olevat kirkot eivät aina ole kuulijan kannalta edullisimmat ja päin vastoin. Laulajalle hyvän kokemuksen laulamisesta antava tila auttaa sekä kuulemaan oman äänen että kokonaisuuden.
Helpossa akustiikassa kuulen hyvin itseni mutta myös muita kuorolaisia, ääni soi pitkään (muttei liikaa), tila kestää sekä hyvin hiljaa laulamisen että kovimmat fortet. Vaikea akustiikka on kuiva ja vähäkaikuinen, tai kolkko; siinä joko oma ääni katoaa tai ei kuule muita - tai kaikki kuuluu mutta rumasti !
Helppo: kuulee hyvin kaikkia muita laulajia, kaikua on sopivasti pehmentämään, ääni ei kimpoa hankalasti takaisin seinästä, katosta, pylväistä tms., laulajien äänet blendaavat hyvin Vaikea: edellä mainitut asiat päinvastoin
Vaikea: muita laulajia ei kuule, akustiikka ei soi, kuin sukkaan laulaminen, liiallinen kaiku Helppo: muita laulajia ja stemmoja kuulee hyvin, kirkossa akustiikka soi sopivasti ja auttaa äänen soinnissa
En ole musiikin ammattilainen, joten arviointikykyni ja sanastoni eivät varmastikaan riitä tyhjentävään vastaukseen. Vastaukseni perustuvat yleiseen ”tuntemukseen”. Mielestäni helppo akustiikka sisältää sekä tarpeeksi kaikua paremmin sietäville teoksille, että napakkuutta rytmisempää kuoromusiikkia varten. YL:n joulukonsertit sisältävät tyypillisesti molempia, joten välimaaston kirkot ovat hyviä. Helppo akustiikka takaa myös normaalissa kuoromuodossa olevalle laulajalle hyvän, nopean ja vireellisesti selkeän kuulokuvan sekä omasta äänestään että muiden laulajien äänestä. Itselleni vaikea akustiikka on tyypillisest liian kaikuisa (malliesimerkki Turun tuomiokirkko) ja/tai ei anna laulajalle tarpeeksi nopeaa ja selkeää responssia omasta äänestään tai kanssalaulajien äänistä. Muut tuntemani laulajat puhuvat usein eri materiaalien akustiikkaeroista, mutta siihen en osaa ottaa kantaa.

Helppo: sopivan pitkä kaiku, kuulee hyvin myös muut laulajat, ei liian kova kaiku Vaikea: liian pitkä kaiku, vaikeus kuulla muita tai tunne siitä, että laulaa yksin, liian kova tai ”metallinen” kaiku
Kokemukseni mukaan, kuin laulajat kuulevat toisensa ja pystyvät reagoimaan toisiinsa, akustinen lopputulos on hyvin soiva myös yleisölle.
Helpossa alistiikassa kuulee sekä oman että muitten äänet.
Helppo akustiikka on sellainen missä kuulee muita stemmoja ja laulajia hyvin ja reaaliajassa (eikä esim kaikuna). Sen lisäksi tärkeätä on kuulla itteään ja vieruskavereita. Tykkään sellaisista akustiikoista mitkä ei ole liian kuivia ja mistä saa paljon "palautetta" eli kuulee vähän miltä kuoro voisi kuulostaa yleisölle. En tykkää siitä kun ääni "hukkuu" (kuulostaa siltä ettei ääni kanna yleisölle vaikka kantaa). Kaiku ei mielellään liian pitkä (tekstin kuuluvuus ja nopeat kuviot hankalia) mutta parin sekunnin kaiku voi olla aika kiva! Akustiilka saisi mielellään pysyä aika samana silloin kun ylwisö on paikalla.
Helppo jos: Kuulee itsensä, oman stemman ja myös muut stemmat. Ääni kantautuu yleisölle ”sopivan” (odotetun, toivotun) voimakkaasti ja ääni elää, mutta ei kaiu pitkään.
Helppo: mukava jälkikaiku, kuulee muun kuoron. Vaikea: ns kuiva akustiikka eli ei jälkikaikua eikä ääni kulkeudu takaisin laulajille
Helppo akustiikka on sellainen, että kuoron muiden stemmojen ja oman stemman laulajien ääntä kuulee pinnistelemättä. Helpossa akustiikassa ääni tuntuu kantavan hyvin. Ääni kaikuu pyöreästi ja kirkkaasti. Vaikeassa akustiikassa ei kuule muita hyvin tai kuulee vain joitakin yksittäisiä laulajia. Akustiikka on "kuiva", äänen sointi sammuu nopeasti. Toisaalta vaikeassa akustiikassa voi olla myös todella pitkä kaiku, joka helposti puurouttaa artikulaation ja tempoa joutuu hidastamaan paljon.
Kuulee kohtalaisen hyvin muut laulajat omassa ja muissa stemmoissa. Hyvä kaiku, joskaan ei liikaa. Harvoin tosin kaikua on liikaa.
Sopivan lyhyt jälkikaiku on mielestäni oleellista. Tärkeää on kuulla itsensä ja koko kuoron balanssi.
Helppo akustiikka: muiden laulajien kuuleminen tuntuu helpolta, ja tila edesauttaa varman yleisolon syntymistä esiintyjälle. Vaikea akustiikka: muiden laulajien kuuleminen on vaikeaa, ja/tai tila luo epävarman olon esim. totuttuun harjoitustilaan verrattuna.
Laulajan kannalta vaikea akustiikka on sellainen, jossa laulajalle tuleva kuulokuva tuo hyvin vajavaisen vasteen koko kuoron soinnista ja toisaalta omasta laulusta, esim. kuulee vain itsensä ja muutaman vierustoverin tai ei kuule itseään juuri lainkaan ja sitä kautta on hankalaa reflektoida omaa laulamaista suhteessa kuulemaansa koko kuoron sointiin.

