Thomas Köll

“I cannot hear the Altos!”

An experiment on choir formations and spacing to improve the hearing within the choir in concert halls with dampened acoustics

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# Table of content

1. Introduction .................................................................................................................. 3

2. Research questions and methods ................................................................................. 6

3. Berwaldhallen's acoustics ............................................................................................. 7

4. Terminology and Definitions ....................................................................................... 11

5. Formation choice ........................................................................................................... 12
   Formation F1, single choir ............................................................................................... 13
   Formation F1, double choir ............................................................................................. 13
   Formation F2 .................................................................................................................... 14
   Formation F3 .................................................................................................................... 15
   Formation F4 .................................................................................................................... 15
   Formation F5 .................................................................................................................... 17
   Formation F6 .................................................................................................................... 18

6. Results ............................................................................................................................ 19
   The choir's perspective ................................................................................................... 19
   Formation F1, single and double choir .......................................................................... 20
   Formations F2 and F3 ..................................................................................................... 21
   Formation F4 .................................................................................................................... 21
   Formation F5 .................................................................................................................... 21
   Formation F6 .................................................................................................................... 22
   The producer's perspective ............................................................................................. 22

7. Conclusion ...................................................................................................................... 23

8. References ...................................................................................................................... 27

9. Appendix ......................................................................................................................... 29
1. Introduction

“I cannot hear the Altos!” is a statement I often hear as a choir conductor and singer, especially when a choir is moving from the rehearsal room to a new sound environment such as the stage of a concert hall. The last time I heard this phrase was from myself. In August 2015 I became a member of the Swedish Radio Choir and just three months later I joined the choir on a tour to Japan. One of the concerts took place in a concert hall in Miyazaki, a city on an island south of Osaka. As we warmed up in the concert hall and rehearsed some parts of the program, which we knew very well by that time, I suddenly felt that something was different. The initial measures of simple homophonic pieces were extremely challenging to intonate. It was difficult to listen to the other side of the choir; in fact they could hardly be heard at all. In the first movement of Fest- und Gedenksprüche by Brahms (double choir), the first choir drifted apart from the second choir in rhythm and intonation. We tried to stand closer and sing softer to be able to hear the others better, but nothing seemed to work. The concert hall was literally sucking out the sound of the choir and we received nothing in return. It was as if one sang completely alone, isolated from the rest of the choir.

The same phenomenon appears in Berwaldhallen, the concert hall of the Swedish Radio Symphony Orchestra and the Choir. The acoustics for an a cappella concert are very challenging since the stage is wide and deep. In order to fill the stage, the distance between singers is longer than in the rehearsal studio. Additionally, the architecture of the concert hall makes it impossible to stand in a perfect semi-circle, because the stage has built-in podiums.

Physical difficulties can often be solved by changing something physical, like the formation or the distance between singers. Sometimes, though, it’s not possible to do a lot of experimenting on stage. In the case of the Radio Choir:

- Productions are short and rehearsal time is precious. Excessive experimenting on different formations is impossible due to little time on the concert stage (mostly just one rehearsal before the concert on stage).
Changing the formation in the last rehearsal of a two week rehearsal process creates a different sound environment which effects the singers, and can make them feel insecure and is therefore counterproductive.

All concerts of the radio choir are recorded or broadcasted live. Due to that, the producer provides the stage with microphones, which can't be moved easily. Therefore, changing the spacing and moving around on the stage could result in a loss of recording quality.

In November 2015, issues regarding choir formations in concerts were raised in the Radio Choir. The conclusion of the discussion was that the choir is unsatisfied with the acoustics on the stage in Berwaldhallen. The singers were interested in experimenting with how changes in formation affected their ability to hear the other sections of the choir.

After I talked to Arne Lundmark, manager of the choir, about my intentions of running an experiment on the effect of different choir formations on the hearing of other voice parts, he offered me an opportunity to work with the radio choir on the next information day.

On February 2, 2016 we had the first planning meeting in Studio 2 at Radiohuset. Birgit Lundmark (choir and orchestra director), Arne Lundmark, Martin Igelström (producer) and I discussed the realization of the test. We decided to run the experiment on March 8 between 11:00 and 12:30. In this experiment, two pieces would be sung in varying standing orders to find a formation which improves the ability to hear the voices between the choir, contributing the sense of ensemble, intonation, etc.

