The influence of room acoustic aspects on the noise exposure of symphonic orchestra musicians

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INTRODUCTION

Musicians in a symphonic orchestra are exposed to the noise of a large number of different sound sources. The noise exposure can vary largely and has many aspects of influence. One group of aspects are musical aspects, like the orchestra size and composition, the musical piece and its interpretation by the conductor and orchestra. The other group of aspects are architectural and room acoustic related which may contribute to a variation in noise exposure, independent of the musical aspects to some extent. On one hand, the size of the stage or orchestra pit may determine the distance between the musicians, which typically influences the direct and early reflected sound paths. Besides that, the room acoustics of the stage and the hall can increase the noise exposure dramatically. In this research, the contribution of stage size and acoustics to the total noise exposure and instrument balance is investigated for 7 concert halls A to G as described by van Luxemburg et al. (2009).

METHOD

A model for the prediction of sound levels within a symphonic orchestra is used to investigate the influence of the architectural and room acoustical aspects. This model is based on measurements of the sound power L_W and directivity Q of the various instruments, a generic orchestra setup and measured values of the room acoustical parameters sound strength G and the early to late reflection ratio LQ_{7-40} [Braak & van Luxemburg 2008] in different concert halls. The background of the model is described in Wenmaekers et al. (2010, 2011) and is briefly summarized in Figure 1. For every source and receiver pair, the direct sound level L_{direct}, early reflected sound level $L_{early;refl}$, late reflected sound level $L_{late;refl}$ and total sound level L_{total} is estimated.

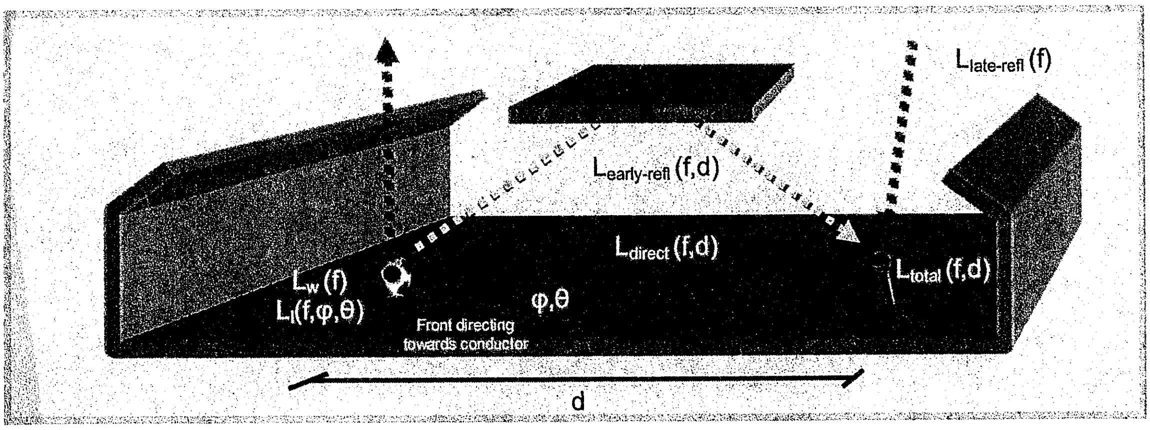

Figure 1: Summary of the source – receiver model

The directivity $L_l(f,\varphi,\theta)$ has been determined from anechoic recordings of separate musicians by Pätynen et al. (2008) and Pätynen & Lokki (2010) for 125 Hz to 8000 Hz octave bands averaged over several tones within the instruments range. Besides that, separate instrument recordings were made of different orchestral pieces of music. From the front microphone recordings of the Mahler Symphony no. 1 sample (2:12 min) and Bruckner Symphony no. 8 sample (1:27 min) and a calibrated reference signal, the equivalent sound levels have been determined using Dirac 5. From the directivities and frontal sound levels, the sound power L_W is calculated. Figure 2 shows the A-weighted sound power level per instrument per musical piece. Only large differences occur between the two pieces at the violin sections and horn section. Because of relatively small differences between the two pieces and because the Mahler piece has a percussion part, only Mahler was used for further calculations.

