LIVE AUDIO HANDBOOK

Best-practice hearing management for audio engineers
musicians, event organisers and those who enjoy sound

by Dr Stephen Compton
PhD, MA, BA(Hons), Dip. Sound Engineering

version 4.3

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He that has an ear, let him hear ...

Version 4.2, June 2023

whakataukī (Maori Proverb)

Me he wai tā tieke

Like the saddleback sprinkling itself with water.
Good in moderation, but one can have too much of a good thing.
There is value in moderation but danger in excess.

CONTENTS

FOREWORD

The live-sound 'experience' is powerful, connecting feelings, memories and people: physically, emotionally, socially and spiritually.

Within the live-sound 'experience', the audio engineer stands in a pivotal and rarely understood role as a creative multitasker and problem solver.

From the stage, the talent may provide the source audio, but it is the audio engineer that makes crucial decisions that weigh up all contributing sonic influences, and the opinions and expectations of others.

They are a gatekeeper, directing the flow, by which the 'experience' is shared.

Why do audio engineers make the choices they do? Behind the production of this handbook is a study documenting audio engineering culture, working alongside audio engineers to improve the live-sound 'experience' for all participants.

02

01

The author with a lot going on inside that head

02

Selwyn Sounds
- Christchurch, NZ, 2018
(SC FoH Tech)

"My job was to get a balance and be invisible, to be a servant of the music and provide the technology to establish an emotional connection between the musicians and audience."
– Bryan Bell, FOH engineer

03

03

Mix Position Miss Saigon,Show-biz, Christchurch, NZ, 2019 (SC Sound Op)

04

Ed Sheerran, 2023, Wellington, NZ

Invisible sound: event audio at an appropriate level, tone, and balance, such that the audience focuses on the performance, presentation, story, experience, and emotion without consciously noticing the sound level, tone, or balance.

This Quick Guide aims to:

- present an overview of the audio engineer's most essential and often misunderstood tool,
- provide practical steps for audio engineers to prepare for critical listening,
- promote hearing longevity,
- povide a glimpse into audio engineering culture, and
- provoke discussions that improve live-sound practice.

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"As a practitioner of this craft you have to simultaneously understand your equipment and your input - meaning the artist on stage or whatever the content is - as well as who is listening to the results of your work."
- David Scheirman, mix engineer system consultant

04

HEARING MANAGEMENT BENEFITS [1]

Hearing management and 'making sense of sound' benefits the audio engineer by:

- maximising their critical listening ability to help make informed sonic decisions, to hear any audio issues before audience does, to maximise the participant 'experience', and to enhance the potential profitibility of the current and future events,
- enhancing communication, connection vs isolation, delaying cognitive decline, improving motor skills, avoiding the physical, social and financial effects that hearing damage causes, and
- being an enjoyable way to make a living, appreciating music and sound on a deeper level.

05

05

Toto, Hagley Park, 2018,
Christchurch, NZ

"

"You only get one shot to give them a positive experience."
- David Scheirman, mix engineer/ system consultant

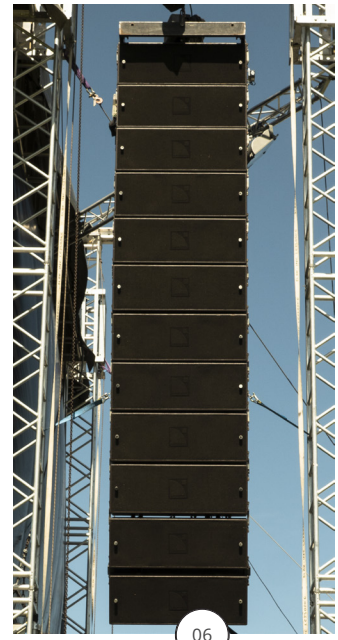
"

"If something happens on stage and you're working for the President of the United States, you want to walk calmly, with authority, and go up and fix it. You don't want to run, because the Secret Service will shoot you in the ass."
- Mike Bourne,
All-Star Audio Systems

THE APPEAL OF 'LOUD' MUSIC [2 3 4]

People react to loud sounds physically and emotionally in different ways. Loud music activates a sense of 'touch without being touched'. High-intensity sound waves ('loud' sounds) cause larger vibrations within the inner ear than quieter sounds, which stimulate a larger number of hair cells. leading to a higher rate of nerve impulses reaching the brain. [5] Many people associate enjoyable times with loud music and in the mind of the individual, enjoyable times and loud music become linked. Therefore, people expect that live events should be loud as a cultural norm.[4]

To the listener, increases in 'volume' can soothe and mask internal thoughts, can motivate, stimulate arousal, draw people together, encourage physical movement and enhance a sense of personal identity. Both in the ear's balance and sensory organs and body cavities, loud sounds can provide pleasurable vibrations. The music itself often contains an 'emotional contagion' where the listener responds to a similar emotion as the performer, can conjure memories or visual imagery, and facilitate social cohesion or intimacy. Sudden or dissonant sounds can also induce a reflex important for survival.



06

Throughout this handbook, SPL (Sound Pressure Level) will be regarded as being synonymous with the commonly used term audio 'volume'.

06 Line Array, Selwyn Sounds 2020

07 Apple Airpods Pro

07

"When you turn up the kick in a large arena with a massive PA, it's something you never forget. Once you've mixed, you always want to mix."
- Dave Natale, FOH engineer

SPL AND LOUDNESS

Are Not the Same Thing [6]

SPL (Sound Pressure Level measured in dB) can be measured using a sound meter.

Sound Pressure (in pascals) within a space can differ, dependent on location and the distance from the source. Doubling the distance from the source measures a 6 dB reduction.

Sound Power (in watts) - is the total airborne sound energy radiated by a sound source per unit of time. Adding two of the same sound waves together (coherent signals) results in a 6 dB increase in sound power. Adding two different (incoherent) signals of the same power results in a 3 dB increase. Two different electric guitarists playing at 85dB each in the same space: 85 + 85 = 88 dB.

Sound Intensity is calculated by sound power (watts) per unit area.

Loudness is the psychological description of the magnitude of auditory sensation corresponding most closely to the physical measure of sound intensity. The listener may describe higher limits as being uncomfortable, but the reaction may not necessarily be related to the SPL value. A 10 dB increase is perceived as sounding twice as loud.

MEASURING SPL

Sometimes noise and music can feel like the same thing! [7]
Measuring the SPL and the effects of noise and music commonly requires different considerations.

As humans, we generally react differently to noise than to music. Noise is as an often uncontrolled, less constrained, statistically random and commonly unwanted sound. In contrast, music is a dynamic, multifaceted, and multisensory phenomenon that is 'experienced'. Music contains informationally rich events that cannot be reduced to simple perceptual dimensions of pitch and rhythm. [3]

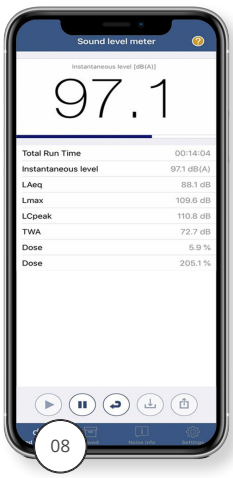
Despite being at similar SPL levels, noise, pleasant musical sounds and unpleasant musical sounds each can yield different effects on our physical hearing mechanisms and our emotional responses. [8] [9] [10] [11] [12] [13] [14]

Measuring the intensity of sound vibrations, SPL, requires metering devices like those shown in *Figs. 08, 09 and 10*.

Many types of machinery produce a consistent level of 'noise'. This consistency of SPL can be measured using a simple sound meter (*Fig. 09*) to determine the average level and peak.

The SPL of music is not consistent and varies with every beat, bar, song and act. Establishing the average SPL (Leq) for music requires a sound meter capable of recording an average SPL over time.

Meters that record Leq (Average Level) are often more expensive (*Fig. 10*); however, the free iOS NIOSH App (*Fig. 08*), is effective in measuring instantaneous SPL, Leq and exposure (dose).



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"Tom (Petty) and the band have taught me over time that there's just as much skill in revealing something as there is in bringing something up. It's not always about louder, it might be a matter of pulling something back so something else shines through."
- Robert Scovill, FOH engineer

08 iOS NiOSH APP. Monitor SPL, LEQ and Dose

09 Inexpensive SPL meter. Instantaneous SPL only

10 SPL meter capable of recording Instantaneous SPL, LEQ, PEAK, frequency spectrum data, delay times, reverberation times, audio and more

METERING TERMS

LA_{eq} LA_{max} and LC_{peak}

L = Level
A = A-weighted
C = C-weighted

Leq = Average Level (constant equivalent)
peak = peak level
max = maximum RMS level

A / C Weighting *See page 12.*

Decibel (dB) Relative measure of the level of sound.

Dose Average SPL (audio 'volume') over the time exposed.

Exchange rate For every increase of the exchange rate (e.g. 3 dB), the allowable exposure time is halved.

L fast Used to show varying SPL over a 125 ms time constant.

L slow Used to smooth the SPL readings to make it easier to read over an approximate 1 second time constant.

L_{Aeq} Level - A-weighted - constant equivalent *(average).* For use over the whole performance.

$L_{Aeq(5min)}$ Level - A-weighted - constant equivalent *(average)* over 5 minutes. For use over the period of a song.

$L_{Aeq(15min)}$ Level - A-weighted - constant equivalent *(average)* over 15 minutes. For use over several songs to allow the engineer to make changes that could impact SPL readings over a performance.

85 dB L_{Aeq} Level - A-weighted - constant equivalent *(average)* of 85 dB.

$L_{Aeq(8hrs)}$ Level - A-weighted - constant equivalent *(average)* over 8 hours.

L_{90} Level 90% of the time. An L90 is commonly used for measuring background sounds present 90% of the time, where short excesses are not quantified. On some occasions where a band plays for 3.5 mins and a crowd cheers and claps for 30 secs an L90 possibly could display the level of the band without the influence of the cheers and clapping.

Metering Class Sound metering equipment accuracy as defined by international standards: IEC 61672-1:2002 (or BS EN61672-1:2003). **Class 1** is a standard for equipment taking accurate calibrated measurments. **Class 2** is a standard for equipment taking calibrated, measurements within an accepted higher tolerance than that of Class 1 devices.

SPL Sound Pressure Level, commonly referred to as audio 'volume'.

TWA Time weighted average. A worker's daily exposure to occupational noise (normalized to an 8 hour day), taking into account the average levels of noise and the time spent in each area. The TWA is used by the US OSHA Regulations.

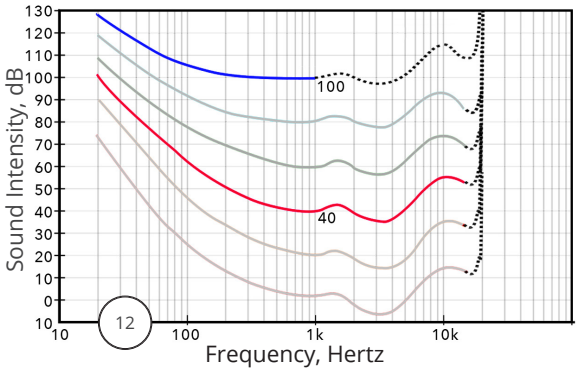
11 Theatre Tools (SC Sound Op)

"

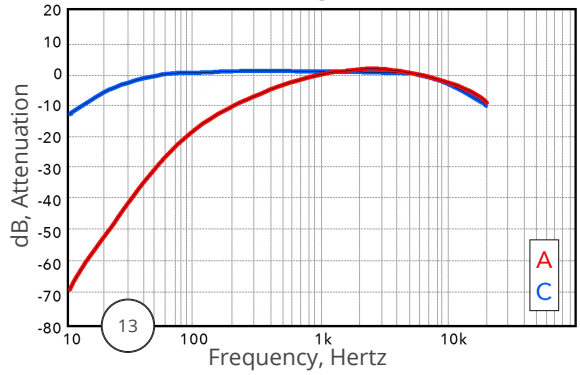
"Two hard-earned observations:
1) No matter how much I yell at the crew, it never makes it sound better;
2) If I act like there's a huge problem, people will know there's a huge problem."
- Dave Rat, FOH engineer, Rat Sound

EAR SENSITIVITY RELATING TO 'WEIGHTED' CURVES

Equal Loudness Contours



A and C Weighted Curves



The equal loudness contours graph (*Fig. 12*) shows how audio frequency perception varies depending on the SPL. For example in red, a 1 kHz tone at 40 dB is perceived to be a similar level to 100 Hz at 62 dB (22 dB difference).

At louder concert levels, our perception of audio frequencies follows closer to the blue line where 1 kHz at 100 dB is perceived as a similar level to 100 Hz at 105 dB (5 dB difference). The curve is much flatter.

Human hearing is most sensitive to frequencies that benefit speech and communication, particularly at sibilant frequencies around 4 kHz, where we hear 's' and 't'.

