Safe listening in video gaming & esports

A World Health Organization background study

World Health Organization

This report is a compilation of available safe listening in video gaming and esports activities, based on systematic scoping review of literature, international online gaming survey and stakeholder interviews. The review has been undertaken by Mr Peter Mulas in collaboration with WHO and ITU.

Authored by:

Mr Peter Mulas

Consultant, World Health Organization

Reviewed by:

Dr Shelly Chadha

Technical Lead, Ear and Hearing Care

Department for Noncommunicable diseases,

World Health Organization Geneva, Switzerland

Dr Carolina Der

Technical Officer, Ear and Hearing Care

Department for Noncommunicable diseases,

World Health Organization Geneva, Switzerland

Contributors:

Dr Lauren Dillard

Postdoctoral Fellow

Medical University of South Carolina

Dr Nicola Diviani PhD

Senior Research Fellow Swiss Paraplegic Research

Lecturer at University of Lucerne

Contents

Glossary....4

Acronyms....7

Executive Summary....8

1. Introduction....11

2. Purpose and scope of this background paper....24

3. Component 1: Systematic scoping review (Dillard et al., 2023)....25

3.1 Purpose....25

3.2 Method....25

3.3 Results....25

3.4 Conclusions....29

4. Component 2: International online survey of gamers and esports participants (Diviani et al,. 2023)....31

4.1 Purpose....31

4.2 Method....31

4.3 Results....31

4.4 Conclusions....34

5. Component 3: Stakeholder interviews....38

5.1 Purpose....38

5.2 Methodology....38

5.3 Results....39

5.4 Conclusions....60

6. Discussion....64

7. Looking to the future....69

8. Bibliography....71

Glossary

Audiometric threshold

A measurement of the lowest intensity level a person is able to detect for a specific tone or frequency

Distortion Product Otoacoustic Emissions

An objective measurement of hearing function which aims to detect low-level sounds emitted from the cochlea in response to two closely spaced stimulating tones

Casual Gaming

Simple, accessible video games with easy controls, short playing sessions, and wide appeal, often found on mobile device platforms.

Console

A dedicated hardware device designed for playing video games, for e.g., Sony PlayStation or Microsoft Xbox.

Esports

Competitive gaming at a professional level in an organized format (a tournament or league) with a specific goal (i.e., winning a title/prize money) and a clear distinction between players and teams that are competing against each other.

Esports Athlete/Pro Gamer

An individual who competes in esports at a professional level

Game Developer

A game developer is a software developer specializing in video game development – the process and related disciplines of creating video games.

Gamer

A gamer is a person who plays video games as a hobby or profession.

Gaming

The activity of playing games on computers and other electronic devices, whereby the player controls moving pictures on a screen, typically by pressing buttons on a controller device

Gaming Hardware

Refers to any gaming components, devices or operating systems that allow for the installation of game software.

Gaming Software

Refers to the game titles that are installed and played on consoles, personal computers and mobile devices to provide entertainment, competition and/or practice for gamers.

Live Streaming

The practice of broadcasting video game content in real-time over the internet to an audience of viewers

Mobile Gaming

Mobile gaming refers to playing video games on mobile devices, such as smartphones, tablets or handheld style gaming devices.

Operating System

The computer software that manages and controls the hardware resources of a computer or gaming console and provides a platform for running video games and other software applications.

Platform

An established computer system specifically made for playing video games

Pro Gaming

Competitive playing of video games at a high level for monetary gain or recognition

Safe Listening feature

Any addition to a game or system that is designed to reduce the risk of sound-induced hearing injury. Such a feature may do so by reducing the sound level and/or, reducing the duration of exposure; and/or reducing the frequency of exposure (i.e., being exposed less often).

Screen time

Screen time refers to the amount of time that an individual spends looking at a screen, such as a computer monitor, television, smartphone, or tablet.

Sensorineural hearing loss

Hearing loss that is caused by damage to the inner ear structures; typically, permanent and often caused by noise exposure.

Sound Designer

A sound designer is a professional who is responsible for creating and manipulating sound effects and music for various media, such as film, television, video games, and other forms of multimedia.

Tinnitus

Tinnitus is the perception of sound in the absence of an external source. The most common symptom is a ringing sound in the ears, but it can also be described as buzzing, hissing, roaring, or clicking. Tinnitus can be mild or severe, and it can be constant or intermittent.

UX Design

The process of creating the user experience (UX) for players when interacting with a video game. It involves designing the elements and interactions within the game to provide an enjoyable, engaging, and intuitive experience for players.

Virtual Reality (VR)

In the context of gaming is a simulated environment that allows users to interact with a virtual world using a headset or other device. VR games are designed to provide a realistic and immersive experience and can be used to create a variety of different gaming experiences, such as first-person shooters, racing games, and role-playing games.

Acronyms

AV – Audio/Video

CI – Confidence Interval

FPS – First person shooter

HDMI – High-Definition Multimedia Interface

ITU – International Telecommunication Union

PC – Personal computer

WHO - World Health Organization

Executive Summary

In March 2015, WHO launched its initiative to Make Listening Safe, based on the estimate that over one billion young people across the world could be at a risk of hearing loss due to their unsafe listening habits[1] https://www.who.int/activities/making-listening-safe.

Following the WHO-ITU Joint stakeholders' consultations on safe listening, it was agreed to conduct a background study on gaming, to establish what risks to hearing exist for those who take part in video gaming and esports activities. This background study is a compilation of available information on the current state of safe listening within gaming and esports, compiled by Mr. Peter Mulas, under the review of Dr. Shelly Chadha, Technical Lead for Ear and Hearing Care (WHO). It comprises three parts, (1) summary of a systematic scoping review, (2) brief results of an online international survey of gamers and esports participants and (3) anonymized analysis of interviews with gaming and esports industry stakeholders.

The key points from the report are summarized as below:

A systematic scoping literature review conducted as part of this background study revealed that:

- Published evidence on the topic of gaming, esports and risk to hearing is limited.
- Games are often played at sound levels and for lengths of time that exceed permissible exposure levels, and gaming has been associated with poorer audiometric hearing thresholds and tinnitus.
- Therefore, evidence available from scientific and grey literature indicates that gaming may be a source of unsafe listening and thus could put gamers worldwide at risk for permanent noise-induced hearing loss and/or tinnitus.

An international online survey of gamers and esports participants (n = 488, mean age = 28.4, 92 countries) undertaken as part of this background study revealed that:

- Sound is considered important during gaming; however protective hearing behaviors are not widely practiced.
- Less educated respondents and those who spend more time gaming tend to have higher volume settings, and almost half of respondents report auditory symptoms related to hearing damage, including tinnitus and fullness of ears.

[1] Unsafe listening refers to the common practice of listening to recreational sounds (e.g., music) at loud volume or for prolonged periods of time.

- Participants are aware of the risks of hearing loss associated with gaming and esports but perceive their susceptibility to it as relatively low.
- Perceived barriers to hearing loss prevention include the belief that reducing volume would limit gaming enjoyment, despite players' confidence in their ability to modify listening behavior.
- Participants show varying levels of readiness-to-change, with more educated participants being more likely to take action to prevent potential hearing loss.
- Targeted education and intervention programs are needed to promote safe listening habits among gamers and esports participants; respondents indicate trusted sources of information are healthcare professionals, governmental or international agencies, device instruction manuals, and dedicated websites.
- Healthcare professionals, governmental or international agencies, and the gaming and esports industries should play a role in promoting safe listening habits.

A series of interviews with various stakeholders within the gaming and esports field revealed that:

- Most stakeholders had limited awareness of specific safe listening features in video games, often citing features meant for different purposes that could be used to improve listening safety instead.
- Most stakeholders lacked knowledge about safe listening regulations or standards in gaming and esports. Some commonly provided examples included local regulations for live events (applicable to some esports events), occupational health and safety or labor laws for professional gamers and global standards for headphones such as EN IEC 62368-1.
- Hardware-level implementation of safe listening features was preferred by participants, although some features at the game software-level were discussed. Educational programs and endorsements from esports professionals and medical practitioners were seen as beneficial.
- Participants expressed positive attitudes towards the willingness of gaming and esports industries to implement safe listening features, if they don't compromise entertainment or immersion.
- Barriers to implementation included poor user experience, technical constraints, gamer indifference, developer redundancy, competitive forces, and financial considerations.

Conclusions

- Existing evidence available from scientific and grey literature suggests video gaming activities are a source of unsafe listening. Considering recreational sound exposure from comparable personal listening devices shows 24% of young adults are at risk from unsafe listening practices, should similar trends exist within video game activities, and the combined total of 1.7 billion PC and console players, there are potentially hundreds of millions of gamers at risk of hearing damage video game activities.
- Safe listening features and guidelines should be developed and implemented in video gaming and esports, focusing on risk mitigation by offering options to limit volume and inform users about safe listening practices.
- Such features and guidelines can potentially leverage existing global safe listening standards, such as WHO-ITU H.870 for personal devices and systems, and/or WHO Global standard for safe listening for live venues and events.
- Due to the complexity and variability of gaming devices and systems, the development of a coordinated approach from stakeholders is needed. This includes technical agreement from gaming and esports stakeholders on safe listening features within gaming systems and software, as well as safe listening promotion programs involving gaming associations, gaming federations, gaming and esports influencers, healthcare professionals, governmental and relevant international agencies, such as WHO and ITU.

Introduction

1.1 How excessive sound exposure affects hearing

Hearing damage caused by loud noise has been documented for over a century. Loud sounds can cause the sensory cells in the ear to become fatigued, leading to temporary or permanent hearing loss. Temporary hearing loss is characterized by muffled hearing or ringing in the ears (tinnitus), and it usually resolves within a few hours or days. However, prolonged exposure to loud sounds can cause permanent hearing loss, which is irreversible (WHO & ITU, 2019).

Hearing loss from loud sound exposure, also known as “noise-induced hearing loss” can have a significant impact on a person's quality of life. It can make it difficult to communicate, participate in social activities, and enjoy hobbies. In some cases, it can also lead to depression and anxiety.

Initially, noise exposure was considered an occupational hazard that may result in hearing loss and tinnitus. The study of the relationship between noise exposure and damage to the auditory system eventually led to the development of legislated workplace noise exposure limits in many parts of the world, based on sound dosage, i.e., sound level and duration. More recently, recreational noise has also been recognized as a potential hazard for hearing, and research into sound levels from a range of sources, including entertainment venues and personal listening devices (PLDs), has been undertaken, and the World Health Organization now estimates that more than one billion young adults are at risk of hearing loss due to unsafe listening practices from recreational sound sources (Dillard, et al., 2022).

1.2 Hearing loss prevention through safe listening

Safe listening refers to listening behavior that does not put an individual's hearing at risk. The risk of hearing loss depends on the level (loudness), duration (time period) and frequency of exposure to loud sounds (WHO & ITU, 2019).

In 2015, the WHO created the “Make Listening Safe Initiative”, a collaborative initiative aiming to change listening practices and behaviours through raising awareness and implantation of evidence-based standards that can facilitate behaviour change in target population groups (WHO, Make Listening Safe, 2023).

This initiative has resulted in the 2018 joint collaboration between WHO and the ITU to create safe listening standards and features for sound devices and systems (WHO & ITU, 2019), and

another standard was developed in 2022 for live venues and events (WHO, 2022) both being acknowledged as common sources of sound exposure for the public.

These standards outline recommendations to mitigate the risk of hearing damage from these recreational based activities whilst still enjoying the activity, using scientifically established safe levels of sound level exposure versus duration (also known as “sound dosage”). Safe sound dosage is understood to be 80 dB (A-weighted) for 40 hours per week for adults and 75 dB (A-weighted) for 40 hours a week for children (also known as “weekly sound allowance”.

The standards also use the ‘equal energy principle’, which states that the total effect of sound is proportional to the total amount of sound energy received by the ear, irrespective of the distribution of that energy over time – i.e., equal amounts of sound energy are expected to cause equal amounts of hearing loss, regardless of how and when the exposure occurs. The amount of energy doubles for every 3 dB increase in sound intensity. Hence, a person may receive the same “sound dose” listening to music at 80 dB (A-weighted) for 8 hours a day as listening to 100 dB (A-weighted) for 5 minutes.

Safe sound dosage (Adult)	**Safe sound dosage (Children)**
80 dB (A-weighted) for 40 hours a week	75 dB (A-weighted) for 40 hours a week
83 dB (A-weighted) for 20 hours a week	78 dB (A-weighted) for 20 hours a week
86 dB (A-weighted) for 10 hours a week	81 dB (A-weighted) for 10 hours a week
89 dB (A-weighted) for 5 hours a week	84 dB (A-weighted) for 5 hours a week
92 dB (A-weighted) for 2.5 hours a week	87 dB (A-weighted) for 2.5 hours a week

Table 1. Safe sound dosage based on equal energy principle.

1.3 Gaming as a source of sound exposure

Despite work in similar areas of recreational sound exposure, playing or viewing video games has not been noted as a significant avenue for sound exposure for the general public, despite video gaming becoming one of the most accessible and popular leisure activities across genders and age groups (Kiraly, et al., 2017), and at this time video gaming and/or esports activities have been omitted from WHO and ITU’s safe listening standards, pending further investigation which is the main motivation of this background paper.

Earliest examples of video games for entertainment purposes began as far back as 1958, when physicist William Higinbotham of the Brookhaven National Laboratory created the first interactive video game titled 'Tennis for Two' with the available laboratory equipment (Chodos, 2008). The first consumer video game console, the Magnavox Odyssey was launched more than a decade later in 1972 without sound capabilities, a feature not available until 1975's Atari 'Pong for home' system, which included a "sonar-blip" sound generated by the unit when the pong ball was hit (Chang, Kim, & Kim, 2007).

Today, gaming is a multi-billion-dollar industry; consumer spending in 2022 totalled $197 billion USD, and is predicted to reach $268 billion in 2023, and projected to continue rising (Statista, 2023). Game audio quality has also dramatically improved, thanks mostly to the development of computational processing power, memory capacity and speed. No longer constrained by hardware limits, modern gaming platforms support high resolution, multi-layered digital audio sound which can be received in 3D surround over speakers or wireless headphones, providing enhanced spatial dimensionality and improving immersion (Shuman, 2020).

Individuals who partake in video game activities are referred to as 'gamers', (Willaert, 2019). Currently surveys suggest there are more than 3 billion gamers in the world which includes casual, hobbyist and professional types of gaming on a range of different platforms including mobile, console and computers (Statista, 2022) with most surveys reporting the average age of a gamer being 31-35 years, depending on region (ISFE, 2022; ESA, 2022; IGEA, 2022). Gamers are predominantly male, however in certain regions the distribution is narrowing, for example in the United States, 44% of gamers are female (ESA, 2022). Whilst Asia is the largest gaming market in the world with almost 1.5 billion gamers, other regions demonstrate a higher percentage of gamers per population, with 50% of European and US populations identifying as gamers. (Jovanovic, 2023)

Once limited to communal game arcades, gamers can now access gameplay 24 hours a day, 7 days a week on a variety of devices and platforms, typically using fixed formats personal computing (PC gaming) or console (such as Microsoft Xbox or Sony PlayStation), with an approximate total of 1.7 billion gamers[2] regularly participating on these platforms (Newzoo, PC & Console Gaming Report, 2023). Mobile gaming formats have recently gained much popularity as a result of processing power, video graphics and battery efficiency improvements in portable devices (e.g., Android, iOS, Steam Deck, Nintendo Switch Lite etc.),

[2] Combined reported total of 1.1bn PC gamers and 611 million console players from 2022. Some gamers may play both platforms which would reduce the overall total (Newzoo, 2023).

with cloud-based gaming (e.g., GeForce Now) and futuristic leisure activity concepts such as the metaverse, which utilizes augmented reality (AR), virtual reality (VR) and spatial audio technologies to create a virtual environment.

This abundant cross-platform access combined with the social connection that gaming provides has led to a substantial upsurge in video game consumption, with gamers reporting that they play online games for more than eight and a half hours per week (Limelight Networks, 2021). Trends are also suggesting that both the average weekly playing time and binge-gaming are on the rise. Limelight networks (2021) reported a 14% increase in the average time individuals spent gaming from 2020 to 2021, and that one-third of gamers report binge-playing, continuous gaming over five hours, a 13% increase from 2020 to 2021.

Whilst these trends and figures show that video game consumption is on the rise, it's important to note that they mainly cover the behaviors of "casual" gamers; the popularity of gaming is such that a whole new market, "esports" and category of gaming participant, "spectators", who actively watch esports competitors both online and/or at live events now exist.

