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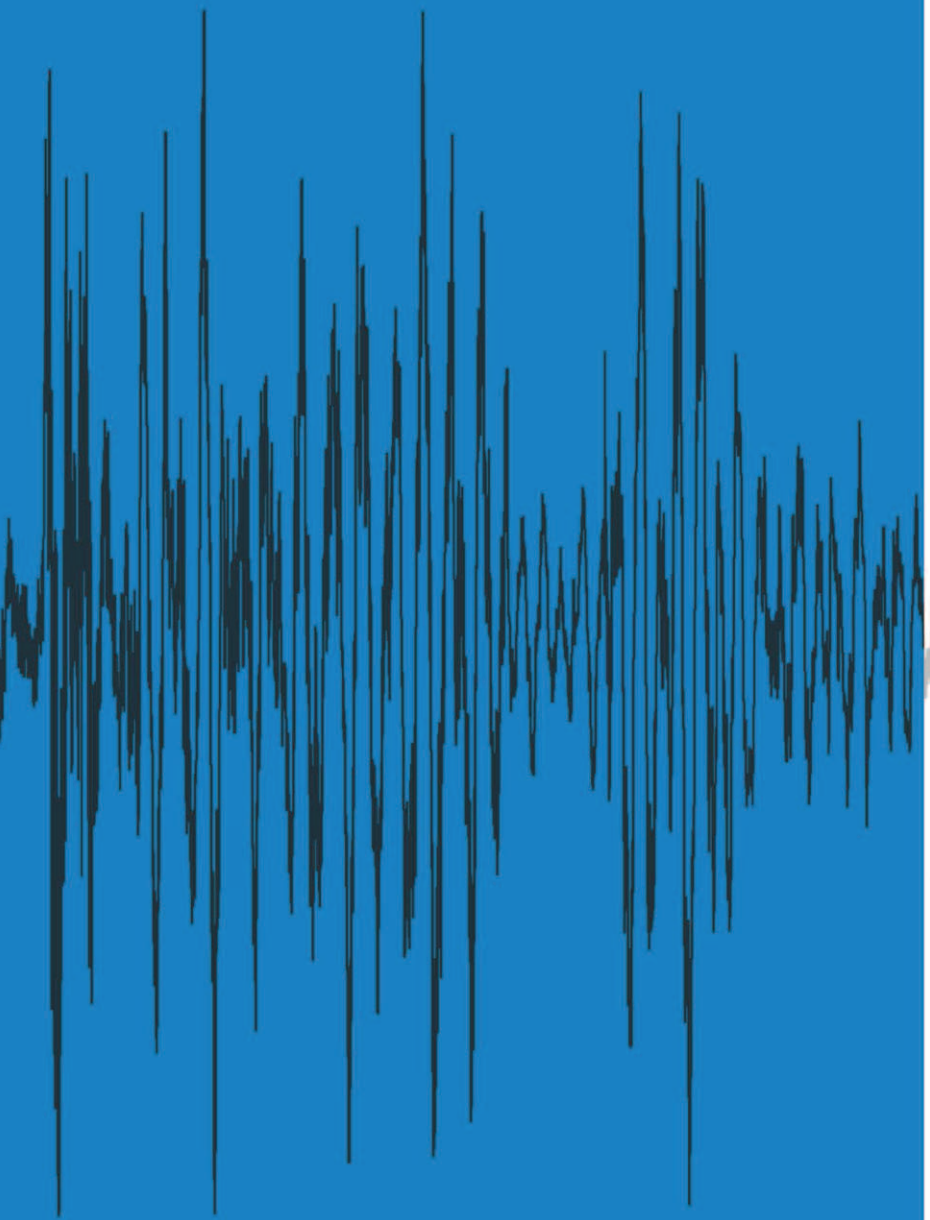