Weighted curves* adjust SPL measurements to human perception and are approximately an inverse of the equal loudness curves. The A-weighted red curve (*Fig. 13*) approximates the inverse of the red contour measured at levels around 40 dB (*Fig. 12*) and the C-Weighted blue curve (*Fig. 13*) approximates the inverse of the blue contour measured at levels around 100 dB (*Fig. 12*). [13]

For live events and for most noise standards and guides, the A-weighted scale is used despite not being representative of the human perception at higher SPL. At concert levels the A-Weighted scale does not account for the effect of 'sub' frequencies which contain significant energy, and creates a skew between the measured value and the nuisance experienced by neighbors.[18]

A-weighting - 1 kHz at 40 dB.
C-weighting - 1 kHz at 100 dB.
Z-weighting - flat response.

- The A-weighted curve is only representative of human perception below 70 dB, and was originally intended for levels up to 55 dB.
- At higher SPLs, A-weighting does not account for low-frequency energy which can cause high-frequency damage. [15] [16] [17]
- A-weightings do not adequately quantify low-frequency nuisance and may be inappropriate when prominent low-frequency components are present.[18] [19]
- C-weightings more accurately represent the ear sensitivity at the higher SPLs commonly reached at live-sound events.
- Z-weightings (no weighting) more accurately measure SPL peaks than A or C-weighting.

12 Equal Loudness Contours

13 A and C-Weighted Curves

"

"Sonic excellence occurs when you capitalize on the best opportunities for reinforcing the sound that's already being created onstage. Do that, and then you don't have to vwork so hard the rest of the time."
- Brett "Scoop" Blanden, FOH engineer

* Quantified in ISO 226
** Quantified in IEC 61672

NOISE STANDARDS

A Brief History of Noise Standards Development [13 20]

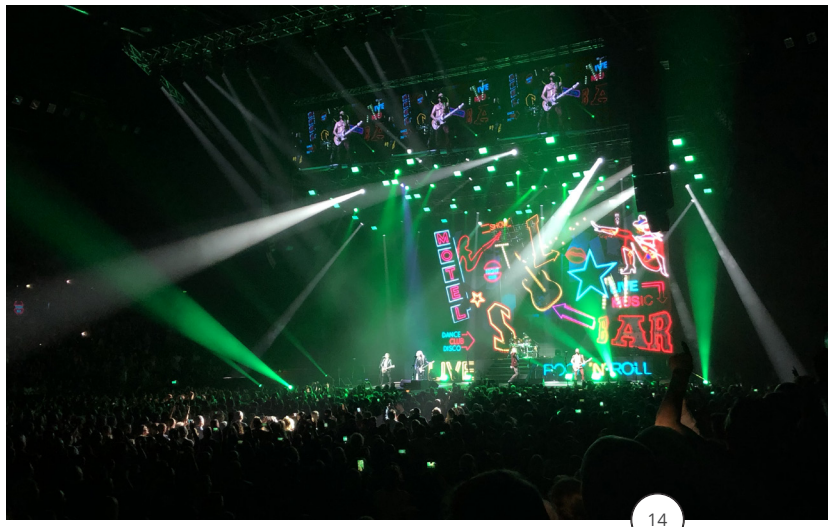
Noise standards were developed from a desire to protect individuals primarily from hearing damage that would affect communication.

The United States began formalising Hearing Conservation regulations in the late 1960s. Internationally since 1969, noise standard developments have weighed the acceptable levels of risk against the cost to implement a safer practice.

Noise standard calculations relate to the individual's exposure to sound levels over the course of a 40-hour working week through their working life. While many countries choose to calculate based solely on exposure times, the USA OSHA standards factor in taking breaks away from the noise.

Definitive data on human sound exposure tolerances are difficult to obtain without risking research participant's permanent hearing.

While the effect that noise exposure levels have on hearing is well documented, the determination of responsibility for managing and facilitating hearing protection for live-sound personnel differs internationally.



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Def Leppard 2018, Auckland, NZ

> **"At the end of the day, the guy sitting in the third row doesn't care how long it took to hang the PA, or how light weight it is. He just wants it to sound good, and so do I."**
> **- Kevin Margolin, co-founder, Atomic Professional Audio**

QUANTIFYING AND BALANCING RISK

Any human activity involves an element of risk.

The exposure to sounds over 70 dB presents some risk to hearing function. The ambient sound levels of many city streets, public spaces, and transportation and the prevalent use of personal music devices, commonly exceed 70 dB. [7 18 19 20] The following table estimates the risk associated with average 'volume levels' over a given exposure time.

RISK COMPARISON[13]

when exposure is similar over a 40 hour week, over a working career

Workplace NZ, World Health Organisation, and many other countries
8% risk
(to hearing function)

Average SPL	Exposure Time	Exchange Rate
85 dBA	8 hr	3 dB

Exchange rate: for every **3 dB** increase the recommended exposure time limit halves.

OSHA (USA)
25% risk
(to hearing function)

Average SPL	Exposure Time	Exchange Rate
90 dBA	8 hr	5 dB

Exchange rate: for every **5 dB** increase the recommended exposure time limit halves.

The 2021 World Health Organisation's World Report on Hearing:

"To avoid irreversible noise-induced hearing loss, exposure to loud sounds through leisure noise and personal audio devices should be limited to:

80 dB L_{Aeq} over 40 hours in a week for adults, and
75 dB L_{Aeq} over 40 hours in a week for sensitive users, e.g. children." [21 22]

15

Average Level	Exposure Time
85 dBA	8 hrs
88 dBA	4 hrs
91 dBA	2 hrs
94 dBA	1 hr
97 dBA	30 mins
100 dBA	15 mins
103 dBA	7.5 mins
106 dBA	3.7 mins
109 dBA	1.8 mins

15 Noise Standard Risk Comparisons.

"

"There will always be a desire for good sound and a general lack of understanding in attaining it. So not everybody will just be able to throw together a sound system with any sort of good or even mediocre results."
- Jim Long, Electro-Voice

The World Health Organisation (WHO) Global Standard for Safe Listening Venues and Events [22]

(Published March 2022)

This standard recognises the challenges event organisers face in meeting 'safe' limits. The standard has sought to balance: **artistic integrity, audience satisfaction**, and **safety,** proposing six suggestions that are further detailed in the document:

1. Maximum of100 dB $L_{Aeq(15min)}$ with a limiter on the sound system to avoid peaks above L_{Cpeak}140 dB. For events with children: 90 - 94 dB $L_{Aeq(15min)}$, L_{Cpeak}120 dB.
2. For each event, there should be a written safe listening policy/contract signed by organisers, engineers, crew and musicians. Audio levels should be monitored by a responsible person, with actions taken to keep the levels within 'safe' limits. Levels to be displayed to the engineer but not the public.
3. Optimise sound-system design and acoustic treatment. Place exclusion zones in front of loudspeakers and manage onstage sound bleed.
4. Provide ear plugs.
5. Provide quiet zones.
6. Provide information and training to staff on safe listening.

Side note: Recognising that for most event participants the exposure is for a single event and not the daily average over a career, this 'acceptable level of risk' would only allow 15 minutes of exposure for those consistently exposed to this level of sound. [21 22]

NZ NOISE STANDARDS

Safety Standards protect individuals and the environment. In New Zealand, more than one regulation refers to noise. The 1995 Health and Safety in Employment Regulations and Worksafe NZ provide general noise exposure recommendations. Section 322 and 326 of the Christchurch City Council Resource Management Act are shown here as examples of local NZ council regulations that refer to noise.

Health and Safety and Worksafe NZ [23]

The 1995 Health and Safety in Employment Regulations in New Zealand state that employers should take all reasonable steps to ensure that employees are not consistently exposed to noise above 85 dB for an 8-hour working day, whether or not the employee is wearing a hearing protection device (e.g. earmuffs or earplugs). Health & Safety Regulations set a maximum peak noise level limit of 140 dB.

The public, customers and attendees are included in Worksafe NZ standards as 'other persons'.

Health and Safety at Work Act 2015 (22-25): [24]

Employers...have a duty to weigh up the likelihood or risk concerning the degree of harm from a hazard/ risk that they ought to know...resulting in the loss of a bodily function.

Section 6 of the HSE Act requires employers to take all practicable steps to ensure the safety of employees at work and to provide a safe working environment.

Points to note on NZ Regulations: [13] [23]

- The Health and Safety Work Act 2015 should recognise hearing as a 'bodily function'.
- LA_{EQ}85 over 8 hours still contains an 8% risk of damage.
- Acoustic shock (symptoms a person may experience after hearing unexpected or loud sounds) and instantaneous hearing loss can occur at a lower SPL than LC_{PEAK}140.

Worksafe New Zealand

PCBU (Persons Conducting a Business) primary duty of care is for workers and non-workers (other persons). [24]

- Section 22 lists the relevant health and safety matters they are to weigh.
- Section 23 lists the loss of a bodily function as a category where PCBUs must protect.
  Author note: "hearing, is a bodily function".

Local Council Plan [25] [24]

Council District Plans have various rules that state the average (L_{Aeq}) and max level (L_{Amax}) relating to the impact of noise to others particularly at residential dwellings or residential zones. Inner City, residential, commercial and rural zone activities may each have different allowable limits. The rules are outlined in each NZ Region's District / Resource Management Plan.

- Events maybe granted approval to exceed the District Plan Noise limits but may have to comply with various conditions concerning noise activity times and allowable levels.
- Christchurch: CCC Resource Management Act details in Section 326 that excessive noise is any noise under human control...that may...interfere with the peace and comfort and convenience of any person.
- Section 322 mentions an abatement notice may be served on any person ... if an activity is likely to be noxious, dangerous, offensive or objectionable...to the extent that it has an adverse effect on the environment.

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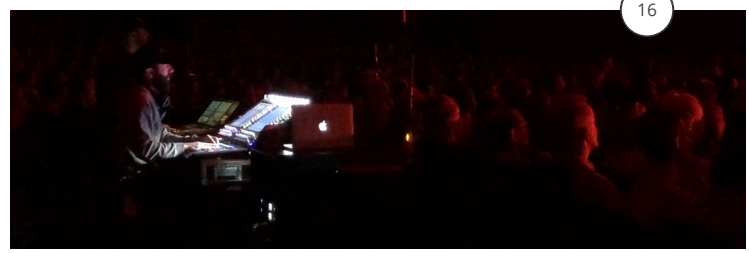
"Whatever sounds good on a particular instrument on a particular day, we move forward with that."
- George Cowan, FOH engineer

Lauren Daigle 2020, Christchurch, NZ



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INTERNATIONAL NOISE STANDARDS

Noise standards vary between countries.

Most countries allow higher noise exposure levels for events than the World Health Organisation's general career audio exposure limit recommendations. The following examples demonstrate a few of differences between international noise standards:

Brussels

Brussels has three different categories of sound levels:

1 < 85 dB $L_{Aeq(15min)}$ No requirements.

2 85-95 dB $L_{Aeq(15min)}$, 100-110 dB $L_{Ceq(15min)}$ - must display sound levels.

3 95-100 dB $L_{Aeq(15min)}$, 110-115 dB $L_{Ceq(15min)}$ - display sound level.
Provide earplugs for free or at cost price and provide a rest area.

France

1 < 102 dB $L_{Aeq(15min)}$, < 118 dB $L_{Ceq(15min)}$ - maximum level.

2 < 94 dB $L_{Aeq(15min)}$, < 104 dB $L_{Ceq(15min)}$ - maximum level for < six year olds.
Inform the audience. Provide free headphones. Offer a quiet zone that is < 80dB. Record and store A and C-weighted levels.

Switzerland [52]

1 < 93 dB $L_{Aeq(1hr)}$ -No action. Upper limit for children, sensitive people;

2 93-100 dB L_{Aeq} -Notify authorities; Prominently display safety posters and warnings; Distribute hearing protection; Monitor hourly level

3 96-100 dB $L_{Aeq(5min)}$ - Record hourly level; Provide a Quiet Zone ≤ 85 dB that must be smoke free

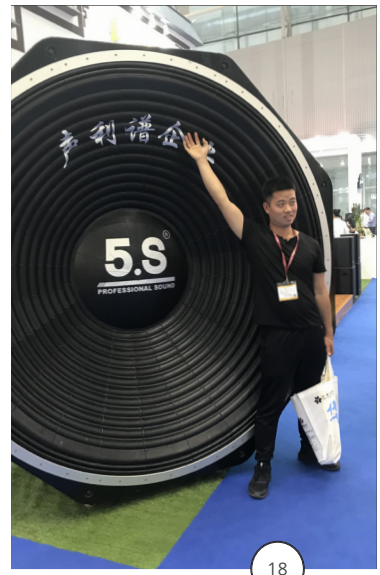
4 100 dB $L_{Aeq(1hr)}$ Limit Sound Levels

5 Provide “quiet areas” for events whose duration exceeds three hours

6 Acoustic events > 93 dB display posters, provide hearing protectors

Recognising Low Frequencies in Noise Standards

The UK, France and Belgium recognize by using C-weighted scales that low-frequency has an impact on potential hearing damage while A-weighted scales used by many countries do not. [16 17 28]



18

17 NASDA Hair Ashburton, NZ (SC Sound Design and Op)

18 Trade Show 2018, Guangzhou China

ENFORCEMENT AND RESPONSIBILITY

19

New Zealand:

- Local City Councils monitor SPL at the event/public boundaries to limit the event's interference on the peace and comfort of neighbours and not for event participants within the event boundary.
- In NZ, any litigation regarding noise control is to be funded by the complainant, and
- Identifying the responsibility for any participant hearing damage is difficult to connect to a particular event, as the participant's total noise exposure also includes the contribution of personal audio devices, workplace and environmental noise.