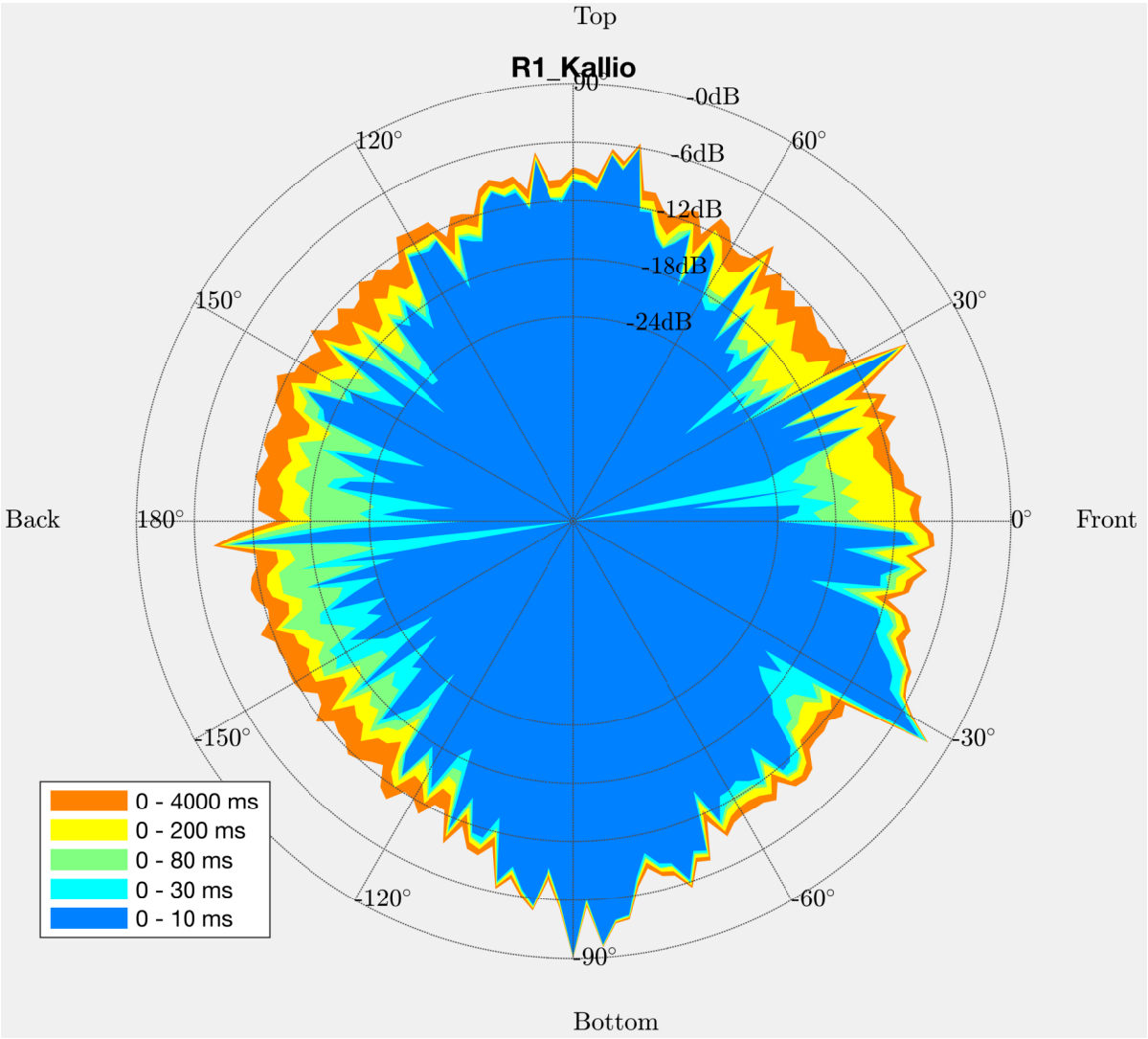
Helpossa akustiikassa kaiku antaa tukea tuotetulle äänelle, koko kuoron sointi on kuultavissa lavallakin (kaikki äänet) ja myös oman äänensä kuulee ilman, että on tarvetta laulaa ylikovaa tavoiteltuun dynamiikkaan nähden.
Helpossa akustiikassa kuulee hyvin muut laulajat/stemmat mutta kuulee myös oman äänensä ja laulaminen tuntuu vaivattomalta, ääni kantaa. Helppo akustiikka ei ole liian kuiva mutta siinä ei saa olla myöskään liikaa jälkikaikua. Huonossa akustiikassa kuulee vain vierustoverin äänen tai vain omansa ja virittäminen on vaikeaa.
Laulajan näkökulmasta "helppo" akustiikka: kuulen itseni, kuulen toiset stemmat, kuulen tilan soinnin. Vaikea akustiikka: edellisten vastakohta
Minulle helpon akustiikan tuo miellyttävä kohtuullinen kaiku, joka auttaa musiikkia kantamaan. Hankala akustiikka puolestaan on kuiva ja tumppuinen, josta ei saa responssia tai jonne ääni hukkuu. Myös liian pitkä kaiku voi olla hankala, mutta jotkut teokset sopivat myös hyvin kaikuisaan akustiikkaan.
Päällimmäisenä kaksi asiaa: se, miten tila tukee laulamista ihan teknisesti eli tulee kokemus, että on helppo laulaa ja ääni kantaa tilassa sekä se, miten kuulee kuoron muut laulajat - sekä vierustoverit että muut stemmat. Jos nämä toteutuvat, on helppoa, jos taas ei, niin on vaikeaa -> tulee tunne, että laulaa studiossa ja yksin.
Helppo on ilmava akustiikka ja vaikea on paksu
"Helpossa akustiikassa" kuulen kuorotoverini sopivan tasapainoisesti, laulaessa ei tule tunnetta, että äänen voimakkuutta pitäisi lisätä jotta laulu kuuluu yleisölle kunnolla, ja kaikua on "sopivasti".
Helppo: kuulee muut laulajat hyvin. Kuulee myös itsensä hyvin. Vaikea : jää tunne että laulaisi yksin, vaikka paikalla on toki muitakin. Sopraanona kuulee yleensä bassot hyvin, muttei esim. tenoreita ja/tai alttoja.
Helppo akustiikka: hyvä lavakuuluvuus (eli kuulee myös mitä toinen pää / eturivi) laulaa; mutta toisaalta taaempi rivi ei tule liian kovaa (esim. ns. jenkkityyppiset kuorolavat joissa takasein buustaa takarivin ääntä aivan älyttömästi). Myös salin sopiva kaiku joka ei liian kivinen (toki sopiva kaiku riippuu aikapaljon esitettävistä biiseistä), helpottaa hengityksiä. Vaikea akustiikka: ei sali kaikua, joten legaton joutuu tekemään täysin itse, tila ei auta. Huono lavakuuluvuus, esim. jos lavan verhot imevät toisen laidan ääntä, eikä takaseinäkään auta kuulemaan kuoron toista laitaa; toisaalta myös jos eturivi ei kuulu takariviin.
Helppo: Tarpeeksi kaikuisa ja absoluuttisen hiljainen tila mikä innoittaa soivien sekuntien virittämiseen, kun kuulokuvasta erottuu myös oma stemma soinnuissa. Kaiussa ei kuitenkaan synny rytmitajua sotkevaa syvän tilan vaikutelmaa. Vaikea: Tila missä äänen tuotto tuntuu työntämiseltä ilman feedbackkiä ja johtaja joutuu/innostuu mikromanageeraamaan yksilöiden äänenkäyttöä, jolloin kuoro sointi häviää kenties vielä lisää. Tila, jossa on häitseviä sivuääniä erityisesti esim. nauhoituksia ajatellen.