It would have been ideal to run the test on the stage in Berwaldhallen. Unfortunately that was not possible, since the Radio Orchestra occupied the stage at the same time. Instead we used Studio 2, the usual rehearsal room with very good acoustics. Since the studio is quite small, therefore making it easy to hear all voice parts, the perceived difference between varying formations would be smaller than on the stage in Berwaldhallen.
To test a formation, two excerpts of a homophonic and a polyphonic piece were sung. The choral music was excerpted from Ingvar Lidholm's *Laudi* (ending of the first movement) for SATB voices, and Johannes Brahms' *Fest- und Gedenksprüche Nr. 1 (Unsere Väter)* for SATBSATB voices. The piece by Brahms is just partly polyphonic, but very valuable for the test since it caused some troubles in Japan.

While searching for scientific literature on choir formations, I soon had to accept that there is none, at least in a scientific way. There is a lot of literature about acoustics, even choir acoustics, but it seems as though studies on the impact of choir formations on the hearing of reference sound have not been made, yet. I decided therefore to design my own formations, based on the knowledge about the Radio Choir and the acoustics at Berwaldhallen.

All audio and video recordings from the experiment on March 8 were documented by *Sveriges Radio* and myself and can be requested from the author. Audio examples of formation F3 and F4 are attached to this work.

The other part of my examinations is a concert with the Swedish Radio Choir on May 27. Other graduating conducting students and I will share the concert, where I will conduct *Dopo la Vittoria* by Arvo Pärt and newly composed piece by Paul af Malmberg Ward. The concert will be recorded for documentation purposes only.

At this point I would like to express my thanks to Arne Lundmark and the Swedish Radio for inspiring me towards this work and for the opportunity to test my formations with the Radio Choir. I would also like to thank Sten Ternström from the Royal Institute of Technology, Stockholm, who gladly answered all my questions regarding acoustics. Last but not least I want to thank Mats Nilsson, who conducted the Radio Choir during the experiment in Studio 2.

1 The excerpts from the choral music can be found in the appendix under A5 and A6.

2 The formations F3 and F4 can be found on page 15.
2. Research questions and methods

The purpose of the experiment on March 8 was to improve the hearing within the choir by finding suitable choir formations and thereby making it easier to integrate the singers, especially from the back row of the choir, into the overall sound and create a more chamber music-friendly environment. This way, intonation would be improved and difficult acoustics in concert halls would be neutralized as much as possible. Furthermore, the formations will be evaluated on their suitability for recordings. From that derive the following research questions:

- Which formations improve hearing within the choir?
- Which formations suits a recording best?

Before I started to choose and design different formations, I gave a questionnaire to the Radio Choir choristers to find out the status of the situation in Berwaldhallen and learn more about their thoughts regarding choir formations and spacing. The results of the questionnaires and literature research was the foundation for the choosing of the formations. Also important for the formation choice is the understanding of where the problems of a cappella singing in Berwaldhallen originate.

The scheduled time for the test with the Radio Choir was from 11 o’clock until 12:30. During this 1.5 hours it was possible to test as many choir formations as wished. The chosen pieces to perform were sung in every formation and recorded by Martin Igelström, producer of the Radio Choir, to be able to compare different settings. Furthermore, all singers marked on the questionnaire where they were standing. With that information I should be able to find out which of the tested choir formations received the best hearing grades and which one sounded best on the recording.

3 The questionnaire can be found in the appendix under A1.
3. Berwaldhallen's acoustics

The problems of *a cappella* singing in Berwaldhallen are applicable to other concert halls with difficult acoustical conditions. Knowing the reasons for the acoustical difficulties on stage at Berwaldhallen, should make it easier to understand the acoustical problems of other concert halls.

The singers' response to the questionnaire showed that many perceive the situation on stage differently. In general, singers hear themselves well or well enough on stage. Some altos and basses wrote that they have problems hearing themselves when they stand in the middle of the choir.

Other investigations have found that choirs appear to adapt their sound level and voice usage to the room acoustics. Choral singers appear to use a higher laryngeal position and to over-sing in more absorbent rooms, and in absorbent rooms, one's own voice can sound much louder to the singer (though not to the audience) than the sound from the rest of the choir (this is especially so for sopranos singing at higher frequencies, who will sing sharp in such circumstances without noticing it). Sundberg speculates that room acoustics primarily influence the level at which singers hear the rest of the choir, yet may also affect an individual singer's intonation depending on how loud one hears one's own voice. If the choral reference sound is more than 5 dB louder than the feedback from one's one voice, intonation errors increase significantly.