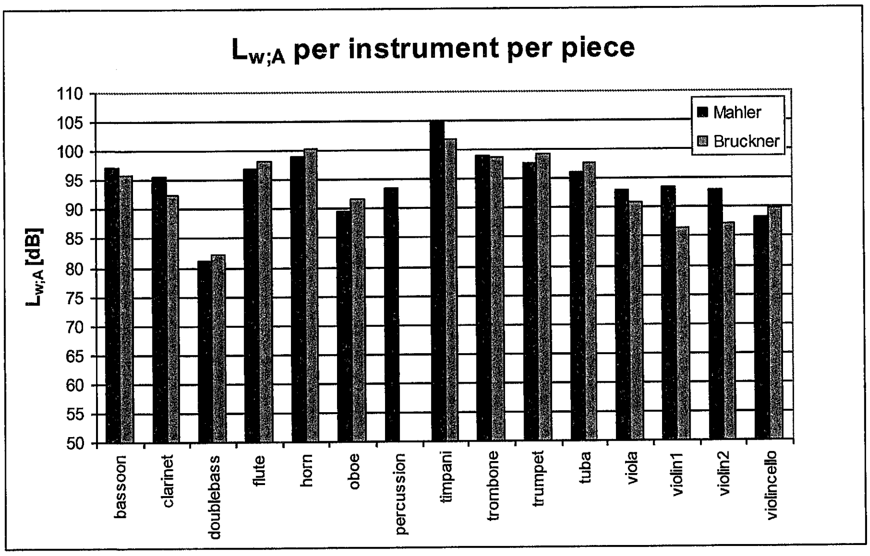

Figure 2: Average A-weighted sound power per instrument for different musical pieces

Based on the typical Mahler Symphony 1 orchestration and the typical American orchestra layout (Meyer 2009), an orchestra setup is chosen for the model with all musicians positioned on a rectangular grid, see Figure 3. The receiving musicians investigated further in this paper, are highlighted in red. Musicians 56 to 74 are elevated by 0.3 m and musicians 59 to 79 are elevated by 0.6 m to simulate risers.

					clr		perc	timp	bso	trb				tba	
	59	60	61	62	flu	81	82	80	obo	75	76	77	78	79	
hrns	56	57	58		64	65	66	67	68	69	70		72	73	74
	23	24	25	48	49	50	51	52	53	54	55		trp		
vi2	17	18	19	20	21	22	30	31	32	33	vla				
	11	12	13	14	15	16	26	27	28	29		cel	46	47	dbl
	6	7		9	10				38	39	40		44	45	
vi1	1	2	3	4	5		100	cond	34	35	36	37	42	43	

Figure 3: Generic orchestra setup for Mahler Symphony 1 (receivers used in paper are marked red)

Strings: 1-14: 1st violin, 15-25: 2nd violin, 26-33: viola, 34-41: violoncello, 42-47: double bass
Woodwinds: 48-51: flute, 52-55: oboe, , 63-66: clarinet, 67-70: bassoon
Brass: 71-74: trumpet, 75-78: trombone, 79: tuba
Separate instruments: 56-62: french horn, 80: timpani, 81-82: percussion

RESULTS

To study the impact of room acoustics on the noise exposure the contribution of each instrument (82) is calculated for all receiver positions (83). The contribution is subdivided in direct, early, late and total level and calculated for 7 octave bands and for A-weighted spectrum. All calculations have been performed for hall A to hall G (van Luxemburg et al. 2009). In total this yields over 1.5 million calculation results.

In the next paragraphs, only results are presented for hall C with a relatively high amount of early sound and low amount of late sound; and hall F with a relatively low amount of early sound and high amount of late sound. The same mutual distance between musicians is used to simulate average stage size: 1.3 m (width) and 1.6 m (depth), see Table 1. All presented values are A-weighted.

Figure 4 shows the mapping of the exposure level contribution of every individual instrument towards the receivers 8, 41, 63 and 71 per room acoustical parameter for hall C. In the direct sound, the highest contribution is made by the instruments close to the receiver with a large spatial decay rate. The sound power of the instruments seems less distinct, but also shows some influence. In the early reflected sound, less high individual levels occur and the contribution is more spread over the orchestra, clearly showing a stronger contribution of louder instruments. This is even clearer in the late reflected sound, which is only dependant on the sound power of the instruments and the late sound strength of the hall. This results in the same graph for every different receiver. Finally, the total level shows that both distance and sound power are important factors, so even distant instruments can have a large contribution to the total noise level at a receiving position. Also, the highest individual noise levels are produced close to the receiver but the early and late reflected sound may have a large contribution to the noise exposure of the full orchestra.