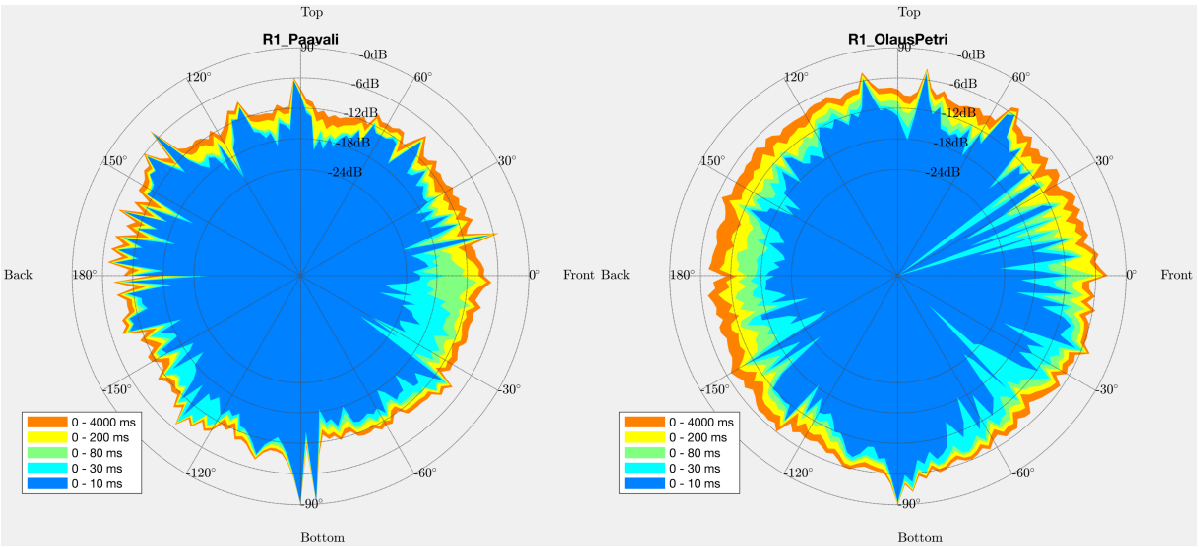
Kuiva ja soiva, jossa kuulee oman ja stemmakaverien äänet eritellysti, on helppo. Helppossa ääni ei jää ”massana pyörimään” tai tule soutavaa ja raskasta tunnetta laulaessa. Vaikeassa kaikki tuntuu ja kuulostaa pöpperöltä. Laulu ei tunnu kantavan tai ei saa akustiikasta tukea.
Helppo akustiikka on sellainen, jossa kuulokuva koko kuoron sointiin on vaivatonta. Vaikeassa akustiikassa ainoa kuulokuva on oma ääni tai ei sitäkään. Vaikeassa akustiikassa lisäksi jälkikaiku on pitkä.
Helppo kuulla muut laulajat, ei liikaa eikä liian vähän kaikua
Kuorolaulajan kannalta helpointa on mielestäni laulaa, kun kuulee mainiosti sekä lähimmät laulajat viereltä että riittävän hyvin myös laulajia/toisia stemmoja kauempaa. Lisäksi helppouteen liittyy se, että kuulee oman äänensä (mikä ei välttämättä ole hyvä yleisön kannalta)
Keskinäinen kuuluvuus (hyvä tai huono), kaikuvuus/kantavuus (kannatteleeko akustiikka, kuinka kevyesti/maltillisella teholla voi laulaa luottaen, että tila soi ja kantaa myös matalan rekisterin), erottelevuus (risteää keskinäisen kuuluvuuden kanssa, mutta tarkoitan kokonaisuuden hahmottumista laulaessa tai keskinäistä kuuluvuutta koko kuoron tasolla oman tai viereisten stemmojen sijaan)
Helpossa akustiikassa on mukavasti jälkikaikua mutta ei liikaa, saundi kiertyy ympärille, kuulee sekä itsensä että muut. Vaikeassa akustiikassa ääni katoaa kirkkoon eikä kuule itseään eikä muita jolloin alkaa puskea. Myös tosi kuivat akustiikat ovat vaikeita. Joskus moderneissa kirkoissa ääni ”littaantuu” eli se jää tosi helposti alavireiseksi.
Helppo akustiikka antaa sopivasti feedbackia laulajalle, ei liikaa eikä liian vähän. Hyvässä akustiikassa laulajat kuulevat hyvin toisensa.
Helppo akustiikka... Kuulee oman äänensä ja muut laulajat suht tasapainoisesti ja laulaminen tuntuu helpolta. Vaikea... Ei kuule omaa ääntään, ei kuule muita, ääni sammuu tai ei soi.
Vaikeassa akustiikassa en kuule muita laulajia tai ääniä kunnolla,ääni ikäänkuin projisoituu ei palaudu laulajille. Yhteisvoluuminnymmärrys katoaa ja oma ääni ylikorostuu. Se myös vaikeuttaa virittämistä. Olen myös tottunut kuulemaan hengitystauot kuorohengityksen ajoittamiseksi omalta stemmalta tai tietyt lähdöt tietyiltä laulajilta. Liian pitkä kaiku taas voi tehdä myös vaikeaksi nopeatempoinen musiikin mutta koen sen olevan enemmän johtajan ongelma ja hänen tarvitsee valikoida musiikkia joka sopii sellaiseen tilaan.
Laulajalle helppoa on tila, jossa kuulen muita laulajia, eikä tunnu ihan siltä kuin ääni loppuisi seinään. Liian voimakas kaiku on myös haasteellinen.
Helppo: Kuulee hyvin kaikki stemmat, ääni ei puuroudu (kaiku yms), esiintymistila riittävän suuri ja porrastus hyvä (telineillä tai ilman). Vaikea: äänikuva vääristyy (saliin kuuluu hyvin, mutta itsellä vaikutelma, ettei kuulu - tai päin vastoin), näköesteitä johtajaan, solistit, urut tai muut musiikkivälineet hankalissa paikoissa, jolloin kontakti heihin heikko

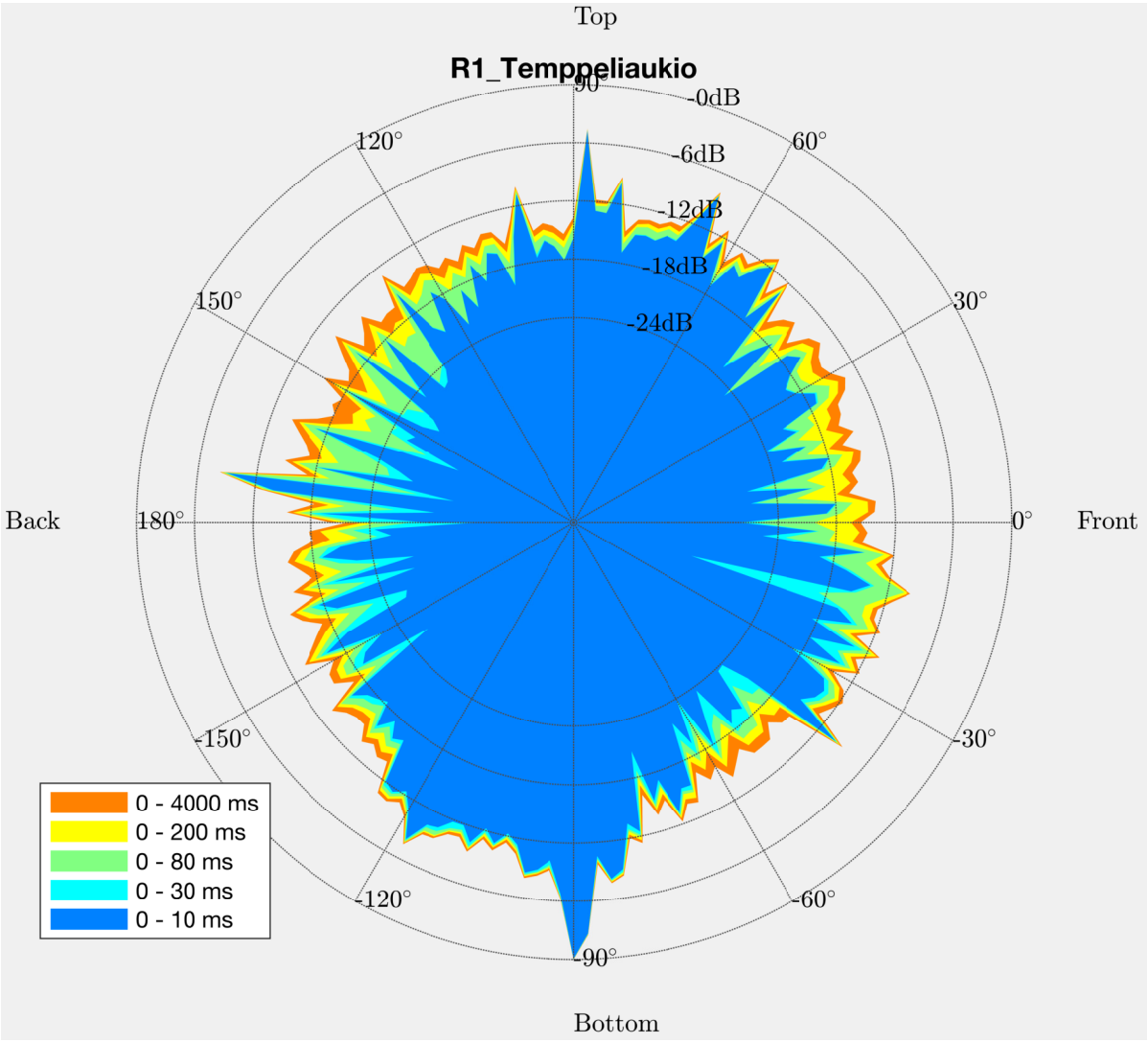
Helpossa akustiikassa kuulee laulaessaan sekä välittömässä läheisyydessä olevat stemmakaverit että kauempana laulavat muut stemmat. Kaiku ei myöskään kantaudu häiritsevän voimakkaana laulajan korviin. Hyvin vaikeassa akustiikassa "on kuin pussiin laulaisi": omaakaan ääntä ei välttämättä kuule, muista stemmoista puhumattakaan. Kaikua ei ole ollenkaan, tai se puurouttaa kaiken.