When asking Radio Choristers about the quality of the reference sound (hearing others) on stage at Berwaldhallen, the most frequent answer was that hearing others on stage is very difficult. Many mentioned in the questionnaire that it is most difficult to hear the basses, yet some say that certain frequencies seem to

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4 Ternström, Sten (1989), Acoustical aspects of choir singing.

5 Sundberg, Johan (1987, 140), The science of the singing voice.

6 Ternström, Sten (1989), Acoustical aspects of choir singing.
disappear. Research shows that this is indeed true. The reverberation time of frequencies between 125 and 250 Hz is just about 1.2 seconds, while the reverberation time for frequencies of the voice range of the rest of the choir is around 2 seconds. This means that musicians playing or singing in this frequency band will always be heard softer than the rest of the ensemble. 125 - 250 Hz is about an octave between B - b, so basically the middle range of the male choir.

Reverberation spectrum of Berwaldhallen with the frequency in hertz on the x-axis and the reverberation time in seconds on the y-axis. The solid line indicates the spectrum after the sound became 15 dB softer, the dashed line shows the spectrum after the sound became 30 dB softer.

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7 Analysis of questionary A1.

8 Pålsson, Westerlund (1985, 22), En jämförelse mellan akustiska projekterings- och mätmetoder och subjektiv upplevelse i konsertsalar.

9 H or B natural = 123.5 Hz, h or b natural = 246.9 Hz, both in equal temperament

10 Pålsson, Westerlund (1985, Appendix), En jämförelse mellan akustiska projekterings- och mätmetoder och subjektiv upplevelse i konsertsalar.
If we take a closer look onto the Radio Choir on stage in Berwaldhallen, there are some difficulties of which to be aware:

- A deep and wide stage provides enough space for the Radio Orchestra. For choir though, the distance between the back row and the wall makes reflections hardly audible (around 5 meters in the middle and 5,7 meters in the edges)\textsuperscript{11}.

- The platforms of the stage are built into the floor and can just be changed in height. The shape is more semi-elliptical than semi-circle. The distance between the wings of the back row is with 13 meters. That is 2,5 meters more than in the rehearsal studio.

\textit{The Swedish Radio Choir on stage at Berwaldhallen on September 19, 2015. Conductor: Peter Dijkstra.}\textsuperscript{12}

\footnotesize
\textsuperscript{11} A map of Berwaldhallen can be found in the appendix under A3.

\textsuperscript{12} http://sverigesradio.se/sida/artikel.aspx?programid=3989&artikel=6306492 (2016-02-15)
The depth of the stage requires a tight spacing in order to compensate the weak sound reflections from the walls behind. But to create visible and audible contact between the wings, the choir needs to stand quite spread out in order to attach to the elliptical shape of the stage.

In addition, the architecture of the concert hall brings its own difficulties with it. For example, with 30 - 50 milliseconds, the reflecting sound is on the limit to be perceived as an echo.\(^\text{13}\) That's because the concert hall is quite broad (38,9 meters in the middle) and high (13,8 meters in the middle) and the stage reaches almost to the middle of the room. Therefore musicians sitting or standing close to the center of the hall are the farthest distance from the reflecting walls.

\(^{13}\) Pålsson & Westerlund (1985, 18), En jämförelse mellan akustiska projekterings- och mätmetoder och subjektiv upplevelse i konsertsalar.
4. Terminology and Definitions

While the term "spacing" unmistakably means the space around the singers, the terms "formation" and "seating arrangement" are understood differently from conductor to conductor. Some understand "choir formation" as the standing order of singers to get the best blend in the choir. Others use the term choir formation when they speak about the shape of the choir (e.g. sections standing in a semi circle) and the space between singers. For some, the "arranging of the formation" is understood as the changing of the order of singers to get at better blending of voices.

In this work, choir formation means the shape of the choir including spacing and placement of the voice parts. The individual placement of a singer within a voice part, which is to be understood as seating arrangement, is the task of the conductor and is not considered here.

James F. Daugherty, associate professor of choral/vocal pedagogy from the University of Kansas, created the three terms close, lateral and circumambient spacing. Close spacing means standing basically shoulder to shoulder with a neighbouring singer and is therefore not used in good amateur or professional choirs as sound pressure levels of singers are much higher than in amateur choirs with uneducated singers. The Radio Choir is standing in either lateral or circumambient spacing. Under lateral spacing you can envision a circle of about 0,4 to 0,7 meters distance from a singer to a neighbouring singer. In circumambient spacing, that circle is greater than 0,7 meters, or about the length of an arm.