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Original Article

Sound Exposure of Choristers

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Abstract

Choir singing is a very popular activity with 4.5% of the European population regularly participating. London South Bank University was approached in January 2019 by St Paul's Cathedral to undertake noise dosimetry for the Music Department. Rehearsals and performances were identified and measured using acoustic instrumentation to determine if the choristers, adult choir, choir master or organist were compliant with the Control of Noise at Work Regulations 2005. These data were then matched to the daily and weekly work schedules of the musicians and the sound exposure estimated. The adult choir, organist and choir master were found to be under the set daily limits, 85 dBA ($L_{EP,d}$). The most exposed chorister was above this limit. However, when adjusted for their shorter working year and using the weekly noise exposure limit of 87 dBA ($L_{EP,w}$), the estimated exposure was compliant with the regulations. Recommendations were presented to the Music Department focusing on management techniques to reduce the weekly exposure of the choristers without effecting the spirit, tradition or musicality of the performance. It was also strongly suggested to reduce the number of performances for the boys by introducing a second choir.

Keywords: choir singing, chorister, musician, noise exposure

Key Messages: Sound levels were found to be significantly higher than the noise regulations allow but only for short durations typically found in choral performances; when combined with a short working week and a very short working year the sound exposure for the boys was calculated to be compliant with the regulations.

INTRODUCTION

In 2019 St Paul's Cathedral Music Department asked for assistance with the assessment of sound exposure of their Choristers, Organist, and Choir Master, This investigate was a direct result of their query. The aim of the study was to carry out a sound exposure assessment to ascertain if the Music Department was compliant with the Control of Noise at Work Regulations 2005. The objectives were to undertaken sample acoustic measurements of typical performances, to combine this data with the work schedules, and from this to estimate overall daily, weekly and annual sound dose.

Choral singing is a very popular activity and an estimated 37 million people regularly take part in collective singing in over a million choirs across Europe. This represents around 4.5% of the European population according to a survey, "Singing Europe" undertaken by the European Choral Association in 2015.[1] A 2017 survey of choral singing in the United Kingdom by Voices Now [2] estimated that 2.14 million people regularly sing in one or more of over 40,000 choirs. Choir members range in age from 6 years to over 100 years old and were from all backgrounds. For this research the focus was on St Paul's which is an Anglican church where the "A Cappella" style of singing is at the fore. However, unusually no specific reference was made to this style in the survey.[3]

Singing is considered noise under the Control of Noise at Work Regulations 2005.[4] These regulations are enforced by the Health and Safety Executive. There are two types of sound exposure: Peak levels measured using the acoustic parameter L_{Cpeak} and average levels measured using the acoustic parameter L_{Aeq} [see Table 1]. To give a normalised daily average a time period of 8 hour is used, this gives the acoustic parameter $L_{EP,d.}$ If the $L_{Ep,d}$ was 85 dB then the noise dose, a linear value, would be 100%. Peak sound exposure limits

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were designed to capture explosive type sounds e.g. shooting and clashing. If the exposure was above the 137 dBC limit value then it is likely that immediate hearing damage would occur.

Average sound exposure limits were designed to measure over time sustained noise levels, for example construction, mining or factory noise. These would cause a slow, but noticeable, decline in hearing acuity, called noise induced hearing loss. There is a small risk at 80 dBA as averaged over an hour 8 day over a 40 year working life of noise-induced hearing loss, based on ISO 7029 and ISO 1999.[8] This risk increases at 85 dBA assuming the same work pattern, 8 hour day, 40 hours a week and a 48 week year.

SOUND EXPOSURE MONITORING OF MUSIC

O'Brien *et al.* [5] stated that due to the nature of orchestrated music noise exposure is difficult to measure. The associated hearing health problems in musicians have been extensively reported, for example Royster *et al.* [6] However, not much known concerning noise-induced hearing loss in choir singers. Steurer *et al.* [7] did find that professional choir singers did suffer from a permanent threshold shift compared to normative data [8] in the 125 Hz and 250 Hz frequencies. This matches the fundamental vocal frequencies produced by trained singers as measured in men and women by Okten.[9]