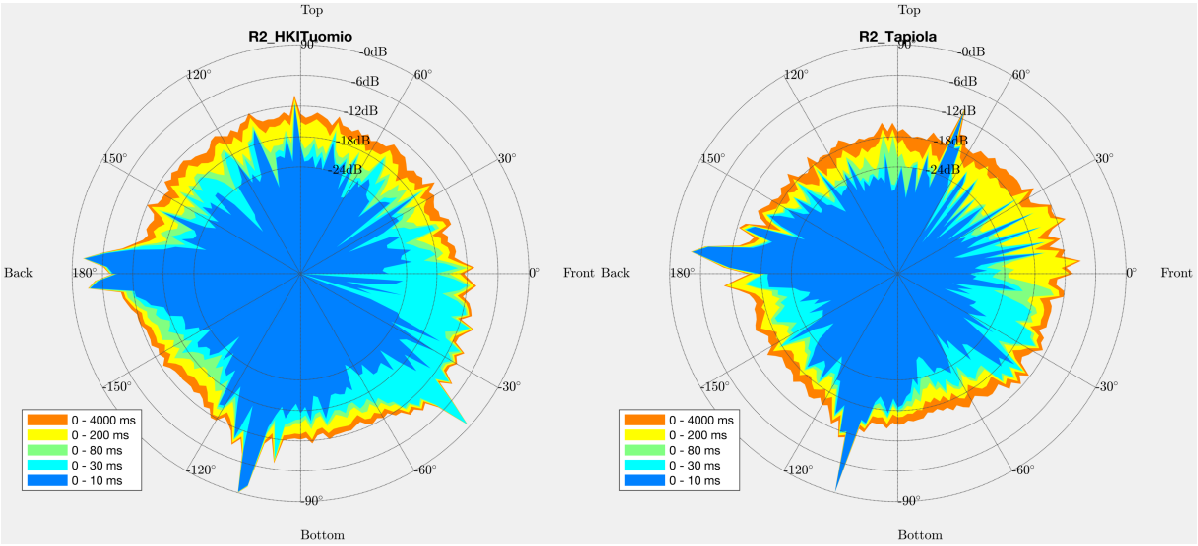
Appendix IV – Vertical SDM plots

R1

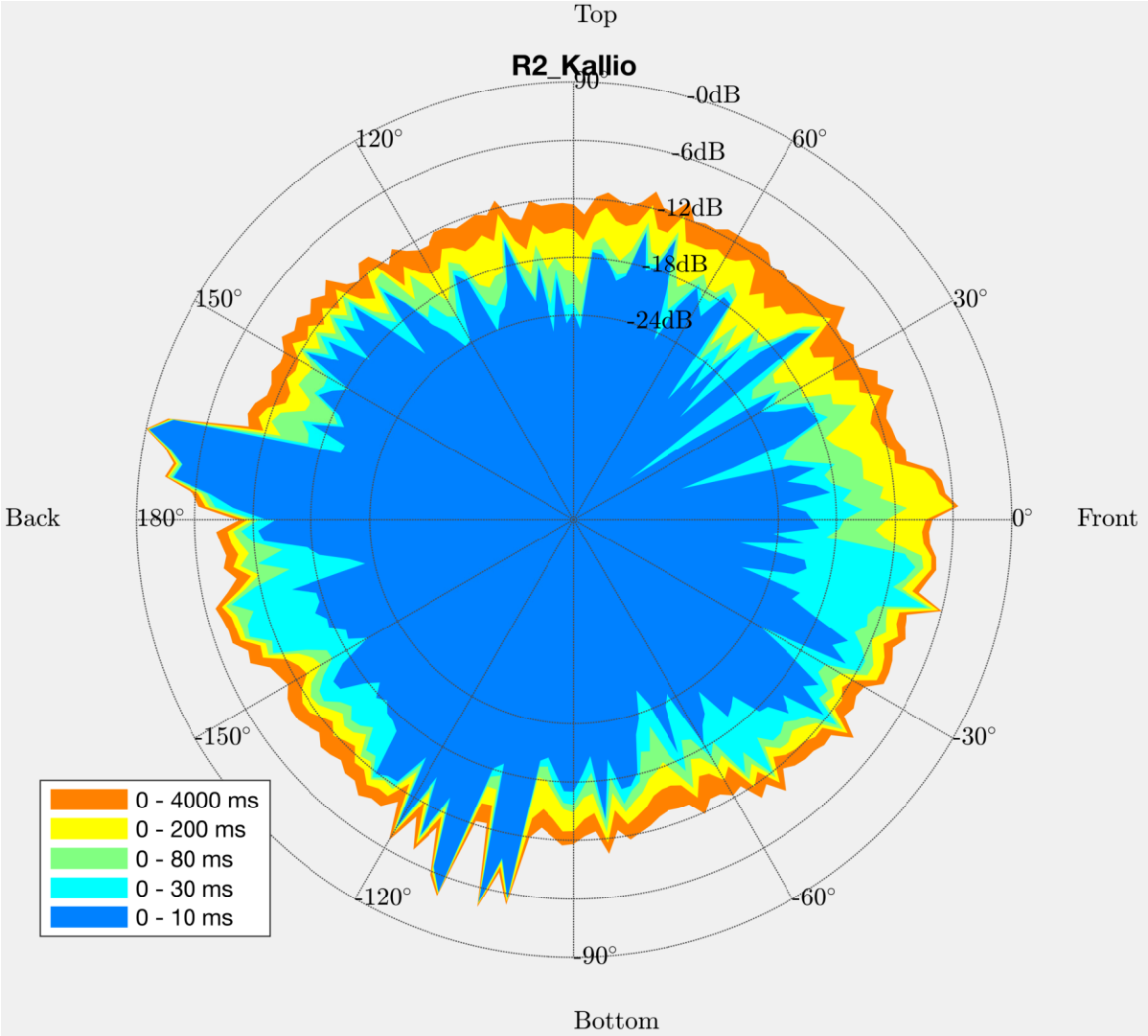


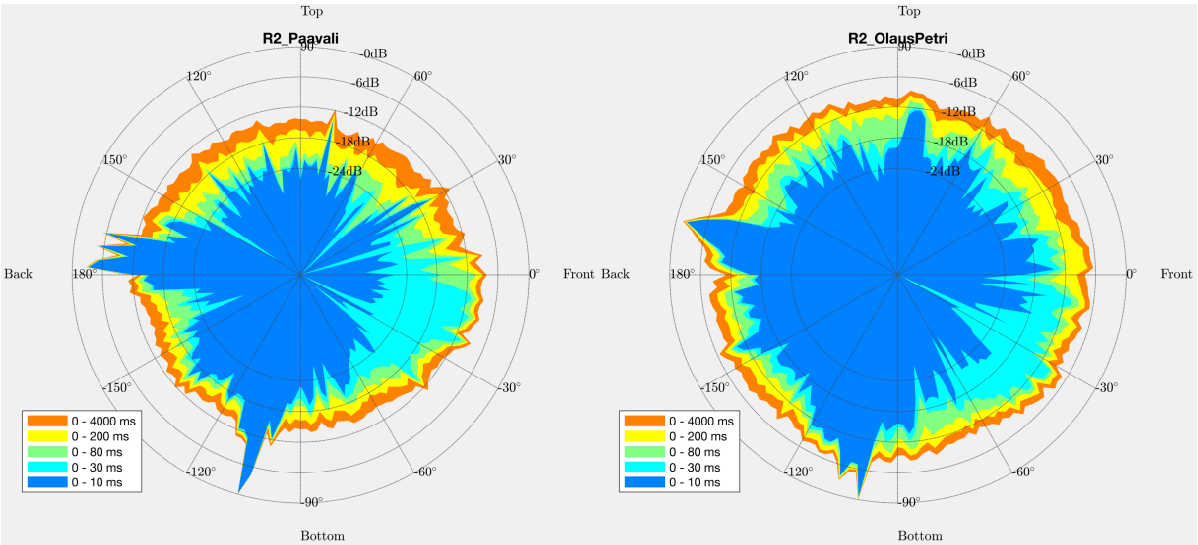


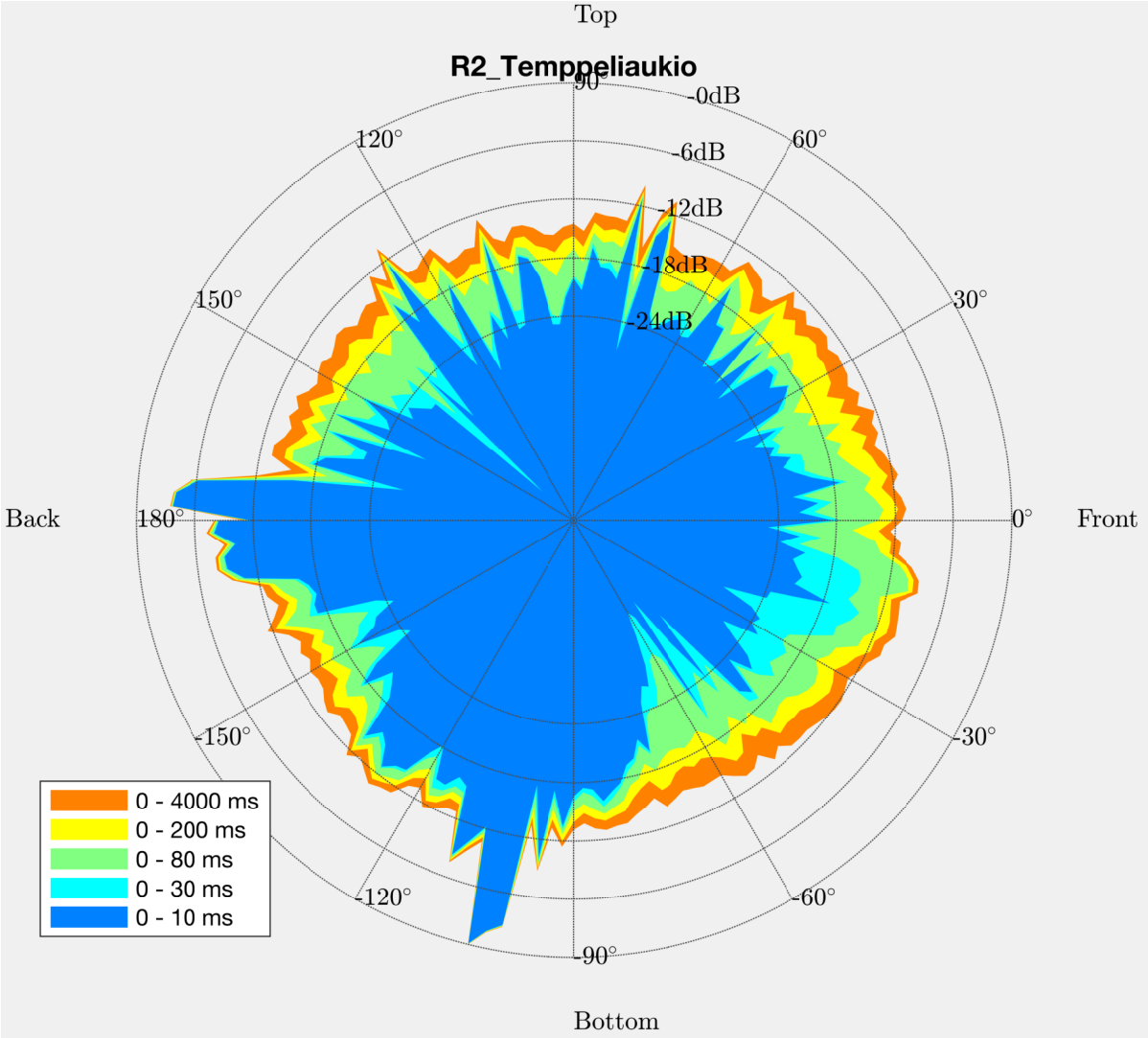

Top
R1_Temppeliaukio
90°
-0dB
120°
60°
-6dB
-12dB
-18dB
150°
30°
-24dB
Back
180°
0°
Front
-150°
-30°
-120°
-60°
-90°
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms
Bottom