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16 http://www.choralresearch.org/volumeone/ijrcs1_1_daugherty.html (2016-04-01)

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17 Daugherty established in his tests 24 inches between singers for lateral spacing, 42 inches for circumambient spacing and about 1 inch for close spacing (shoulder next to shoulder). 1 inch = 2,54 cm; 24 inch = 60,96 cm; 42 inch = 106,68 cm. For this experiment I defined lateral spacing with max. 0,7 meters space around a singer, for circumambient more than 0,7 meters.
5. Formation choice

The planning of the time schedule for the experiment revealed that it was possible to test 6 different choir formations. The formations F1, F2 and F3 are standard formations of the Radio Choir and are used in many concerts. In order to have a comparison to the designed formations (F4, F5, F6), I decided to start singing in the known formations,

The questionnaire regarding standing preferences showed that the farthest apart a chorister would want to stand from the next singer in Berwaldhallen is between 0,7 meters and 1 meters. When sitting in the standard position, the distance between two singers in the back row in Studio 2 is about 0,7 meters and around 0,55 meters in the front row.

I made models of every choir formation in the form of a seating plan. Due to simplification, all models are shown as two straight rows of singers with the viewpoint from the audience. In reality all formations were tested in an almost perfect semicircle.\(^{18}\)

\[\begin{array}{cc}
T & B \\
S & A \\
\end{array}\]

Conductor

\(^{18}\) The models were constructed for the setting of the Radio Choir \((N = 32)\), with equally 8 singers in S, A, T and B section.
Formation F1, single choir

<table>
<thead>
<tr>
<th>B2</th>
<th>B1</th>
<th>T2</th>
<th>T1</th>
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</thead>
<tbody>
<tr>
<td>S1</td>
<td>S2</td>
<td>A1</td>
<td>A2</td>
</tr>
</tbody>
</table>

According to Mats Nilsson, assistant professor of choral conducting at the Royal College of Music in Stockholm, formation F1 is the so called ‘Swedish’ choir formation. Legendary choral conductor, Eric Ericson, started to use it with Kammarkören, which is nowadays known under Eric Ericson’s Chamber Choir. The second basses are on the left wing of the second row, followed by the first basses and second tenors in the center and the first tenors on the right wing. The female choir is mirrored with the first sopranos on the left wing and the second altos on the right wing. The idea is to improve intonation when sopranos stand in front of the basses, and in early music it is possible, according to Ericson, to exchange altos and tenors due to possible balance problems. Most Swedish choirs are using that formation today, including the Radio Choir when singing homophonic music or less advanced polyphonic music.

Formation F1, double choir

<table>
<thead>
<tr>
<th>T</th>
<th>B</th>
<th>B</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>A</td>
<td>A</td>
<td>S</td>
</tr>
</tbody>
</table>

When singing pieces for double choir, like Brahms or the Mass for double choir by Frank Martin, the Radio Choir often stands in this position. I called it F1 double choir, even though the characteristic similarity to F1 single choir (basses behind the sopranos) is missing. The advantage of this formation is the connection of the bass section in the back row, at least when choir one and two are not separated by a gap in the middle, to create a better stereo feeling of the double choir piece.

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Formation F2

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<th>2</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>S</td>
<td>B</td>
<td>T</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

F2 is a common block formation with all the second voices of a voice part (A2, S2, B2, T2) in the back row and the first voices in the front row (A1, S1, B1, T1). Sometimes the blocks are called oratory blocks, since this formation is often used in oratory performances together with an orchestra or for polyphonic a cappella music where all voice parts are equally important. In the Mozart Requiem for example, the standing order of the blocks can be adjusted to the seating order of the trombones, who double the alto, tenor and bass part.\(^{20}\)

The benefit of standing in blocks is the good connection with your voice colleagues when singing complex music. One disadvantage is the long distance between tenors and altos. When the choir is standing in straight lines, the distance between tenors and altos may result in intonation problems and rhythmic problems due to bad visible and audible connection between the voice parts.

The Radio Choir often sings with the bass block next to the soprano block, in the center of the choir. In this way the top and bottom voices of the choir are in the middle of the stage, surrounded by the middle voices on both wings. A clear advantage for recordings in this formation is the stereo effect. When the choir is singing a renaissance piece, it is very easy to hear the cantus firmus and the basses in the middle of the room, whereby altos and tenors are heard in the left and right ear.