Choir singing noise exposure has been measured using a number of different methods that are compatible with the choral environment. Seaton [3] made recording using a cheap MP3 calibrated recording which was post-processed; Behar *et al.* [10] undertook measurements of music teachers in schools using industrial dosimeters finding that the noise level limit, $L_{EP,d}$ was exceeded in 39% of classes. In Nigerian churches the sound level had been measured using Android sound level meter app based on the results in this NIOSH report.[11] It was found that for the 30 church services measured the Catholic congregation had an average $L_{EP,d}$ of 90.3 dBA, the Anglican services 83.4 dBA, and the Pentecostal a very high $L_{EP,d}$ of 95.4 dB.[12] It should be noted that [11] recommended using iOS based apps and they would not be compliant with IEC 61252.[14] It is known that children, who are part of the congregation, could be more easily damaged by extremely high sound levels than adults.[13]

For the noise measurement of the choristers it was decided to use standard dosimeters which meet IEC 60252: 1993.[14] The Audio^{3}SoundBadge was found to be more compatible with children given the device's small size and lightweight dimensions.[15] Three dosimeters were used each was calibrated before and after each measurement using a sound calibrator meeting the requirements set out in IEC 60942: 1997.[16] In addition, calibrated Class 1 sound level meters meeting IEC 61672-1 [17] were used to take survey measurements.

Table 1: Noise exposure limits

	LAeq	LCpeak	Noise dose
Lower exposure limit $L_{EP,d}$	80 dBA	135 dBC	50%
Upper exposure limit $L_{EP,d}$	85 dBA	137 dBC	100%
Weekly exposure limit $L_{EP,w}$	87 dBA	137 dBC	159%

CHORISTER SOUND EXPOSURE MEASUREMENTS

Four representative sound exposure measurements were undertaken over the course of five weeks during the Spring of 2019. Each measurement usually consisted of a rehearsal and performance and included multiple performers. Measurements were either taken using dosimeters worn on the shoulder, or sound level meters positioned at ear height behind the performer.

Performance 1: St John's – The Passion

Measurements were taken during the full performance of Bach's St John's the Passion. A 20-minute warm-up in the rehearsal room was measured for the choristers before the full 120 minute performance, which took place under the Dome of St Paul's Cathedral, see Table 2. The performance consisted of a large number of musicians including 26 choristers, an 80 member amateur choir, 18 professionals in the adult choir, and a ten-piece Baroque orchestra which considered of Strings/Woodwind, and a small organ.

Hence, from Table 2, the warm up and performance gave an average level (L_{Aeq}) of 84.4 dBA over the 138-minute measurement. This is equivalent to an $L_{EP,d}$ of 78.4 dBA or 25% of the allowed noise dose. It can also be seen that all the peak levels were well below the allowed levels.

Performance 2: Quire rehearsal and performance (chorister only)

Measurements were taken during a Quire rehearsal and Evensong performance. This was an unusual situation as the BBC wanted to film the performance and hence dosimeters could not be used. The choristers were positioned on the left side of the Quire on the lower two pews for the rehearsal and performance for television [see Figure 1]. Two sound level meters were located on the rear pew behind the boys at ear height for the rehearsal [see Table 3 and performance, Table 4].

Combining the sound exposure levels for the rehearsal and performance, Tables 3 and 4, gave an average level, L_{Aeq} of 74.1 dBA (worst case). This is equivalent to a 2.0% noise

Table 2: Choristers sound exposure: St John's – The Passion

	LAeq (dB)	LCpeak (dB)	Duration (minutes)
Warm up	85.5	125.0	20
Performance Part I	84.1	114.5	38
Performance Part II	83.1	106.1	77

Figure 1: Choristers all on one side of the Quire

Figure 2: Choristers in their normal positions in the Quire

Table 3: Quire rehearsal measurements

	LAeq (dB)	LCpeak (dB)	Duration (minutes)
Pew left rear	73.8	N/A	32
Pew right rear	75.5	121.1	32

Table 4: Quire performance measurements

	LAeq (dB)	LCpeak (dB)	Duration (minutes)
Pew left rear	70.9	N/A	44
Pew right rear	73.0	104.9	44

Table 5: Rehearsal measurements (choristers)

	LAeq (dB)	LCpeak (dB)	Duration (minutes)
Pew left rear	81.5	108.2	37
Pew right rear	82.2	109.0	37
Pew left front	86.3	112.8	37
Pew right front	85.9	111.6	37

Table 6: Rehearsal measurements (adults)

	LAeq (dB)	LCpeak (dB)	Duration (minutes)
Choir master	84.9	114.0	37
Male singer (tenor)	87.0	117.0	19
Female singer (Mezzo)	77.4	113.8	19

Table 7: Measurements of the evensong performance in the Quire (choristers)

	LAeq (dB)	LCpeak (dB)	Duration (minutes)
Pew left back	73.8	107.8	40
Pew right back	75.2	109.0	40
Pew left front	78.2	111.4	40
Pew right front	76.7	103.7	40

dose. The peak noise levels, 121 dBC, were well below the peak noise limit of 137 dBC.