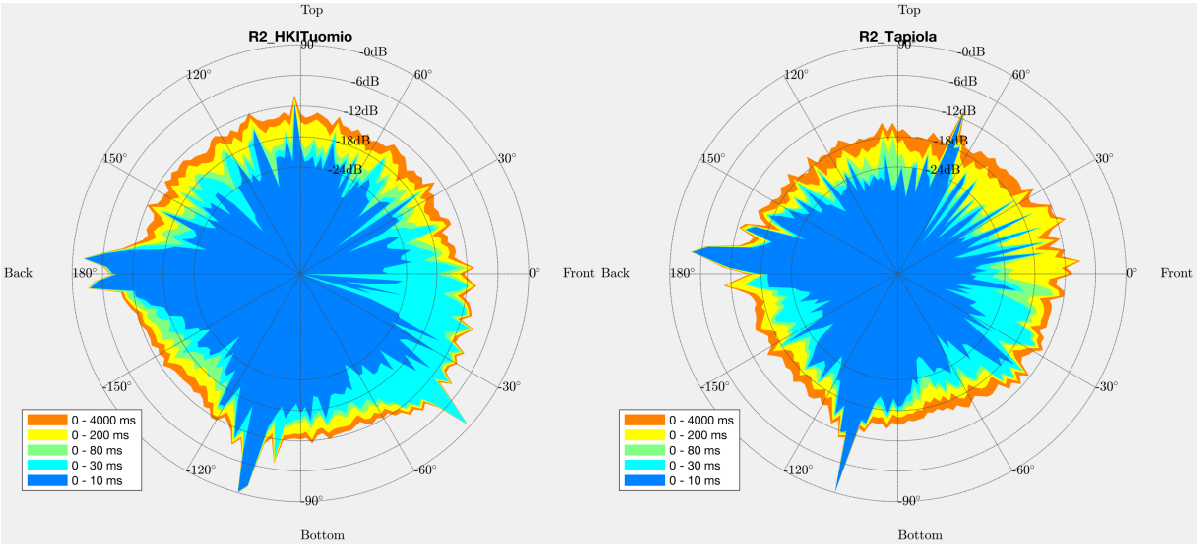

Top
R2_HKITuomio
Back
Front
Bottom
R2_Tapiola
Top
Front
Back
Bottom

R2

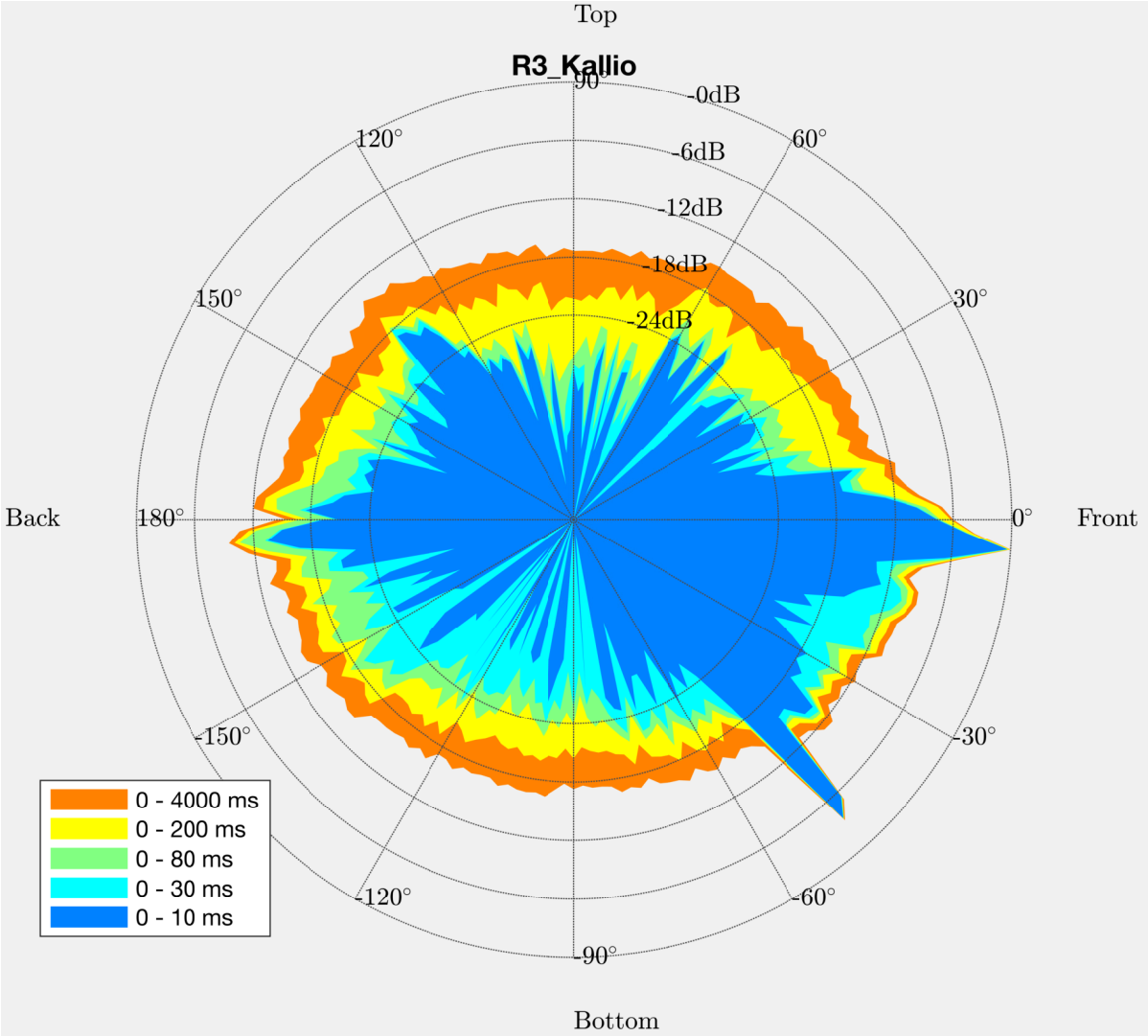

Top
R2_Kallio
90°
-0dB
120°
60°
-6dB
-12dB
-18dB
150°
30°
-24dB
Back
180°
0°
Front
-150°
-30°
-120°
-60°
-90°
Bottom
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms

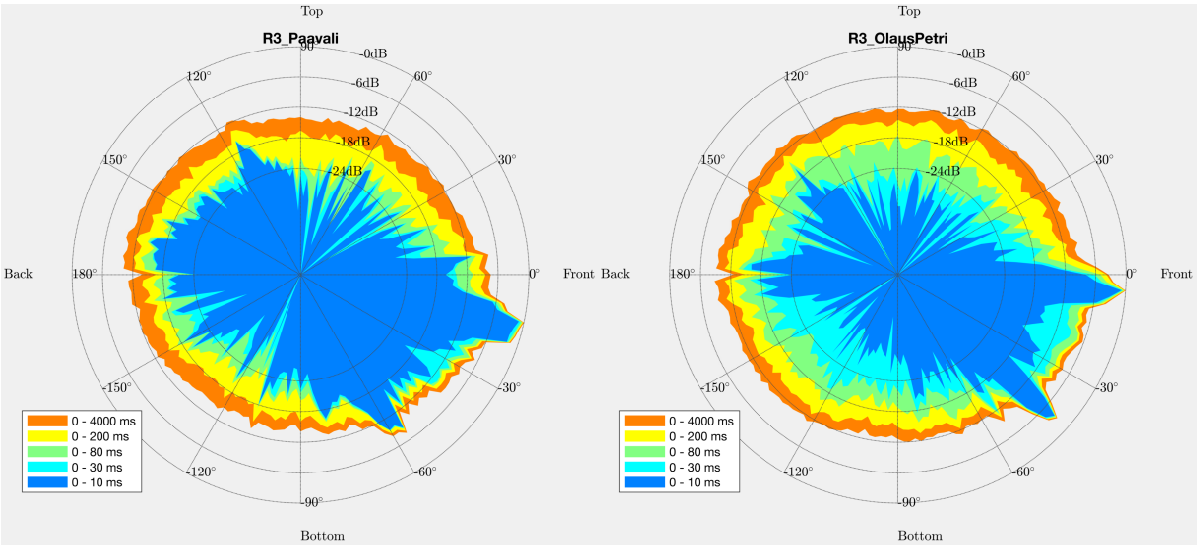

Top
R2_Paavali
Back
180°