1.4 Esports and professional esport athletes

Esports has various definitions, but can be described as, "competitive and organized computer and video gaming, in which two or more parties (individuals or teams) face each other under regulated and balanced conditions" (Riatti & Thiel, 2021). Esports revenue exceeded 1.4 billion USD in 2022 and is projected to be a multi-billion-dollar industry from 2026 (Statista, 2023). Apart from this increasing market growth, esports is also gaining important credibility amongst the competitive sports industry with the International Olympic Committee (IOC) hosting an Olympic Esports Series in 2023, which some believe may pave the way for inclusion in mainstream Olympic games in future.

Competitive esports events exist as both in-person and online events (simultaneously and/or concurrently) and can attract many spectators. For example, the 2019 League of Legends World Championship Final attracted more than 100 million viewers worldwide over the entire event, with a peak online viewership of 44 million people and with 15,000 people at the live event itself (Webb, 2019). Other events, such as 'PGL CS:GO Major Antwerp 2022', reported the attendance of 20,000 people at its Final[3] (PGL, 2022). It is believed that the global esports

[3] *Attendance figures publicized by event organizer and not independently verified.*

audience, both occasional and enthusiast views, will reach more than 500 million by 2023 (Newzoo, 2022).

Gamers that compete in esports events are collectively referred to as professional or "pro-gamers" or "esports athletes", and reports estimate there are almost 20,000 active professional gamers globally (Gough, 2023). Like athletes of any sport, they may be amateur or professional (Freeman & Wohn, 2020) which affects the number of hours spent training for events. A general study of competitive esports players found that players practiced between 3 and 10 hours per day (Kiraly, et al., 2017). Another study of professional esports players reported an average 5.28 hours per day dedicated to training, although this figure could include physical exercise and not exclusively training through the playing of a video game (Kari et al., 2018).

The popularity of online gaming and esports is such that an entire new way to consume gaming has been created, in the form of video game "livestreaming" which refers to a real-time social media experience where one or a group of gamers publicly stream their video game session to an active online audience. Several online platforms exist to promote this format, including Twitch.tv, YouTube, Facebook Gaming, Huya Live, DouYu, and Bilibili (ISFE, 2021). This source of video game entertainment contributes to additional sound exposure for both gamers and livestream viewers, with average concurrent worldwide viewership of almost 2.5 million people at any one time for the Twitch platform alone (TwitchTracker, 2023), and gamers aged 18 to 35 reportedly spending an additional four hours a week watching other people play video games (Limelight, 2021).

With esports emerging as a lucrative industry with some competitions rewarding athletes with prize money akin to major sporting tournaments, there is extensive information regarding the health and wellbeing of esports athletes (Block & Haack, 2021, Ward & Harmon, 2019, Riatti & Thiel, 2021) as well as many studies that focus on the health consequences of gaming and esports activities (Kelly & Leung, 2021). However, while these studies explore many facets of gamer's and esport athletes' health, consideration of auditory health is reflected minimally in the literature.

1.5 Audio in gaming and esports

Audio is an important part of the gaming experience and can greatly enhance the immersion and realism of the game. A recent international survey, included as part of this background paper, showed the majority of surveyed gamers rate sound as being "very" or "extremely" important (Diviani et al, 2023), and other studies showed that sound, specifically sound effects

are critical for a game to be considered “good”, as game sound conveys both specific event information via sound effects (such as competitor location or calls to action for player input) and background music which is a key element with regard to conveying tension, danger or ambience (Andersen et al., 2021).

Influence of game genre on audio

Video games are often organized into different genres, a process which categorizes video games into similar characteristics and play styles. Game genres can often have different purposes for game audio and sound design, and thus the importance of game sounds, and their detection, will often be different from genre to genre.

For example, in one of the most popular video game genres, first-person shooters (FPS), the player controls a character from their first-person perspective, often using weapons to combat enemies and achieve objectives. FPS games are typically fast paced and visually dense, so game audio is used to provide important supplementary information that can be difficult to represent visually. This information can include the location of enemies, the player's health status, the gathering of items, speech prompts from in-game characters or other team members, environmental ambience, impairment from enemy tactics or devices, or alarms and warning sounds (Ng & Nesbitt, 2013); sounds that are so important to hear they can mean the difference between winning and losing, especially in competitive esports.

In contrast, in video games of the sports genre, which simulate real world sports, game audio and sound design is less about supplementary information delivery and more about immersion and excitement. Game audio for sports genre video games can include crowd noise, sound effects that indicate the actions of the players (for example the kicking or bouncing of a ball) and voice acting that provides commentary on the game, with music being limited to menu systems or between rounds.

Single player vs. multiplayer game style

Also, of importance is whether a game is single player or multi-player. “Single player” games refer to games that are designed for only one player to engage with the game's content, on their own. The player typically controls a protagonist or character and progresses through the game's story or objectives independently, without the involvement of other human players, although they may interact with game generated “non-player characters” (NPCs).

In single player games, the audio design often focuses on creating an immersive and cinematic experience for the individual player. The audio elements, such as background music, sound effects, and voice acting, are carefully crafted to enhance the storytelling, atmosphere, and emotional impact of the game. The audio cues and feedback are primarily tailored to the actions and interactions of the single player, providing important information and guiding them through the game's narrative or challenges.

“Multiplayer” games involve multiple players, typically human, interacting with each other within the game. Multiplayer games often offer cooperative or competitive gameplay experiences, where players can compete against each other in various game modes or activities.

The audio design in multiplayer games tends to prioritize real-time interaction and collaboration among players. Voice chat systems or in-game communication tools are often integrated to enable players to strategize, coordinate movements, or simply engage in social interaction during gameplay. The audio cues in multiplayer games may also emphasize player interactions, such as the sounds of footsteps, weapon fire, or character dialogue, to provide situational awareness and facilitate teamwork or competition.

Audio options from gaming devices

Earliest examples of gaming consoles and PC gaming used onboard or integrated speakers to generate sounds associated with the games that were loaded (Chang et al., 2007). Whilst integrated speakers are still used in smaller, portable handheld gaming units such as the Nintendo Switch Lite or Steam Deck, and in laptop computers, typically gamers will connect an audio output from the gaming console or PC to a separate sound reproduction system, such as a television, AV receiver or headphones, either by way of physical audio connection, or wirelessly via Bluetooth signal.

In the context of game audio, most common audio connection formats for gaming consoles and computer systems are as follows:

Signal type	Connection type	Purpose
Analogue (wired)	3.5mm audio jack RCA	Connection used for wired headphones and microphones Connects analogue audio signal to TV or AV receiver
Digital (wired)	USB type C	Connection used for headphones, microphones, sound cards etc.
Digital (wired)	HDMI Optical Audio	Connects digital audio and/or video information from console to a television or monitor Connects digital audio signal to AV receiver, TV, PC etc.
Digital (wireless)	Bluetooth	Connects digital audio from gaming system to wireless headphones or speaker system (e.g. soundbar).

Table 2. Commonly used audio connections for gaming systems

To access sound, gamers experience audio in one of two main ways, via loudspeaker, or headphones. However, within those two categories substantial variation exists, especially as some gamers may also opt to further enhance their audio quality by selecting higher quality headphones with higher impedance values or adding in intermediary audio accessories, such as headphone amplifier and/or sound card. The type of audio system used typically depends on the game being played, the competitive setting, the importance of audio cues to game success, and the equipment that is available.

Loudspeaker use in gaming and esports

Loudspeakers consist of integrated television or gaming unit speakers or standalone speakers as part of a stereo or surround array or sound bars. Sony, manufacturer of popular gaming console, PlayStation, estimates around 50% of console gamers utilize television speakers for game audio (Nair, 2015), and this is also reflected in a 2005 user survey on playback preferences completed by game developer Codemasters (Goodwin, 2009).

Loudspeakers typically provide a broader frequency range due to the inclusion of multiple drivers producing different ranges of sounds, and as such may be preferred to deliver more detail in gaming. Loudspeakers may also be preferable for gaming from a practical standpoint, especially if it is the only option available to a gamer as part of a television system.

Loudspeakers have some inherent limitations; they may be disruptive to others in the vicinity, and they may not provide as immersive an experience as headphones, which is why they are not used in esports competitions to deliver personal game audio. Loudspeakers are also subject to the acoustics of the room in which they are used, which can affect the quality of the

audio output and, in turn, the overall gaming experience. Listeners have been shown to prefer higher loudspeaker volume (measured as a 2 dB increase) when compared with listening to the same material over headphones (McMullin, 2017), suggesting there may be additional sound dosage risk when using loudspeakers as the method for game sound delivery.

Headphone use in gaming and esports

Gamers may also experience audio through headphones, or similar ear worn devices including earphones and ear buds. Many gamers opting for ear worn devices, use high-quality headphones specifically designed for gaming, which can provide immersive soundscapes and deliver three dimensional, spatially located audio using digital signal processing incorporating an acoustic filter representation of the human head and external ear (referred to as "Head Related Transfer Function"). This allows gamers to hear and perceive the location of important sound effects relevant to the game, for example footsteps, gunshots, and other in-game sounds with greater clarity and precision, which can give them a strategic advantage when gaming. Headphones also provide sound directly into gamer's ears, avoiding the potentially negative influence of acoustics and background noise. Elimination of background noise can be further improved using headphones featuring active and/or passive noise cancellation (Soel, et al., 2022).

The use of headphones brings an increased risk of sound dosage. Iannace et al (2020) showed that when using headphones, some gamers may listen at levels which exceed the lower limits of European Union's 'Directive 2003/10/EC (2003), exceeding average dosage levels of 80 dB (A-weighted) even sound exposure was supplemented with a rest break with low background noise. Studies have also established that the use of headphones with other media, such as mobile gaming applications, has been linked to subclinical hearing loss (Gupta et al., 2022).

Headphones are the preference of esports athletes, especially during competitive events. Esports athletes typically use circum-aural headphones to provide clear audio to receive needed information from in-game sounds. Headphones may also feature an additional microphone to facilitate inter-team communication. Additionally, some esports athletes wear both smaller, earphones and larger circum-aural headphones simultaneously; the smaller, inner earphones are used to monitor in-game sounds, while the larger, outer headphones are used to block out external noise (O'Neill, 2020).

Esports professional athletes also report that active noise cancellation is not effective for the speech-based noise, often found at esports events, such as the sound of the audience, thus

the larger, outer headphones in the dual set are often used to send broadband noise to the competitors, which is more effective than active noise cancellation alone. This dual headphone setup effectively masks distractions, provide optimum performance and ensures team communications are within competition limits (Get Hyped Sports, 2022), but can lead to other issues such as increased sound exposure, a loss of game audio sensitivity due to the continuous white noise, and some studies even advise against earphone use due to increased development of ear wax blockage (O'Neill, 2020. Emara et al., 2020)

Audio systems for large venue live esports events

Headphones for esports athletes make up only one part of a complex live esports event audio system. For large scale esport events, the audio system caters for three groups: (1) competition teams and associated staff, (2) audience and announcers (3) esports online broadcast and streaming personnel (O'Neill, 2020).

Audio system for competition teams and associated staff

The purpose of this audio system is to allow esports competitors to hear in-game audio, communications from their team members and communications from officials. It is vital that external sound from the audience, announcers, and other team is not audible as it could influence the outcome, which is why dual headphone/earphone systems are often used and some esports event organizers go to the extent of outsourcing management and operation of audio systems to guarantee they are not favouring one team over another (O'Neill, 2019).

As the source of noise at these events is typically speech based (audience noise) and dynamic in nature, active noise cancellation via headphones is often considered ineffective for esports live events. This is why esports competitors often opt for white or pink noise to be sent through their larger external headphones, and in some instances, players are isolated in transparent sound treated booths (O'Neill, 2020; Daley, 2019).

Audio system for audience and announcers

The purpose of the audio system for audience and announcers at an esports event is to provide the audience with a clear and immersive experience, by providing the audience a running commentary of what is happening during the event. Announcers are typically referred to as “shout casters” because they often shout to the audience to maintain a high level of tension during the event. The audio system is typical of a live venue event, with large format

loudspeakers, microphones, and mixing console, reproducing mostly audio signals from the game being played and shout casters.

As with any live event in a venue, esport event sound reproduction for an audience will be subject to local regulations regarding volume limits. Currently, there are no available studies that provide recorded sound pressure levels at large format esports events, however one online source reports measuring a peak level of 132.7 dB (C-weighted) from the audience at the 2017 Insomnia Gaming Festival (Roberts, 2017). Whilst sound pressure levels monitored over a longer period of time are much more common in determining whether a live event has exceeded volume limits, this particular event's peak level would exceed certain existing legislated peak limits from Switzerland (125 dB C-weighted) and Norway (130 dB C-weighted) (Tronstad & Gelderblom, 2016).

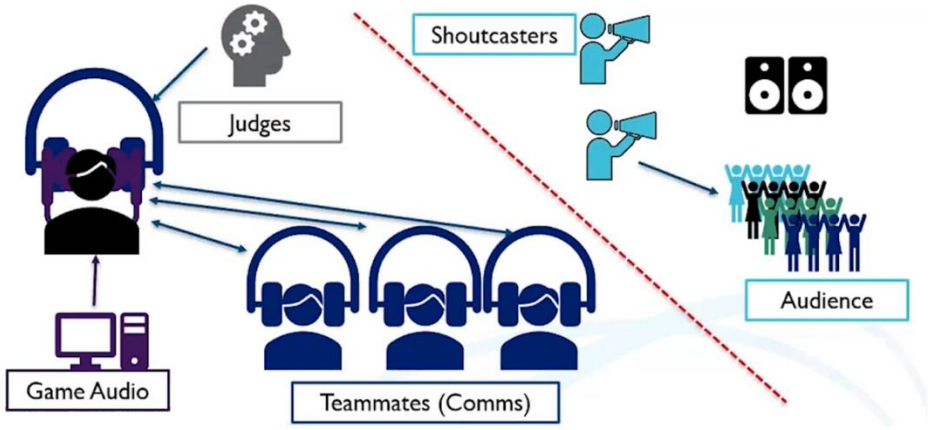


Figure 1. 'A diagram of audio challenges at Esports events. (Harman, 2020)

Audio systems for esports online broadcast and streaming

In situations where the esports event is also being simultaneously broadcast to an online audience, a separate audio system is used to mix audio levels from the esports event (game audio, team communications audio, shoutcaster/announcer audio, audience audio) to suitable levels for broadcast, typically to online platforms such as Twitch.tv or YouTube.

1.6 Existing WHO-ITU Safe Listening Standards

Whilst there is currently no universal standard for safe listening in video gaming or esports with respect to sound levels, exposure, or their measurement, WHO and ITU have published standards in related fields of recreational exposure:

H.870 WHO-ITU Guidelines for safe listening devices/systems

H.870 is a set of guidelines for safe listening devices/systems developed by the International Telecommunication Union (ITU) in collaboration with the World Health Organization (WHO). It was first published in 2018 and updated in 2022. The guidelines provide recommendations for the safe use of audio devices, such as smartphones and personal music players, as well as headphones, earbuds, etc, using a process called dosimetry, which measures the average sound dosage over a period of time.

Gaming content was specifically omitted from the H.870 standard due to (1) the complexity of gaming as an activity and sound source, which can involve a variety, dynamic audio signals and audio components and (2) at the time research on the effects of hearing from gaming was limited.

WHO Global standard for safe listening venues and events

This standard aims to establish a shared understanding of safe listening practices in entertainment venues and events, and consists of six key features that, when implemented, enable audiences worldwide to enjoy amplified music while safeguarding their hearing and maintaining the artistic integrity of the experience (WHO, 2022).

The features are as follows:

Feature	**Description**
Feature 1: Sound level upper limit: below 100 dB $L_{Aeq;\,15\,min}$	An upper limit of 100 dB $L_{Aeq,15\,min}$ is imposed keeping sound safe and enjoyable for the audience
Feature 2: Sound level monitoring	Live monitoring of sound levels is performed by a designated staff member using calibrated equipment.
Feature 3: Venue acoustics and sound systems	Sound system and venue acoustics are optimized ensuring safe listening and improved sound quality.
Feature 4: Personal hearing protection	Hearing protection, such as earplugs, with appropriate instructions, are available to audience members.

Feature 5: Quiet zones	Designated quiet spaces are available, allowing audience members to rest their ears and thereby decrease the risk of hearing damage.
Feature 6: Appropriate training and information	Both audience members and staff are made aware of practical steps they can take to ensure safe listening.

Table 3. Features of WHO Global standard for safe listening venues and events

The standard was developed for the protection of audience members from amplified music, with no consideration of esports events, however considering the similarities in audio experience for audiences, the WHO Global standard for safe listening venues and events does offer a potential framework for audience protection when attending a live esports event.

2. Purpose and scope of this background paper

From a public health perspective, several studies have associated video gaming and esports to consequential risky health behaviours such as sedentary lifestyle, repetitive strain injuries and internet gaming disorders (Kelly & Leung, 2021). With trends suggesting that average weekly playing time and binge-gaming are on the rise, and new forms of gaming-based sound exposure in the form of esports and game livestreaming being readily available, it is crucial that the listening habits of those participating in video gaming and esports is further investigated.