Performance 3: Choristers and adult choir rehearsal and quire performance

Measurements were taken during a rehearsal and Evensong performance and consisted of 24 choristers and 12 adult members of the choir [see Figure 2]. The adults (11 male, 1 female) joined the choristers half way through the rehearsal. Measurements were taken using four sound level meters positioned at ear height around the vaulted rehearsal room [see Table 5]. In addition, three dosimeters were put on the adults: choir master, a male and a female member of the adult choir [see Table 6].

It can be seen from Table 5 that the front sound levels in the rehearsal room were higher than the rear. This is in line with the position of the male tenor [see Table 6]. Hence, the main sound source was very likely to be the tenor. This agrees with the measurement of the Choir Master, 84.9 dBA, who stood at the centre of the rehearsal room. The adult female singer was significantly quieter, L_{Aeq} of 77.4 dB, she stood at the rear of the room. All the peak measurements were found to be well below the allowed limit value.

The rehearsal was immediately followed by Evensong hence the dosimeters were restarted and the sound level meters reset. The sound level meters were positioned at ear height behind the boys on the second and third row of pews, measurement shown in Table 7. The dosimeters were kept

Table 8: Dosimetry measurements of the evensong performance in the Quire (adults)

	LAeq (dB)	LCpeak (dB)	Duration (minutes)
Choir master	72.0	109.0	40
Male singer (tenor)	84.8	114.3	40
Female singer (Mezzo)	77.8	112.7	40

Table 9: Combined rehearsal and performance noise exposure

	LAeq (dB)	Noise Dose %
Choir master	82.0	8.0%
Male singer (tenor)	85.6	14.1%
Female singer (Mezzo)	77.7	2.3%
Chorister (worst case)	84.6	15.1%

Table 10: Measurements in the rehearsal room

	LAeq (dB)	LCpeak (dB)	Duration (minutes)
Rear pew	87.9	120.7	40
Left pew	90.4	119.5	40

on the same people for the 40-minute performance [see Table 8].

Evensong produced noise levels that were lower than for the rehearsal [see Tables 6 and 8]. However, the tenor was again the nosiest, 84.8 dBA, and the choir master was the quietest 72.0 dBA. The Choir Master was positioned substantially further away from the choristers and choir than in the much smaller rehearsal room. The chorister measurements were consistent at approximately 76±2 dBA [see Table 7]. All the peak measurements were found to be well below the limit value.

From the datasets it was possible to calculate the sound exposure of four different people: worst case chorister, choir master, tenor and mezzo for the combined rehearsal and performance [see Table 9].

The combined results, Table 9, show that all the performers were well within the allowed limits for noise dose. The tenor, although loud was only singing for a short duration, less than one hour, and hence only received a 14.1% noise dose. The worst case chorister, standing in front of the tenor, received a marginally higher noise dose 15.1 %, due to an additional 18 minutes of exposure.

Performance 4: Choristers and adult choir rehearsal and quire performance with organ

Measurements were taken during a rehearsal, in the rehearsal room, and Evensong performance in the Quire. The performance consisted of 24 choristers, 12 adults in the choir and the organist. The adults (11 males, 1 female) joined the choristers half way through the rehearsal. Measurements were taken with two sound level meters

positioned at ear height around the vaulted rehearsal room [see Table 10]. In addition, two dosimeters were put on the tenor and the chorister who stood directly in front of the tenor, measurements are shown in Table 11.