0°
Bottom
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms
Top
R2_OlausPetri
Front Back
180°
0°
Front
Bottom
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms

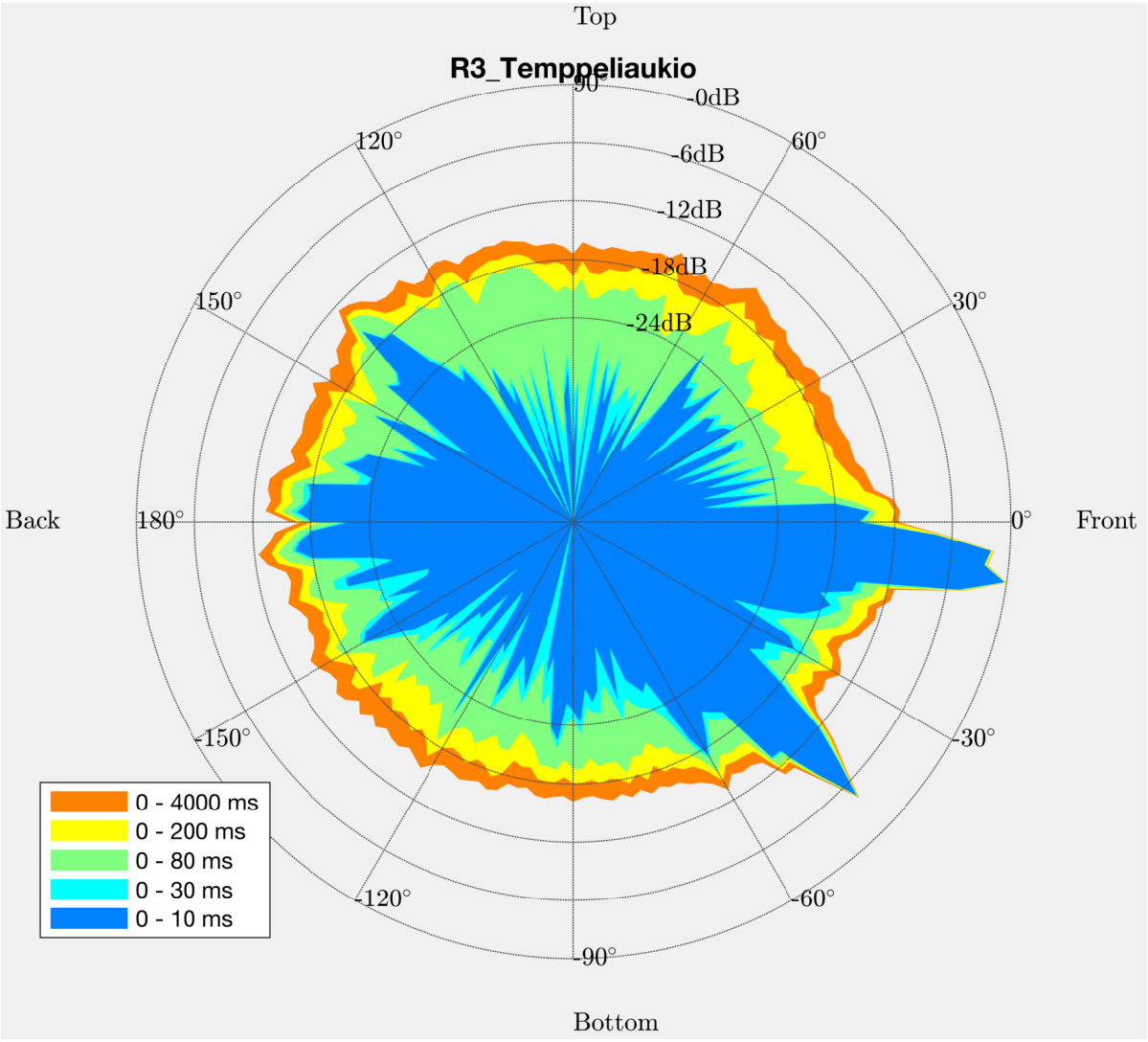

Top
R2_Temppeliaukio
90°
-0dB
120°
60°
-6dB
-12dB
-18dB
150°
30°
-24dB
Back
180°
0°
Front
-150°
-30°
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms
-120°
-60°
-90°
Bottom