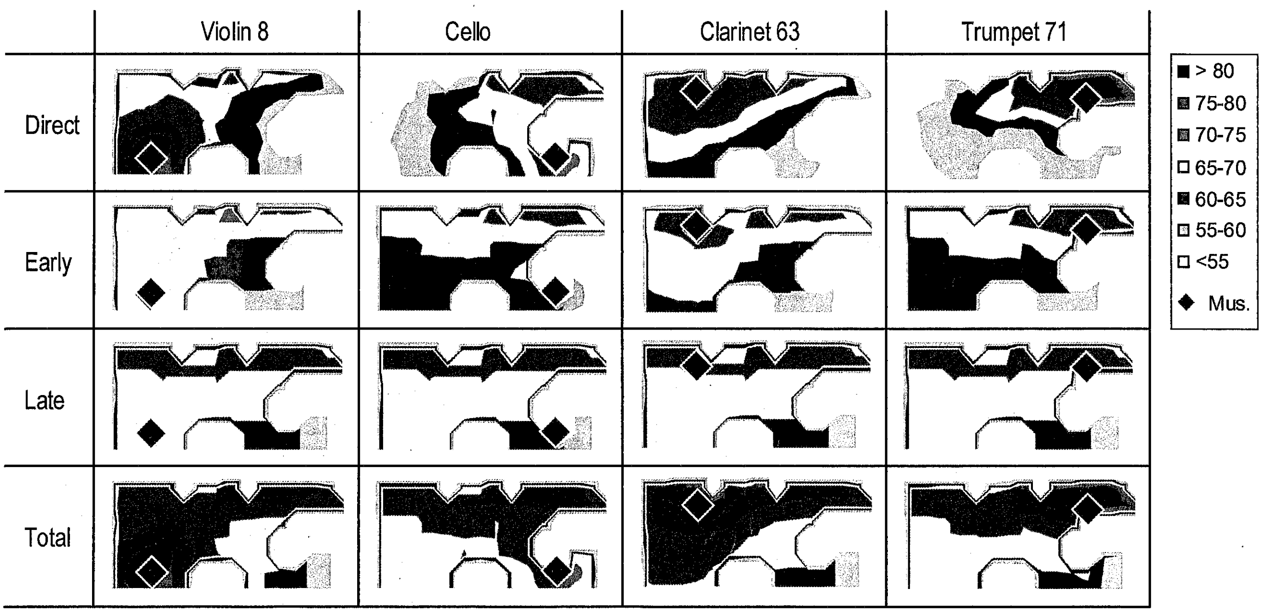

Figure 4: Contribution to noise exposure level at single musician from all other musicians (hall C)

Figures 5 to 8 show the balance of the contribution to the noise exposure level of different instrument groups in hall C and hall F at receiver position 8, 41, 63 and 71 respectively. The total contribution of each instrument group on the exposure level is shown for every room acoustical aspect. The presented values show energetically summed levels over all instruments within the same group. Also, the exposure level of the own instrument is presented using dashed bars. The results show that in most cases, the exposure level of closer instrument groups is mainly determined by direct sound transfer while the exposure level of distant instrument groups is mainly determined by late reflected sound. Also, in most cases the noise exposure from the own instrument group is the highest, except for the cello, and the noise exposure from the loudest group is higher than from the own instrument in all cases. In both halls, the late reflected sound is louder than the early reflected sound. However, in hall C, for distant instrument groups, the early reflected sound can be louder than the direct sound, while in hall F, the direct sound is always louder than the early sound.

Figure 9 shows the exposure level of the full orchestra for every instrument group per room acoustical aspect in hall C and hall F. Also, the total exposure level of the own instrument within its group is presented using dashed bars. The presented values show arithmetically average levels over all instruments within the same group. Results show that, for hall F, the noise exposure from early sound is > 5 dBA lower than from late sound, while in hall C, the noise exposure from early sound is < 5 dBA lower than from late sound. Differences between instrument groups can rise up to 5 dBA. It also shows that the contribution of own, direct, early and late sound can be in the same order of magnitude.