This paper aims to serve as a review of the current state of safe listening within gaming and esports activities, with a view to identify existing gaps in knowledge and practice, and to inform future steps to promote, encourage and motivate safe listening attitudes within gaming and esports industries, which may include development and implementation of the first universal standard for safe listening in gaming and esports with respect to sound levels, exposure and/or their measurement.

The scope of this paper covers insights from available relevant scientific data, user attitudes and stakeholder input from the gaming and esports industries to document the current state of safe listening within these activities. This background paper comprises of three main components:

(1) Systematic scoping review of available literature
(2) International online survey of gamers and esports participants
(3) Stakeholder interviews

3. Component 1: Systematic scoping review (Dillard et al., 2023)

3.1 Purpose

The purpose of the systematic scoping review study was to review available scientific and grey literature sources, to compile what evidence exists on the hearing risk in gaming and esports.

3.2 Method

A systematic scoping review followed the PRISMA-ScR guidelines and searched multiple databases and grey literature sources using specified search terms to identify studies published in English, Spanish, and Chinese that evaluated the relationship between video games, esports and hearing loss and/or tinnitus or mentioned gaming as a risk factor for hearing loss.

Titles and abstracts were screened by one reviewer, and full texts were screened by two reviewers. Data were extracted using pre-developed tables and data are synthesized in the results section below. Given the nature of this review, no critical appraisal of individual sources of evidence was conducted.

3.3 Results

A total of 63 non-duplicate citations were identified from the systematic search that focused on relationships between gaming and hearing or tinnitus. After the final review, 14 articles were included in this study.

Studies were from 8 countries, corresponding to representation from American (n = 2), European (n = 4), South-East Asian (n = 6) and Western Pacific (n = 2) regions. Twelve studies were published in English, and one was published in Korean and translated to English for review, and one was published in Chinese.

Studies that provide data on gaming loudness

Three cohort studies reported the loudness of gaming, as measured by a sound level meter (Shin & Kim, 2005; Wickasono et al., 2018; Yu & Han, 2016). In a study that focused on mobile device gaming, the average loudness of the games was 43.2 dB(A) (Yu & Han, 2016). In cohort studies focused on gaming centers, one study reported the average loudness to be 84.5 dB(A);

another study reported the minimum and maximum loudness to be >80 dB(A) and <90 dB(A), respectively (Shin & Kim, 2005, Wickasono et al., 2018).

Two cohort studies focused on the use of hearing protection during loud activities, including gaming, and reported that use of hearing protection is uncommon among gamers (Bhatt et al., 2017; Beach et al., 2016).

One study measured the sound output of headphones attached to a gaming console to describe the typical loudness experienced by users of 5 different video games (Iannace et al., 2020). Authors conclude that the daily level of noise exposure from video games will exceed maximum permissible levels based on EU regulations.

Two other studies aimed to evaluate sound levels in several game centers or arcades (Mirbod et al., 1992; Plakke 1983). Importantly, those two studies were conducted in years 1992 and 1983, and were based on arcade gaming systems, and thus may be limited in their comparability to modern gaming. All three studies described in this section additionally aimed to determine whether consistent exposure to these sound levels may exceed permissible levels of noise exposure.

Studies that provide data on gaming duration

Two cohort studies focused on gaming centers reported some details on duration of exposure. One study reported that on average, participants visited gaming centers for 3 hours per visit, and 5.2 times per month, and the other study reported participants used headphones in gaming centers for an average of 1-2 hours per visit (Shin & Kim, 2005; Wickasono et al., 2018).

Four additional cohort studies included details on the duration of exposure. Two studies, conducted using a large, school age cohort study (referred to as the OHRKAN study) (Dehnert et al., 2015; Dreher et al., 2018), reported participants played video games via headphones for a median of 3.1 hours/week (cross-sectional analysis) (Dehnert et al., 2015), and ii) for a mean of 3.1, 3.5, and 3.0 hours/week (longitudinal analysis) across three study cycles conducted over 5 years (Dreher et al., 2018).

In another cohort, authors reported among those who play video games, 14.4% play daily, 14.1% play 2-3 times per week, 30.5% play once a week, and the remaining 21.7% play once a month or less (Swerniak et al., 2020).

Lastly, in a study focused on gaming centers, authors reported that among those who visit gaming centers, 95% do so for at least 1 hour per day (Rhee et al., 2019).

Two studies evaluated differences in gaming behaviours between males and females. Taken together, results indicated that boys (vs girls) played video games more often, for longer periods of time, and at louder levels (Dehnert et al., 2015; Shin & Kim, 2005). No studies evaluated whether associations of gaming with hearing loss or tinnitus differed by sex.

Studies that provide data on prevalence of gaming

Five studies reported the prevalence of gaming in their samples. The prevalence of video game play ranged from approximately 20% to 78% (Dehnert et al., 2015; Dreher et al., 2018; Swierniak et al., 2020). Two studies conducted in the same cohort in South Korea reported the prevalence of use of gaming centers to be approximately 60% (Rhee et al., 2019; 2020).

A study conducted with data from nearly 37,000 participants of the household-based National Health Interview Survey (NHIS) extrapolated survey results on exposure to noise from video or computer games (defined as at least 10 exposures per year) to the general US population. Authors reported over 10 million individuals in the US may be exposed to loud or very loud noise from video or computer games (Bhatt et al., 2017).

Studies that report associations with hearing loss and/or tinnitus

Four studies evaluated associations or correlations of gaming with self-reported hearing loss (Beach), audiometric thresholds (Rhee et al., 2019, Wicaksono et al., 2018), or tinnitus (Rhee et al., 2020). Two of those studies presented associations after adjustment for relevant confounders (Rhee et al., 2019; Rhee et al., 2020), one presented unadjusted correlations (Wicaksono et al., 2018), and the modelling approach was unclear in one study (Beach, et al., 2016).

Two studies conducted in South Korean middle and high school students within the same cohort found that after multivariable adjustment, use of gaming centers (vs non-use) was associated with increased odds of severe tinnitus and increased odds of bilateral high frequency hearing loss but not speech frequency hearing loss (Rhee et al., 2019; Rhee et al., 2020). Furthermore, one of those studies reported individuals who used gaming centers for more cumulative time were more likely to experience high frequency hearing loss (Rhee et al., 2019). Another large cross-sectional cohort study reported that playing egames was associated with increased odds of self-reported hearing loss severity (Beach et al., 2016). Finally, another study reported a correlation between the number of gaming center visits per month and audiometric thresholds at 4.0 kHz in the right ear only but did not report whether hearing thresholds at other frequencies were measured (Wicaksono et al., 2018). That study

did not detect correlations of hearing thresholds with frequency or duration of earphone use or duration of gaming center visits (Wicaksono et al., 2018).

Studies that report associations with aural fullness

Aural fullness is an auditory symptom that often manifests as a feeling of ear pressure or clogging sensation and is often associated with hearing disturbances and/or related conditions such as Meniere's Disease and Sudden Idiopathic Sensorineural hearing loss (Park, et al., 2012).

This scoping review located one study that reported on association of gaming via headphones with aural fullness, but not with high frequency or speech frequency hearing loss (Zhang, Wang, & Chen, 2019).

No studies were found investigating hearing loss and esports

Importantly, no studies in this review focused on esports, either for the individual esports gamer, or for esports spectators, as a potential source of unsafe listening. This highlights an important gap in the scientific literature because esports gamers may be at particularly high risk of unsafe listening, as they play video games frequently and for many hours per day, and the competitive context provides motivation to listen more loudly. Given that esports are rapidly growing in popularity, research to understand the potential impacts of esports gaming on hearing, for both players and spectators is warranted.

Grey literature sources

Similarly, there were 14 grey literature sources (4 abstracts or conference papers, 4 newsletters or magazines, 1 letter to editor, 5 theses or dissertations) that mention gaming as a potential source of noise exposure, but do not cite relevant empirical evidence showing an association between gaming and hearing loss.

Additionally, one dissertation aimed to evaluate preferred listening levels of individuals while playing a video game through headphones, as well as the audiological implications of these listening levels (Layfield, 2016).

In this experiment, thirty individuals with normal hearing played a first-person shooter game for 20 minutes and used headphones set to their preferred listening levels. Results indicated that preferred listening levels ranged from approximately 60 to 90 dB SPL and there were significant increases to their audiometric thresholds at 2.0, 6.0, 8.0, and 12.5 kHz (averaged

across both ears) but not to distortion product otoacoustic emissions after game play. Authors conclude that gaming headphones can reach unsafe listening levels, which could place gamers at risk of noise-induced hearing loss.

3.4 Conclusions

The systematic scoping review showed in samples of children, gamers:

- Had 6% higher likelihood of self-reported hearing loss compared to non-gamers.
- Had 52% higher likelihood of self-reported tinnitus compared to non-gamers.
- Were more than twice as likely to have measurable high-frequency hearing loss compared to non-gamers.

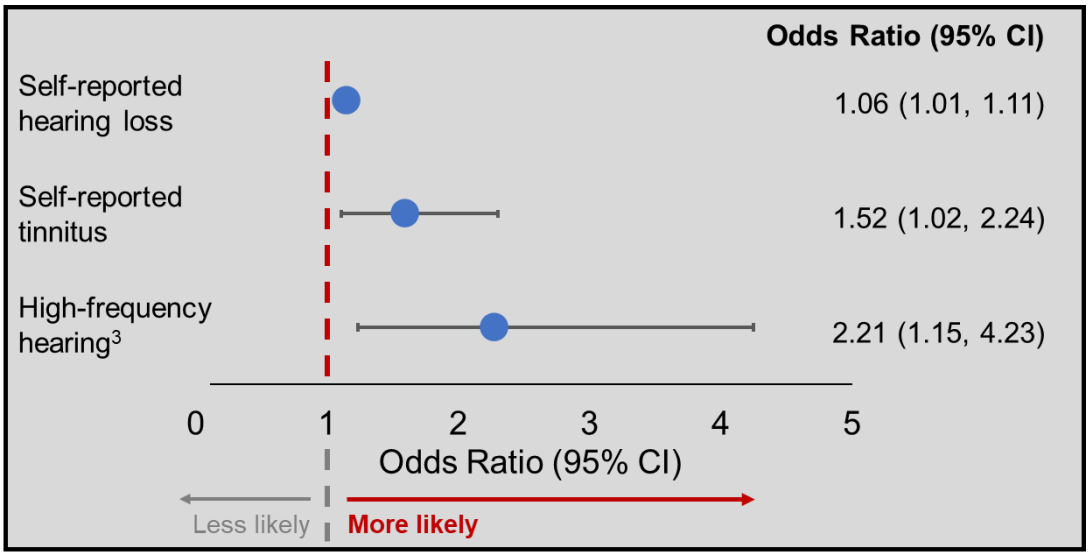


Figure 2. Odds ratios of auditory symptoms in samples of gamer children vs non-gamers (Rhee 2019, 2020, Wicaksono 2018, Zhang 2019; Dehnert 2015, Dreher 2018, Wicaksono 2020, Shin 2005, Yu 2016)

- Time spent gaming associated with higher odds of hearing loss.
- Boys played at louder volumes and for more time than girls
- Studies included in this review report an average weekly gaming duration of 3-4 hours/week for children and an average loudness of 85 to 90 dB (A-weighted). These durations and levels would exceed permissible sound exposure levels for children (Table 1).

[4] *Audiometric hearing (3.0, 4.0, 6.0, 8.0 kHz ≥15 dB, both ears)*

- Preferred listening levels in gaming, especially in FPS, may exceed acceptable sound exposure levels for adults and children, including peak intensity levels for children.

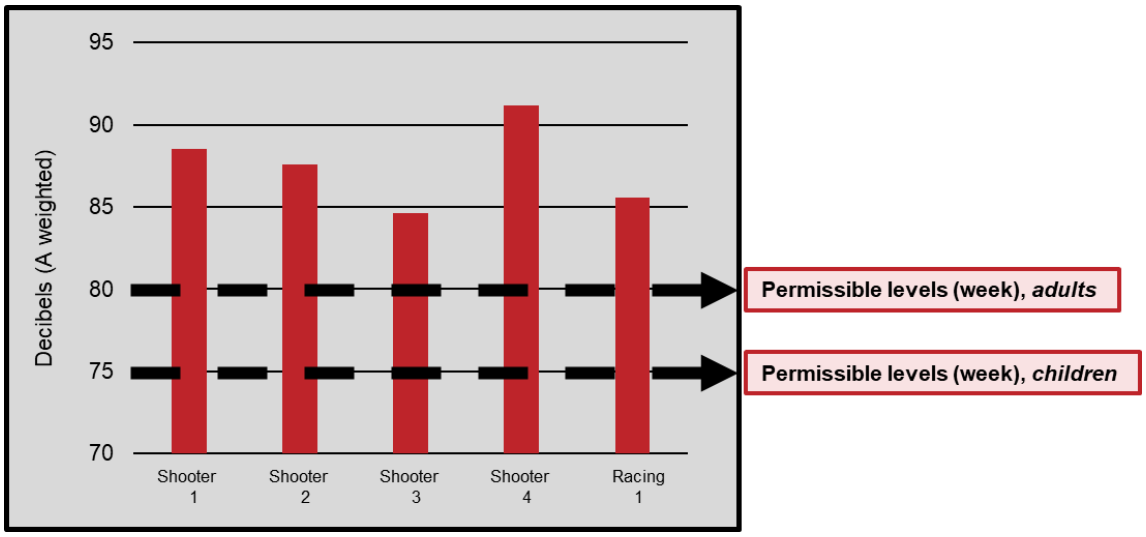


Figure 3. Average output of various game titles vs. permissible levels (Iannace, 2020)

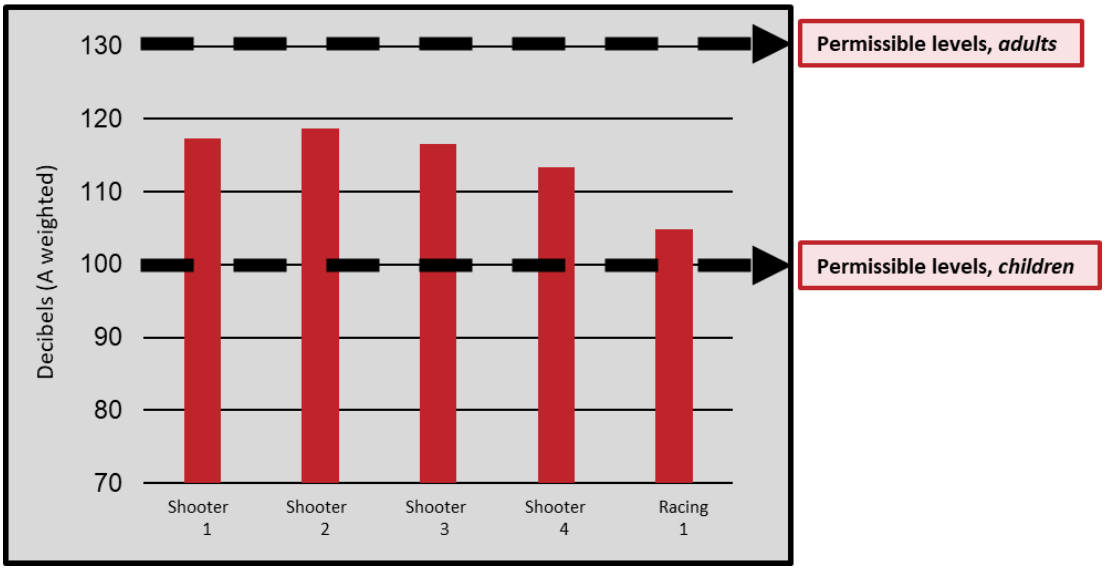


Figure 4. Peak output levels of various game titles vs. permissible levels (Iannace, 2020)

The limited available evidence collated in this systematic scoping review indicates that gaming may be a source of unsafe listening and thus could put gamers worldwide at risk for permanent noise-induced hearing loss, tinnitus, and/or other auditory symptoms.

Findings from this study highlight the need for additional research focused on risk of hearing loss from gaming. Furthermore, results indicate there is a need to prioritize interventions, such as initiatives focused on education and awareness of the potential risks of gaming, that can help promote safe listening among gamers.

4. Component 2: International online survey of gamers and esports participants (Diviani et al,. 2023)

4.1 Purpose

The purpose of this survey was to assess the listening behaviors, awareness, beliefs, and readiness to change among video gamers and esports viewers and players.