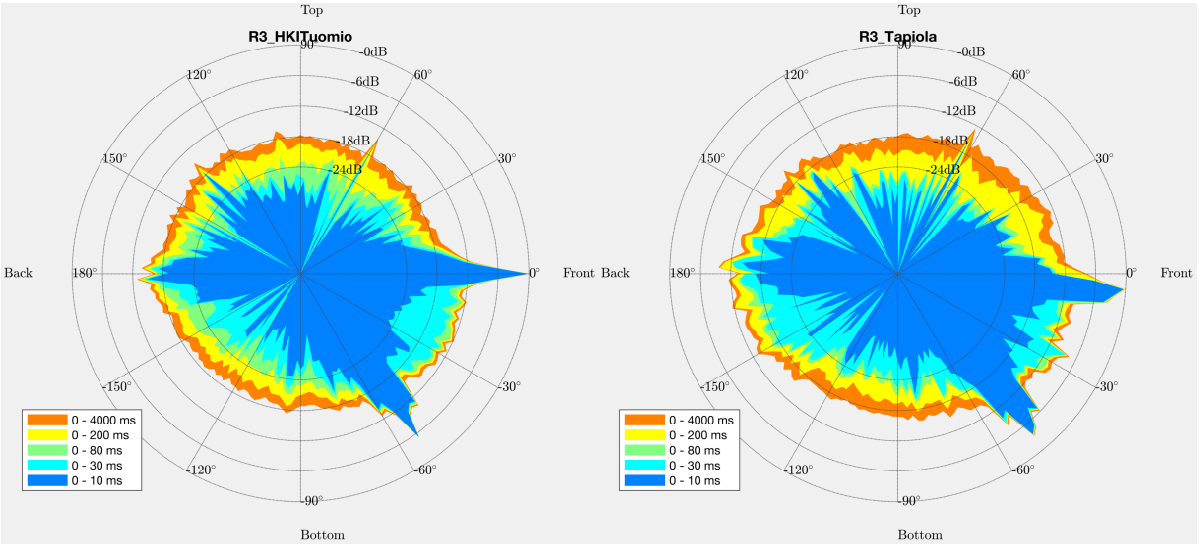

Top
R2_HKITuomio
Back
180°
0°
Front
Bottom
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms
Top
R2_Tapiola
Front Back
180°
0°
Front
Bottom
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms

R3

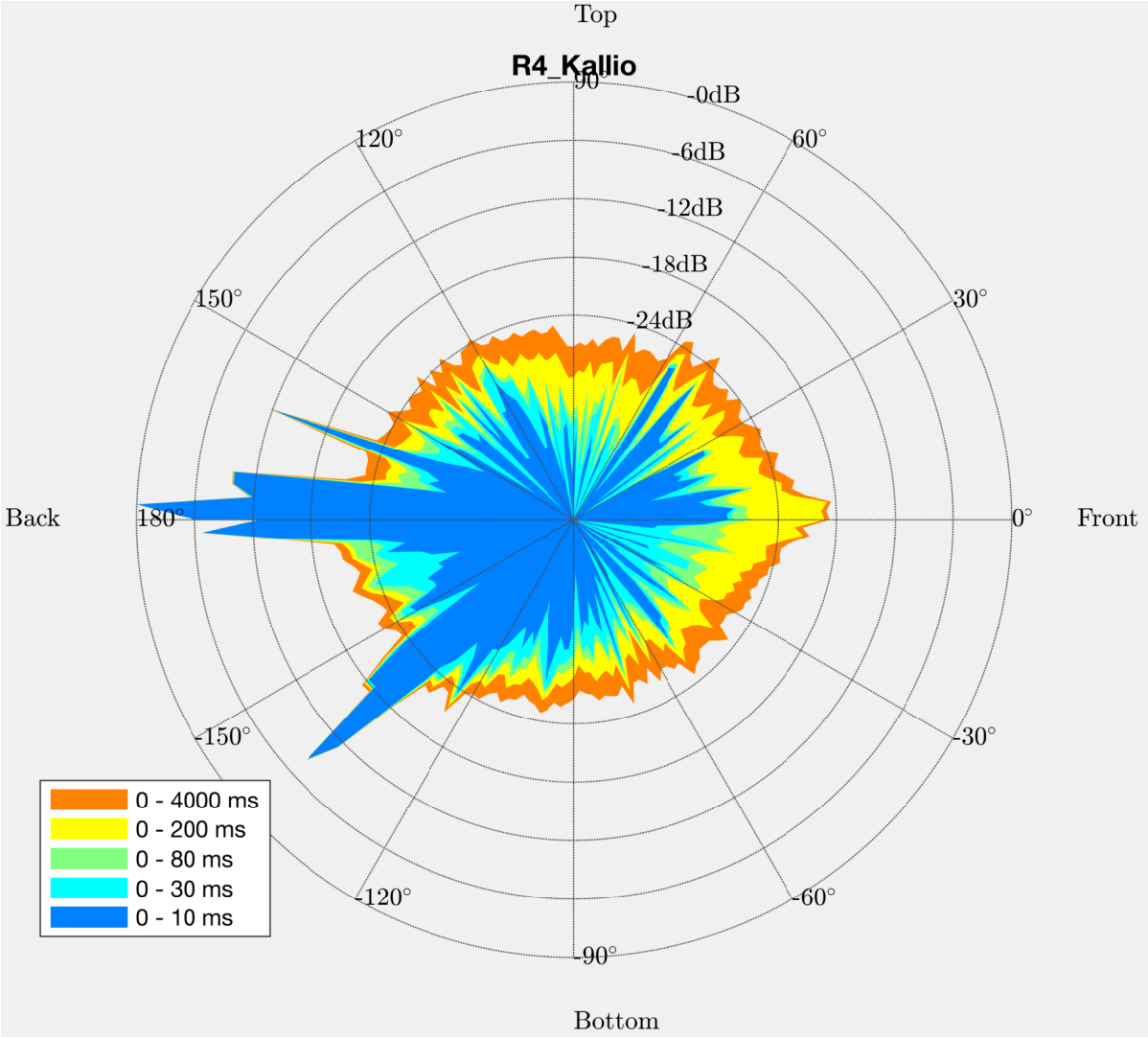

Top
R3_Kallio
90°
-0dB
120°
60°
-6dB
-12dB
-18dB
150°
30°
-24dB
Back
180°
0°
Front
-150°
-30°
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms
-120°
-60°
-90°
Bottom