It can be seen from Table 10 that the sound levels were significantly higher than in previous rehearsals. The personal noise exposure levels on the chorister and tenor were higher still [see Table 11]. This indicates that tenor was again the primary sound source in the room, with the chorister exposure even higher due to their relative positions in the pews. All the peak measurements were found to be well below the allowed limit value.

For Evensong the dosimeters were kept on the same people with the organist badged for the 59-minute performance [see Table 12].

Evensong produced noise levels that were similar to that measured during the rehearsal [see Tables 11 and 12]. The tenor and the chorister standing directly in front of him were equally exposed, 95.1 dBA. The organist was relatively quiet during Evensong but then played the procession out of the cathedral which significantly increased his noise exposure.

From the datasets it was possible to calculate the noise exposure of the three performers: chorister (worst case), tenor and organist [see Table 13].

When calculating the combined noise dose for the day for the three performers under investigation it can be seen from Table 13 that the daily limit was exceeded for the tenor (82-minute exposure) and the chorister (99-minute exposure) by a significant margin, 160% and 219% respectively. However, the organist was significantly below the 85 dBA daily limit and due to the short duration (64 minutes) and lower noise level, giving a noise dose of only 7.6%.

CALCULATION OF THE WEEKLY AND ANNUAL SOUND EXPOSURE

Working closely with the Music Department it was possible to estimate the weekly dose value for the Choir Master, worst case chorister, tenor and organist based on the schedule [see Table 14]. It should be noted that the long rehearsals had a duration of 70 minutes.

Table 11: Dosimetry measurements in the rehearsal room

	LAeq (dB)	LCpeak (dB)	Duration (minutes)
Male singer (tenor)	93.4	118.0	23
Worst-case chorister	95.4	121.5	40

Table 12: Dosimetry measurements of the evensong performance with organ

	LAeq (dB)	LCpeak (dB)	Duration (minutes)
Male singer (tenor)	95.1	119.5	59
Worst-case chorister	95.1	N/A	59
Organist	79.7+91.0	102	59+5

Table 13: Combined rehearsal and performance noise exposure

	Averaged level (dBA)	Noise dose %
Adult tenor	94.7	160.2%
Chorister	95.2	218.9%
Organist*	82.6	7.6%

*Organist played out the procession

Table 14: Weekly schedule for the musicians

Choristers	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	Warm-up 2 rehearsal	Warm-up 2 rehearsal evensong	Warm-up 2 rehearsal evensong	None	Warm-p 2 rehearsal evensong	Warm-up 2 long rehearsals evensong	Warm-up 2 rehearsals 3 services
Adult choir	No	Yes	Yes	Yes	Yes	Yes	Yes
Organist	No	Yes	Yes	No	No	Yes	Yes
Choir master	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 15: Daily noise exposure for four musicians

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Worst-case chorister	4.7%	144.8%	144.8%	N/A	47.3%	146.2%	444.0%
Choir master	4.7%	33.0%	33.0%	N/A	20.0%	37.0%	66.0%
Tenor	N/A	140.8%	140.8%	17.6%	6.5%	140.8%	441.7%
Organist	N/A	7.6%	7.6%	N/A	N/A	7.6%	22.8%

Taking the schedule and combining the representative measurements given in section 3 it is possible to create an estimation of the noise exposure of four performers [see Table 15].

It can be clearly seen from Table 15 that the tenor and worst case chorister were the musicians with the highest sound exposure. When compared to the normalised daily noise dose, 85 dBA for 8 hours giving 100% or the higher weekly noise dose based on 87 dBA over a 40 hour week is equivalent to a 159% daily noise dose, the estimated doses were all below this noise exposure limit except for Sunday. It should be noted that Sunday is the busiest day with one warm up, three rehearsals and three services.Summing the worst case chorister's weekly noise dose gives an estimated noise exposure of 931.7%. This is higher than the weekly allowance of 792.4%. However, when the school year is considered, a 40-week year, rather than the 48 week working year considered as normal in the regulations, the adjusted apparent annual sound exposure is reduced to 776.4%. This is marginally below the allowed limit, although it should be emphasised that children are more at risk of hearing damage due to high noise exposure levels [13].