4.2 Method

A cross-sectional online survey was conducted among 488 participants from 92 countries. The survey included questions about video gaming and esports behaviors, related listening habits, protective behavior, consequences of listening, awareness and knowledge, beliefs, readiness to change, and communication needs and preferences. Multinomial logistic regression analyses were performed to assess the factors associated with being in one of three stages of change: pre-contemplation, contemplation or action.

4.3 Results

Demographic information

Of the survey participants, the majority were male (67.7%, n = 355), with an average age of 28.4 years (SD = 10.8). The highest level of education attained by most respondents was a high school diploma/GED (20.7%, n = 101) or a four-year college degree (21.9%, n = 107). Although respondents hailed from 92 different countries, the largest number of respondents came from the USA (14.3%, n = 70), followed by the UK (10.5%, n = 51) and India (8.2%, n = 40)

Participation and gaming duration summary

Of the participants, 90.8% engaged in video games (n = 443). Around one-third of participants (35.7%, n = 158) reported playing for up to 6 hours per week, followed by a second group (33.2%, n = 147), who played between 6 and 15 hours per week, and a third group (31.1%, n = 138) who played more than 15 hours per week.

More than half of the study participants (57.6%, n = 281 reported engaging in esports, with most of them only viewing (75.8%, n = 213) and approximately one-fifth (19.6%, n = 55) both viewing and participating. A small percentage (4.6%, n = 13) reported only participation. Among *viewers* (n = 268), the majority viewed monthly (29.5%, n = 79). Males were found to watch esports events more often ($p < .01$).

Participant perceptions on game audio

Most respondents engaged in video gaming indicated that game sounds are either extremely (37.5%, n = 166) or very (34.1%, n = 151) important when playing video games. Male respondents, on average, placed greater importance on video game sounds than female respondents ($p < .01$).

Esports viewers and players consider sounds in esports either somewhat (29.2%, n = 82), very (30.2%, n = 85), or extremely (24.2%, n = 68) important. On average, sounds were perceived as more important by younger respondents ($p < .05$) and by those with lower education ($p < .01$).

Participant average volume setting information

The average volume setting reported by participants engaging in video games was just below 50% (M = 47.6, SD = 21.3), with almost one in four respondents listening at high or very high volume (24.8%, n = 110). No significant differences were found across genders, ages, or educational levels. However, we observed that those playing videogames between 6 and 15 hours per week listened on average to a higher volume compared to those playing for less than 6 hours ($p < .05$)

The average volume setting reported for esports viewing or participation was slightly below 50% (M = 45.6, SD = 20.4) with almost one in five respondents listening at a high or very high volume (18.3%, n = 49). Participants with lower educational levels reported significantly higher volume settings ($p < .05$), while no significant differences were observed across gender or age groups.

Survey participant reports of auditory symptoms

Nearly half of the video game players reported experiencing a ring in their ears after playing (42.9%, n = 190), and over half reported fullness or fuzziness in their ears (53.5%, n = 237). Among esports players, 45.9% reported a ring in their ears, and 50% reported fullness or fuzziness.

Among esports *viewers*, less than one-third reported having experienced a ringing in their ears (30.6%, n = 82) or a feeling of fullness or fuzziness (30.2%, n = 81) after watching esports. Among esports *players*, this percentage increased to 46.3% (n = 31) for the ringing in their ears and to 50.7% (n = 34) for the feeling of fullness or fuzziness.

Participants rated the severity of hearing loss as high but perceived their susceptibility to it as low. Healthcare professionals and governmental or international agencies were the most trusted sources of information. Respondents expressed a keen interest in expanding their knowledge on hearing loss and safe listening.

Safe listening behaviour and awareness

Only about one-third of video game players (34.3%, n = 152) reported taking a break from sound every hour. Just one in ten (10.2%, n = 45) reported checking the sound dosage information provided by the gaming device. For esports players and participants, over one-third of them (37.7%, n = 106) reported taking an hourly break, and only a few reported checking the sound dosage (15.3%, n = 43).

The majority of participants rated the perceived severity of hearing loss as high (M = 5.84, SD = 1.31), while their perceived susceptibility to it was relatively low (M = 3.70, SD = 1.54).

Participants recognized the benefits of preventing hearing loss (M = 5.84, SD = 1.22), but also faced significant barriers to doing so (M = 4.53, SD = 1.56), such as the belief that turning down the volume would limit their enjoyment of video games and esports. Despite this, respondents demonstrated high confidence in their ability to modify their listening behaviour (Mean = 5.24, SD = 1.57).

Readiness to change

The study observed a balanced distribution of participants into the three readiness-to-change groups. Most of them (35.3%, n = 173) could be categorized as belonging to the “contemplation” stage, followed by the “action” stage (34.2%, n = 167), and the “pre-contemplation” stage (30.3%, n = 148)

Communication needs and preferences

More than half of the participants (n = 249; 51.0%) expressed an interest in expanding their knowledge on the topics of hearing loss and safe listening in the context of video gaming and esports.

While investigating the preferred channels for obtaining such information, it was found that no single mode was favoured, however noteworthy options included instruction manuals for gaming devices, dedicated websites, and user interfaces integrated into gaming devices.

Regarding trusted sources of information, respondents showed a clear preference for healthcare professionals and governmental or international agencies (e.g., WHO), while traditional media and religious leaders were among the least trusted sources.

Female respondents showed significantly more trust in governmental or international agencies ($p < .01$). Younger respondents showed more trust in healthcare professionals ($p < .001$), governmental or international agencies ($p < .05$), and producers of gaming devices ($p < .001$). Those with low education had significantly less trust in newspapers and magazines ($p < .05$), while those with a high education showed less trust in producers of gaming devices ($p < .05$).

4.4 Conclusion

Key conclusions of most relevance to this background study are as follows:

Reported gaming activity

A significant number of participants (90.8%) in the study reported actively participating in video games, highlighting the importance they placed on sound during gameplay. Notably, over half of the study participants (57.6%) were also involved in esports, primarily as viewers. Like video gaming, sound was found to be integral to the esports experience for most respondents. However, the study revealed differences in listening habits, indicating that individuals with lower education levels and those who spent more hours on gaming and esports tended to prefer higher volume settings.

Reported duration of exposure and volume settings

The survey results indicate that a significant majority of gamers (almost two-thirds) who participated in the survey spend more than six hours per week playing video games. Additionally, nearly one-third of the respondents reported playing for more than fifteen hours per week. These findings align with other reports that suggest the average global weekly gaming consumption is estimated to be around 8.5 hours. (Limelight Networks, 2021; Statista, 2022).

Participants in the study reported an average volume setting slightly below 50%, while 18% of respondents mentioned listening at high or very high volumes. It's important to note that this study couldn't provide specific average sound dosage amounts in equivalent dB SPL levels due to variations in audio equipment used. However, it's worth mentioning that the World

Health Organization (WHO) considers volumes below 60% of the device's maximum to be likely delivered at a safe level (WHO, 2015).

Gamers who played more frequently, specifically between 6 and 15 hours per week, were found to listen to games at higher volumes compared to those playing less than 6 hours per week. This observation highlights an intriguing trend that could be explored in future studies focusing on the actual sound dosage levels among gamers and esports professional athletes. By delving deeper into this area, valuable insights could be gained regarding the potential impact of extended gaming sessions on sound exposure and volume preferences.

Reported protective behaviour

Around one third of gamers and esports participants reportedly took regular hourly breaks during gaming sessions, and only 10% of gamers and 15% of esports participants reported checking the sound dosage information from their gaming devices. It is worth noting that respondents expressed concern that reducing the volume would diminish their gaming enjoyment. Considering these findings, promoting breaks during gameplay and implementing user-friendly features to allow gamers and esports participants to easily monitor their sound dosage could potentially offer an opportunity to reduce sound exposure without compromising the enjoyment derived from gaming.

Reported auditory symptoms

Almost half (43%) of the video games players reported having experienced ringing in their ears at least once after playing video games, and more than half (53%) have experienced fullness or fuzziness in their ears. Considering the association between tinnitus and noise-induced hearing loss, unsafe listening behaviour of respondents is possible (Le et al., 2017).

Perceptions and attitudes towards hearing and safe listening

The study found that gamers perceived their susceptibility to hearing loss as low, despite rating their understanding of hearing loss, and the severity of hearing loss as high.

The study observed a mixed readiness-to-change, with participants spread across contemplation, action, and pre-contemplation stages. More educated participants were more likely to be ready to act to prevent potential hearing loss, and those in the action stage reported lower listening volumes in video games.

Respondents from this survey also report healthcare professionals and governmental or international agencies play a significant role in providing trusted information to the gaming industry, and whilst no preferred communication channel was provided, respondents indicated they are amenable to information provided across a variety of channels including manuals for gaming devices, dedicated websites, and user interfaces integrated into gaming devices.

These results, combined with other results showing respondent interest in expanding their knowledge on hearing loss and safe listening, suggest a need for targeted education and intervention programs to promote safe listening habits among video gamers and esports viewers and players. Specifically, these programs should:

- Focus on increasing awareness of the risks associated with loud sound exposure and providing practical strategies for reducing exposure to potentially harmful sound levels.
- Suggest that healthcare professionals and governmental or international agencies should be utilized as trusted sources of information on this topic.
- Urge gaming and esports industries to play a role in promoting safe listening habits by incorporating sound dosage information and warnings into their products.
- Address the barriers to preventive action, such as perceptions that gaming enjoyment is reduced with volume reduction.

Limitations

This study has several limitations that should be considered when interpreting the results. First, the study relied on self-reported data, which may be subject to bias and may not reflect actual behaviours.

Secondly, the study was cross-sectional, which precludes causal inferences.

Thirdly, the study sample was predominantly male and may not be representative of the entire video gaming and esports community.

Fourthly, the study did not assess the use of noise-cancelling headphones, which may reduce the risk of hearing damage.

Finally, due to sample size and make up, the study cannot be considered extensively representative, however the study's focus on identifying associations allows it to be used to draw meaningful conclusions, especially as the consistency of our results with previous

studies on related topics should provide confidence in their validity (Diviani, et al., 2019; Diviani, et al., 2021).

Future research should address these limitations and investigate the effectiveness of educational interventions in promoting safe listening habits among video gamers and esports participants.

5. Component 3: Stakeholder interviews

5.1 Purpose

The purpose of this component was to gain an insight into current state of awareness regarding the risks of hearing loss due to unsafe listening, actions being implemented by concerned stakeholders for safe listening and understand their perspectives.

5.2 Methodology

21 interviews with 28 participants were conducted. The primary focus of these interviews was to explore topics related to safe listening practices within gaming and esports, as well as explore the various methods involved in creating, delivering, and consuming game audio, and the willingness for stakeholders to implement and use safe listening features should they be deemed necessary.

Recruitment

Stakeholders from the gaming and esports industries were invited to take part in short interviews. Upon receiving acceptance to take part in interviews, participants were provided with the main research questions and any other requested information.

Participants

Those that accepted represented the following gaming and esports stakeholder groups (with some participants representing multiple groups):

- Gamers (casual, amateur, and professional) (n=5)
- Game audio developers, audio directors and sound designers (n=6)
- Live esports audio system designers (n=1)
- Gaming hardware and accessory manufacturers (n=8)
- Academics with expertise in audio design, music technology, gaming audio, esports and/or digital culture (n=5)
- Esports physicians and sports psychologists (n=3)
- Representatives from software, gaming and/or esports associations (n=3)

Interview process

Interview participants were given a brief overview of WHO's Make Listening Safe initiative and the goals of the background study. The following questions were used as a guideline for

discussions, however on occasion, questions were adapted or supplemented to the interviewees area of expertise.

- What, if any, safe listening features currently exist in gaming devices and systems to protect the hearing of their users?
- What, if any, regulations, or legislations exist that ensure the safe listening of gamers and esports participants?
- What safe listening features could be implemented into video game products and esports events to promote safe listening features?
- What is the readiness (awareness and willingness to act) of the gaming and esports industry to promote safe listening and implement related listening features into their products and events?
- What are possible limitations and/or barriers to the implementation of safe listening features in gaming and esports products and events?

Data analysis

This study used thematic analysis in an open-ended way to investigate insights and perspectives from gaming and esports stakeholders on the topic of safe listening. Both consistent themes as well as unique but relevant answers to each question were established and are discussed below.

5.3 Results

Question 1: What, if any, safe listening features currently exist in gaming devices and systems to protect the hearing of their users?

Interviewees provided a variety of examples of existing listening features that they were aware of that can be categorized as either direct or indirect safe listening features.

Direct Safe listening features

Examples of safe listening features that participants considered to be specifically implemented as safe listening features were coded as ‘direct’ safe listening features. Such features include:

Text based safe listening features

A commonly reported safe listening feature was the inclusion of warnings within a gaming device’s user guide and/or manual. These warnings offer general hearing-related advice,

including recommendations of limiting volume intensity, exposure duration and may also give examples of symptoms that may occur if unsafe listening has taken place, for e.g., ringing or buzzing sounds in the ear (tinnitus). Some utilize standardized imagery, such as Example 1, displaying IEC 60417-6044 (Graphical Symbols for Use on Equipment).

Hearing Damage

- To prevent possible hearing damage, do not listen at high volume levels for long periods.

Example 1. Health and Safety Warnings user guide, (Left).
IEC 60417-6044 graphic symbol for use on equipment; avoid listening at high volume (Right)

- Permanent hearing loss may occur if the headset or headphones are used at high volume. Set the volume to a safe level. Over time, increasingly loud audio may start to sound normal but can actually be damaging your hearing. If you experience ringing or any discomfort in your ears or muffled speech, stop listening and have your hearing checked. The louder the volume, the sooner your hearing could be affected. To protect your hearing:
  - Limit the amount of time you use the headset or headphones at high volume.
  - Avoid raising the volume to block out noisy surroundings.
  - Lower the volume if you can't hear people speaking near you.
- Do not use the headset or headphones if they cause discomfort to your skin. If the headset or headphones cause discomfort to your skin, discontinue use immediately. If symptoms do not subside even after discontinuing use, seek medical attention.
- When using the headset or headphones in particularly dry air conditions, you may sometimes experience a small and quick (static) shock on your ears. This is a result of static electricity accumulated in the body, and is not a malfunction of your headset or headphones.

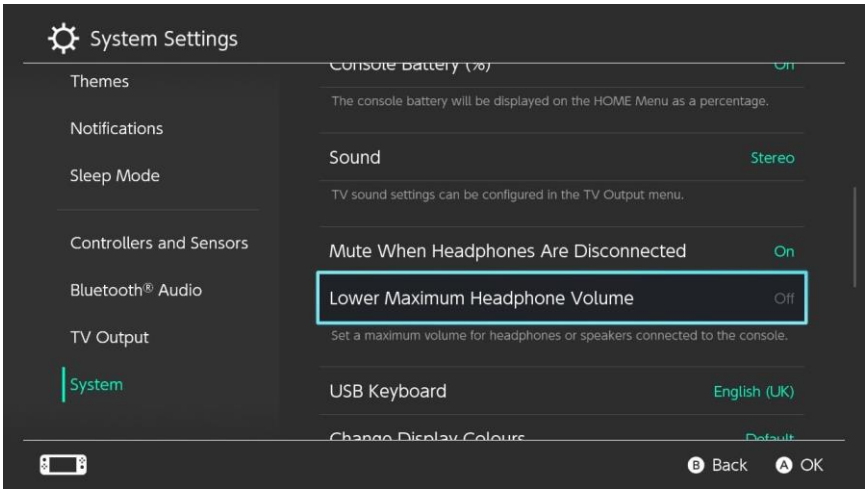
Example 2. Gaming console Safety User Guide

Volume based warnings and limits

Interview participants discussed several examples where a game and/or system will limit volume:

(1) On one gaming system, audio volume is restricted by default, and can only be changed via parental control menu access.

(2) Some systems provide the user with the ability to set a volume limit (Example 3), which when deactivated also provides a safety warning *"Be careful of the volume when using headphones. This may affect your hearing. Please set a volume where you can hear surrounding sounds, and refrain from use over a long period of time. If you experience abnormalities such as ringing in your years, seek medical care."*



Example 3. Maximum Headphone Volume limit setting

Some gaming systems provide a warning when volume is set too high or at maximum limits (Example 4).

⚠ WARNING **System Alerts**

For your protection, you should take immediate action when prompted by system alerts. The headset may provide you with the following alerts:

- **Overheating Alert.** An audible and visual alert in the event the headset is overheating. If that alert appears/sounds, to reduce the risk of personal injury, immediately remove your headset and let it cool down before continuing use.
- **Sound Volume Alert.** A visual alert in the event of high volume levels. If that alert appears, lower the sound volume to reduce the risk of hearing loss.