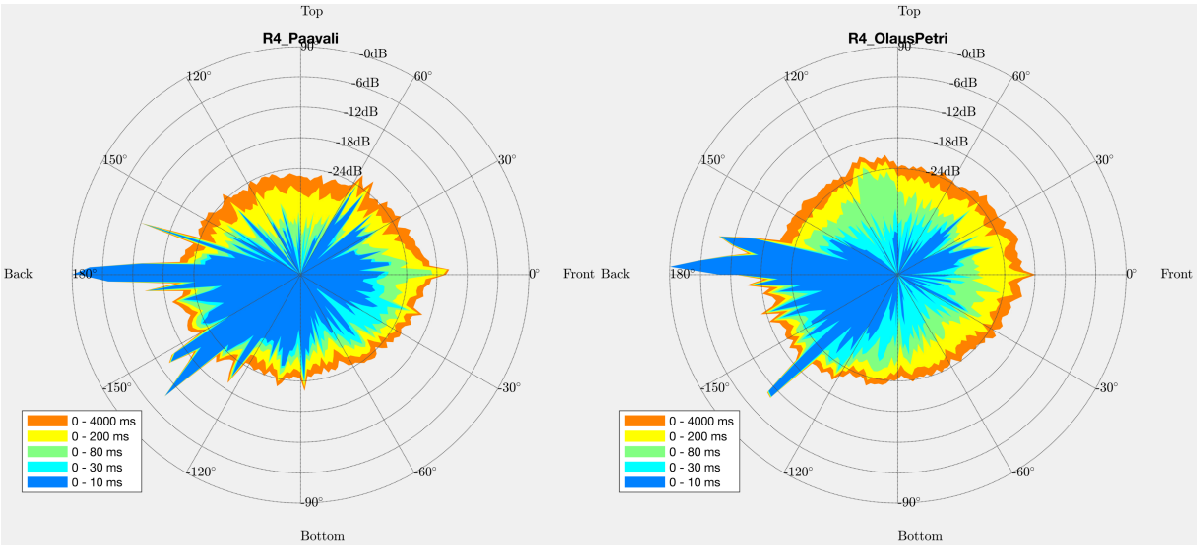

Top
R3_Paavali
Back
Front
Bottom
Top
R3_OlausPetri
Front Back
Bottom


Top
R3_Temppeliaukio
90°
-0dB
120°
60°
-6dB
-12dB
-18dB
150°
30°
-24dB
Back
180°
0°
Front
-150°
-30°
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms
-120°
-60°
-90°
Bottom

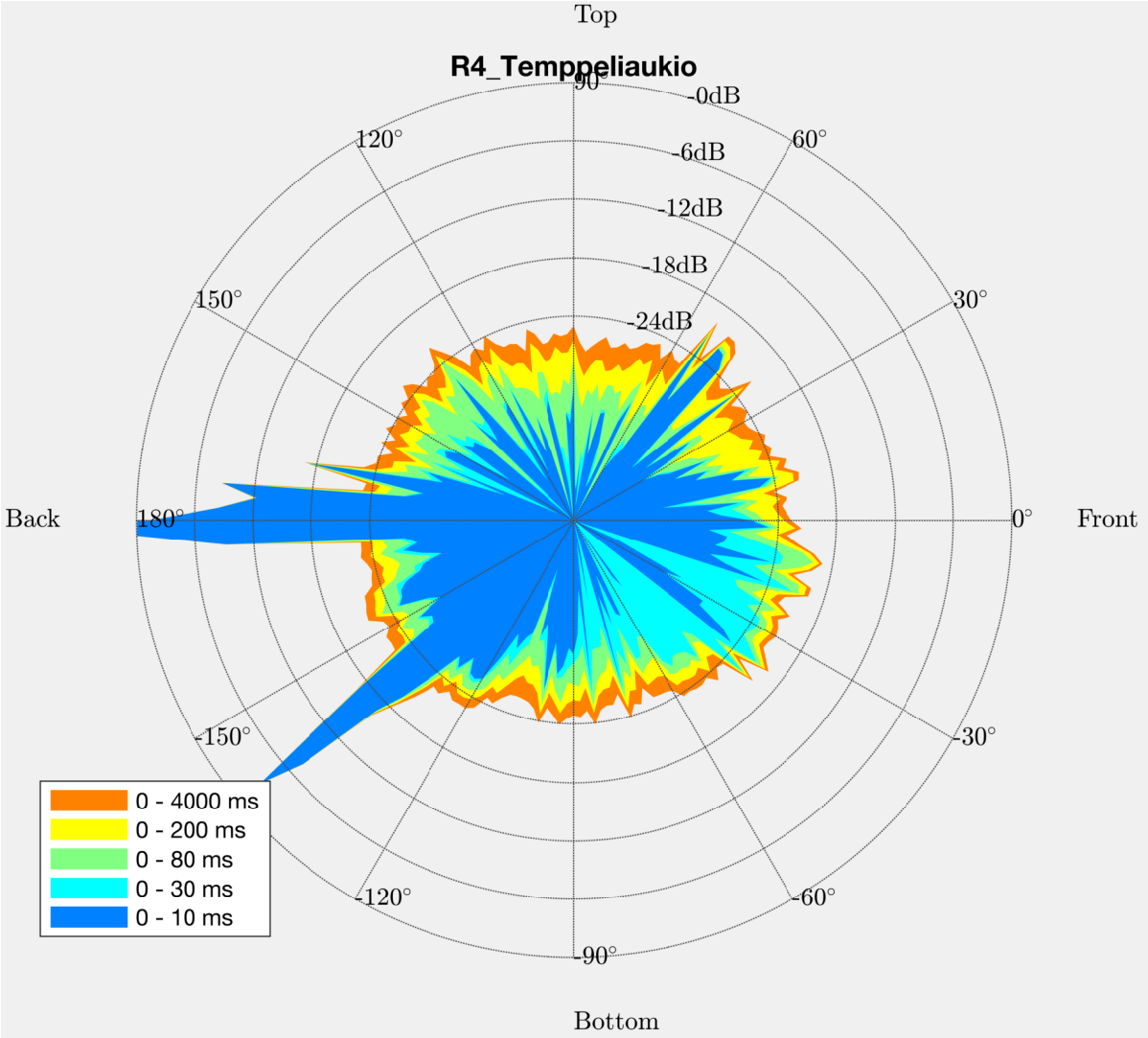

Top
R3_HKITuomio
Back
180°
0°
Front
Bottom
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms
Top
R3_Tapiola
Back
180°
0°
Front
Bottom
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms

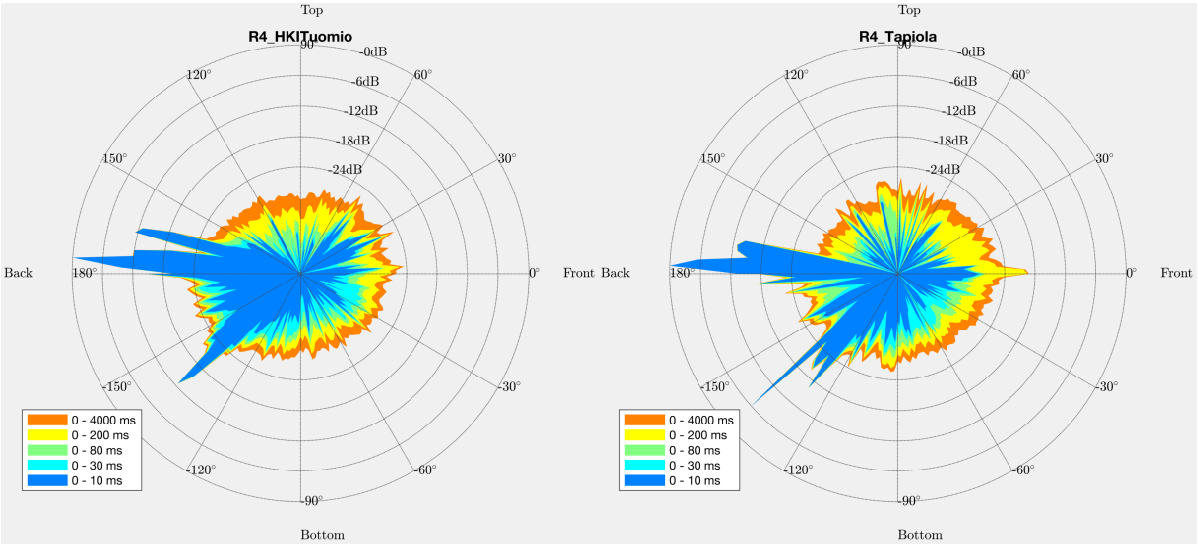
R4[32]





[32] As in Section 4.4.4, the orientation of the probe stays the same for R4. Imagine that the choir conductor is turned to face the audience.


Top
R4_Temppeliaukio
90°
-0dB
120°
60°
-6dB
-12dB
-18dB
150°
30°
-24dB
Back
180°
0°
Front
-150°
-30°
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms
-120°
-60°
-90°
Bottom


Top
R4_HKITuomio
Back
180°
0°
Front
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms
Bottom
Top
R4_Tapiola
Front Back
180°
0°
Front
0 - 4000 ms
0 - 200 ms
0 - 80 ms
0 - 30 ms
0 - 10 ms
Bottom