In 2018, a UK landmark High Court case, found the UK Royal Opera House, was at least partly responsible for a viola player's hyperacusis (hypersensitivity to noise) caused during the rehearsal of an orchestral piece that acoustically peaked at 137 dB. After losing an appeal in 2019, the musician was awarded £750,000. [27]

This legal precedent acknowledges that the responsibility for personal hearing protection IS shared with live-performance management.

Internationally:

Internationally, the enforcement of noise standards varies significantly, where some impose financial penalties for exceeding local standards.

While regulating sound exposure at events by legal enforcement means is an option, a 2020 international audio engineer survey reveals legislation is one of their least favored hearing management solutions. [1 20]

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"This business is not for the squeamish. You can get squashed like a bug, but if you can survive it, you can make a comfortable living, you can work half the year. You've just got to pay attention and stay out of jail."
- Jim "Redford" Sanders, wmix engineer

19

Hillsong Manhattan, 2018, NY, USA

HEARING MANAGEMENT

Managing The audio engineers most essential critical listening tool

REDUCING HEARING FATIGUE (TTS)

Hearing fatigue is a reduced response to some audio frequencies and is known as a temporary threshold shift (TTS).[7] TTS can lead to a permanent threshold shift (PTS). When a traumatic occurrence causes hearing loss, the threshold shift classification is a noise-induced hearing loss (NIHL), or music-induced hearing loss (MIHL).[7]

Hearing/listener fatigue (TTS): [7 29]

- occurs from listening to audio at high volumes,
- is affected by elevated body temperatures, as in those who exercise,
- occurs faster when the listener has some prior hearing damage,
- when the hair cells that translate a particular frequency die, the brain needs to work harder to process incoming information, making reaction times slower,
- may increase for in-ear monitor (IEM) wearers and monitor engineers who wear headphones or earphones. Blocking the ear canal and creating a pressure chamber dampens sounds, making them appear to be not as loud as they are, and
- artefacts left by audio processing (e.g. high compression), or distortion also increase the brain processing required.

Managing Hearing Fatigue and Preparing to Mix

To minimise hearing fatigue and prepare for critical listening: [30]

- schedule rest periods without earplugs or headphones,
- wear hearing protection on planes and other noisy vehicles or environments, and
- minimise the time exposed to high SPL.

Can we prepare for high sound pressure levels?

Some would say there is no way to prepare hearing mechanisms for loud sounds without hearing protection. Sound contains a potential for damage.

We could liken loud sounds to putting our hand over a flame. Our hand is not naturally designed to cope with being over an open flame. If our hand is far enough away or we only have exposure for an extremely short time, we may be safe enough. By wearing appropriate protection, we can be exposed for longer periods.

20

'Hearing Fatigue?'

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"To me the greatest compliment a band can pay you is to rehire you." - Deb Hutchins, monitor engineer

REAL WORLD EXAMPLES [1]

In a 2020 audio engineer survey [1], 97% of respondents said their personal hearing ability and longevity were a concern, citing their career, critical listening, and ability to mix as the main reasons, closely followed by a personal enjoyment of music, film, being a musician, and listening in general.

Hearing Challenges That Affect Critical Listening

Ninety-one percent of audio engineers have considered the impact of any hearing impairment, while 54% report they have some hearing impairment that affects their critical listening. In assessing audio engineers' hearing, only 4% of those surveyed rated their hearing as excellent, 11% above average, and 18% as good, average, or adequate. Some of the engineers surveyed described their hearing as:

"Impaired but still accurate."

"Excellent, but threshold shifted."

"Great compared to normal folk, ok compared to sound engineers."

"High functioning but have some damage."

"Slightly impaired, but I know my curve and can compensate for it usually."

"Ok for my age. I had a test last year, and I'm borderline ready for a hearing aid, but I seem to be able to hear what matters for mixing—usually, I get positive feedback on the mix and levels, including from people who would be pretty honest with me."

"Hearing test a couple of years ago suggested it was fairly normal, not outstanding."

"...part of my hearing problems I solve with knowledge, I have a more trained ear than [when] I was young."

"My frequency response is far from perfect and uneven between the ears."

Fig. 21 shows the percentage of audio engineers that experience various types of hearing loss. The *Fig 22.* audiogram was supplied by one of the audio engineer survey respondents and displays their hearing loss particularly in the frequency bands that provide clarity to speech.

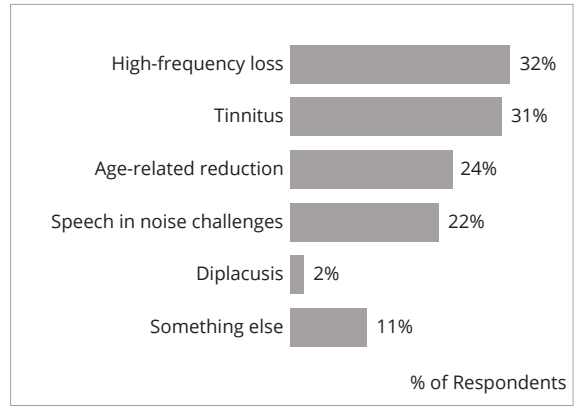


Fig. 21 The percentage of audio engineers who experience various hearing types of hearing challenges.

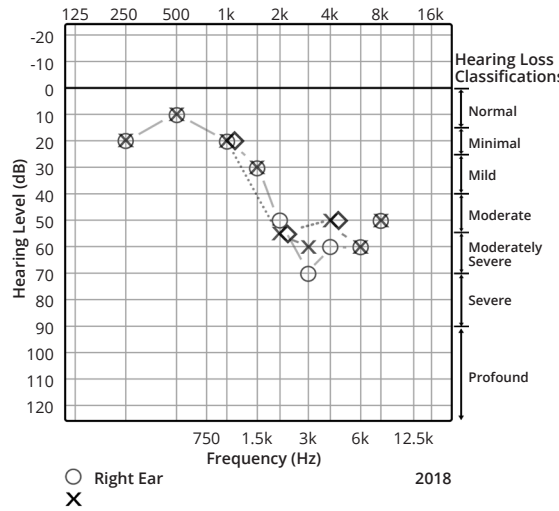


Fig. 22 Audiogram supplied by a working audio engineer taken in 2018 *(see page 22).*
- permission granted to use on condition of anonymity

OTHER HEARING CONDITIONS THAT AFFECT CRITICAL LISTENING

A healthy auditory pathway provides the audio engineer with the best opportunity to listen critically, which in turn guides their choices.

Other conditions affecting critical listening can include:

- **conductive hearing loss -** excess wax build up, ruptured eardrum, fluid in the middle ear *(see page 40),*
- **acoustic shock** - damage to the auditory system caused by high sound pressure and exposure, [7]
- **tinnitus** - (*more details on the next page*),
- hair cell damage causing a **loss in sensitivity**, often beginning around 4kHz and then spreading to adjacent frequencies,
- **hyperacusis** - a hypersensitivity to sound where quiet sounds appear loud, [14]
- **diplacusis** - hearing one tone as two tones of different frequencies in each ear making tuning perception difficult, [14]
- **distortion** of tones, [14]
- **presbyacusis** - age-related high-frequency loss, where the perception of higher frequencies reduce as we age, [5 21 31]
- **PTS** - permanent threshold shift - which is a permanent loss of hearing at particular frequencies, [7]
- **Meniere's disease** - is an inner ear disease, causing vertigo, dizziness, balance issues, tinnitus and pitch perception, [5 32]
- **physiological changes** affecting auditory perception - can be a reduced sensitivity to weak sounds, or 'loudness recruitment' where the sensitivity to some loud sounds increases, the effects of which reduces the accepted dynamic range and may also affect the ability to perceive pitch accurately, [33] and
- **recruitment** may affect the listener's tolerance to increasing loudness over-proportionally. If the damage is in one ear only, the perceived loudness grows faster in the normal ear until the same perceived loudness in both, [6 34]
- **disruption to the auditory pathway** between the cochlear hair cells and the brain which can be caused by long-term noise exposure. [12]

There is currently no way to precisely predict the susceptibility to damage that loud sounds pose to a particular person.

23

23

Theatre Opening Performance
Brisbane, Australia (SC Tech)

"

"I've done everything from schlepping gear, to setting it up, to designing it, to mixing on it. I like it all. It's a good day's work."
- Phil Scobee, mix engineer/system consultant

TINNITUS [7 14 35 36 37 38]

Tinnitus is the term used for a noise that is heard but does not come from an outside source. Tinnitus is often described as a 'ringing in the ears' but can be experienced in other ways, like a buzzing or hissing, waves, cicadas or even a thumping sound. It can be faint or loud, constant or occasional, steady or pulsing. The effects can range from not bothersome to very annoying. Tinnitus is more noticeable in quiet times, at night or when tired or stressed and can be triggered by exercise and loud sounds.

The risk of tinnitus is twice as high in musicians compared to the general population, with 50% of professional musicians reporting tinnitus.[27] In one investigation, more than two-thirds of live-sound respondents reported tinnitus as the most common effect of changes in their hearing, followed by a loss of response to specific frequencies. [34]

24

- 34% of audio engineers report experiencing tinnitus, [1]
- Tinnitus affects 54% of percussionists, [14]
- Tinnitus affects 58% of professional musicians versus 44% of amateurs, [14]
- 60% of violinists experience tinnitus in one ear only, [14] and
- 24[37]-30% of orchestra musicians find tinnitus bothersome and 6% highly bothersome.

Tinnitus masks audio frequencies making it more difficult to assess their actual level.

25

24 Ear Trumpet - Tinnitus

25 Jimmy Barnes, Selwyn Sounds, Christchurch, NZ, 2018 (SC FoH Tech)

"

"They're just tools, not a magic safety net. No single person who wants to truly succeed as a mixer can do it by relying on a machine." - Wayne Pauley, mix engineer

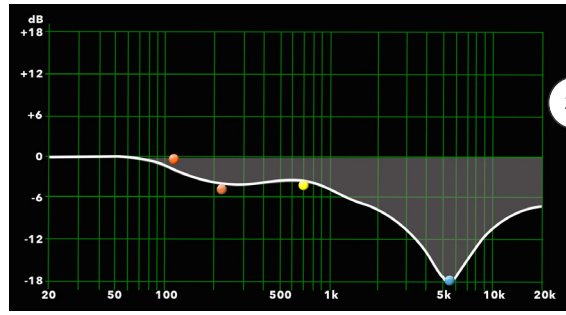
WHAT COULD A TYPICAL AUDIO ENGINEER'S HEARING LOOK/SOUND LIKE?

In one study, sixty-nine pop musicians, four disk-jockeys, four managers, and six live-sound engineers, had their hearing tested. [40]

In a more audio engineer recognisable parametric equaliser form, *Fig. 26* displays their average hearing response. [40] Someone with this shaped audiogram is said to have '**mild**' hearing loss.

If an engineer were to have the hearing loss described in *Fig. 26*, they could conceiveably compensate for this loss by increasing frequency content as shown in *Fig. 27*.

An earlier study amongst audio engineers found that 10% of the participants demonstrated a '**moderate-to-severe**' hearing loss at around 4000 Hz. [38] We can overlay a parametric equaliser representation of the *Fig. 22* 2018 audiogram on *page 19,* onto the 'mild' hearing loss graph in *Fig. 26* and can see the impact of 'moderate-to-severe' hearing loss shown in *Fig. 28)*.



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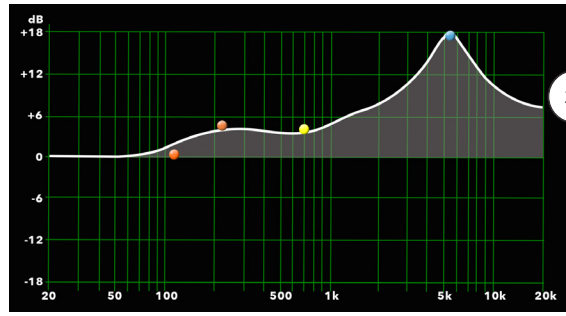

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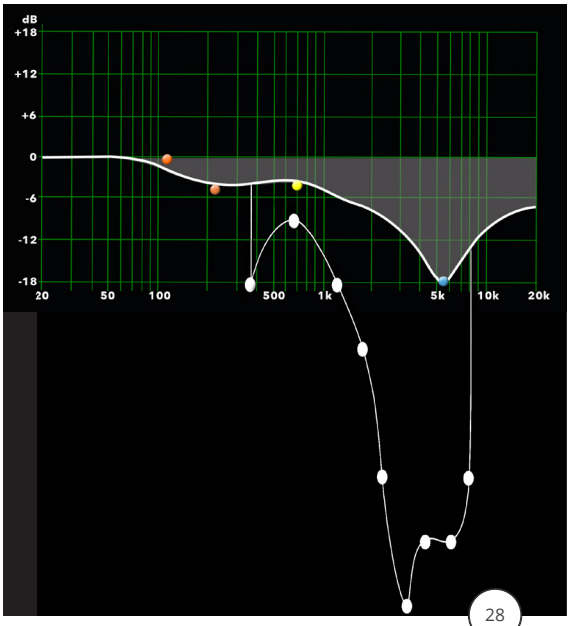

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How would implementing these EQ curves in fig.25, 26 and 27 affect a given sound?