Example 4. Health and Safety Warnings user guide

Participants also offered examples related to mobile device operating systems (such as Android OS, available on mobile phone handsets and tablets) which when used for gaming which provide prompts and warnings when volume settings exceed a predetermined level, or a symbolic indication that the device is at its volume limit (represented by the volume indicator range turning red). These features are not specific to gaming activity on mobile devices, and as such occur whenever the device records volume levels that it deems are unsafe.

Headphone detection compensation

Interview participants reported safe listening features, available in gaming systems that attenuate volume upon detection of headphone use as a safety precaution, and for the comfort of the player, although a specific dB reduction was not supplied. This particular

feature works for all types of headphone connections, including wireless Bluetooth and wired/USB variants.

A specific in-game feature reported by two participants related to a listening feature called “headphone safety mode”, which is available in certain educational games designed for children on mobile devices.

Example 5. Headphone safety mode (activated on left, deactivated on right)

“Headphone safety mode” attempts to account for the potentially higher volume output of a set of headphones versus the integrated speaker on a mobile phone. When headphones are detected, the volume output of the mobile phone or tablet is programmed to drop by 5 dB automatically, and a visual indication appears on the screen in the middle of the screen.

Some headphones marketed as gaming products for children and teenagers also employ a volume limiter on the output of the headphone, attenuating signals to no louder than 85 dB SPL.

Example 6. Gaming headphones manufactured for children, limited to 85 dB SPL.

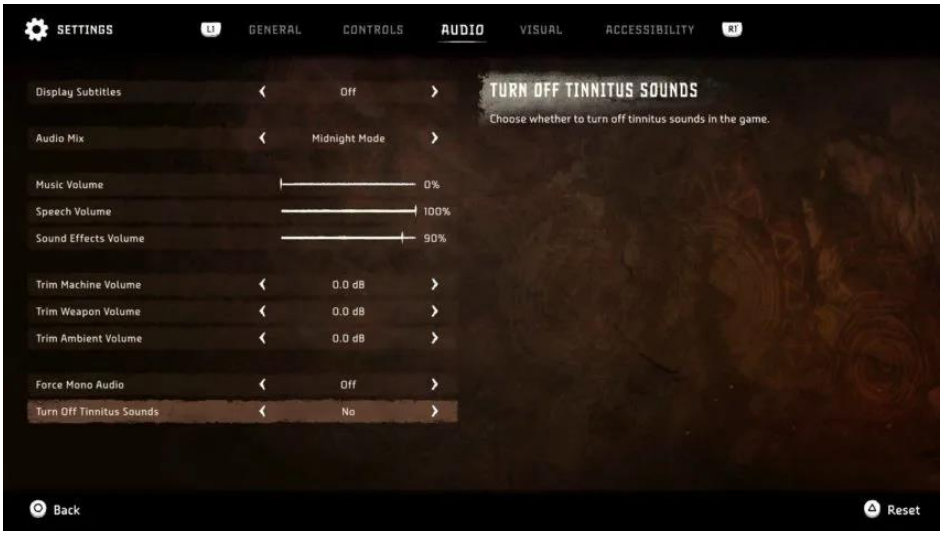
Interview participants with live esport event experience suggested in principle, any venues hosting esports events should abide by any existing live venue sound limit regulations, and as

such, these regulations serve as safe listening features, at least for audience members. In practice however, interview participants with direct experience with live esports events remark that volume limits were not considered during competitions.

Safe listening features related to Tinnitus

Some interview participants discussed the inclusion of specific features to reduce the chance of tinnitus occurring which can occur because of specific types of sound effects triggered within a video game. This phenomenon most commonly occurs in action or FPS styles of video games, where usage of certain weapons triggers high pitched sound effects which in turn causes a tinnitus reaction (Williams, 2022).

Some specific games offer an in-game feature to turn such features off, such as the "Turn Off Tinnitus Sounds" feature found in Sony Interactive's "Horizon Forbidden West". Another reported solution to ease tinnitus exacerbation was a software modification (also referred to as a "mod") which attenuates offensive frequencies that contribute to a player's tinnitus (Williams, 2022).



Example 7. 'Tinnitus sounds' setting menu example

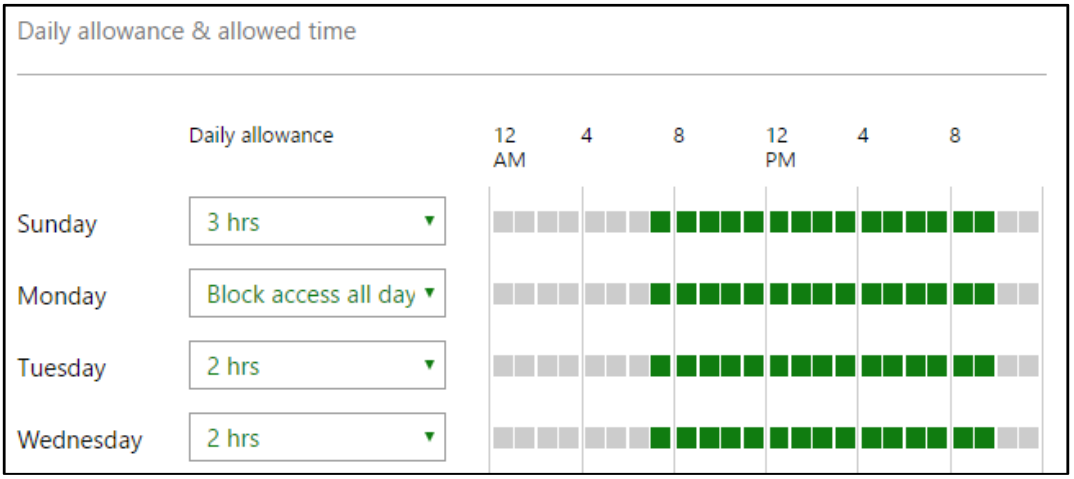
Indirect Safe listening features

Interview participants also provided examples of features which were included for other purposes, which could indirectly act as safe listening features.

Screen time limits/digital well-being controls

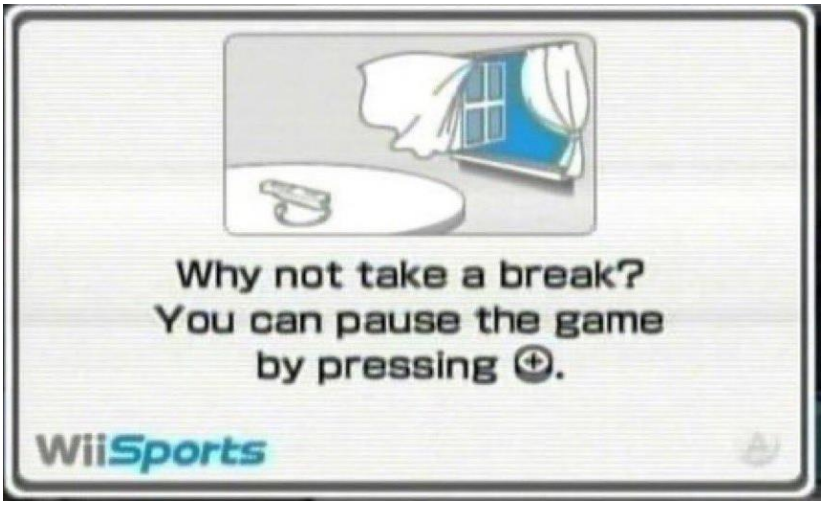
Console, PC gaming and mobile operating systems often offer controls that monitor and limit screen time, which can be used by parents or guardians of gamers to limit gameplay. These

controls, whilst typically used to limit the length and frequency of gaming during a specific time period (e.g., on weekdays), can also encourage safe listening as they can reduce the amount of time a person participates in gaming, therefore reducing overall sound exposure.



Example 8. Screen Time Limit settings

Some games (namely movement or gesture-based gaming such as Nintendo Wii or Xbox 360 Kinect) also encourage the gamer to take breaks which, when followed, can reduce overall sound consumption.



Example 9. Prompt to take a break screenshot.

In game sound controls

Video games will often provide the gamer with some level of control over sounds that are triggered throughout the game. Most commonly, a sound menu will include independent controls over the level of sound effects, music and voice over levels (Example 7).

Interview participants (n=5) reported these controls as being particularly useful with regards to safe listening as they allow gamers to reduce or remove sounds that may interfere with more important sounds resulting in better perception of important sounds at lower volumes, and less overall continuous sound dosage.

Example 10. Sound control menu options

Voice Chat control features

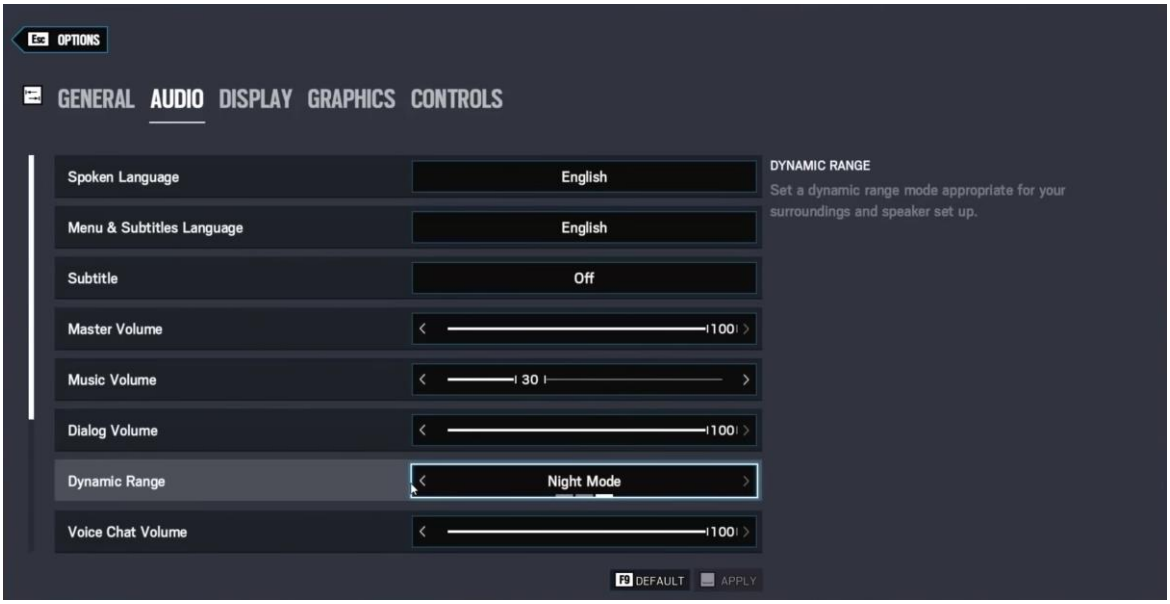
In multiplayer competitive games, a frequently encountered sound component is "voice chat" or “voice communications”. As its name implies, this feature enables gamers to communicate with one another via their own microphones, and the sound arrives with other in-game sounds during gameplay. Voice based communication can be a valuable tool for strategic communication in team-based games, but it can also contribute to a high sound volume during gameplay, especially if a player decides to use this for distracting or unsportsmanlike reasons.

According to feedback from interviewees, the unpredictability and sometimes overwhelming volume of voice chat sounds can be challenging to deal with, and so features such as ‘voice chat squelch’ (available in the video game “Overwatch”) which mutes other players if they are broadcasting loud or distracting sounds to other players, can serve as useful safe listening features in competitive gameplay.

Night mode for audio (dynamic range reduction)

One interview participant suggested a feature known as “Night mode”, could serve protective purposes for hearing. Night mode for audio is intended to reduce the overall dynamic range of the audio output, resulting in more sounds from the game audio playback being audible at lower volumes.

Dynamic range reduction features also exist to calibrate the game audio dynamics to suit the available audio playback system, such as smaller, less capable laptop computer speakers. (Bussy-Paris, 2016). Whilst this feature is not specifically designed as a protective feature, the resultant effect of dynamic range reduction could result in a lower overall gaming volume, or as an option to reduce impulse sound effects.



Example 11. Dynamic range control “Night Mode”

It’s worth noting that whilst such features attempt to make game audio more audible at lower volumes or on less capable speaker systems, if inappropriately activated on louder systems, the reduced level differences caused by dynamic range reduction run the risk of resulting in consistently higher average sound intensities.

Complimentary visual interface options

Some participants suggested that any in-game feature that used visual information to allow a game to still be enjoyed at lower listening levels could be considered as indirect ‘safe listening

features', as use of such feature may encourage lower sound dosage. Specific examples include:

Closed captions

Closed captions provide written versions of in game sounds for the purpose of allowing those who cannot rely on audio information to understand sounds being triggered by the game (Microsoft, 2023).

Captions are typically displayed at the bottom of the screen. Enabling this accessibility feature effectively allows a player to reduce or event switch voice dialogue sounds off via sound menu if available, lowering overall sound dosage.

Example 12. Closed caption subtitles

Visual sound effects

Two participants discussed visual sound effects as a method to participate in gaming at lower volumes. Visual Sound Effects is a feature introduced in Epic Games' Fortnite, and it was originally conceived as an option for the mobile version of Fortnite to supplement poorer sound quality of mobile handset speakers which may be unable to show where sounds are coming from. Visual sound effects provide visual feedback for certain in game sound effects, portrayed as a particular ring color around the central character. For example, an orange ring around the player indicates an explosion or gunshot sound effect has been triggered, a gold ring indicates a loot chest sound has been triggered or a white ring indicates footsteps, animals and/or vehicle sounds have been triggered (Banerjee & Çakır, 2023).

Using Volume Sound Effects allow for a gamer to understand important cues provided by the game at lower volumes, and thus were considered by an interviewee as an indirect safe listening feature.

Example 13. Visual Sound Effects enabled, portraying sounds as orange rings around the central character

Active and passive (damping) noise cancellation

Participants with experience with gaming hardware development (n=5) offered “active” (an onboard headphone system that works to cancel external noise via an additional microphone array that captures external noise and provides it to the wearer in its opposite phase, thus cancelling the noise) and “passive” noise cancellation (technically known as damping, or the attenuation of external sounds via the physical attributes of the headphone device) as possible indirect safe listening features for gamers and professional esports athletes. Both systems offer a gamer the ability to listen to game audio at lower levels where noise is present, making it a potential safe listening feature.

Equalizer tuning on gaming headphones

Stakeholders suggested that gaming headphones often are designed with specific equalization settings applied to the headphone audio output that are either enabled by default or can be activated via a special ‘gaming mode’.

Stakeholders suggest that the equalization is designed to accentuate in game sounds of most important, such as footsteps in FPS style games, whilst attenuating louder sounds such as gunfire or explosions which would mask softer footsteps. Doing this may result in an overall lower volume requirement whilst remaining competitive. Whilst no evidence exists that sound

exposure is in fact reduced by this equalization, it is possible that such lower frequency attenuation could result in lower sound dosage, and thus is an indirect safe listening feature.

Question 2: What, if any, regulations, or legislations exist that ensure the safe listening of gamers and esports participants?

Many interview participants reported a lack of awareness of specific regulations or legislations that exist with respect to safe listening. Situations where regulations, legislations or standards were cited or discussed are explained as follows.

Gaming device regulatory protections

Interview participants with experience in gaming hardware development (n=7) cited the following regulations that exist to ensure the safe listening:

(a) Consideration of European Union's Noise at work directive
(b) Adherence to European Telecommunication Standards Institute (ETSI)'s long duration disturbance limit of 118 dB (A weighted) for exposure above half a second.
(c) International Electrotechnical Commission (IEC) 62368-1:2018 standard for the safety of electrical and electronic equipment within the field of audio, video information and communication technology, and business and office machines with a rated voltage not exceeding 600 V. This standard provides guidance for maximum dosage of 80 dB (A-weighted) over a 40-hour period, however due to the wording of the standard, it is only applicable to gaming headphones, and not gaming consoles or systems themselves.

Game audio development standards and guidelines

From a game audio development perspective, interview participants reported no awareness of any regulations or legislations that govern safe listening for gamers or esports participants.

Participants from the area of game sound design did however explain the process behind how in-game sound level is produced, which includes usage of mostly voluntary standards and processes, which are based on comparable digital television audio standards.

Many game audio development teams look to follow audio production guidelines set out by the 'Sony Worldwide Studios Audio Standards Working Group' (ASWG) which were developed to ensure audio from games played on consoles were comparable in loudness to other digital television formats.

The guidelines suggest that the game audio soundtrack should have an average loudness level of -24 loudness units measured in Loudness K-weighted Relative to Full Scale (LKFS), along with a true peak (TP) level of -1 dB, measured over a minimum thirty-minute time window. ASWG standards for game audio were based on International Telecommunication Union Radio (ITU-R) standard BS.1770-3, a widely accepted global broadcast standard, and compliance to these game audio guidelines is voluntary, and not found in all games. While initially established by Sony Worldwide Studios, these guidelines have since been adopted by other game studios as well *(Audio Standards Working Group, 2013)*.