At the request of the choristers even Brahms was sung in this formation without changing to double choir.

\(^{20}\) SATB is a common order of blocks.
Formation F3

This formation is quite similar to F2. The only difference is that the bass and soprano blocks switch places. This block formation was tested at Igelström’s request. Also here, both pieces were sung in the same position without changing to a double choir version.

Formation F4

Formation F4 is a mixed formation that was designed by the author. The results of the questionnaire A1 show that many choristers wanted to try out a mixed standing in order to improve the ability to hear other voice parts better. Therefore I designed the formation F4 as 8 quartets with the 4 quartets of the second voice parts in the center and the first voice parts on the wings of the choir. Another advantage is the option to place the quartets in double choir position. Since the singers stand mixed anyway, this eliminates the need to change positions between a homophonic piece and a double choir piece.

Daugherty found that tenors and basses in a twenty-member chamber choir sounded best with lateral spacing, while sopranos and altos sounded best with circumambient spacing. The distance from the first to the second row in Studio 2 is around 1,2 meters, between two singers in the back row around 0,7 meters. This means that the Radio Choir is usually rehearsing in a mixed type of these

\[ http://www.choralresearch.org/volumeone/ijrcs1_1_daugherty.html (2016-04-01) \]
spacing versions, but for simplicity I defined it lateral spacing, even though the distance between the rows is 1,2 meters.

To create the effect of circumambient spacing for the female voices, I chose a different order of voices in the first row than in the second one (SATB against TBSA). All voices of the same voice part spread out equally over the whole choir. The distance between a soprano of the back row to a soprano of a front row is then about 1,4 meters.

On demand of the choir we even tested F4 with a greater depth distance, which can then be understood as circumambient spacing. The distance between singers in the back row changed from 0,7 meters to about 1 meters. Since the stage in Studio 2 is quite small, the distance between the rows was about 1,5 meters; just 30 cm more than with lateral spacing. I called F4a the formation version with lateral spacing, F4b the version with circumambient spacing. Due to time limit, only Brahms was performed in F4b.

Daugherty speculated that mixed formation is probably a poorly executed spacing phenomenon, i.e., the separation of voices that produce like frequencies. However, I think it is the best way to create a good sound environment when a choir is bound by the shape of a stage in a room with difficult acoustics. An advantage of this formation regarding recordings is that all voice parts from first soprano to second bass are equally distributed on the microphones. However, this could result into a “mono” effect of the recording.

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Formation F5

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>B1</th>
<th>B2</th>
<th>B2</th>
<th>B1</th>
<th>S2</th>
<th>S1</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2</td>
<td>A1</td>
<td>T2</td>
<td>T1</td>
<td>T1</td>
<td>T2</td>
<td>A1</td>
<td>A2</td>
<td></td>
</tr>
</tbody>
</table>

choir one           choir two

In formation F5 I wanted to put the basses and tenors into the center of the choir. Since Berwaldhallen poorly carries frequencies in the range of notes H to h, I wanted to have the tenors and particularly the basses singing directly into the room. Therefore I placed sopranos and altos on both wings, which avoids needing to transition into double choir and is an abstract version of circumambient spacing of the female voices for homophonic music. Second basses and first tenors form the center of the formation, followed by first basses and second tenors, second sopranos and first altos, and the wings are formed by first sopranos and second altos. The sopranos are placed in the back row as sopranos are always more audible than altos. By placing them in the back row, the altos are hopefully more audible.

The advantage about having the basses in the middle is that all voices are closer to the harmonic foundation. Since the choir is standing in a semicircle (or an elliptical shape at Berwaldhallen), the voices on the wings have visual contact with the bass section, improving the hearing within the ensemble.

As with F4, F5 was tested in two versions with different distances between singers. F5a is the version with 0.7 meters distance between singers in the back row, F5b with 1 meters distance between singers in the back row. The depth distance was kept the same (1.2 meters). Like in F4b, only Brahms was sung in F5b.
Formation F6

The design of formation F6 is based on the idea to separate all voice parts, similar to a mixed standing, but to keep pairs of voices together to create a better sound environment for eight-part polyphonic music. In F6, four double-quartets are formed whereof every double-quartet contains a first and a second voice part of a section, choir two is mirroring choir one. A block out of 4 basses in the back row and 4 altos in the front row form the center of the choir. Left and right wing are formed by soprano one and tenor one.