Could these examples explain why some audio engineer's 'mixes' are louder and contain significant high-frequency content?

26 Audiogram viewed as an EQ curve

27 Audiogram EQ with frequency-loss compensated

28 The 'moderate to severe' loss from the audiogram on page 19 overlayed on fig. 24.

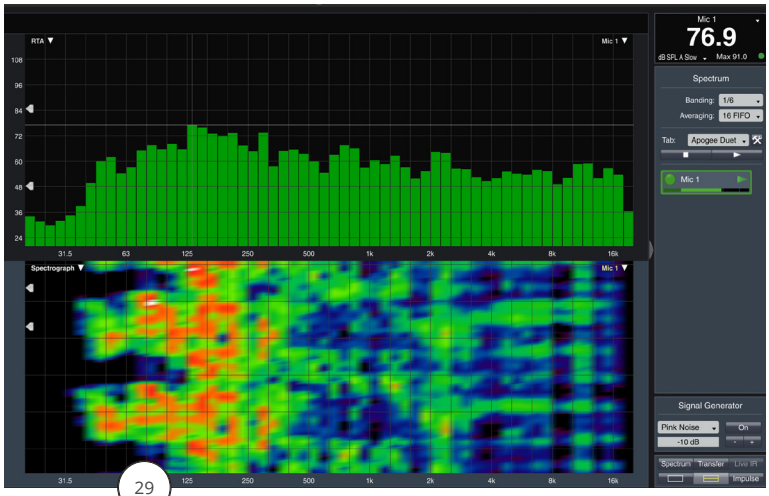
"

"I look at it this way. There's 24 hours in the day, and sometimes 22 of them can suck pretty good. However, when the lights go down, and the people stand up and start screaming, I get two hours that make it all worth it."
- Jim "Redford" Sanders, FOH engineer

AUDIO ENGINEERING WITH SOME HEARING DAMAGE

Within the hearing process, the human brain consumes significant energy to convert and process audio vibrations. [8] **Impaired hearing will affect the audio engineer decision-making process.**

Despite some hearing loss, audio engineers may still be able to function, adapting any physical changes as if navigating in a new city or location, relying on other navigation techniques and signposts. A sound engineer may still have hearing abilities that make sense of sound better than people with similar physical hearing function. [8 41] An experienced engineer can also retain valuable motor, problem-solving and interpersonal skills that are more advanced than the novice, even when some frequency discrimination is compromised.



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An impaired audio engineer may be assisted by:

- a spectrum analyser (e.g. Smaart *Fig. 29*) to provide visual cues on frequency content that has been masked or is missing,
- a trusted colleague with fresh, undamaged hearing acting as 'second ears', and
- critical listening to high-quality and related-to-the-performance audio material, where the engineer can establish a reference point for their 'mix'.

29

Rational Acoustics's Smaart Spectrum Analyser

UNPLEASANT SOUNDS AFFECTING HEARING LONGEVITY?

The effects of music on hearing and any potential for damage is different than it is for noise, perhaps because music provides less stress than industrial noise. [11]

At similar levels, unpleasant sounds are more likely than pleasant sounds to cause temporary threshold shifts (TTS) and have a negative impact on health. [8 9 10 12 14 44 45]

These findings put greater onus on the ability of the audio engineer to make the mix 'pleasant' to maximise the listener's health and their 'experience'.

Conversely, the potentially most dangerous stimuli are perhaps the least bothersome as we allow ourselves to be exposed to music at higher levels for extended amounts of time because we find it less disturbing than noise. [44]

"

A talented sound engineer can get a better-than-average sound from an average sound system, while a less talented sound engineer may achieve a lesser-than-average result from a superb sound system.
- Tony Edwards, Director, Sound Choice Pro Audio NZ Ltd

FACTS, STATISTICS AND EFFECTS WITHIN THE MUSIC INDUSTRY [20]

The audio engineer is a musican whose instrument is their mixing technology. The following hearing management statistics relate to musicians and music listeners.

- The WHO suggest that 1.1 billion young people could have some form of music-induced hearing loss. [21 22]
- Over 50% of professional musicians have hearing loss, mostly around 4-6 kHz. [14]
- Musicians are four times as likely to experience noise-induced hearing loss than non-musicians.[43]
- 68-74% of pop/rock/jazz musicians have hearing disorders. [14 47]
- Percussionists and brass players have the worst hearing thresholds of all musicians. [47]
- Hearing loss tends to be more prevalent in male musicians than female musicians.
- Diplacusis is present in 18% of musicians, 5% in orchestra players. [14 39] Diplacusis produces a notably different perception of a single frequency tone in the two ears of up to 15-20%. A 200 Hz tone in one ear may sound like 240 Hz in the other ear.
- 24% of musicians, 12% being orchestra players, report a distortion of tones, overtones and harmonics where these appear unclear, fuzzy or out of tune. [14 39]
- 39-79% of musicians report hyperacusis compared to 15% of the general population. Women report a higher rate than men, . [14 47]

Asymmetry

Male jazz or rock musicians that play in amplified sound environments report significantly weaker hearing thresholds in their left ear. Amongst classical orchestral musicians, violinists, violists and drummers may have reduced hearing ability in their left ear, while flute and piccolo players may have reduced hearing ability in the right ear. A flautist may still have reduced hearing ability in their left ear due to the location of trumpet players on their left side. [14]

30

GOOD NEWS!!! 50% of musicians and 43% of audio engineers have found ways to work in a noisy industry without experiencing hearing damage!

"

"How [do you] tell a loved one they're coiling cables wrong?"
- Tom K

30

Les Miserable, Showbiz Chch, Christchurch, NZ, 2018 (SC Sound Op),

OTHER HEALTH AND SOCIAL EFFECTS [21 48]

While not all hearing damage is the result of acoustic trauma, the effects of reduced hearing function are also not just restricted to hearing processes and include:

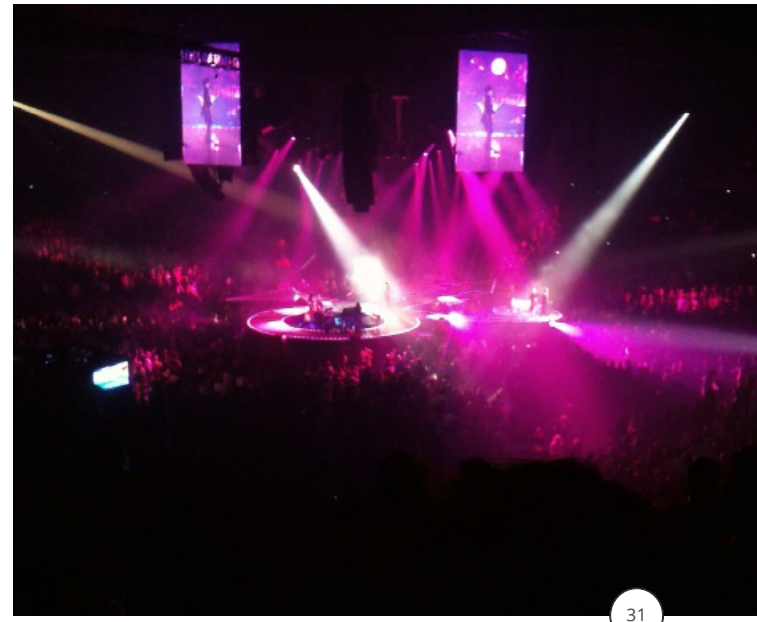
- headaches,
- nausea,
- balance issues,
- anxiety,
- hypersensitivity,
- fatigue,
- depression,
- insomnia,
- declining cognitive ability,
- reduced ability to perform musically,
- social isolation,
- fluttering in the ear, [49]
- effects on concentration and morale, and
- mitochondrial DNA damage [50]

MASKED RECOVERY [51]

In the days following a concert, our hearing may seem to have recovered from any threshold shift, where the shift is no longer significant. What may take longer to recover from, possibly over a period of a week or two, is the ability to perceive words in noise.

FINANCIAL COST [21 48]

The estimated total financial cost of hearing loss within NZ in 2016 is NZ$4.9 billion, with the cost to the NZ economy at NZ$957.3 million. These figures present a cost to each New Zealander of NZ$5556 in contributions toward assisting individuals with hearing loss issues.



31

Of persons aged 12–35, 50% are at risk of hearing loss due to exposure to unsafe levels of sounds in recreational settings. 1.5 billion people experience hearing loss, and this figure could grow to 2.5 billion by 2050. Without hearing loss intervention, the global economy is estimated to lose close to one trillion dollars each year. The World Health Organisation estimates that investing in ear care and hearing management could bring a return of sixteen dollars for every dollar spent.[21]

"

"Some people see every other company in the world as competition, as in, 'they're my enemy.' But I see them as trying to live their dreams like I'm living mine."
- Mike Bourne, owner, All-Star Audio Systems

31

Prince, 2016, Brisbane, Australia

SECTION 2

The content in this section is from the author's PhD research into audio engineering culture. The data is from an international audio engineering culture survey conducted between April and May 2020 with 98 audio engineers. [1] One paper from this research has been published by the International Audio Engineering Society Journal.[1] The other has been accepted for publishing by the International Journal for Applied Positive Psychology.[54] By understanding current audio engineering culture we can then make improvements for the betterment of the live-sound participant experience, health and well-being.

AUDIO ENGINEER CULTURE AND PRACTICE

An ongoing study as part of PhD Research [1]

Few people understand what audio engineers do and what is involved in producing a high-quality sound.

Audio engineering with skilful musicians and high-quality equipment in a venue with an appropriate acoustic makes the audio engineer's role easier but a good sound is not guaranteed. The audio engineer is the final link in the audio chain. They mix the audio sources musically, adjusting dynamic, tone, and space while balancing participants' expectations. Their knowledge, skills, character, preparation, personal hearing ability, and musicality affect the final audio product. Amidst a seamless well-balanced mix, the audio engineer may go completely unnoticed.

There are factors beyond the engineer's control that affect the resultant sound. Often preparation time is limited. Not every sound source can be 'fixed in the mix'. Challenging their ability can be the amount of stage 'noise', the mix-position, acoustics, weather conditions, the expectations, bias and preference of live-sound participants, the musicality and 'connection' by performers, and more.

The audio engineer's 'invisibility' contrasts with the necessity of engineers to build and maintain trust with musicians, organisers and the audience. These relationships keep audio engineers employed and help ease the effect of any unforeseen technical distractions that may arise in the course of a live event. Establishing trust with other participants requires evidence of skill, knowledge, diligence, reliability, punctuality, calmness under pressure, focus and an ability to deliver what is needed. An audio engineer benefits from the knowledge gained through personal research, watching and asking others, trial and error, and practice.

32

"

And that fake smile you put on when the artist starts singing and you realise there's nothing you can do to make that sound good.- unknown

32

Chicago, The Court Theatre, Christchurch, NZ 2017-18 (SC Sound Op/ Sound Design)

Musicianship:

75% of audio engineers play an instrument, perform, compose or arrange music.

Education:

58% of audio engineers have had some formal audio engineer education. Of those who have had formal education, the highest qualification these engineers have attained is:

- 31% Certificate / Diploma,
- 46% Degree,
- 11% Honours / Masters,
- 4% PhD, and
- 7.5% Other.

Audio Engineers otherwise learn their skills:

- 93% observing and working alongside someone else,
- 88% through trial and error,
- 82% asking someone else,
- 63% 'how-to' books,
- 60% online videos,
- 15% only searching when they can't work something out, and
- 21% learn through manufacturer workshops and informal training.

Enjoyment and Satisfaction:

Like many people, audio engineers continue an activity if they find the rewards and benefits outweigh the costs and negative aspects. Ninety-eight audio engineers rated their audio engineering enjoyment and satisfaction out of ten: ten, the highest level of satisfaction and enjoyment, and one, the least *(Fig. 33)*.

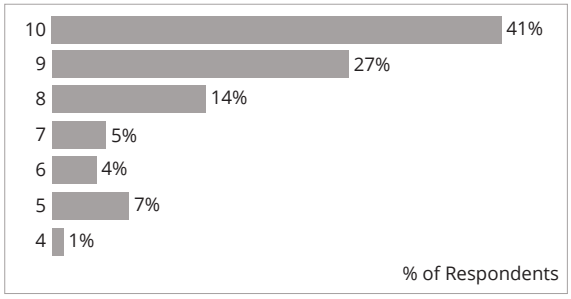


Fig. 33 How audio engineers enjoy their work (scale of 1-10).