For the tenor the calculated weekly sound exposure was found to be 888.2%. Again this is higher than the allowed 792.4% exposure limit, although the tenor does not sing all year and as such the apparent annual noise exposure is marginally below the exposure limit value.

CONCLUSIONS

A study was undertaken with the full cooperation of the Music Department of St Paul's Cathedral on the noise exposure of the choir master, choristers, choir and organist. Based on a representative sample of measurements of both rehearsals and performances the daily, weekly and yearly noise dose was estimated.

It was found that the choir master and organist were both well below the allowed daily noise exposure limit. However, the chorister directly in front of the tenor (worst case location) was above the daily and the weekly exposure limit. This was mitigated by the shorter working year of the school children and hence the apparent exposure was just within the allowed exposure limit.

All the measured peak levels were found to be well below the exposure limit value for all musicians for all rehearsals and performances measured.

RECOMMENDATIONS

Although St Paul's was found to be compliant with the Control of Noise at Work Regulations, it is strongly recommended that two managerial techniques be used to reduce the health risk to the choristers. Both approaches would keep the centuries old tradition of singing at St Paul's without compromising quality, spirituality or artistic interpretation.

Firstly, it is recommended that the choristers be rotated on a daily basis when singing with the adult choir. This would significantly reduce the sound exposure for the boys. Equally, the rotation of the adult choir would also work.

Secondly, a large number of rehearsals and performances were scheduled on Sunday resulting in a very high noise dose. One possibility is to introduce a second choir; they could rehearsal and perform once on Sunday, and provide cover for Mondays and Thursdays. This would reduce the weekly noise dose by an estimated twenty percent. By combining both mitigation measures the weekly noise exposure of the choristers would be below that of the upper sound exposure limit.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Bartel R, Cooper C. Singing Europe [Online] Bonn, European Choral Association (ECALEC). Available at europeanchoralassociation.org/activities/cooperationprojects/singing-europe/accessed [accessed 1 August 2019]
2. Voices Now. The Big Choral Census 2017. Available at: https://voicesnow.org.uk/wp-content/uploads/2018/03/FINAL-Voicesnowreport-July-2017.pdf [accessed 1 August 2019]
3. Seaton R. Pitch drift in A Cappella Singing, PhD Thesis, Open University, 2019
4. Control of Noise at Work Regulation 2005, Published by the Health and Safety Executive Her Majesty Government, UK
5. O'Brien I, Wilson W, Bradley A. Nature of orchestral noise. J Acoust Soc Am 2008;124:926-39.
6. Royster JD, Royster LH, Killion MC. Sound exposures and hearing thresholds of symphony orchestra musicians. JASA 1991;89.
7. Steurer M, Simak S, Denk DM, Kautzky M. Does choir singing cause noise-induced hearing loss? Audiology 1998;37:38-51.
8. ISO 1999. International Standard ISO 1999 second edition: Acoustics – determination of noise exposure and estimation of noise-induced hearing impairment 2013.
9. Okten G. Effects of room acoustics on vocal loading of Opera singers, PhD Thesis, London South Bank University, 2016.
10. Behar A, MacDonald E, Lee J. Noise exposure of music teachers. Journal of Occupational and Environmental Hygiene 2004;1:243-7.
11. Kardous C, Shaw P. Evaluation of smartphone sound measurement applications, Department of Health and Human Services, Center for Disease Control, National Institute for Occupational Safety and Health, EPHB Report No. 349-12a, December 2013.
12. Lilly-Tariah O, Nwosu C, Ikenga V, Mbalaso O. Sound pressure levels in churches in Port Harcourt: A study of some catholic, Anglican and Pentecostal churches. Glob J Otolaryngol 2017;9: GJO.MS.ID. 555758.
13. Berglund B, Lindvall T. Community Noise, World Health Organisation, 1995.
14. IEC 61252:1993. Electroacoustics – Specifications for personal sound exposure meters, Geneva, Switzerland www.Audio-3.com [accessed on 1 August 2019]
15. IEC 60942: 1997. Electroacoustics. Sound calibrators, Geneva, Switzerland
16. IEC 61672-1:2014. Electroacoustics – Sound level meters – Part 1: Specifications, Geneva, Switzerland