I wanted the basses to stand in the back row, so that they can be heard by the choir. Altos therefore should stand in the first row to be present in the sound picture. Sopranos are as well positioned in the second row.

To create an even better singing environment, the double-quartets on the wings could just contain singer from the first part of the voice section and the double-quartets in the center singers from the lower part.

Laudi was performed in a circumambient version called F6b with 1 meter's distance between singers in the back row. F6a is the version with lateral spacing (0,7 meters between singer in the second row).

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23 e.g. the soprano voice pair includes a first and a second soprano.
24 e.g. back row, from wing to center: S1 S1 B1 B1 S2 S2 B2 B2
6. Results

The questionnaires that each singer filled out after testing a formation contained questions about the hearing of oneself (HS) and hearing others (HO) and allowed for comments concerning the individual perception of a formation. On the day of the experiment, there were 28 members of the Radio Choir singing and evaluating. For the determination of how well singers can hear themselves and others, they put a cross on a scale from very good to very bad. Later I assigned the scale with integer values and investigated the arithmetic average of every formation. In this way it was possible to determine the best setting concerning hearing oneself best and hearing others best.

The choir's perspective

<table>
<thead>
<tr>
<th>Formation</th>
<th>Hearing oneself (HS)</th>
<th>Hearing others (HO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1, single choir</td>
<td>4,4</td>
<td>3,7</td>
</tr>
<tr>
<td>F1, double choir</td>
<td>4,5</td>
<td>3,5</td>
</tr>
<tr>
<td>F2</td>
<td>4,4</td>
<td>4,1</td>
</tr>
<tr>
<td>F3</td>
<td>4,5</td>
<td>4,1</td>
</tr>
<tr>
<td>F4a</td>
<td>4,4</td>
<td>4,2</td>
</tr>
<tr>
<td>F4b</td>
<td>4,6</td>
<td>4,0</td>
</tr>
<tr>
<td>F5a</td>
<td>4,0</td>
<td>3,7</td>
</tr>
<tr>
<td>F5b</td>
<td>4,4</td>
<td>4,4</td>
</tr>
<tr>
<td>F6a</td>
<td>4,6</td>
<td>4,1</td>
</tr>
<tr>
<td>F6b</td>
<td>5,0</td>
<td>4,4</td>
</tr>
</tbody>
</table>

Formation F6b shows the best values concerning hearing oneself and hearing others, even though the other formations still got marks like ‘good hearing’ or ‘ok

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25 The questionnaire can be found in the Appendix under A2.
26 N = 28; 32 singers except me and 3 unavailable singers;
27 very good = 5, good = 4, ok = 3, bad = 2, very bad = 1
hearing’ as it is in case of formation F1 double choir. Generally, all values are quite close to each other, which is probably due to the good acoustics of the relatively small Studio 2.

All formations tested in lateral and circumambient spacing showed noticeably better values in HS and HO in the version of circumambient spacing than in lateral spacing. That is a good requirement for Berwaldhallen. In lateral spacing, singers complained about high sound pressure levels when standing in the front row, specially in the center. Altos preferred to not stand in front of tenors or sopranos. When they were supposed to stand in the front row, they rather stood in front of the basses, but with at least 1,5 meters distance to the second row. While the alto section of the Radio Choir likes standing mixed, sopranos and some basses preferred to stand in their own section to be able to hear their voice colleagues better and for better blending. In the formations F4, F5 and F6 they said that HO is better than in F1, F2, F3, where they stood in a line or in blocks. In this context, HO referred to hearing other voice parts rather than hearing the own section. Even though mixed or semi-mixed standing improved hearing other voice sections, especially in the circumambient version, singers perceived the tendency to use their voices in a more soloistic way than when standing in their own section. As a result they thought it is harder to hear the balance of the total sound picture, even though intonation improved in mixed standing, like some singers recognized. Sopranos and tenors felt more lonely in circumambient spacing, but on the other hand they appreciated the quality of HO.