"

"If you want to make a million in audio, you know how you do it? Start with two million."
- Ryan Jenkins, owner, Arizona Concert Sound Solutions

Many elaborated that they like:

- the variety of work,
- the art and creativity,
- the challenge of making a great sound,
- the opportunity to support the band and enhance the emotion that musicians on stage bring to an audience,
- the thinking and ongoing learning required,
- the contact with the people involved,
- the process of improving their craft through practice,
- the role of inspiring others,
- the satisfaction and reward from getting a good sound,
- observing positive responses from the participants,
- the blending of a passion for music and technology, and
- travel.

"I can do a 70-hour week and still be hungry for more gigs at the end."

"I have the best job in the world! I still can't believe I get paid to travel and go to concerts all the time."

"I like playing a large role in 'the sound,' not just what we hear...I like getting it right."

"I enjoy the methodicalness of set up and pack down; the solving of problems, seeing how things work; and being able to serve."

"I do not feel that I'm working doing this!"
"I like the responsibility of it...to provide the best experience possible. I like being able to craft a sound to sound exactly how I want it."

"It's a very weird, challenging, rewarding occupation."

"It's a sickness, perhaps. But I love making performances or programs sound great, be accessible to the audience (without straining), and having an artistic hand in how the delivered result sounds."

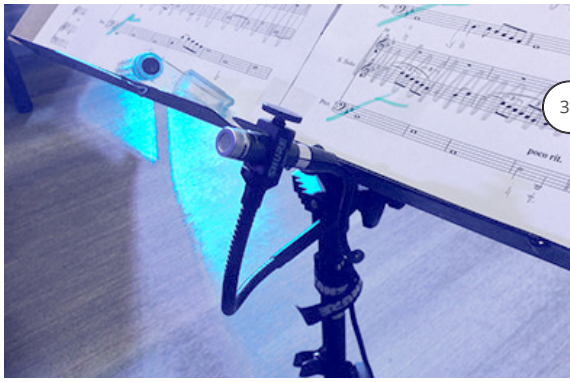
"Because I love it! Even on bad days!"

"I get a buzz every time I turn the console on, and get the pleasure of mixing bands."

"I really enjoy mixing when the band is good, the gear is good and there are no issues... on those days I would score a 10."

"It's such a pleasure...on lucky days to enhance the emotion that musicians on stage bring to an audience."

"Very satisfying when all elements come together to deliver the required outcome."



34

34

Discreet microphone technique (Shure beta 89a)

36

When the Music is Good

A Mix of the Good and the Bad:

The challenge of translating a performance to an audience does has challenges. Engineers said:

"I really really love what I do, but it's tough on the mind, body and general life outside work."

"Yes, there can be struggles but I believe they are there to challenge you and to develop your abilities."

"...stressful when I do mix a larger event, as it requires more focus."

"...it's a bit ungrateful and the hours are sometimes rough."

"Some days I love it, some days it's just stressful. I think when the artists are giving you request after request and you just can't keep up... [and] also the stress of bigger crowds knowing something could crap out and all eyes will be on you."

"Some days, it's brilliant. Some days it's an endurance test."

"...depends on the genre I'm working with... some music is soul-destroying."

"It's not a career you will ever survive in if you rate it any lower than a 10 as it is a passion beyond 'just a job'."

With many variables affecting the result, the role may not suit perfectionists as two engineers said:

"I would say one show out of every 100 I am almost completely satisfied with. It is a stressful occupation. I am also a perfectionist, which means I am usually left slightly disappointed."

"I'm...constantly afraid of messing up."

Factors that Provide the Least Enjoyment and Satisfaction:

Eighty-two percent of audio engineers indicated that interactions with other people provided the least satisfaction and enjoyment *(Fig. 35)*.

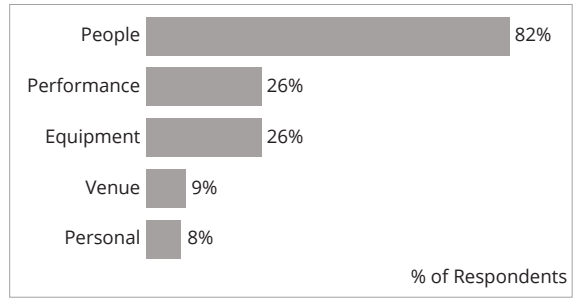


Fig. 35 Factors that audio engineers least enjoy

After interactions with people, the choice of performance content and delivery, equipment, venue (and mix position) followed in ranking as contributing to the least enjoyable aspects of the audio engineer role. Personal skills (8% in the figure above) correlate to knowledge and experience, confidence, critical listening, fatigue, health, etc. The factors mentioned undoubtedly impact the ability of the audio engineer to perform. Research has shown that job demands can contribute most to exhaustion, whereas less-than-ideal job resources can contribute most to cynicism. [50]

36

37

NZSSSO, Christchurch NZ, 2021,
(SC Video/Audio Recording and Post-Production)

An Impossible Job Description?

If someone were to prepare a job description listing the traits and skills required to be an effective audio engineer, the list would look something like the following as described in the 2020 audio engineer survey:

Personal Skills and Character

Despite arguably the strongest association to audio engineering, only 50% of audio engineers identify technical ability and 60% identify musicality as most important audio engineer skills. The two highest polled attributes relate to personal character (68%) and people skills (65%), many of which would be favorable within any profession:

- having good communication skills,
- being prepared,
- being able to focus,
- possessing stamina,
- exhibiting patience,
- being able to make good decisions under pressure,
- able to take criticism,
- being teachable,
- demonstrating humility,
- possessing a perceived calming nature,
- being open-minded,
- having a good work ethic,
- acting professionally even if they don't particularly like the material,
- being confident,
- being committed,
- being able to see the big picture,
- being able to own their mistakes,
- possessing a positive attitude,
- being passionate,
- being self-motivated, and
- being someone who shows initiative.

Three engineers summed up the key skills they believe audio engineers should possess:

"Ability to focus and discriminate. Good hearing. Willingness to stick with things to figure them out. Sense of musicality - what things should sound like. Logical mind that can develop repeatable habits/ steps to success. Ability to fake being calm, even if you aren't. Ability to visualize the signal flow. Ability to hear oddities and make good guesses about where they are coming from and how to solve them (clipping, slapback, distortion, bad [signal to noise], impedance mismatch, etc. An 'always scanning' mind that can be one with the music but at the same time able to notice when a driver has blown, or a coat has been draped over a speaker cabinet."

"I think there is a range of skills that are important. Technical proficiency…communication and teamwork. A familiarity with the programme material: how it has been presented in the past, and what the typical expectations are. Self-initiative/motivation…an ability to pay attention to detail while maintaining a view of the 'bigger picture'."

"I would divide these skills into two categories: skills that make you good at your craft and skills that make you successful in the music business. For the former (craft), I would say first and foremost is your ability to listen critically, followed by an understanding of the music you're working on, and operate/manipulate the tools needed to achieve musical goals. The business side of things is very different: humility, interpersonal communication skills, the ability to balance a budget, and tenacity in pursuing work."

The novice or less-experienced engineer may face more uncertainty or make less-than-ideal choices due to their inexperience:

"It is sometimes difficult, especially when starting out, to be strong in your opinion when you are responsible for a mix and have a lot of other strong opinions on what you should do."

"I think for newer people, it's harder to stand on what you think as you may not be sure of yourself, etc."

Pressure in the Live-Sound Industry?

As with many activities, performing at a high standard under time and financial constraints can generate pressure for those involved. While time and financial pressures could be anticipated, over 71% of audio engineers said they experience pressure to perform audio tasks differently than they would otherwise prefer.

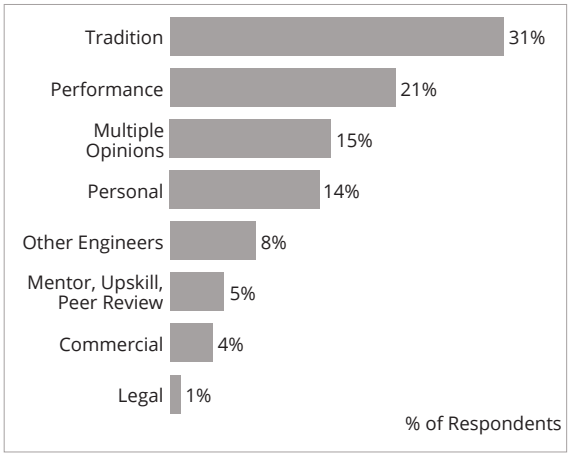


Fig. 38 The pressures on audio engineers to deliver audio differently than they would otherwise prefer.

Tradition

Tradition and expectation, how live events have been carried out before, can lead participants to continue a known successful formula:

"The main purpose of a lot of engineers is to please a production with the standard they expect."

"You deliver a product that they and their audience expect."

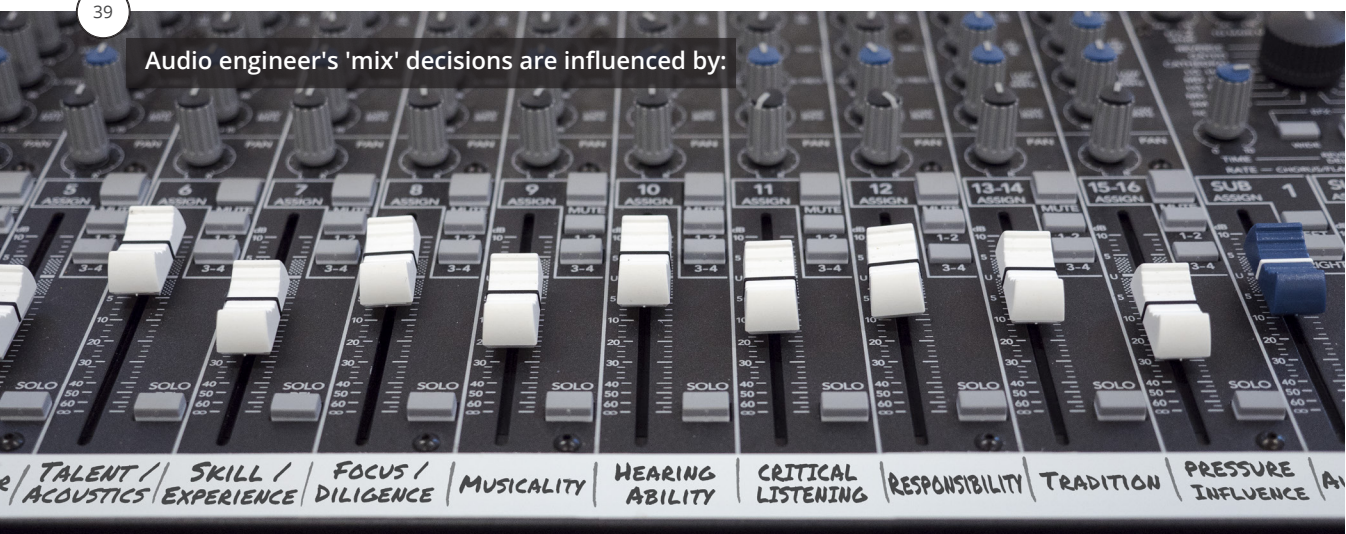
"If certain music is always mixed in a certain way, people have come to expect that, so it's very common to go along with that, instead of against it."

Performance Pressure (Event Organiser/Artist/Manager)

There are numerous people, cultural and practical matters that affect audio engineer performance, the audio mix, and the levels chosen. Only 4% of engineers said that the organiser's commercial/financial considerations affected their mix decisions *(Fig. 38)*. In *Fig. 35*, 82% reported interpersonal and organizational matters negatively affected their enjoyment and satisfaction, specifically mentioning: poor leadership or organisation, miscommunication, criticism, ingratitude and disrespect, and poor attitudes by artists, techs, organisers, or audiences.

One commented that *"...some participants are employed with not enough ability to fulfill the expectations of the role."* Four respondents mentioned *"...being confronted with sexism at work"* within a male-dominated industry. One said this occurred *"...daily."* Others noted not enough *"...preparation time," "...last-minute changes,"* and *"...unrealistic expectations without the budget to realize them."* Some pointed out that those running events commonly *"...had a lack of understanding [about] what is involved or required..."* to get a good sound. One said organisers had exhibited *"...a lack of creativity (art)."*

"I often find the attitude and behavior of some selected engineers, promoters, and managers in this sector to be completely unacceptable. These individuals undermine working environments and generally ruin what should otherwise be an experience where all technical staff are working toward the collective goal – successful[ly] delivering the show."



There seems to be an expectation for live performances to sound *"... like the record,"* which has influenced production, requiring engineers to adapt to using more technology and prerecorded tracks to supplement and enhance stage content. Pressure to use more complex tools puts less-experienced engineers in front of equipment they may not fully understand. Eighty percent of audio engineers believe that the number of tool/process options affects some engineers adversely. By prioritizing the tools and processes, some lose focus on the final product or can become overwhelmed with the complexity or number of available choices:

"...driving engineers to use all the tools even if they don't need to (a perception that complexity is better)."

"...also, there will always be certain dynamic/FX units/ plug-ins that are 'en vogue' at the time, and people will use them maybe without really understanding what they're doing."

"Marketing within the industry convinces many engineers that they need all the latest effects/plug-ins to do their work. This shifts the focus from the stage to the mixing desk, usually with poor results."