As an alternative approach to the gaming loudness standard set by ASWG, some interview participants report following loudness guidance put forth by European Broadcast Union (EBU) standard R 128. This standard dictates a loudness level of -23 loudness units (+/- 0.5), measured in Loudness Units Full Scale (LUFS), an equivalent measurement to LKFS, and therefore 1 loudness unit louder than ASWG standard.

While these guidelines are not intended specifically to promote safe listening, they ensure that the average loudness levels of game audio remain uniform with other media being consumed on gaming consoles, TVs, etc., thus minimizing differences in volume for gamers across different media and avoiding potential significant increases in volume when moving from one media format to another.

When discussing approaches to game audio production with interview participants from that field, it was often discussed that whilst these standards provide benefits in terms of hearing fatigue and overall sound quality, these standards only specify the final audio levels a particular game is mastered to, they cannot take into account unpredictable variables (such as live multiplayer inputs) and are ultimately still overridden by the gamer's audio playback system volume level.

Regulations and legislations relevant to esports

Interview participants with relevant experience in the esports industry reported live esports events held at large venues with an audience present should adhere to local regulations or legislations that cover protections to audience members of the venue. Such regulations may include monitoring requirements, peak sound level limits, time limits for residential areas, etc.

Interview participants representing esports professional athletes suggest that local occupational health and safety regulations should also apply to esports professional athletes, and thus these regulations should dictate sound exposure levels a professional esports gamer experiences, for e.g., Occupational Safety and Health Association (OSHA) requirements in the US. This would also apply to any professionals who use gaming equipment as part of their profession (e.g., game developers, sound designers, game engineers, etc.).

As far as the interview participants were aware, there were no imposed regulations with regards to individual sound dosage via headphones during the event, nor were there any limitations placed on how long they would play for.

Question 3: What safe listening features could be implemented into video game products and esports events to promote safe listening?

Interview participants provided several strategies or ideas as to where and how safe listening features could be implemented. Some consistent themes were observed and are as follows:

Gaming hardware safe listening features

Interview participants consistently offered the opinion that any safe listening features can most easily and effectively be implemented at the gaming hardware level (for example gaming console, PC system or headphones) and not at the game software level for the following reasons:

- Any efforts by the game audio developers themselves to control audio levels can quickly be overridden by the gamer's console or PC audio volume level.
- Adoption of safe listening at the game development level would require much more coordination and effort due to the sheer number of game developers that exist.
- Implementing safe listening features at the game system level is far more efficient and allows game developers to focus on game development.
- Other features, such as accessibility features, or screen time management features, have been much more successfully developed at the system level. Safe listening features could be implemented as an extension of these system features.
- Gaming hardware often connects directly to headphones, via Bluetooth or via USB type C connection. This direct digital connection provides a potential way to distribute recorded sound pressure levels measured at the gamer's ears onto the gaming hardware system itself and may be made easier if the brand of headphone is

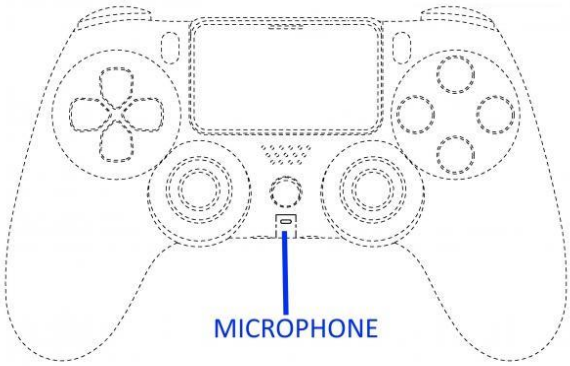
the same as the gaming hardware itself, and thus is a logical point to consider implementation of safe features.

Examples of gaming hardware safe listening features

Several participants suggested safe listening features may be the simplest to implement at the audio playback end point, which is most likely the headphone level. As most headphones now include microphones for noise cancellation processing, and "intelligent" headphones now offer the ability to track the sound pressure level output, gaming headphones could be designed to monitor and warn the gamer if levels exceed unsafe levels, or for younger gamers, volume limits could be enabled.

Ambient background noise and/or acoustic level monitoring

Possible safe listening features could leverage microphones that are integrated into headphones and game console controllers (Example 11) which are ideally located to record acoustic information from the listener position. Several participants presented concepts involving the measurement of gaming environment acoustic levels to feed back into the gaming system that can (a) determine risk to hearing from game audio sounds arriving acoustically from loudspeakers and/or (b) warn or alter the volume of game audio if acoustic levels are measured to be too loud.



Example 14. Example of controller featuring on board microphone location

Some participants (n=3) commented on a somewhat common trend amongst casual gamers whereby they listen to both in game audio, combined with a separate audio signal, typically alternative background music or media, which is disconnected from the game experience.

This behaviour presents a challenge in terms of safe listening as it presents an additional acoustic signal that needs to be considered when calculating a gamer's sound dosage.

To account for this listening behaviour, one participant suggested the development of a wireless, "smart" sound level sensor, akin to an air quality or temperature sensor, which is located within proximity of the gamer's seating position. Whilst "smart" noise monitors already exist (e.g. Minut noise monitoring solution, Rayven Noise Monitoring IoT solution etc), to customize such a device for gaming contexts it should be able to both detect ambient sound levels from acoustic sources in the room via calibrated microphone (e.g. for game sounds via loudspeaker system and/or background noise), as well as connect to smart headphones to calculate sound dosage via dosimetry should they be used for game and media consumption instead. The device would also be able to provide quick visual feedback when listening risk is detected, either by changing color or through other universal symbology.

Software based safe listening features

Whilst interview participants commonly expressed features at the hardware level would be more effective, and simpler to coordinate, some participants did suggest safe listening features within games were possible.

Audio loudness calibration

Some participants explained that many games include an initial setup process for video quality, prompting the gamer to set contrast and brightness settings by how an image looks on their screen setup. Games could offer a similar initial setup process for a gamer's audio settings to establish a comfortable listening level and dynamic range, which in turn could be used to provide listening information to the gamer or set their audio system in a way to limit the number of sounds that are perceived as loud to the gamer.

Certain audio engines used by game software can also provide different sound level calibrations if headphones are detected and are used by the gamer. Whilst the gamer will still have ultimate control over the final volume level of the headphones, game engine software, such as Wwise could provide game audio developers and sound designers with a way to optimize sound levels for gamers when headphones are detected (using Wwise mix states), making it less likely that loud levels are required (Bridgett, 2015).

In-game presentations

Several interview participants suggested in-game messaging or presentations offer an opportunity to educate gamers on the topic of safe listening, as well as warn them of unsafe behavior, provided they are handled in a way that does not break immersion or devalue entertainment.

One participant used an example of airline safety, where some airlines convey safety information by packaging information in an entertaining and aesthetically interesting way to increase engagement. Games could include in-game safe listening content, made within the theme of the game, so that information can be provided to the gamer without it being immersion breaking or interruptive.

Other participants suggested game software warnings may be effective, provided they used information sensitive to the gamer's situation and were delivered at an appropriate time. An example provided was to ask, "are your ears ringing?" at the end of a round or gaming session, as opposed to a notification popping up mid game.

Quote: "If it was a pop-up that says "are your ears ringing? If so, your game volume might have been too loud...something like that that [gamers] could check, and would be helpful to them, is the way I would approach it."

Features like this already exist for other health concerns, such as warnings for gamers that may experience epileptic episodes as a result of visual sequences from a game (Example 15).

Example 15. Epilepsy warning example which appears each time game is loaded.

Software prompts to encourage headphone use

As previously discussed, participants remarked that the inclusion of onboard microphones and intelligent features on modern headphones makes them ideal in provision of safe listening features to gamers. Some participants suggested the game software itself could encourage use of headphones to take advantage of these safe listening features by adding in splash screens that suggest headphones provide the best listening experience.

Extended configurable audio options

Many games provide some basic volume control over audio elements included in games, for example, independent control over sound effects and music levels.

Participants indicated that expanding these controls to include even greater control over in-game sounds may prove useful in arriving at a lower overall volume setting. An example provided by participants was footstep sound effect volume control, which is an important sound to listen for when competing in FPS multiplayer games, which is often set substantially lower in volume than louder gun type sound effects. Without independent controls, a gamer may increase overall volume, meaning louder sounds (such as gunfire) become even louder, which risks increasing sound dosage per gaming session.

Automatic volume reduction between rounds

In first-person shooter (FPS) games, gameplay is divided into short rounds that last a few minutes. If a competitor is defeated during a round, they are removed from the game until the round ends. During this time, the defeated player can watch the remaining competitors' screens and listen to their in-game audio.

Where possible a game developer could consider reducing volume in between rounds after a competitor has been defeated, or whenever sound is not important to gameplay.

Quote: "Developers could offer more customizable audio settings, such as the ability to decrease volume when spectating one's teammates. This could reduce one's noise exposure quite a bit."

Education and supplementary materials to promote safe listening

Many participants indicated education plays an important role as part of any guidance provided on the topic of safe listening to gaming and esports participants.

Participants with relevant experience in gaming health and wellbeing suggested that there is low health awareness amongst gamers and esports professionals, and it is especially low or non-existent for beginners in the space.

Quote: "Young people playing games on the pathway up to professionalization have very limited information about what a healthy lifestyle is"

These interview participants suggest that educating gamers about the importance of safe listening practices early on could be a very effective way to protect their hearing as it would help them develop good listening habits from the start of their gaming experience which can carry over to competitive esports contexts if they pursue those avenues.

Promotion of safe listening initiatives from esports personalities

Several interview participants suggested the effectiveness of any safe listening features can be further enhanced if promoted by current and retired esports personalities. Participants with direct esports competitive experience suggest that many young, up and coming gamers will often look to successful esports for technical advice, to help their own performance.

Quote: "That's why when you look at [esports athlete]'s link trees, you look at their YouTube bio, their twitch bios …the first thing they're asked all the time is "what mouse do you use, what's your sensitivity, what's your screen resolution? You could work with them to do some education on sound settings, with a disclaimer in there about [safe listening]".

Interview participants suggest incorporating esports personalities with their listening experiences in hearing could become important advocates to encourage safe listening practices.

Question 4: What is the readiness (awareness and willingness to act) of the gaming and esports industry to promote safe listening and implement related listening features into their products and events?

Most stakeholder interview participants shared a positive outlook that the industry would be ready and willing to act upon a safe listening initiative for the betterment of hearing for the gaming and esports industries, especially at the gamer level.

- Safe listening is good for the health and wellbeing of gamers and esports professionals

- The game audio industry has shown previous collaboration for improved sound quality with the adoption of broadcast audio-based standards

Quote: "People coming into our platform, they're going to join young, and they're going to play games and have amazing entertainment experiences, and we want to keep them for their lifetime along with the platform".

Quote: "Our values are very centred on caring for the audience and about health and wellbeing is a central theme for us"

Quote: "it's about the sustainability of players health when using your games"

Other participants reasoned that considering the gaming industry has already adopted screen time, parental control and other accessibility features, there is a willingness to help empower families to manage game exposure to younger gamers, and there is no reason why safe listening features can't be a part of that.

Despite this optimism, some participants (n = 4) expressed some skepticism with regards take up especially from gaming vendors and events coordinators if adopting safe listening features becomes financially prohibitive or negatively received from a brand perspective.

Some interview participants also expressed the possibility of potential negative reactions from members of gaming and esports industries, should specific guidelines and/or standards be developed only for gaming and esports activities, as it may be interpreted as these industries being singled out for their behavior, whilst other industries don't have the same level of scrutiny. Participants suggested to circumvent this negative reaction, it may be more logical to extend the existing WHO-ITU standards for personal listening devices and systems, and venues and live events to cover video gaming and live esports events respectively, as these standards do seem amendable to cover these activities.

Question 5: What are possible limitations and/or barriers to the implementation of safe listening features in gaming and esports products and events?

The purpose of this interview question was to examine what stakeholders thought may be inhibiting inclusion of safe listening features, now and into the future. Across all stakeholder interviews, there were consistent themes observed, which fall into the following categories.

Poor user experience

User experience refers to a person's perceptions and responses that result from the use and/or anticipated use of a product, system, or service (ISO, 2019). Several participants (n = 5) suggested that barriers could arise if the features themselves resulted in a negative user experience that detracted from a main purpose of gaming, entertainment.

For example, participants expressed the opinion that if a safe listening feature caused a significant loss of function when gaming, such as reduced awareness of competitors, or notifications that interrupted concentration, they would not be receptive to such features, even if these features provided a long-term benefit to the gamer's hearing.

Technical reasons

Several interview participants (n = 5) expressed there may be technical limitations and barriers that may influence the implementation of safe listening features, based mostly on the variability of gaming and sound devices a gamer may use.

Implementation of safe listening features within a gamer’s gaming system may not be possible where the gamer uses a complex combination of external audio equipment or devices that cannot be adapted to provide feedback to the listening feature (for example analogue wired headphones).

PC gaming systems encounter greater technical complexity due to a greater number of hardware component combinations being used, meaning integrating safe listening features at the hardware and/or operating system level is more difficult.

To ensure consistency across gaming genres, platforms and contexts, implementation of safe listening features at the headphone output level may require rigorous “end point calibration” for the manufacturers of headphones which is time and resource intensive.

Finally, adding in situ volume measurement mechanisms for gaming products (e.g., microphones within headphone earcups that can measure sound pressure level) adds technical complexity to the design and development process.

Gamer Indifference

Some participants in the interview process suggested gamer indifference to the risk of hearing damage may cause barriers to the use and awareness of safe listening features.

Some participants suggest whilst older gamers (aged thirty years or older) might be more receptive to safe listening features, younger gamers may not have an appreciation for the risk

or consequences of hearing damage (such as loss of hearing sensitivity or tinnitus), which they may view as an issue for older populations. This perception from younger gamers may not only result in indifference towards safe listening features, but also to towards any initiatives that may be used to promote or spread awareness about recreational noise exposure if they are not delivered in an appropriate way.

Quote: "The people you are dealing with in that space are like 17 or 18 years old. They don't care about this, they think they're invincible, they don't think it's a problem".

Whilst education and promotion of safe listening could go some way to reducing indifference, uptake may be poor if not presented in an engaging way by appropriate gaming stakeholders, such as current and/or retired esports professional athletes, esports health professionals, esports league representatives and esports coaches.

Participants also noted that recreational noise exposure is still an issue affecting many recreational activities, and specific efforts to develop safe listening features, guidelines and standards designed to help the gaming and esports industries could have the opposite intended effect.

Finally, if a gamer prefers the experience of gaming when provided with loud audio, they will find a way to override the feature, despite its intended benefits:

Quote: "Primarily people will do whatever they want. If cranking up the audio is the good experience for them, then that's what I expect most people will do"

Development redundancy

As the gamer ultimately has control over the final volume levels they listen to, some participants (n = 4) suggested there may be some barriers gaining agreement from gaming developers to implement in-game safe listening features that could be easily overridden by the gamer.

Competitive forces

Participants expressed several potential barriers, and limitations caused by the competitive nature of gaming and esports.

In competitive gaming, game audio is essential for success. Sound effects that provide movement information and directional location are often delivered at high volumes to help gamers gain an advantage. Additionally, there is a strong correlation between the amount of

practice and the quality of performance a gamer will give during competitive events. For these reasons, interview participants concluded that safe listening features that recommend lower monitoring volumes and/or shorter exposure durations may experience implementation barriers from gamers and esports athletes, especially if they experience a performance deficit, or their competitors are not using such features.

Quote: "You want the sound as high as possible because you don't to have the potential that you'll miss a sound and then you'll lose a round because of it...so you crank that up as loud as you can, and it's very often when you're at live events that you'll stand behind someone and you can hear everything, that's how loud their headphones are...they're basically strapping speakers to their head at that stage"

Participants with experience with esports competitions and tournaments also suggested how limiting exposure to game sound can also be difficult, due to the demands of the tournament which may require competitors to play for hours at a time both in practice and competition contexts, especially where average game duration is long.

The esports community may also be reluctant to introduce safe listening features because they could interfere with the legitimacy of esports competitions. In large esports events, game audio is broadcast to competitors in a particular way to allow event organizers to monitor communications to prevent cheating. Any safe listening feature that could affect the integrity of these broadcasts could face significant opposition from stakeholders in the esports community.

Financial and/or resource driven

Common responses provided by interview participants also considered the financial or resource costs associated with implementing safe listening features. If implementation of safe listening features was to impact production deadlines, budgets, or sales of a game title or gaming system, there may be resistance from developers to include them as a priority or even at all.

In a similar way, resistance to safe listening implementation within esports events may also occur if they are cost prohibitive or affect the business viability of an event in any way.