Formation F1, single and double choir

F1 single and double choir got a relative bad rating of HO compared to other formations. Since the singers of a voice part were standing in a line next to each other, the distance from one to the other side of the choir was too big to hear voice sections on the other end of the choir as wished. In addition to that, female voices suffered under the high sound levels of the male sections in the back row. Altos even had problems hearing themselves when they were standing in front of the tenor section. Vice versa, many male singers said that they can’t hear the altos well.
Formations F2 and F3

The formations F2 and F3 were improving HS and HO. Altos preferred to stand in blocks because they were not exposed to high sound pressure levels of other voices behind their back. All sections commented that singing in blocks made it easier to blend with their voice colleagues and that they felt more like a section than a sum of single voices. On the other hand, singers tended to take less initiative when standing amongst their voice colleagues and therefore intonation became a problem, as singers noticed. When singers spoke about HO in F2 and F3, they meant hearing other voices of their section rather than hearing the bigger picture. Many missed hearing the overall choir sound, which is, in the end, most relevant for singing in Berwaldhallen.

Formation F4

The perception of hearing the bigger picture in F4 was satisfying, even better than F2 and F3. By standing in quartets, singers automatically took more initiative and contributed to the intonation, as many singers recognized. Many perceived the sound as very loud. Singers would sing forced because they were isolated (sic!) from their voice colleagues and felt disconnected to the choir when standing circumambient spread out. Thinking about that, F4 is not suitable to test further in Berwaldhallen.

Formation F5

The problems in F5a derive from the sopranos standing in the back row, singing into the alto section, who had problems hearing themselves. Even some tenors felt that the sopranos were dominating the sound picture and were disturbed not hearing the alto section as they wished. These problems got significantly better when standing circumambient. Most of the singers perceived an improvement in intonation and in hearing other voices, specially more overall sound than single voices. Some sopranos had the feeling that standing in the back row helped them hearing other voice parts better.
Formation F6

Formation F6b received outstanding comments, as with F6a. The idea of forming double-quartets so that singers have a voice buddy, but as well have the feeling of a smaller ensemble, was appreciated by many singers. The sopranos and basses liked standing next to each other in pairs in the back row. Even though they missed hearing other voice colleagues in order to adjust loudness and blend, they were able to HO very well in circumambient spacing. As in all formations with two spacing versions, the altos complained less about the level of the sound coming from behind them. The sopranos and tenors standing at the wings felt a bit isolated though. They perceived HO less intense than in lateral spacing, but rated it quite high compared to F5b.

The producer’s perspective

Martin Igelström recorded all formations including their spacing version with 5 microphones facing the choir and with 2 room microphones. The microphones stood in the same position during the whole experiment in order not to affect the recording of a particular formation.

In a conversation with Igelström he said that he is not sure if it is just out of habit, but he thinks that the recording of F1a and F1b sounded best. The problem with mixed formations like F4-6 is the mono effect they are creating on a recording. While with F1-3 you have a clear picture of where the sections stand, it is not possible to locate the direction of a section by hearing. The advantage for singers in F4-6 is standing mixed and thereby improving hearing themselves and others, and stabilizing the intonation. The disadvantage from the recording perspective is just that they are standing mixed.

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28 E-mail conversation on March 31, 2016.
7. Conclusion

The experiment showed that the F4-6 mainly contributed to the hearing within the choir when standing in circumambient spacing. Studio 2 is quite small and the sound levels during a choir rehearsal can get very high, concentrated by the semi-circle shape of the podiums and boosted by the room size. In this way, lateral spacing already coursed hearing problems because of the high sound levels. Almost every time, circumambient spacing improved HO and HS.

Despite some choristers who believe that the Radio Choir should try to stand more circumambient in Berwaldhallen, I think the choir stands too spread out most of the time. Of course it depends on which row a singer is standing in, but I think that the circumambient versions of the tested formations might have had a different effect on HO in Berwaldhallen, since reference sound is much softer than in Studio 2. My assumption derives from experience, but is also based on Sten Ternström's explanation of the relationship between room acoustics and the distance between singers:

“[..] the difference in loudness between the feedback [HS] and the reference [HO] depends on two room acoustic factors, which to some degree can be controlled. One is the spacing between singers: if the singers are placed further apart, they will hear less of the reference, thus favouring the feedback. Another factor is the reverberation of the room: since reverberation contributes to the total energy of the sound, a choir singing with a given effort will be louder in a reverberant room than in a damped room. Hence each singer will find it harder to hear his feedback in a reverberant room. These effects can be computed. [..] The figure on the next page shows an estimate of the difference in decibels between the feedback and the reference, under certain simplifying assumptions. The curves reflect how this difference would vary with the reverberation time of the room and with the average distance between singers.”