During a live event, a producer or manager may push for a particular level or 'sound':

"I can't say how many times I have had a manager say to [make] it louder to grab people's attention."

"The producer may have a differing idea as to what they expect from their event and as a professional, it is your job to see that idea through to the best of your ability."

The cultural and traditional etiquette for festival-type events with multiple artists and engineers can also influence mix and SPL decisions:

"In a festival, if your band is not the first one in the setlist, you have to adjust to the level/tone/etc. of the prior band, at least in the beginning."

"A lot of people believe they have to mix at least as loud as the person/band before them to make an impact."

"In festival situations, many bands think louder means better, so there is pressure on the engineer to be louder than everyone before them."

The Differing Opinions of Live sound Participants

One audio engineer respondent summed up the underlying sentiment on differing opinions saying that for different people, the sound might be both:

"...too quiet and too loud at the same time. Too much reverb, or not enough."

Several engineers elaborated on these differences of opinion and expectation:

"Audio is largely an art therefore heavily opinionated on what is the 'right option'."

"The bigger the show, the more interests are involved."

"Everyone judges everyone else's mix, regardless of if they say anything. Everyone usually has an opinion that they could do it better or different."

"There is always pressure because everyone wants something different but it is the engineer's job to do what they think is best."

"Usually, there is a team consensus on what is required from those on stage, but you, after all, are there to serve, and it is a matter of balancing the needs of the musicians and audience. Many have unrealistic expectations...however, if it makes sense and they have the authority, I will try and accommodate their wishes without a fuss."

"We work for the artist. Ultimately our job is to do what they want. Aside from the artist, there is the manager, agent, promoter, significant others of the artist, and friends, and everyone has an opinion. The drummer's wife thinks the drummer should be the loudest thing in the mix, and so does every drummer in the audience. The guitar player's wife feels the same about the guitar, etc."

"

And that fake smile you put on when the artist starts singing and you realise there's nothing you can do to make that sound good.- unknown

41

Outdoor Concert

Other Engineers

Of all live-sound participants, audio engineer peers should understand better than non-engineers the complexity of the audio engineer role and the various demands they face. Despite this presumption, not all respondents regard other engineers' influence as constructive, noting:

"Each engineer is different, and in live audio, there is a big culture of trying to prove skill levels and industry knowledge by telling other people what to do."

"The industry is flooded with novices with over-exaggerated egos who don't accept constructive criticism, as well as proven industry professionals that only care about self-promotion & selling the next greatest device whilst not mentoring any of the younger kids who have a real interest in audio. The 'middle-class' of audio engineering is vanishing."

"...more about showing off than good sound."

"...the pressure...in our industry, which is noxious, is the "macho" way of thinking about our work: who can be the loudest, have the greatest PA, etc."

"I believe it is driven by insecurity."

Some engineers do provide constructive influence:

"I always get soundies asking me what I am doing and why."

"...peer review and mentorship where lessons are passed on."

"...when you're pushed to use a particular effect or sound...it forces us to stay open to what we think is 'the right sound'."

"...we tend to copy the behavior of others whom we feel are successful, or at least working with well-known artists."

In less-than-ideal live-performance conditions, whether poor acoustics, poor mix position, or excess stage noise, 36% of audio engineers communicate with other technical crew, colleagues, or musicians to get advice to then change what they can.

Audience

By observing audience reactions, audio engineers can get a sense of and gauge the quality and appropriateness of their mix.

"I like...how I can influence how people feel."

"...to witness the presence and reactions of the audience."

"It's great to get a good mix and see the resulting level of enjoyment of the people."

"Satisfying when an audience erupts into applause."

42

42

10cc, Selwyn Sounds
Christchurch, NZ, 2020
(SC Guitar Tech)

"If you think it's expensive hiring a good sound engineer, try hiring a cheap one."
- unknown

How Audio Engineers Respond to Differing Opinions and Expectations

Whether SPL-related or a combination of physics, art, tradition, bias, preference, and expectation, audio engineers must assess differing opinions. Even with a considered approach, their resulting audio mix actions are unlikely to please everybody. The graph below indicates the engineer responses to differing participant views *(Fig. 43)*.

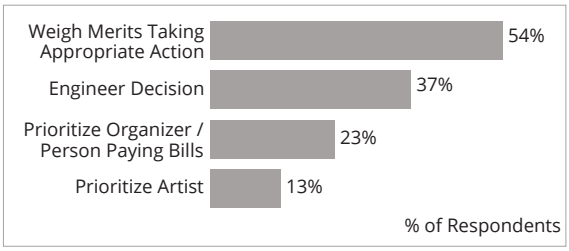


Fig. 43 How audio engineers respond to differing opinions and expectations.

44

SC designed fully adjustable system to hang and steer microphone/s. 'Finding solutions where current options are limited'

When asked how they dealt with differing participant opinions, engineers said:

"Diplomacy is one of the greatest skills an engineer should develop. Sometimes it can be a bit of a balancing act. It mostly depends on who you are working for."

"Always take on board criticism from those who understand or know what they want, especially those who are paying the bill. I am definitely guilty of ignoring the "I used to be a sound man" punter who had a garage set up in the '80s."

"Do what I think sounds best, and make small tweaks if I agree with any opinions that have been offered to me. If I don't agree, I won't change it. I'll alter monitor mixes for performers."

"You can't make everybody happy, so I would opt to make my employer happy."

"Everybody is to be listened to at the right time: Performer in the rehearsal, soundcheck, pre-production, organizers at soundcheck, maybe in pre-production. [and] attendees after the concert. During the concert nobody should give an opinion, it's just about me and the music."

"The performer is always for me the most important opinion for me, within reason, as it is their emotional content. Organizers and attendees chose a performer to be there, with their whole vision of a performance."

"You have to do what you think is best - I'm the one with the audio engineering training, and therefore I ultimately make the final call. I'm good at my job, so I trust my own ears."

"Smile and nod."

Yamaha CL5 - Monitors

45

'LOUD' AND THE AUDIO ENGINEER

Audio engineer beliefs on the appeal of 'loud':

The Sound

- Sounds 'better', clearer, punchier and more energetic.
- More harmonic content making richer sound.
- Lower volumes are perceived to have less 'life'.
- At higher SPLs, the ear response curve flattens, making the audio sound 'better'.
- Despite perceptions that loud is better, maybe it doesn't have to be 'loud' to sound good.

The Physical

- Arouses and affects the body physically, more than just hearing mechanisms, particularly with low-frequencies.
- Helps to cause pleasurable sensations from natural bodily chemicals and processes.
- As more harmonic content becomes audible, hearing-lossed frequencies may be perceived as the brain extrapolates the missing fundamental.
- At higher SPLs, people can hear and feel the parts of music, particularly bass, that may not be heard on small portable and home devices.

The Connection

- Participants feel connected to the music, the artist, and other people.
- Creates an immersive event where listeners feel enveloped by the sound, providing an 'escape' to 'get lost' in or to feel part of something 'big'.
- Reduces distractions and helps people to focus on the music/event. For performers, high SPL ensures their sound is foremost in an audience's mind.
- Interactions between participants in loud environments require people to be more energetic to be heard, adding to the 'vibe'.
- Drowns out the singing of attendees, so each can sing along without their own voice being heard.
- May be more appealing to particular groups, genres and ages.
- Triggers emotions.
- May have an addictive side.

'Loud' can be a subjective term and does not necessarily reflect a potentially damaging SPL. Audio engineers describe what they believe 'loud' may mean:

- the performance is louder than the sounds individuals hear in their everyday life,
- the lyrics cannot be heard over the music,
- attendees struggle to talk to each other over the performance,
- the style or content is not favourable,
- there are issues with the performer's pitch, timing or rhythm,
- the listener has unrealistic expectations of the event sound,
- the SPL is not appropriate for a particular genre,
- the frequency content of the mix is not balanced.
- a well-balanced 'mix' may subjectively **feel** less 'loud' than a quieter and less-balanced 'mix',
- the SPL may obscure or mask the listener's ability to hear and interpret all the intended sounds,
- the quality of the equipment or the lack of system optimisation process has a detrimental effect on the sound quality,
- the listener was not in an ideal location with respect to the sound source and the PA,
- that hearing damage has impacted the individual's perception,
- an audience member may mention the sound is too loud as a means of 'control',
- compression or distortion artifacts fatigue the listener,
- there is minimal dynamic variation where the ear can rest,
- the room acoustic or stage sound bleed adversely affects the front-of-house mix,
- one sound source cannot be heard over another, and
- that "you can't please everyone".

46

Shovel Guitar - 'making something musical out of something that may not obviously be'. (SC made). Has an 'earthy' sound. Does it need a 'pick'?

47

'Loud!'

"Too Loud"

Finding the appropriate SPL for an event is not an exact science. Seventy-eight percent of audio engineers have had an event attendee say the event audio is *'too loud.'* Following the *'too loud'* statement respondents described their interpretation of, or possible action resulting from the comment *(Fig. 48)*.

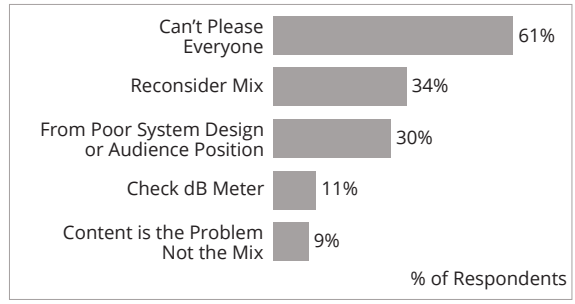


Fig. 48 How audio engineers interpret audience comments that the sound is 'too loud.'

Audio engineers describe that many live events are considered 'loud' due to:

- traditional expectations of a high SPL 'standard',
- the 'Loudness War',
- large venues requiring a high SPL at the stage, to reach people at a distance,
- lifting SPL over the stage noise,
- lifting SPL over the crowd noise,
- people being desensitised to high SPL,
- ignorance of the effects,
- demands by performers, manager or director,
- an artist's or engineer's ego or insecurity,
- peer pressure from other audio engineers,
- the final act being the loudest act,
- maintaining SPL continuity throughout the duration of an event or festival,
- an engineer's desire to use the power available and to push the limits,
- the perception that engineers that can handle louder audio power are seen as more skilled, and
- hearing impairment that may cause a desire for a louder sound to produce the desired neural stimulation.

49

University of Canterbury, School of Music Gala (SC Sound Op)

"

"The rules of touring are simple. Show up, do your job well, and don't be a jerk. You're living in a submarine with a bunch of other people. You've got to be enjoyable to be around."
- Jamie Anderson, Rational Acoustics

Of the engineers surveyed on attendees experiencing 'ringing in the ears' after an event:

- 79% believed the attendees thought the effects are temporary,
- 53% believed the attendees thought the 'ringing' is normal when attending live events,
- 17% believed the attendees thought that public events are safe, and
- 18% believed the attendees are ignorant about safety, don't care about potential damage, have a sense of invincibility, believe that high SPL is cool or can be bragged about.

Responsibility:

When asked who audio engineers believed is responsible for managing safe noise exposure at live events:

- 40% said personal responsibility,
- 88% said the audio engineer,
- 44% said the Director or Music Director,
- 75% said the event organiser,
- 34% said the local City Council,
- 13% said the Government, and
- 13% said other people - artists, venue owner, crew, consultant.

Monitoring:

46% of audio engineers use a meter to measure SPL at events. Of those:

- 44% use the correct monitoring scale to monitor average levels that relate to WHO and most health and safety recommendations.
- 20% say their adjust their subsequent SPL based on their monitoring.

Personal Hearing:

91% of audio engineers have considered the impact of hearing impairment. 17% of audio engineers have never had a hearing test. 54% of audio engineers *reported* they have noticed challenges to personal hearing that could affect critical listening.
Of these:

- 61% High-frequency loss,
- 57% Tinnitus,
- 4% Diplacusis,
- 40% Reduced ability to hear speech in noisy environments,
- 44% Age-related high-frequency loss,
- 21% Other hearing issues.

Noise Exposure:

The number of days per week audio engineer's are exposed to levels beyond WHO recommendations **:**

- 0 days - 24%,
- 1 day - 32%,
- 2 days - 11%,
- 3 days - 14%,
- 4 days - 11%,
- 5 days - 3%,
- 6 days - 1%,
- 7 days - 4%.

Live-Sound Hearing Management

78% of audio engineers believe the live-sound industry should make a concerted push to address noise exposure, to improve hearing safety, and hearing longevity of participants
18% of audio engineers believe it is a good idea but doubt it is possible,
10% of audio engineers believe the live-sound industry could not be reconditioned to a safer lower average SPL over time.

Audio engineers indicated the following protective measures should be employed to to manage participant hearing at high SPL events:

- 74% believe there should be warnings on tickets,
- 39% believe there should be SPL Indicators,
- 84% believe events should provide hearing protection (earplugs),
- 74% believe there should be quieter zones, where 86% believe it is feasible to provide a consistency of tone throughout a venue with areas at a lower SPL that still retain good visibility
- 80% believe there should be streaming available to portable devices
- 57% audio engineers that operate over $L_{Aeq}85$ should require safety training/certification.