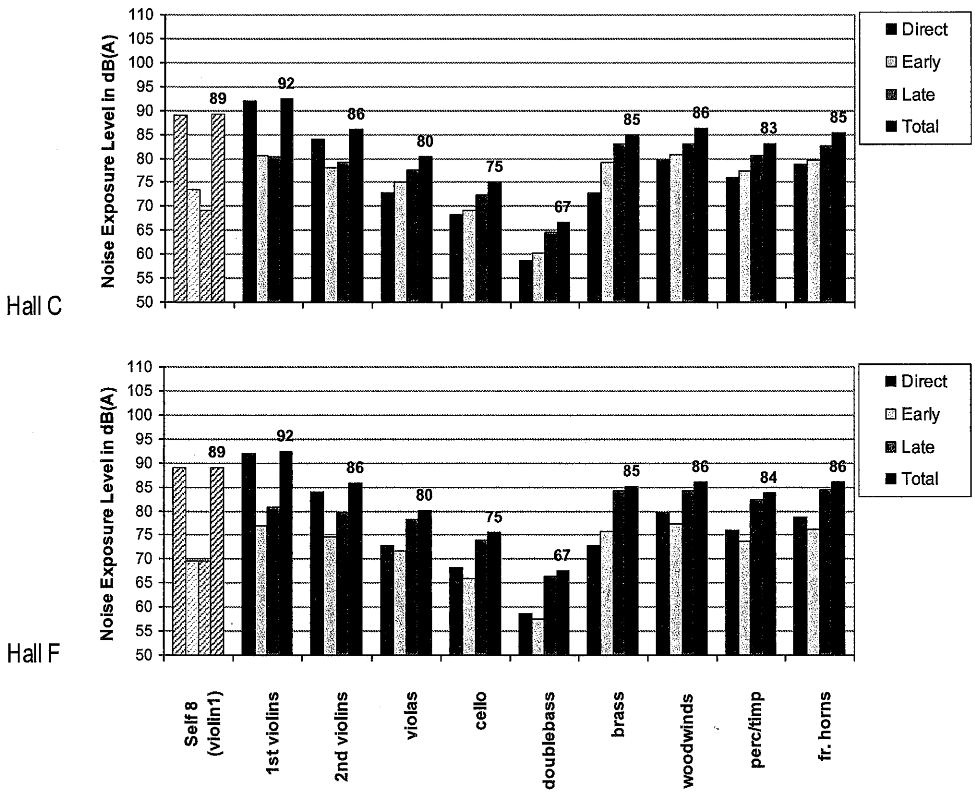

Figure 5: Noise exposure balance: violin pos. 8

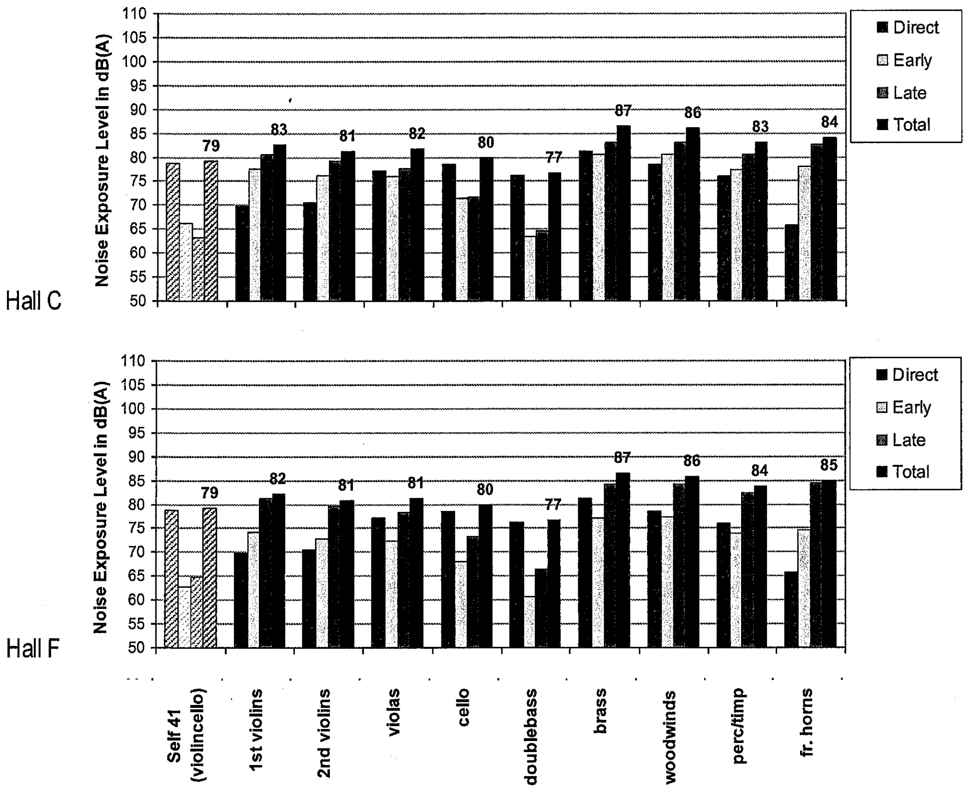

Figure 6: Noise exposure balance: cello pos. 41

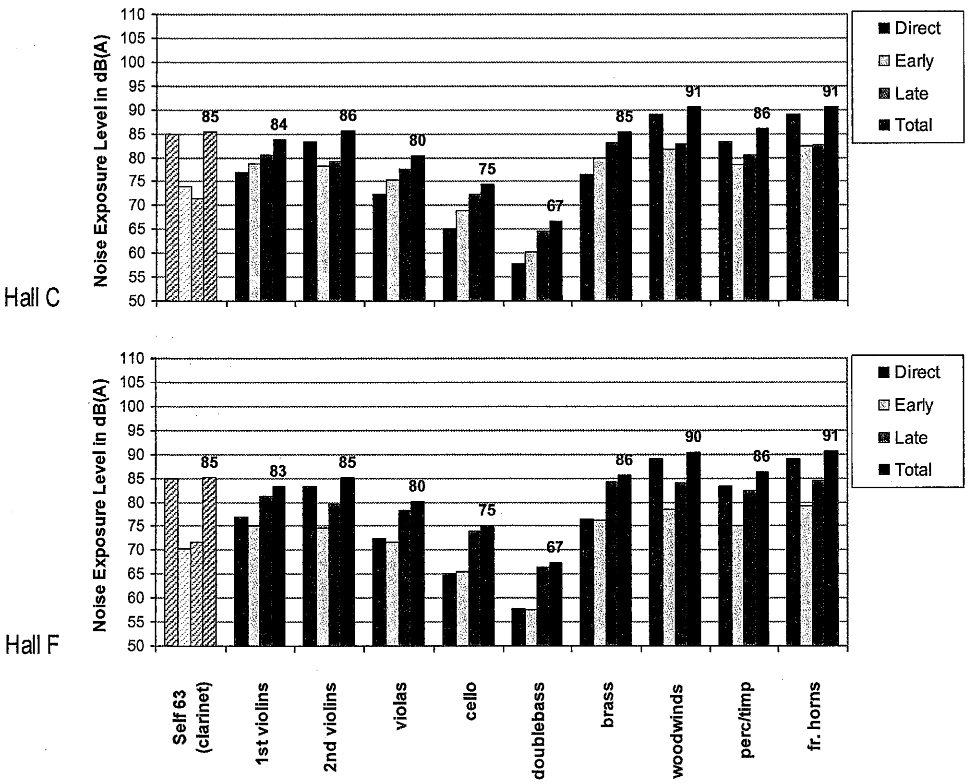

Figure 7: Noise exposure balance: clarinet pos. 63

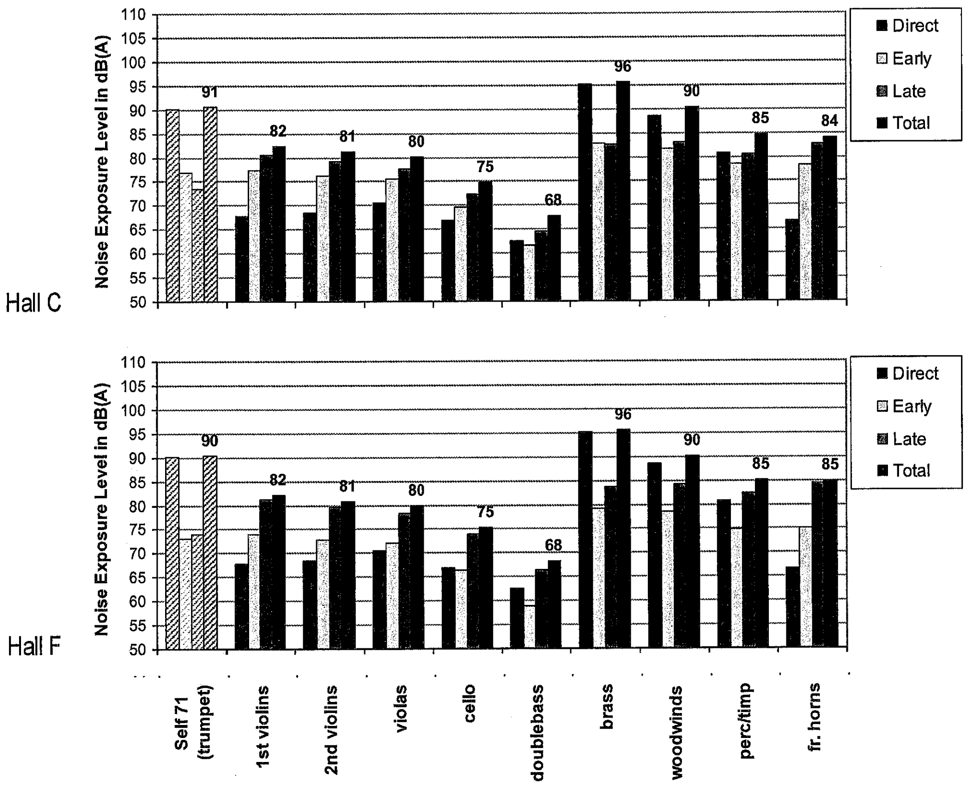

Figure 8: Noise exposure balance: trumpet pos. 71

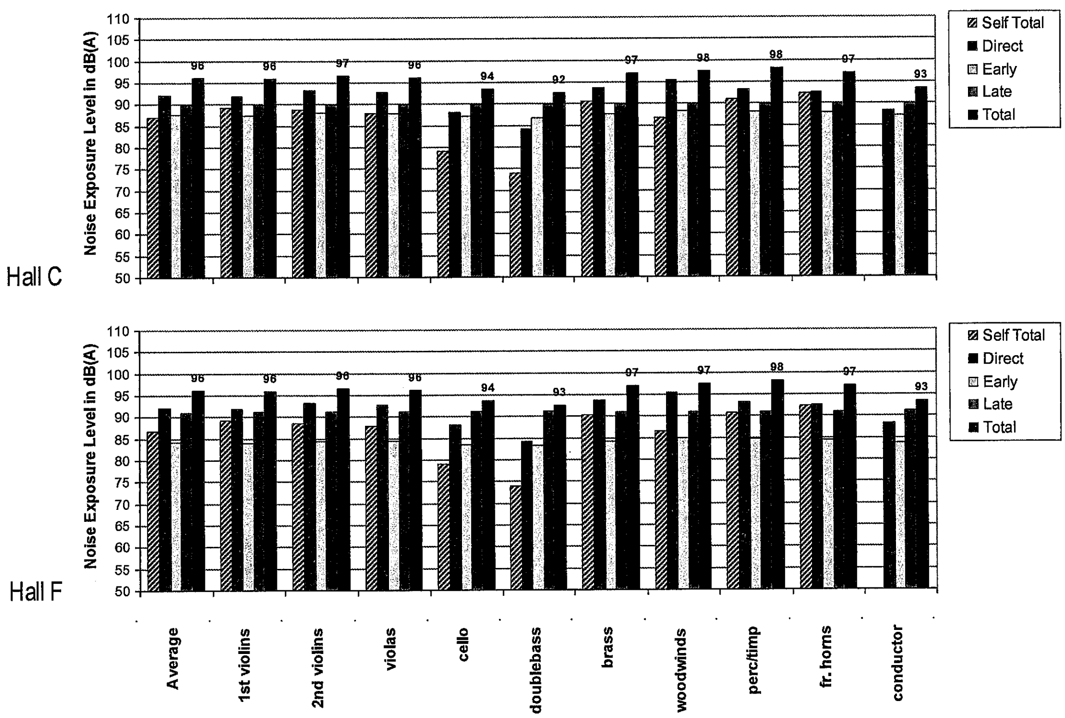

Figure 9: Total noise exposure per acoustical aspect and instrument group

The influence of stage size is investigated for the stages of halls B to G. The dimensions and room acoustical properties of the