5.4 Conclusions and summary of stakeholder interviews

The interviews conducted as part of this background study provided useful insight into the current state of the gaming and esports industry with regards to existing safe listening

features, as well as the potential for their future inclusion. Some conclusions from these interviews are as follows:

Gaming and esports industries offer few safe listening features

Due to sample size, the list of reported features cannot necessarily be relied upon as entirely extensive. However, when asked about safe listening features, most interview participants were unable to provide examples of features that were specifically designed to prevent hearing damage or promote safe listening habits. Often, participants were only able to cite examples of features or settings that *could* be used or adapted for these purposes.

This finding suggests several opportunities:

- There is an opportunity to better promote existing safe listening features that are potentially underutilized. An example of this may be to reconsider the placement of safe listening information, as opposed to only displaying it in user guides which may not get much attention.
- There is also an opportunity to develop new “direct” safe listening features that act to inform gamers of the potential risks involved with risky listening behavior. The development of these new features could also benefit from understanding how gamers and esports athletes currently use other features to indirectly achieve safe listening.

Gaming and esports safe listening regulations are either not well known or don’t exist

Most interview participants reported a lack of awareness with regards to safe listening standards, regulations or legislation related to safe listening in gaming and esports. As one of the fastest growing recreational activities, it is important to consider the development of safe listening guidelines for this type of activity or if possible, expand existing safe listening standards to include gaming and esports activities.

Hardware and/or system level safe listening features are preferred over game level features

Interview participants with experience in game audio development suggested it is likely to be more practical to implement safe listening features at the hardware and/or system level (i.e., implemented at the system level for a gaming console, via the Windows or Mac operating

system level for PC gaming or at the headphone level for smart headphones with ability to measure dosage) as opposed to implementing at the game level.

Once implemented, hardware and/or system level safe listening features could be more centralized and would save each gaming developer implementing their own feature.

A multidisciplinary approach to safe listening feature implementation is ideal

Even if hardware/system level safe listening features are available, interview participants suggest that due to the complex nature of gaming and esports listening habits, such technical features may not completely mitigate risk to hearing from all gaming and esports situations, and supplementary education and promotion is also needed.

For example, a feature that limits headphone volume level may seem like a logical way to protect gamers' hearing, but it would only be a partial solution. This is because it would not be helpful to the 50% of console gamers who use TV speakers, and such features also may provide limited benefit during esports competitions, which often require players to use smaller earphones for game audio as part of a dual headphone setup.

In addition to technical and standards-based solutions, it is important to promote and educate gamers about safe listening practices, and this is especially important for young gamers and their parents who may not understand why safe listening features are helpful.

More experienced gamers and esports athletes may also be more likely to follow advice and guidance from current and retired esports athletes on the topic of safe listening. Therefore, it is important to involve these important stakeholders in the promotion of safe listening features.

Gaming and esports industries would likely be receptive to safe listening feature implementation

There was a general attitude of support from stakeholders towards the implementation of safe listening features provided:

- They do not significantly break immersion or reduce entertainment value of gaming
- They are not technically difficult, expensive or resource intensive to implement
- They do not impact the legitimacy of competitive gameplay or esports events
- They can be shown to be necessary based on research and evidence

Gaps and limitations of stakeholder interviews

The interviews of stakeholders provide introductory insight and perspective on the current state of safe listening in gaming and esports based on the opinions of experts from within each field. Whist the information attained was relevant and detailed, due to sample size it cannot be considered completely exhaustive, despite many attempts to connect with a larger pool of experts and stakeholders. Further development of safe listening features for gaming and esports will continue to benefit from the integration of input from a broad network of stakeholder and experts.

6. Discussion

This background paper aims to document the current state of safe listening in gaming and esports activities and has compiled data from three separate sources: a systematic scoping review, international online survey of gamers and esports participants and stakeholder interviews. Despite widespread acceptance that game audio is essential to both the enjoyment and competitive participation of video games, the three components of this background study reflect that consideration of features to protect the sense that allows a gamer to enjoy game audio possible is concerningly low.

Based on the results of the three components of this background paper, the following observations can be made:

Further research is warranted, but existing studies suggest unsafe listening is likely within video gaming and esports activities

A literature review on hearing and gaming revealed only 14 journal articles that discussed the relationship between gaming and hearing. No articles were found specifically addressing hearing risks in esports activities. Compared to other health factors like sedentary behaviour, obesity, or mental health, which are described in other scoping reviews such as Kelly & Leung, 2021, there is significantly less literature about hearing risks in gaming and esports. Moreover, among the 14 articles, only a few provided data directly indicating the average sound dosage from gaming and its potential impact on hearing.

Some studies, using music and television media as a sound source, suggest the average preferred volume levels for loudspeakers and headphones is around 70 dB (A-weighted) (McMullin, 2017) which is lower than the recommended 80 dB level for 40 hours of weekly exposure (WHO-ITU, 2019). However, other studies have found potential listening levels as high as 89 dB (A-weighted) via headphones (Worthington et al., 2009). Since these studies are based on television programs and/or music, which are non-competitive or interactive media, they may not accurately represent game audio volume preferences.

Other studies looking at the preferred level of adolescents when listening to music via headphones, show that there is a subgroup of 10% of listeners who prefer to listen to music from personal music players via at levels between 90-100 dB for long periods of time (Widen, et al., 2017). Another meta-analysis of unsafe listening practices of adolescents and young adults showed that almost 25% of users of personal listening devices such as smartphones and MP3 players listen to media at unsafe volumes (Dillard et al., 2022) The international

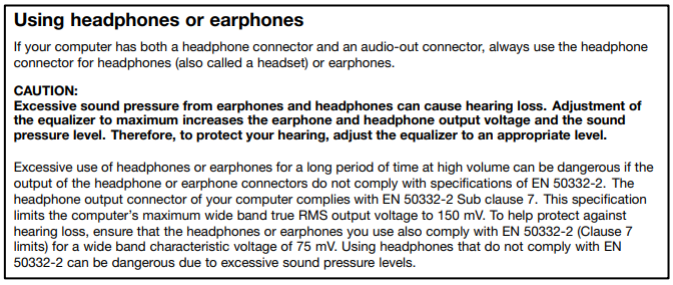
survey completed as part of this background study found that almost 20% of the gamer respondents listened to volumes considered to be high or very high (Diviani, et al., 2023). Considering the global population of gamers has reportedly exceeded 3 billion people, and regular hobbyist gamers using PC and console platforms number in the area of 1.7 billion, should a similar percentage of gamers listen unsafely, there is a possibility that 100s of millions of gamers could also be at high risk of hearing loss as a result of video gaming and esport activities.

Therefore, it is important to conduct more specific sound dosage studies on game audio, game genre, as well as specific types of gamers (casual, amateur esports athletes, professional esports athletes, etc) as each gamer group is likely to have different amounts of exposure.

Despite the dearth of specific sound dosage evidence from video gaming and esports activities, what is known is the global average of weekly gaming approaches 10 hours a week (Statista 2022), and esports professional athlete playing time can approach more than 10 hours *a day*. Considering these durations, as well as studies that do exist that provide dosage information, such as Iannace et al. 2020, and other studies that have reported associations or correlations of gaming with hearing loss or tinnitus (Rhee et al., 2019, Rhee et al., 2020), unsafe listening from video gaming and esports activities is likely.

Safe listening features are not widely available or accessible

The video gaming industry has implemented some measures to mitigate hearing risks to gamers, such as including warning messages in user guides and packaging. However, these are only typically available when purchasing a gaming console or gaming headphone accessory, (although some warnings can be found in laptop user guides, see Example 11), may not provide specific sound dosage information, and are typically one of several health-related warnings provided within the device's support documentation and may be required as part of a particular safety standard.



Using headphones or earphones

If your computer has both a headphone connector and an audio-out connector, always use the headphone connector for headphones (also called a headset) or earphones.

CAUTION:
Excessive sound pressure from earphones and headphones can cause hearing loss. Adjustment of the equalizer to maximum increases the earphone and headphone output voltage and the sound pressure level. Therefore, to protect your hearing, adjust the equalizer to an appropriate level.

Excessive use of headphones or earphones for a long period of time at high volume can be dangerous if the output of the headphone or earphone connectors do not comply with specifications of EN 50332-2. The headphone output connector of your computer complies with EN 50332-2 Sub clause 7. This specification limits the computer's maximum wide band true RMS output voltage to 150 mV. To help protect against hearing loss, ensure that the headphones or earphones you use also comply with EN 50332-2 (Clause 7 limits) for a wide band characteristic voltage of 75 mV. Using headphones that do not comply with EN 50332-2 can be dangerous due to excessive sound pressure levels.

Example 13. Gaming laptop user guide warning

The lack of safe listening features should be compared with availability of other safe gaming features, such as parental controls, which are widely available across many platforms, with the purpose of limiting access to specific content, tracking activity and to ensure age-appropriate screen time is adhered to (Kiraly, et al., 2017).

More effort could be put towards the implementation of similar safe listening features that track and/or estimate likely sound dosage for gamers and esports professional athletes, that warn when exposure is potentially damaging.

Stakeholder interviews revealed that measuring actual sound dosage in gaming can be challenging due to the variability of gamer equipment, whilst the international gaming survey (Diviani et al., 2023) revealed a lack of protective behaviour from gamers, despite almost half had experienced auditory symptoms. While advanced wireless headphones and game audio systems offer great technical potential for understanding sound dosage information in real-time, incorporating non-technical features like in-game prompts to check for negative auditory symptoms (e.g., ringing ears) and more visible materials promoting safe listening practices (such as WHO-ITU dosage limits, taking breaks, and keeping volume below 60%) could also be effective additions in encouraging protective behaviour.

Gamers report interest in learning more about safe listening

The international online survey reported by Diviani et al provides useful insight into the gamer and esports professional mindset when it comes to safe listening. The survey results conclude that whilst respondents demonstrated good awareness of hearing loss risks associated with gaming and esports, they also, potentially incorrectly, perceive their susceptibility to hearing damage as relatively low.

Diviani et al (2023) observed half of the respondents expressed interest in learning more about hearing loss and safe listening in gaming and esports. Preferred information sources included device instruction manuals, dedicated websites, and integrated user interfaces in gaming devices, from trusted information sources including healthcare professionals and governmental or international agencies.

The findings of the survey study also suggest a need for targeted education and intervention programs to promote safe listening habits among video gamers and esports viewers and players. Specifically, these programs should focus on increasing awareness of the risks associated with loud sound exposure and providing practical strategies for reducing exposure to potentially harmful sound levels. The gaming and esports industries are also urged to play

a role in promoting safe listening habits by incorporating sound dosage information and warnings into their products.

Future Safe Listening Guidelines for Gaming and esports can leverage existing WHO-ITU safe listening guidelines

The most important concept to mitigating risk to hearing is sound dosage, and in any recreational context, listening can be made safer by:

- Reducing the sound level; and/or
- Reducing the duration of exposure; and/or
- Reducing the frequency of exposure (WHO, 2022)

Even though a gamer may enjoy the activity of gaming, their auditory system cannot distinguish between sound sources. According to the equal energy principle, sound presented from gaming and esports sources would have the same impact as any other sound source provided the duration and intensity were the same. Therefore, applying similar dosage requirements for gaming systems as those discussed in existing WHO-ITU safe listening standards for devices and systems, and for esports live events as those recommended in WHO global standards for live venues and events, could be an effective strategy (WHO & ITU, 2019; WHO, 2022). As substantial gaming occurs on mobile devices, with surveys indicating as many as 2.6 billion gamers used mobile devices in 2021, it is also logical that safe listening standards for mobile devices, such as H.870, are expanded to gaming content as well (Statista, 2021).

Further studies should also explore the effect of lower volume on the gamer experience, to gauge whether such an approach to safe listening is reasonable. Studies exist within the realm of live events, where it was found no significant reduction to performance appreciation was found when using ear plugs after a 16 week study (Nielsen, Beach, & Gilliver, 2014), so similar studies reviewing gaming experience and lower sound exposure could help provide approaches to safe listening strategies in gaming and esports contexts.

Barriers exist to safe listening feature implementations

However, whilst recommending limits to sound dosage could be the simplest part of developing safe listening guidelines for gaming and esports, this paper has discussed that a practical approach to achieving this may be difficult. The fact that gaming at casual, amateur and professional esports levels, occurs on a variety of platforms, operating systems, hardware

systems, and game audio is produced by an even more complex variety of audio devices, means a single solution for all gamers is difficult. Other factors, such as hesitancy towards reducing gaming volume as it may affect the overall quality of gaming, as reported in the international gaming survey, also reflects a situation that is complex and challenging (Diviani et al., 2023).

Developing a uniform, global standard that is capable of governing such technical diversity and variety gaming system preferences, that does not affect the personal gaming experience or interfere in the legitimacy of competition presents a much more significant challenge to its implementation.

User experience was also reflected in the stakeholder interviews as one of several barriers which could affect the willingness of gaming and esports industries to implement safe listening features, along with gamer indifference, technical reasons, competitive forces and finance/resource driven barriers.

It is entirely possible that similar barriers were discussed when implementing similar health and safety features in gaming, such as limiting screen time or limiting physical risks to health and safety when taking part in VR gaming, yet safety features for both gaming risks were developed. Barriers for safe listening should always be considered when determining the best course of action to mitigate risk to hearing from gaming and esports industries.

7. Looking to the future

- Comparable recreational sound exposure data for young people estimate that 24% of young adults are at risk from unsafe listening practices from personal listening devices (Dillard et al., 2022). Should the rate of unsafe listening for the estimated 1.7 billion PC and console gamers combined worldwide (Newzoo, 2023), there are potentially 408 million people globally who are at risk of preventable and permanent hearing loss from gaming activities. Whilst more work is required to confirm the actual number of gamers at risk, these numbers and the evidence indicated in this background study suggest that the inclusion of safe listening features in gaming and esports is warranted.

- Such features should focus on risk mitigation through:

    - Providing safe listening options to users (e.g., option to limit volume, sound allowance monitoring and others)
    - Informing users about the dangers of unsafe listening and guiding them towards adoption of safe listening practices.

- As gaming and esports covers a range of listening situations, implementation of safe listening features can leverage and/or extend existing global safe listening standards; specifically safe listening for devices and systems (WHO-& ITU, 2019) and the global standard for safe listening in live events and venues (WHO, 2022).

- Due to the complexity and variability of gaming devices and systems, the development of a coordinated approach from stakeholders is needed. This includes not only technical agreement on features within gaming systems via involvement from gaming and esports industries, but also safe listening promotion programs involving healthcare professionals, governmental and international agencies.

- To fully understand specific sound dosage data across gamer types (for example casual, amateur, esports professionals etc.), game genres, game platforms and game audio playback systems, further studies should investigate and explore these factors.

- Future consultation with a broad network of gaming and esports experts and stakeholders will ensure that development of guidelines and standards is effective, appropriate, and sensitive to the needs of gamers and esports participants.

8. Bibliography

(IGEA), I. G. (2022). *Connected by Games Digital Australia 2022.* Eveleigh: IGEA.

Andersen, F., King, C. L., & Gunawan, A. A. (2021). Audio Influence on Game Atmosphere during Various Game Events. *Procedia Computer Science, 179*, 222-231.

Association, E. S. (2022). *Essential Facts About the Video Game Industry 2022.* Washington DC: Entertainment Software Association.

Audio Standards Working Group. (2013, August). Average loudness and Peak Levels of Audio Content on Sony Computer Entertainment Platforms.

Balentine, J., Di-Franceso-Donoghue, J., Schmidt, G., & Zwibel, H. (2019). Managing the health of the esport athlete: an integrated health management model. *BMJ Open Sport & Exercise Medicine, 5*, 1-6.

Banerjee, R., & Çakır, G. (2023, April 18). *How to turn on Visual Sound Effects on Fortnite*. Retrieved May 1, 2023, from Dot Esports: https://dotesports.com/fortnite/news/how-to-turn-on-visual-sound-effects-on-fortnite

Beach, E. F., Gilliver, M., & Williams, W. (2016, September 2). Hearing protection devices: Use at work predicts use at play. *Archives of environmental & occupational health, 71*(5), 281-8.

Bhatt, J. M., Lin, H. W., & Bhattacharyya, N. (2017). Epidemiology of firearm and other noise exposures in the United States. *The Laryngoscope, 127*(10), E340-6.

Block, S., & Haack, F. (2021). eSports: a newindustry. In L. Ulis (Ed.), *SHS Web of Conferences. 92.* EDP Sciences.