The WHO global standard for safe listening venues and events would agree with these suggestions and a few more. [22] These are summarised on page 15.

"

"I think I've done close to 3,000 shows with the guy (Rod Stewart), so we're hoping we're going to get it right sooner rather than later."
- Lars Brogaard, FOH

Lauren Daigle, Christchurch, NZ 2019 50

CORPORATE SOCIAL RESPONSIBILITY (CSR) IN LIVE SOUND EVENTS[53]

Corporate social responsibility seeks an optimum situation for 'the satisfaction of all people involved...or at least [a situation that] satisfies most [people] without being detrimental to others...balancing the burden versus benefit.' The four generally accepted CSR theories are instrumental, political, integrative, and ethical and explained further as:

- meeting objectives that produce long-term profits,
- responsibly using [business] power,
- integrating social demands, and
- contributing to a good society by doing what is ethically correct.

Responsible participants actively align their decision-making power to make improvements by considering their own views, the person who is ultimately accountable, and the community at large.

How does our audio engineering practise align with corporate social responsibility ideals? This is discussed further in the publication: 'Live-Sound Pressure That is Not Measured in Decibels'. [54]

Sting, Christchurch NZ, 2023 51

THE EAR [5 55]

The audio engineer's most essential tool

Can an audio engineer make appropriate audio decisions, if what they hear is different than what other people hear?

An audio engineer's perception of sound is affected by:

- their personal hearing physiology,
- their ability to listen critically,
- any hearing damage,
- their experience, focus and stress,
- the mix / listening position relative to the venue acoustics, and
- the audio reinforcement equipment.

Hearing health checks with an audiologist can be beneficial to:

- help understand how any changes in hearing function may affect audio 'mix' choices,
- monitor and promote hearing longevity,
- provide early detection of damage and
- clear excess ear wax.

Earwax and Ear hair:
The ear canal produces a waxy oil called cerumen (earwax) as a protective mechanism from dust, foreign particles, micro-organisms, and fungi while also lubricating the skin of the ear canal, protecting it from irritation. A build-up of wax can muffle sound. This wax should be removed only by a trained ear practioner. [5 56]

Ear hair also provides a protective barrier against germs, bacteria, and debris. [5 57]

52

52
Four ears

53
Avoid using cotton buds to clear earwax

53

"

"Young guys ask me 'what do I need to do to do what you do?' And I tell them 'first, learn to listen'."
- Stan Miller, FOH engineer

outer ear | middle ear | inner ear

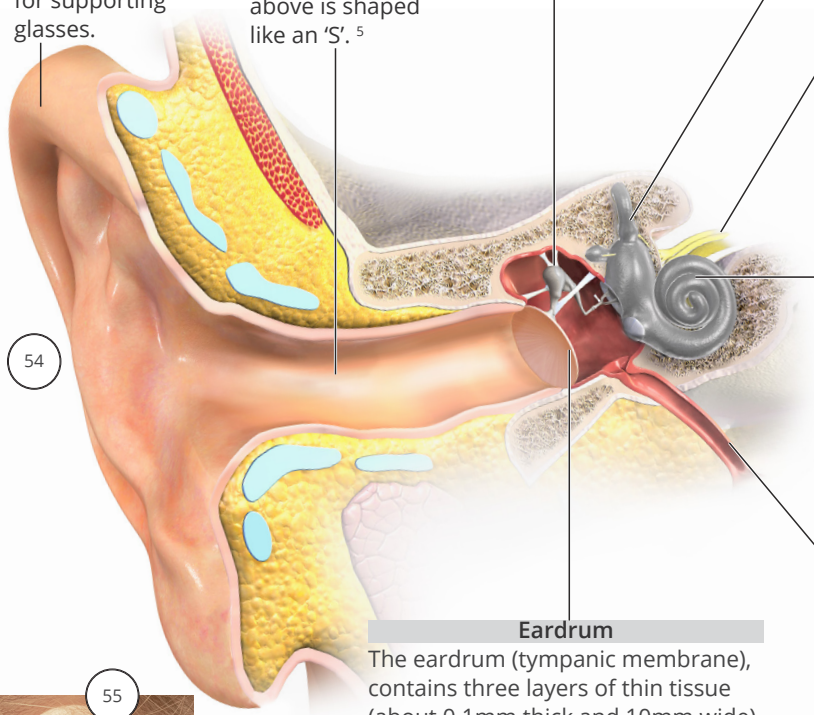
Pinna (auricle)
Provides cues to help the brain locate the direction of sounds, and funnel them into the ear canal. The pinna is also useful for supporting glasses.

Ear Canal
Approximately 25mm long, and 7mm in diameter. The canal is not straight, has a kink in it, and from above is shaped like an 'S'. [5]

Ossicles
Hammer, anvil and stirrup suspended by stabilising ligaments working as a lever or a piston, providing an amplification and impedance-matching system normally in an air-filled cavity. [58]

Semicircular Canals
For balance and motion.

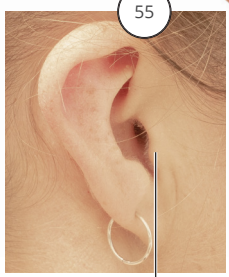
Auditory Nerve
Transports electrical signals from the cochlea to the brain.



Cochlea
Contains 18,000 hair cells in a fluid-filled cavity that produce and send electrical signals to the brain that we interpret as sound.

Eardrum
The eardrum (tympanic membrane), contains three layers of thin tissue (about 0.1mm thick and 10mm wide) and responds to sound vibrations funnelled through the outer ear much like a microphone diaphragm. The eardrum can detect vibrations smaller than half the diameter of a hydrogen atom.

Eustachian tube
Like a valve, the eustachian tube equalises the pressure inside the middle ear with the air pressure outside the body. [5 58]



Tragus
Helps collect sounds from behind and is an effective noise-blocking mechanism when directed over the ear canal by a finger.

54 Ear anatomy

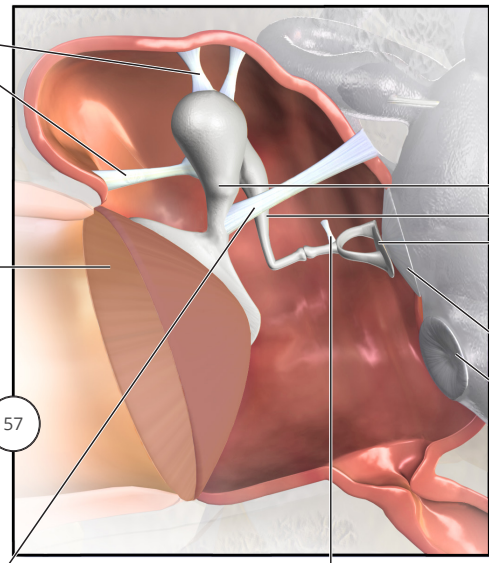
55 Tragus

"If it sounds right, it IS right."
- Joe Meek

THE MIDDLE EAR

Without the middle-ear converting sound energy vibrations, 99.9% of the collected sound energy would be reflected and lost as energy moves from an air-filled cavity to a fluid-filled cavity. [5 58]
The ossicles transfer the small vibrations from the eardrum's large surface area into vibrations 20 times larger over the smaller-surfaced oval window of the cochlea. [5]

Malleus ligaments
Supports the malleus in place and helps to damp the ossicle response to loud sounds.



57

Eardrum
(Tympanic Membrane)

Tensor Tympani muscle
Stiffens in anticipation of loud sounds above 500 Hz, as a protective mechanism. [49]

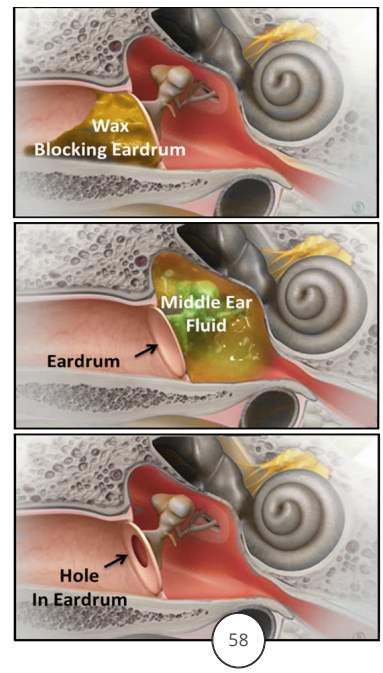
Stapedius muscle
Smallest muscle in the human body (1 mm long) stiffens in 15-20 second bursts in response to loud mid to low frequency sounds, as a protective mechanism. [5 49 58]

56

Ossicles
Malleus (hammer)
Incus (anvil)
Stapes (stirrup) - smallest bone of the human body connecting with the oval window of the cochlea.

Oval window

Round window



58

"

"People don't come to hear me mix, they come to hear the act. I want to present artists as they are. Hopefully, I'm just turning up what they're doing."
- Dave Natale, FOH engineer

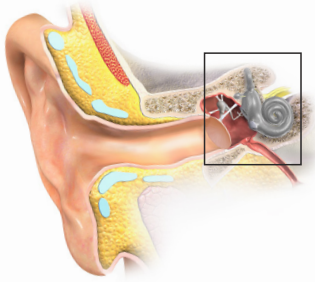
56 ossicle size comparison

57 middle ear cross-section

58 conductive hearing loss

THE INNER EAR (THE LABYRINTH)

Sound vibrations travel along the ear canal, vibrating the eardrum, activating the middle-ear bones. The footplate of the stirrup then transfers sound energy through the oval window into the bony, fluid-filled cochlea. [5]

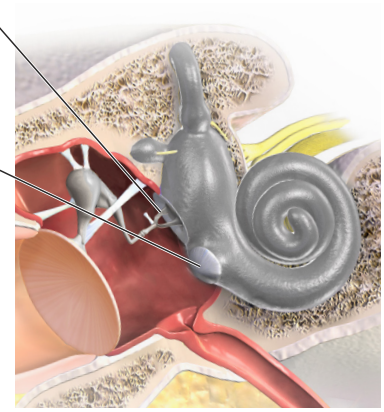


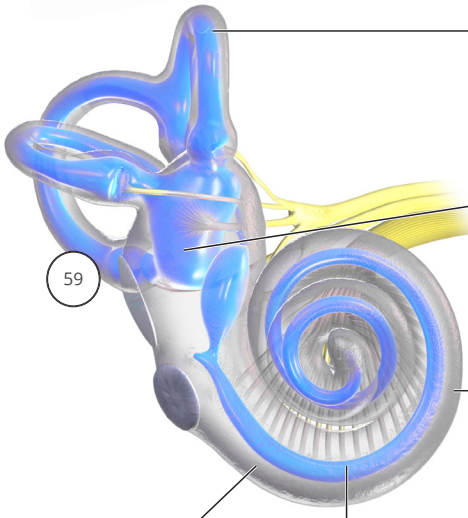
View

The stapes (stirrup)
The smallest bone of the body, transfers sound energy into the cochlea via the oval window. [5]

Round window
Allows the fluid inside the cochlea to move as the stapes pushes and pulls (containing a secondary vibrating tympanic membrane). [5]

inner ear

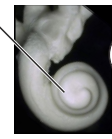




Semicircular Canals
Detects rotational acceleration when we turn our head for equilibrium - balance and spatial orientation. [5]

Vestibule
Detects linear acceleration, like gravity and can also be stimulated by very loud sounds (mainly < 300 Hz). [4] [45]

Cochlea
Where sound vibrations are converted to nerve signals.



actual size
approx. 9 mm
diameter

Bony Labyrith
Membraneous Labyrith

59 vestibular system

60 cochlea - actual size

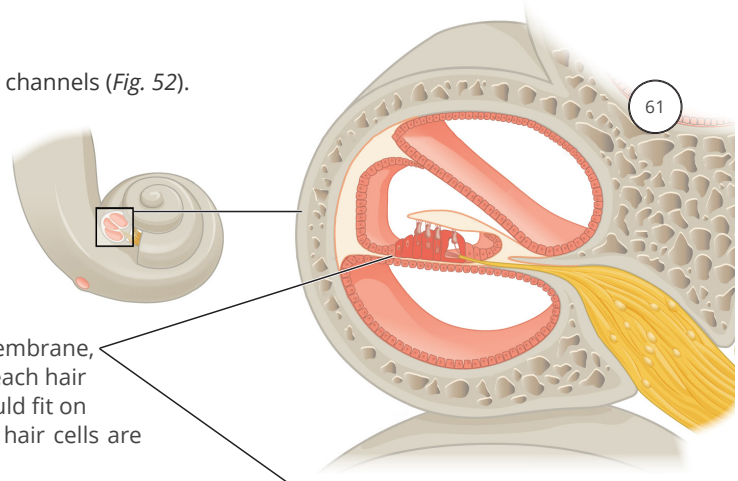
"

"Anybody can provide equipment; it's the way you implement that equipment and the attitude you have that makes for a successful event."
- TC Furlong, founder/owner

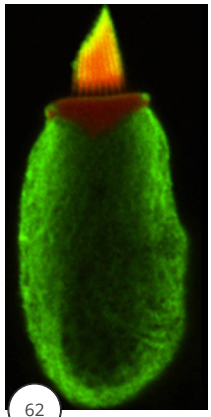
INSIDE THE COCHLEA [5]

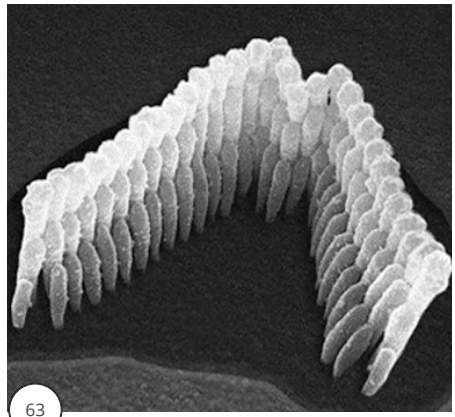
(Cochlea - translated from Greek as 'spiral snail shell')

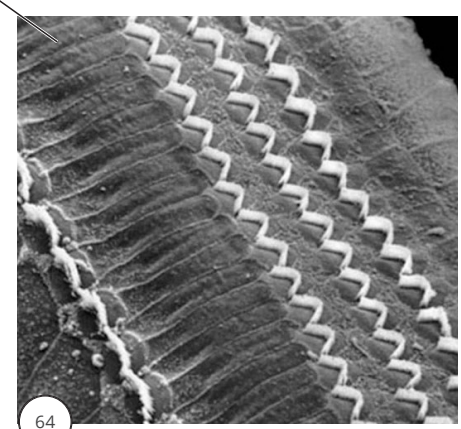
Within the cochlea there are three main channels (*Fig. 52*).



