Symphony orchestra musicians: reduction of sound exposure by physical measures

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• Orchestral musicians are exposed to equivalent sound levels above 85 dB(A), both during individual (often highest) and group rehearsals/performances.

• In the orchestra: ‘musicians feel their own instrument is not noisy, but it is the neighbouring instruments that cause the problems’ (Laitinen, 2005)

• Ear plugs hinder the musical performance and are only used occasionally.

• Physical measures are often suggested when playing in the orchestra, such as more space, risers, screens and acoustic treatment.

But are these measures effective?
Sound level prediction model

$L_{\text{direct}}$: direct sound level
$L_{\text{early-refl}}$: early reflected sound level
$L_{\text{late-refl}}$: late reflected sound level
$L_{\text{total}}$: total sound level
(total = direct, early and late)

Sound paths

Direct sound other instruments:

\[ L_{direct}(f, d) = L_{eq;1m}(f, \varphi, \theta) - 20 \log(d) + \Delta L_{orch}(f, d) + \Delta L_{ear}(f, \theta) \]

Early reflected sound:

\[ L_{early-refl}(f, d) = L_{w}(f) + ST_{early;d}(f, d) - 11 \]

Late reflected sound:

\[ L_{late-refl}(f) = L_{w}(f) + ST_{late;d}(f) - 11 \]

Direct sound own instrument?

Own instrument sound

Estimation model

Measured anechoic room

Sound level measured in an anechoic room while playing scales (fragment of both piano and forte playing) – Left ear

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Meas</th>
<th>Estim</th>
<th>M-E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flute 1</td>
<td>86</td>
<td>87</td>
<td>-0.7</td>
</tr>
<tr>
<td>Piccolo 1</td>
<td>90</td>
<td>88</td>
<td>1.7</td>
</tr>
<tr>
<td>Flute 2</td>
<td>86</td>
<td>89</td>
<td>-3.7</td>
</tr>
<tr>
<td>Piccolo 2</td>
<td>92</td>
<td>89</td>
<td>3.3</td>
</tr>
<tr>
<td>Trumpet</td>
<td>97</td>
<td>99</td>
<td>-2.2</td>
</tr>
<tr>
<td>Flugelhorn</td>
<td>98</td>
<td>100</td>
<td>-2.1</td>
</tr>
<tr>
<td>Bass trombone</td>
<td>96</td>
<td>97</td>
<td>-1.4</td>
</tr>
<tr>
<td>Trombone</td>
<td>97</td>
<td>97</td>
<td>-0.4</td>
</tr>
<tr>
<td>Violin</td>
<td>92</td>
<td>93</td>
<td>-0.9</td>
</tr>
</tbody>
</table>

\[ L_{\text{direct;own}}(f, d) = L_{\text{eq;microphone}}(f, \varphi, \theta) - 20 \log \left( \frac{d_{\text{instrument_to_ear}}}{d_{\text{microphone_to_instrument}}(\varphi, \theta)} \right) \]
Orchestra setup
Calculated sound levels

- A-weighted sound pressure level
- Received level at musicians' ears
- Window 2k samples (fs=48kHz)
- Sound is anechoic, recorded by Pätynen et al.

Validation

- $L_{Aeq}$ per 46 excerpts of the 2 minutes
- Example shown for cello and trumpet
- Trend and level for $L_{Aeq}$ well predicted
- Activity of trumpet player (and nearby instruments) visible as maxima
Validation

- $L_{Aeq}$ for the full movement (2 minutes)
- For three different stages, 65% of the positions are predicted within 2 dB deviation
- Maximum deviation is 6 dB, which can be explained by the more expressive performance of the French horns on stage MGE compared to the anechoic condition.

Accuracy:
- Sound level measurement with a class 2 meter (dosimeter) is +/-2 dB(A)
- Model prediction in 65% of cases within 2 dB(A)
Physical measures

• Available space

• Riser height

• Screens

• Acoustic conditions

A) a large screen positioned at 0.3 m behind musician
B) a hypothetical case with fully surrounding screens

reflected sound changed relative to a concert hall by
A) + 6 dB, similar to a small rehearsal room
B) – 6 dB, similar to a theatre stage with curtains

* Suggested in Dutch regulation
### Results

**For excerpt of Mahler Symphony 1**

<table>
<thead>
<tr>
<th></th>
<th>higher/low risers</th>
<th>more/less space</th>
<th>screens behind</th>
<th>screens surround</th>
<th>+6 dB reflected sound</th>
<th>-6 dB reflected sound</th>
</tr>
</thead>
<tbody>
<tr>
<td>high strings</td>
<td>+/- 0.05</td>
<td>+/- 0.5</td>
<td>-0.7</td>
<td>-2.0</td>
<td>1.6</td>
<td>-0.5</td>
</tr>
<tr>
<td>low strings</td>
<td>+/- 0.1</td>
<td>+/- 0.7</td>
<td>-0.5</td>
<td>-0.9</td>
<td>4.2</td>
<td>-2.4</td>
</tr>
<tr>
<td>woodwind/brass</td>
<td>+/- 0.2</td>
<td>+/- 0.7</td>
<td>-0.6</td>
<td>-2.9</td>
<td>1.7</td>
<td>-0.6</td>
</tr>
</tbody>
</table>

- Riser height and available space do not significantly influence sound exposure. This is because the direct sound of others only changes slightly.

- Screens behind musicians are not effective because they only screen some of the musicians and because reflected sound levels are not affected.

- Hypothetically surrounding screens, that would reduce all other musicians’ direct sound, would influence sound exposure by 1 to 3 dB.

- Reflected sound only significantly influences sound levels at the low strings because the contribution of own and others’ direct sound is relatively low.
Conclusions

• Sound level prediction model for the symphony orchestra is able to predict $L_{A,eq}$ within 2 dB deviation for 65% of the microphone positions taken with a maximum deviation of 6 dB.

• The calculated effectiveness of common control measures to sound exposure of musicians playing in a symphony orchestra is within a limited range of 0.5 to 5 dB and in many cases below the measurement accuracy of 2 dB.

• Extreme unrealistic measures are necessary to achieve the reductions above 2 dB, such as fully surrounding screens or highly damped acoustics.

• Higher equivalent sound levels occur during individual rehearsal compared to group rehearsal for most instruments (which is counterintuitive).

• It seems that orchestral musicians have no other choice than to protect their ears with ear plugs under all circumstances (individual and group playing) if they wish to avoid the risk of developing hearing damage.
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