stages are summarized in Table 1. Figure 10a shows the average noise exposure level of all musicians for every concert hall stage for every room acoustical aspect using an equal mutual distance of 1.3 m (width) and 1.6 m (depth). Figure 10b shows the same graph but with the orchestra setup (Figure 3) stretched out over each stage, in accordance with the actual maximum mutual distances, see Table 1. The results show that only the direct exposure level is clearly influenced by the stage size, with differences up to 3 dBA between the different halls. However, the total exposure level is affected by the stage size by less than 1 dBA. Finally, the maximum difference in average total noise exposure level between the different stages when taking into account the stage size is 1.8 dBA.

Table 1: Concert hall stage properties

hall	width (w)	depth (d)	mutual distance w	mutual distance d	$G_{7\text{-}40}$***	$G_{40\text{-}inf}$***	$LQ_{7\text{-}40}$***
A*	-	-	-	-	0.6	5.7	-4.3
B	16.4	11.2	1.1	1.4	2.8	8.6	-4.5
C	18.0	11.5	1.2	1.4	4.2	6.1	-0.4
D	20.4	13.7	1.4	1.7	1.1	6.4	-4.2
E	17.4	11.7	1.2	1.5	0.7	5.3	-3.6
F	21.6	15.0**	1.4	1.9	-1.0	7.8	-8.2
G	17.5	12.6	1.2	1.6	0.9	7.0	-5.1
Average	18.6	12.6	1.3	1.6	1.3	6.7	-4.3