Bridgett, R. (2015, March). Implementing Adaptive Loudness and Dynamic Range for Mobile Games. Retrieved May 31, 2023, from https://gdcvault.com/play/1022068/Implementing-Adaptive-Loudness-and-Dynamic

Bussy-Paris, M. (2016, November 15). *Audio Dynamic Range Calibration System*. Retrieved May 8, 2023, from audiokinetic: https://blog.audiokinetic.com/en/audio-dynamic-range-calibration-system/

Chang, K., Kim, G., & Kim, T. (2007). Video Game Console Audio: Evolution and Future Trends. *Computer Graphics, Imaging and Visualisation (CGIV 2007).* IEEE Computer Society.

Chodos, A. (2008). *October 1958: Physicist Invents First Video Game.* APS News.

Daley, D. (2019, November 21). *Esports Stadium Arlington Aims To Keep Its Sound Simple*. Retrieved May 25, 2023, from Sports Video Group News: https://www.sportsvideo.org/2019/11/21/esports-stadium-arlington-aims-to-keep-its-sound-simple/

Dash, I., Power, T., & Cabrera, D. (2013). The relation between preferred TV programme loudness, screen size and display format. *AES 134th Convention, Rome, Italy, 2013 May 4–7.* Rome: Audio Engineering Society.

Dehnert, K. R., Perez-Alvarez, C., SteffensT, Bolte, G., Fromme, H., & Twardella, D. (2015). Total leisure noise exposure and its association with hearing loss among adolescents. *International Journal of Audiology, 54*(10), 665-673.

Digenis, A. (2015). Challenges of the headphone mix in games. *56th International Conference: Audio for Games (February 2015)* (pp. 4-1). London: Audio Engineerin Society.

Dillard, L. K., Arunda, M. O., Lopez-Perez, L., Martinez, R. X., Jimenez, L., & Chadha, S. (2022). Prevalence and global estimates of unsafe listening practices in adolescents and young adults: a systematic review and meta-analysis. *BMJ Global Health, 7*, e010501.

Dillard, L., Mulas, P., Chadha, S., & Der, C. (2023, May). Risk of noise-induced hearing loss from exposure to video gaming or esports: A systematic scoping review.

Diviani, N., Chadha, S., Arunda, M. O., & Rubinelli, S. (2021). Attitudes towards Safe Listening Measures in Entertainment Venues: Results from an International Survey among Young Venue-Goers. *Int. J. Environ. Res. Public Health, 18*, 12860.

Diviani, N., Rubinelli, Sara, Chadha, S., & Mulas, P. (2023). Attitudes towards safe listening behaviors among video gamers and e-sports players. Insights from an international online survey. . *Under publication*.

Diviani, N., Zanini, C., Amann, J., Chadha, S., Cieza, A., & Rubinelli, S. (2019). Awareness, attitudes, and beliefs about music-induced hearing loss: Towards the development of a health communication strategy to promote safe listening. *Patient Educ. Couns., 102*, 1506-1512.

Dreher, A., Weilnhammer, V., Gerstner, D., Hendrowarsito, L., Twardella, D., ReiterC, . . . Heinze, S. (2018, December 2). Longitudinal analysis of leisure noise exposure among

adolescents with special focus on portable listening devices: The OHRKAN cohort study. *International Journal of Audiology, 57*(12), 889-897.

Emara, A. K., Mitchell, K. N., Cruickshank, J. A., Kampert, M. W., Piuzzi, N. S., Schaffer, J. L., & King, D. (2020, December). Gamer's Health Guide: Optimizing Performance Recognizing Hazards, and Promoting Wellness in Esports. *Gamer's Health Guide, 19*(2).

Europe), I. (. (2022). *2022 Key Facts about the European Video Games Sector.* Brussels: Interactive Software Federation of Europe.

Europe, I. S. (2021). *The Guide to ESports.* Belgium: ISFE.

Freeman, G., & Wohn, D. Y. (2020). Live Streaming, Playing and Money Spending Behaviors in eSports. *Games and culture, 15*(1), 73-88.

Get Hyped Sports. (2022, February 18). *Why eSports Players Wear Two Headphones*. Retrieved July 18, 2022, from Get Hyped Sports: https://gethypedsports.com/why-pro-esports-gamers-wear-two-headphones/

Goodwin, S. (2009). How Players Listen. *AES 35th International Conference.* London: Audio Engineerin Society.

Gough, C. (2023). *Leading eSports countries ranked by number of active eSports competition players worldwide in 2022.* Statista. Retrieved May 28, 2023, from https://www.statista.com/statistics/780631/esports-competition-country-number-of-players-world/

Gupta, A., Bakshi, S., & Kakkar, R. (2022). Epidemiology and Risk Factors for Hearing Damage Among Adults Using Headphones via Mobile Applications. *Cureus, 14(5)*.

Harman. (2020, Jul 7). *A/V Challenges in Esports with Cameron O'Neill - Webinar*. Retrieved from YouTube: https://youtu.be/zmXEJANf2f0

Iannace, G., Ciaburro, G., & Trematerra, A. (2020). Video games noise exposure in. *Noise & Vibration Worldwide, 51*((1-2)), 3-11.

ISO. (2019, July). ISO 9241-210:2019. Ergonomics of human-system interaction — Part 210: Human-centred design for interactive system. (2). International Organization for Standardization. Retrieved May 5th, 2023, from https://www.iso.org/standard/77520.html

Johnson, D., Gardner, J., & Sweetser, P. (2016). Motivations for videogame play: Predictors of time spent playing. *Computers in Human Behaviour, 63*, 805-812.

Jovanovic, B. (2023, April 7). *Gamer Demographics: Facts and Stats About the Most Popular Hobby in the World*. Retrieved from DataProt: https://dataprot.net/statistics/gamer-demographics/#:~:text=The%20demographic%20of%20gamers%20that,18%20and%2034%20years%20old.&text=The%20average%20esports%20fan%20is,older%20member%20of%20Generation%20Z

Kari, T., Siutila, M., & Karhulathi, V.-M. (2018). An Extended Study on Training and Physical Exercise in Esports. In B. R. Dubbels, *Exploring the Cognitive, Social, Cultural, and Psychological Aspects of Gaming and Simulations*. IGI Global.

Kelly, S., & Leung, J. (2021, March 16). The New Frontier of Esports and Gaming: A Scoping Meta-Review of Health Impacts and Research Agenda. *Frontiers in Sports and Active Living, 3*, 640362. doi:10.3389/fspor.2021.640362

Kiraly, O., Banyai, F., Demetrovics, Z., Griffiths, M. D., King, D. L., Lee, , S. Y., . . . Zsila, A. (2017). Policy responses to problematic video game use: A systematic review of current measures and future possibilities. *Journal of Behavioural Addiction, 7*(3), 503-517.

Layfield, K. (2016). Effects of preferred listening levels when using gaming headphones on hearing sensitivity. *Dissertation. 148.* Retrieved April 20, 2023, from https://digitalcommons.latech.edu/dissertations/148/

Le, T. N., Straatman, L. V., Lea, J., & Westerberg, B. (2017). Current insights in noise-induced hearing loss: a literature review of the underlying mechanism, pathophysiology, asymmetry, and management options. *Journal of Otolaryngology - Head and Neck Surgery, 46*(41). doi:10.1186/s40463-017-0219-x

Limelight Networks. (2021, March 1). *The State of Online Gaming 2021*. Retrieved from Edgio Blog: https://edg.io/resources/blog/state-of-online-gaming-2021/

McMullin, E. (2017, October 18). A Study of Listener Bass and Loudness Preferences over Loudspeakers and Headphones. *Audio Engineering Society Convention Paper 9855.* New York: Audio Engineering Society. Retrieved May 9, 2023, from http://www.aes.org/e-lib/browse.cfm?elib=19252

Microsoft. (2023, 1 4). *Xbox Accessibility Guideline 104: Subtitles and captions.* Retrieved 4 26, 2023, from Microsoft Game Development Documents:

https://learn.microsoft.com/en-us/gaming/accessibility/xbox-accessibility-guidelines/104

Mirbod, S. M., Inaba, R., Yoshida, H., Nagata, C., Komura, Y., & Iwata, H. (1992). Noise Exposure Level While Operating Electronic Arcade Games as A Leisure Time Activity. *Industrial Health, 30*, 65-76.

Nair, V. (2015, June 4). *Sulpha: The new PS4 Mastering Suite*. Retrieved April 4, 2023, from Designing Sound: https://designingsound.org/2015/06/04/sulpha-the-new-ps4-mastering-suit/

Nair, V. (2015, June 4). *Sulpha: The New PS4 Mastering Suite*. Retrieved April 30, 2023, from Designing Sound: https://designingsound.org/2015/06/04/sulpha-the-new-ps4-mastering-suit/

Newzoo. (2022). *Global Esports & Live Streaming Market Report.* Newzoo.

Newzoo. (2023). *PC & Console Gaming Report.* Newzoo.

Ng, P., & Nesbitt, K. (2013). Informative Sound Design in Video Games. *Proceedings of The 9th Australasian Conference on Interactive Entertainment: Matters of Life and Death.* ACM. doi:10.1145/2513002.2513015

Nielsen, L. B., Beach, E., & Gilliver, M. (2014, April). Clubbers' attitude toward Earplugs: Better with use.

O'Neill, C. (2019, November 1). *White Paper: Audio Challenges in Esports*. Retrieved April 17, 2023, from Sports Video Group: https://www.sportsvideo.org/2019/11/01/white-paper-audio-challenges-in-esports/

O'Neill, C. (2020, August 11). *Audio and Video Challenges in Esports*. Retrieved March 14, 2023, from Harmon Pro: https://pro.harman.com/insights/harman-pro/audio-and-video-challenges-in-esports/

Park, M. S., Lee, H. Y., Kang, H. M., Ryu, E. W., Lee, S. K., & Yeo, S. G. (2012, September). Clinical Manifestations of Aural Fullness. *Yonsei Med, 53*(5), 985-991. doi:10.3349/ymj.2012.53.5.985

PGL. (2022, May 24). *PGL CS:GO MAJOR ANTWERP 2022 - the largest indoor esports event ever*. Retrieved 4 18, 2023, from PGL esports: https://press.pglesports.com/191368-pgl-csgo-major-antwerp-2022-the-largest-indoor-esports-event-ever

Plakke, B. L. (1983, July 1). Noise levels of electronic arcade games: a potential hearing hazard to. *Ear and Hearing, 4*(4), 202-3.

Rhee, J., Lee, D., Lim, H. J., Suh, M. W., Park, M. K., Lee, J. H., . . . Oh, S. H. (2019, Jan 4). Hearing loss in Korean adolescents: The prevalence thereof and its association with leisure noise exposure. *PLoS One, 14*(1), e0209254.

Rhee, J., Lee, D., Suh, M. W., Lee, J. H., Hong, Y. C., Oh, S. H., & Park, M. K. (2020, Jul 31). Prevalence, associated factors, and comorbidities of tinnitus in adolescents. *PloS one, 15*(7), e0236723.

Riatti, P., & Thiel, A. (2021). The societal impact of electronic sport: a scoping review. *Journal of Exercise and Sport Research, 52*, 433-446.

Riddle, Karyn, Di, Zhen, Kim, Sunghak, Myung, E., Tay, S. K., & Xu, F. (2017). The unexpected comfort of wearing headphones: Emotional and cognitive effects of headphone use when playing a bloody video game. *Entertainment Computing, 19*, 43-52.

Roberts, C. (2017, July 27). *Noise Monitoring at Insomnia Gaming Festival [Case Study]*. Retrieved March 12, 2023, from Noise News: https://www.cirrusresearch.co.uk/blog/2017/07/noise-monitoring-insomnia-gaming-festival-case-study/

Shin, J., & Kim, H. (2005). Noise Exposure Levels for the Middle and the High School Students. *Journal of Korean Society of Occupational and, 15*(2), 135-143.

Shuman, S. (2020, November 9). *PS5: The Ultimate FAQ*. Retrieved from PlaysStation.Blog: https://blog.playstation.com/2020/11/09/ps5-the-ultimate-faq/#3daudio

Soel, H.-Y., Kim, S.-H., Kim, G.-Y., Jo, M., Cho, Y.-S., Hong, S.-H., & Moon, I.-J. (2022, August 2). Influence of the Noise-Canceling Technology on How We Hear Sounds. *Healthcare, 10*, 1449.

Statista. (2021, Sept 7). *Number of mobile gaming users worldwide in 2021, by region*. Retrieved from Statista: https://www.statista.com/statistics/512112/number-mobile-gamers-world-by-region/

Statista. (2022, October 11). *Average weekly hours spent playing video games in selected countries worldwide as of January 2021*. Retrieved from Statista: https://www.statista.com/statistics/273829/average-game-hours-per-day-of-video-gamers-in-selected-

countries/#:~:text=The%20global%20average%20was%208.45%20weekly%20hours%20of%20gaming.

Statista. (2022, October 25). *Number of video gamers worldwide in 2021, by region*. Retrieved February 15, 2023, from Statista: https://www.statista.com/statistics/293304/number-video-gamers/

Statista. (2023, April 12). *eSports Worldwide*. Retrieved from Statista: https://www.statista.com/outlook/amo/esports/worldwide#revenue

Statista. (2023, April 17). *Global video game market value from 2020 to 2025*. (J. Clement, Editor) Retrieved April 17, 2023, from Statista: https://www.statista.com/statistics/292056/video-game-market-value-worldwide/

Susic, P. (2023, February 24). *50+ Gamer Demographics Facts in 2023*. Retrieved from headphonesaddict.com: https://headphonesaddict.com/gamer-demographics-statistics/#:~:text=There%20are%20around%203.04%20billion,PC%2C%20PlayStation%2C%20and%20Xbox%20gamers

Swierniak, W., Gos, E., Skarzynski, P. H., Czajka, N., & Skarzynski, H. (2020, Sep 17). Personal music players use and other noise hazards among children 11 to 12 years old. *International Journal of Environmental Research and Public Health, 17*(18), 6934.

Tronstad, T. V., & Gelderblom, F. B. (2016). Sound Exposure During Outdoor Music Festivals. *Noise & Health, 18*(83), 220-228.

TwitchTracker. (2023, May 9). *Twitch Statistics & Charts*. Retrieved May 9, 2023, from TwitchTracker: https://twitchtracker.com/statistics

Ward, M., & Harmon, A. (2019). Esport superstars. *Journal of Sports Economics*, 987-1013.

Webb, K. (2019, December 19). *More than 100 million people watched the 'League of Legends' World Championship, cementing its place as the most popular esport*. Retrieved April 13, 2023, from Business Insider: https://www.businessinsider.com/league-of-legends-world-championship-100-million-viewers-2019-12

WHO & ITU. (2019). Safe listening devices and systems: a WHO-ITU standard. Geneva, Switzerland.

WHO & ITU. (2019). *Safe listening devices and systems: a WHO-ITU standard.* Geneva: World Health Organization.

WHO. (2015). Make Listening Safe. Geneva, Switzerland: World Health Organization. Retrieved March 2023, 18, from https://apps.who.int/iris/bitstream/handle/10665/177884/WHO_NMH_NVI_15.2_eng.pdf

WHO. (2022). *WHO Global standard for safe listening venues & events.* WHO.

WHO. (2023). *Make Listening Safe*. Retrieved May 2023, 05, from World Health Organization: https://www.who.int/activities/making-listening-safe

Wicaksono, S. N., Dewanti, L., & Purnami, N. (2018, August 1). Correlation between earphone usage and visiting game centre with hearing threshold. *InJournal of Physics: Conference Series, 1075*(1), 012073.

Widen, S. E., Basjo, S., Moller, C., & Kahari, K. (2017). Headphone Listening Habits and Hearing Thresholds in Swedish Adolescents. *Noise & Health, 19*(88), 125-132.

Willaert, K. (2019, December 8). *THE ORIGIN OF THE TERM "GAMER"*. Retrieved from ACriticalHit: https://www.acriticalhit.com/origin-of-gamer/

Williams, K. (2022, January 27). *Are CSGO flashbangs causing real-life hearing damage to players?* Retrieved 4 20, 2023, from win.gg: https://win.gg/news/are-csgo-flashbangs-causing-real-life-hearing-damage-to-players/

Worthington, D., Siegel, J., Wilber, L., Faber, B., Dunckley, K., Garstecki, D., & Dhar, S. (2009). Comparing two methods to measure preferred listening levels of personal listening devices. *Journal of the Acoustical Society of America,, 125*, 3733-3741.

Yu, J., Lee, D., & Han, W. (2016). Preferred listening levels of mobile phone programs when considering subway interior noise. *Noise & Health, 18*(80), 36.

Zhang, B., Wang, D., & Chen, M. (2019). Influencing factors of hearing habits on hearing loss and related symptoms among medical students. *Chinese Gen Pract, 22*(29), 3602.

World Health Organization

WHO/UCN/NCD/SDR/2023.17 – © WHO 2023. Some rights reserved.

This work is available under the CC BY-NC-SA 3.0 IGO licence.

For more details refer to: www.who.int/health-topics/hearing-loss