In the middle cavity along the basilar membrane, are housed 18,000 hair cells (*Fig. 60*). If each hair cell could be brought together, they would fit on the head of a pin. On the top of these hair cells are hair bundles (*Fig. 61*).







The three rows of 'outer hair cells' on the the basilar membrane (*Fig. 62*) amplify sound vibration by a factor of 1000 (much like a 'pre-amp') so that the single row of 'inner hair cells' can more effectively process most of the sound vibrations. When sound vibrations enter the cochlea fluid, the hair bundles 'dance', elongating and contracting, bending and swaying in the inner-ear fluid like ocean seaweed. [5 37] The cells in the lower part of the cochlea closest to the oval window and stapes respond to high frequencies. [5] Further along and closer to the cochlea's apex, the basilar membrane is wider and more flexible and responds to lower frequency sound vibrations. In healthy young people, the normal hearing range is between 20Hz and 20kHz. [5]

"

"Mixing sound in the live realm is not rocket science. In fact, it's probably closer to voodoo."
- Dave Rat, FOH engineer, Rat Sound

60 cochlea cross-section

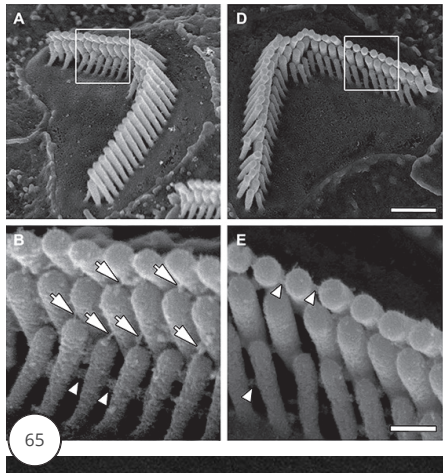
62 single hair cell

63 hair bundle

64 hair bundles on basilar membrane

THE COCHLEA TO THE BRAIN

As the hair cells move, calcium and potassium enter the hair cell and allowing the release of neurotransmitters. The neurotransmitters stimulate nerve endings which activate and send nerve signals to the brain that we interpret as sound. [5]



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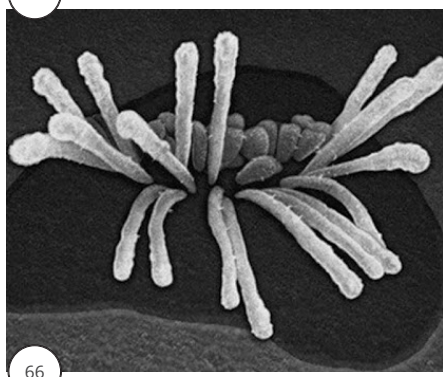

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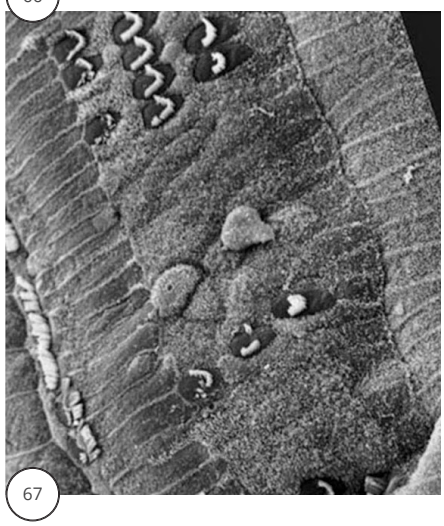


67

A TINY FRAGILE SYSTEM

The bundles on top of each hair cell consist of 40-80 'stereocilium'. Connecting the taller and shorter stereocilium are even tinier proteins called tiplinks (*Fig. 63*). [5]

This system is fragile and loud sounds can permanently damage these structures (*Figs. 64/65*). This kind of damage affects frequency discrimination and can introduce conditions like tinnitus.

Only birds, frogs and fish can repair or regenerate inner-ear hair cells. Humans cannot! [38]

65 tip-links

66 damaged hair bundle

67 damaged inner-hair cells on the basilar mebrane

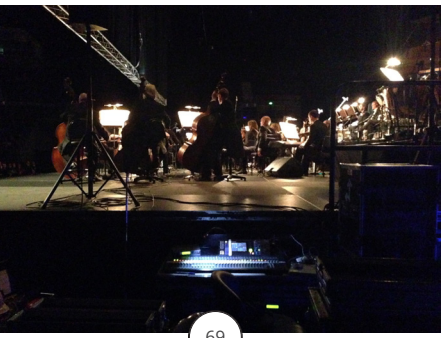
"

"Mixing is way more art and soul than science. We don't really know what we're doing. We've all been faking it for 40 years. We do it because we love music. It's what gets me going every day. It's the love of music first."
- Eddie Kramer

IN-EAR MONITOR (IEM) MANAGEMENT [59]

IEM use provides the wearer with benefits and risks:

- Custom moulded IEMs can provide good isolation, comfort and a desirable appearance.
- Wearing in-ear monitors in both ears appears louder than using a singular IEM. This effect is due to binaural summation, where 90dB + 90dB sounds like 96dB. Binaural summation also makes the bass sound 'fuller'.
- When only one IEM is worn, the wearer loses the summation effect and tends to turn the single IEM up.
- It is common for musicians using IEMs to set levels at the same volume as they experience foldback on wedges. Being isolated from acoustic sounds does mean that levels can be reduced.
- IEM wearers potentially can be trained to accept lower levels of sound over time, particularly as lower levels and shorter exposure times improve hearing longevity.
- Wearing headphones, IEMs, or earphones can increase hearing fatigue (TTS). [30]



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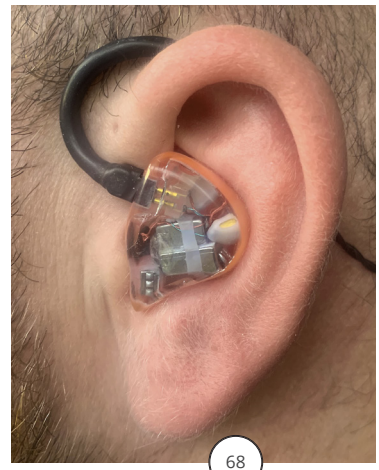


68

EARPLUGS

Balancing safety with the amount of audio level desired by the wearer, not every occasion requires earplugs that provide maximum sound isolation.

Earplugs follow a graded system to indicate the level of possible isolation possible. While foam earplugs can provide significant SPL damping, they are commonly not fitted correctly, which compromises their effectiveness.

Various musician earplugs profess a flatter attenuation so the wearer can still appreciate musical elements at a lower volume. Custom versions can be more visually discreet and comfortable to wear for extended periods.

"

"It's way easier to please 10,000 people than five musicians."
- Sean Sturge, monitor engineer

68 In-Ear Monitors

69 CSO, Pirates of the Carribean, Monitors, Christchurch, NZ (SC Monitors)

70 An Assortment of Earplugs

HOW TO FIT EARPLUGS

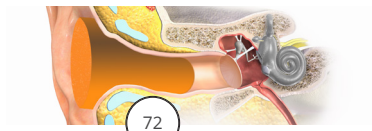
When using earplugs, obtaining a good seal is essential to achieve the sound isolation required.

For foam-type earplugs, **ROLL** into a small thin 'snake' with fingers using one or two hands.

PULL the top of the ear up and back with the opposite hand to straighten out the ear canal. The rolled-up earplug should slide right in.

HOLD the earplug in place for 20-30 seconds until it fully expands to fill the ear canal. A gentle pull on the plug will test the fit and the seal.

71



72

Fitting Foam Earplugs

Foam Earplugs Fitted

Afterwards, remove the earplug carefully so as to not damage the skin on the walls of the ear canal.

"

"There are two approaches to mixing monitors: the 'taking it to a fine art' approach, and the boxing gloves approach."
- Michael Prowda, monitor engineer

SECTION 4

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PS. AUDIO ENGINEER MEMES:

- Puts $10,000 worth of gear into a $500 car to drive 100km to $50 gig.
- Nobody notices what I do until I don't do it.
- Not a magician but I can see why you might be confused.
- Someone who does precision guesswork based on unreliable data provided by those of questionable knowledge.
- I solve problems you don't know you have in ways you can't understand.
- Because 'Bad-ass Problem Solver' is not an official job title.
- When the sound is good, don't ask for the name of the speakers, but the name of the guy that optimised and integrated the system.
- No matter how great the band, if the sound guy sucks, the band sucks.
- Mumbling along to a song you don't really know ... but that 15 second part you do know is coming and you're gonna nail it.
- God made audio engineers because musicians need heroes too.
- And they said the bass didn't feel right so I pretended to turn knobs until they liked it.
- With great power comes great responsibility.
- Passive speakers: "...fine, whatever..."
- A huge shout out to those that dance near the speakers.
- Making musicians sound talented.
- Every machine is a smoke machine if you operate it wrong enough.
- Breaking news: Lead singer helps unload gear. The drummer is now ready for soundcheck on time.
- I am the sound guy but that doesn't mean I can make your band suck any less.
- No ... I don't have any gaffer tape.

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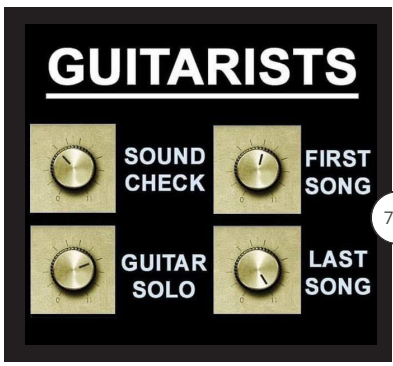

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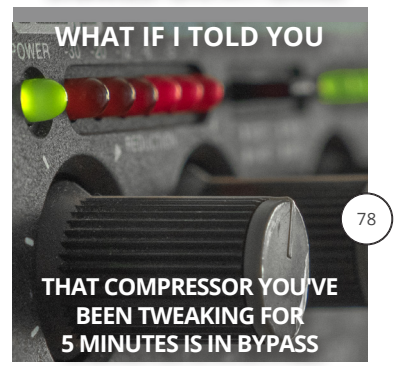

78

79

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THE AUTHOR

I have been fortunate to have audio engineered over 75 professional seasons of theatre, as well as recorded, sound designed, engineered, and assisted in thousands of live events.

I have been a professional audio engineer and was technician/lecturer at the School of Music, University of Canterbury between 2003 -2022, freelancing live, recording and post-production audio and video. Since 2022, I am as Acoustic Consultant with Marshall Day Acoustics, Christchurch, NZ.

I enjoy sharing live-sound techniques, listening skills, and hearing management principles to live sound participants: professional and volunteer audio engineers, university and high school music and music tech students, and the public.

My desire is to enable audio engineers and musicians to manage their hearing for the betterment of their craft, work, health, finances, socialising, and their general enjoyment of music by encouraging a balance between artistic integrity, audience satisfaction and safety.

Dr Stephen Compton
stephencompton@classaudio.co.nz

CONTACTS AND RESOURCES

Talking Through the Effects of Hearing Loss:

Hearing NZ	www.hearing.org.nz
NFDHH	www.nfd.org.nz
NZAS	audiology.org.nz
	0800 625 166
Lifeline Helpline	0800 543 354
Anxiety	depression.org.nz
Anxiety Line	0800 ANXIETY

0800 (2694 389) Further Resources and Training Materials:

Hear-it	www.hear-it.org
Dangerous Decibels	dangerousdecibels.org
NZAS	audiology.org.nz
Class Audio	classaudio.co.nz

"O, it is excellent
To have a giant's strength, but it is tyrannous
To use it like a giant." Shakespeare