* Stage A is not a rectangular stage, so it cannot be defined by width and depth. Therefore it has not been used.
** The real depth of the stage in hall E is 17.5 m, however it assumed that a maximum of 15 m is used by the orchestra.
*** Average of 500 Hz and 1000 Hz averaged over 36 source-receiver combinations per stage (Wenmaekers et al. 2010)

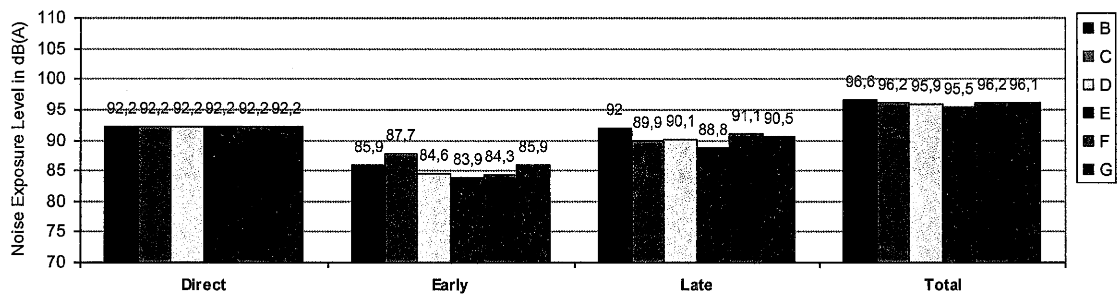

Figure 10a: Musician average noise exposure per acoustical aspect per hall – average stage size

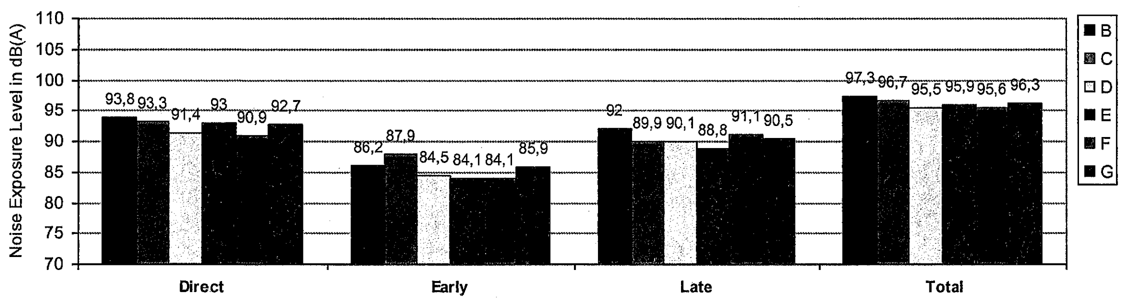

Figure 10b: Musician average exposure per acoustical aspect per hall – actual stage size