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“The estimated difference in sound pressure level between one’s own voice and the rest of the choir, as a function of the reverberation time of the room. The different curves correspond to different distances between adjacent singers. The estimate is based on 40 singers standing in a cluster and all singing equally loud: how loud does not matter. Note that a difference of zero dB does not necessarily mean that the two sounds are perceived as being equally loud.”

The dashed line was added by the author and indicates the reverberation time of Berwaldhallen (except for frequencies from 125 to 250 Hz).

In the figure above, the conditions differ from the situation in Berwaldhallen, but it demonstrates the shrinking of the HS/HO relation with increasing space between singers. While in Studio 2 circumambient spacing encourages a singer’s sensitivity to their individual contributions toward ensemble sound, it diminishes

important reference sound within the choir, especially in the second row. That fact is also applicable to other concert locations with dampened acoustics.

F6b got the best rating in HS and HO and should be tested further in the future so that singers can acclimatize to singing in this formation. F5 should be tested in Berwaldhallen one day. Singers named high sound levels as the reason of hearing problems, but only in the lateral spacing version. These problems might not occur on stage in Berwaldhallen and I can imagine that F5 would produce a nice sound picture and contribute to ensemble sound within the choir. It might be, though, that F5 is not suitable or actually not helpful in eight part polyphonic music, since sopranos and altos are divided into two female sections.

Unfortunately there is no formation that improves HO within the choir and that is suitable for a recording. While Igelström and Lundmark prefer the possibility to be able to locate every voice section geographically when listening to the choir, the favoured formations from a singer's perspective create a mono effect on the recording, which makes individual voices audible in some situations. The Radio Choir is in a relatively unique situation compared to other choirs as all their concerts are recorded and broadcasted. For choirs performing concerts without the demand of high quality live recordings, I am sure that mixed formations increase HO within the choir to a satisfactory amount. If choir concerts take place in churches, the audience is most often a few meters further away from the choir than the microphone stands for a recording. Therefore the listeners in the first row hear a better blend of the overall sound, while the sound on the recording will probably sound more straight.

The relatively bad rating of F5 was somewhat unexpected. The ideology of the formation design was apparently not transparent to the singers. I think that the complaints from the altos about high sound levels from the sopranos behind them could be minimized through enlarging the distance between rows, which is also possible to a certain extent in Berwaldhallen. However, I suspect that some answers in general regarding HS and HO contain a small amount of personal habit and preference. That is to say that if a singer is standing in a
position where he/she does not want to stand, I assume that HS and HO is negatively influenced by their personal preference for the standing position.

Nevertheless, F6 can be used by any choir performing in a room with little sound reflection and short amount of reverberation time. In the context of the Radio Choir on stage at Berwaldhallen, another solution to improve hearing within the choir might be more helpful when considering the influence which mixed formations have on the clarity of a recording. For example, sound mirrors - movable plates behind the second row of the choir - can achieve the desired effect. However, the choir formations must be tested first on stage in Berwaldhallen to ascertain which benefits may be achieved by changing the location.
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9. Appendix

A1) Questionary 1

What voice part do you sing?

Can you hear yourself well enough on stage at BWH, compared to the rest of the choir? If not, describe what you think the problem could be.

Can you hear the rest of the choir well enough on stage at BWH? If not, describe what you think the problem could be.

Is there any choir formation you would like to try out at BWH or any other concert hall, where it is difficult to hear yourself or the rest of the choir?

What would be the farthest apart that you would want to stand in BWH (in cm)?

A2) Excerpt of Questionary 2

Formation F1)

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Where did you stand in the formation? (make a cross)

How well do you hear yourself? O O O O O Very good O O O O O very bad

How well do you hear other voice parts? O O O O O Very good O O O O O very bad

Do you have the feeling that you hear yourself better than in other formations and that this formation contributes to ensemble sense?

Positive about this formation is ...

Negative about this formation is ...
A3) Map of Berwaldhallen, Stockholm
A4) Swedish Radio Choir at the test on March 8, 2016.

Conductor: Mats Nilsson
A5) Excerpt from *Laudi* by Ingvar Lidholm, first movement
A6) Excerpt from the first movement of *Fest- und Gedenksprüche*, Johannes Brahms

Fest-und Gedenksprüche
für achtstimmigen Chor (a cappella)

*Seiner Magnifizenz dem Herrn Bürgermeister Dr. Carl Petersen in Hamburg
tevrehrungsvoll zugeeignet*

Johannes Brahms, Op. 109
(Veröffentlicht 1890)

(J. B. 114)