FURTHER RESEARCH

The presented work is a result of a feasibility study for developing a model to estimate the sound levels within an orchestra. It is shown that the model has much potential for studying the influence of architectural and acoustical aspects on the noise exposure of musicians in a symphonic orchestra. In future, it would be interesting to use the model to study the impact of screens between musicians and different orchestra setups on the noise exposure. Also, more different types of stage environments could be analysed, like orchestra pits and theatre stages. It is shown that the model can give valuable insight in the sound level balance of different instruments in a symphonic orchestra. The results could also be used to study the effect of orchestra setup and room acoustics on ensemble playing (Gade 2010).

The impact of some assumptions and simplifications needs further investigation. The directivity of the instruments and attenuation by the orchestra is not taken into account in the measured room acoustical parameters which may result in an overestimation of the early reflected sound (Dammerud 2010). Also, the time transition point between early and late reflected sound of 40 ms needs further investigation (Wenmaekers et al. 2010). Furthermore, an estimation is made of the own instruments sound level by using a small source-receiver distance using the far field sound power and directivity, while in reality the listener is in the instruments near field.

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Hearing function in workers engaged in industry: Georgian material

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INTRODUCTION

By the prevalence rate noise-induced hearing loss keeps the second place in the list of cochlear pathologies, the first position being occupied by the age-related impairments (Cruickchanks et al. 2010; Helfer et al. 2010). Disturbing effects of high-intensity sounds on health, in general, on inner ear, in particular, have been investigated for a long time. The influence of noise on hearing function in industrial workers was in particular the topic of some special debates (Eleftherioou 2002; Meyer et al. 2002). Noise-induced hearing impairment seems to be the major avoidable auditory disorder (Dobie 1995). Systematic audiometrcal inspection appears thus essential for detection of incipient stages of the pathology. If revealing any dysfunction hints, protective technical procedures have to apply or to reinforce the existing items while specific medical manoeuvres have to accomplish aiming the rehabilitation of happened distortion and/or prevention of its further progressing. Background and regular dynamic audiometric testing should be carried out particularly on individuals being regularly engaged in noisy job affairs (McBride 2004).

The aim of the present study was the tracing of the consequences of systematic industrial noise exposures on hearing function in workers involved in construction of transcaucasian oil-pipe line in Georgia. The distinct purpose of performed investigations was the evaluation of hearing thresholds in industry workers within the wide range, including 10 kHz and 12 kHz frequencies, that being dissimilar from the routine audiometrical examinations where the high-frequency border is conventionally limited by 8 kHz. The referent control probes were in parallel fulfilled on co-workers of neighbor humanitarian organizations.

METHODS

The test group covered 157 workers engaged in transcaucasian oil-pipe line manufacturing jobs. The control group was represented by 115 employees of non-industrial, mostly of educational local institutions. Either the test and control sample was divided into five consecutive decade age subgroups: 20-29, 30-39, 40-49, 50-59, and 60-69 years. The transcaucasian oil-pipe line is relatively a new development. The job noise influences in most test subjects was thus rather limited in time and generally covered months up to the pair of years. In separate individuals only, the service term approximated to 3, 4, 5 years.

Individuals of both test and control groups have been inspected at first otoscopically and tympanometrically and all were proved to own normal outer- and middle-ears. None of the subjects of the control group reported job-related or any other type of high-intensity sound-exposure incident in the past while all individuals of both groups rejected potentially confounding any other hearing disturbing affair: application of ototoxic drugs, hormonal disorders, bilirubinaemia, etc. Hearing acuity has been assessed via the tonal audiometer (ITERA, Madsen) in a sound-proof room. Air- and bone-