Martina Mondonico

Accessibility in Social VR platforms for deaf people

Research on accessibility in physical and digital interaction, and definition of guidelines for an inclusive human-to-human communication in VR

Accessibility in Social VR platforms for deaf people

Research on accessibility in physical and digital interaction, and definition of guidelines for an inclusive human-to-human communication in VR

Candidate Martina Mondonico | 966202
Supervisor Margherita Pillan

Politecnico di Milano Scuola del Design
Master's Degree Digital and Interaction Design

Academic Year 2021/2022

POLITECNICO
MILANO 1863
SCUOLA DEL DESIGN

Index

Abstract English

Hearing the sound of a doorbell, conversing with other people, recognizing the sound of passing cars. These are everyday actions that we are used to taking for granted, but where obstacles occur for people with hearing disabilities.
Deafness has a strong impact on the lives of those affected, leading to consequences in terms of hearing but not only. Indeed, it is a multifaceted condition that leads deaf people to have specific needs to effectively interact with their surroundings: with physical spaces, with digital interfaces, with other people. Hearing impairment changes their needs in terms of interaction at 360 degrees, making as necessary to take their requirements into account when designing new products and experiences.
Hence, it arises the question about how the context currently responds to such specific interaction needs, where the research has highlighted the presence of several guidelines aimed at creating accessible experiences in different areas, from interior design to game design.
In a context that is increasingly advancing in terms of technology, it is also necessary to pay attention to the accessibility of more advanced and evolving technologies such as Virtual Reality, and to comprehend in this case what are the requirements for ensuring an inclusive experience for the deaf.
This thesis, therefore, investigates which are the guidelines for Social VR platforms to provide deaf people with cochlear implants an accessible communication with other individuals, displayed in the form of avatars. To achieve this goal, experiments were conducted with deaf people, through which their needs in terms of accessibility emerged.

Abstract Italian

Sentire il suono del campanello, conversare con altre persone, riconoscere il rumore delle macchine che passano. Si tratta di azioni quotidiane, date per scontate, ma che nascondono ostacoli per le persone affette da disabilità uditiva.
La sordità ha una forte risonanza sulla vita di coloro che ne sono affetti, comportando conseguenze a livello uditivo e non solo. Si tratta infatti di una condizione ricca di molteplici sfaccettature, che conduce le persone sorde ad avere bisogni specifici per riuscire ad interagire efficacemente con ciò che li circonda: con lo spazio fisico, con le interfacce digitali, con altri individui. La disabilità uditiva cambia i loro bisogni in termini d'interazione a 360 gradi, motivo per cui tali necessità devono essere prese in considerazione quando si progettano nuovi prodotti ed esperienze.
Da qui nasce l'interrogarsi su come il contesto attuale risponda a tali bisogni, dove la ricerca condotta ha evidenziato la presenza di diverse linee guida che si pongono l'obbiettivo di creare esperienze accessibili in diversi ambiti, dall'interior al game design.
In un contesto che progredisce sempre più a livello tecnologico, è necessario porre la propria attenzione anche all'accessibilità di tecnologie più avanzate e in fase di evoluzione come la Realtà Virtuale, e chiedersi quali siano in questo caso i requisiti per offrire un'esperienza inclusiva a non udenti.
La tesi si occupa quindi di investigare quali siano le linee guida per le piattaforme sociali di Realtà Virtuale, chiamate Social VR, per garantire alle persone sorde con impianto cocleare una comunicazione accessibile con altri individui, visualizzati sotto forma di avatar. Per raggiungere questo obiettivo, sono stati condotti degli esperimenti coinvolgendo delle persone sorde, attraverso cui sono emerse le loro necessità in termini di accessibilità.

Introduction

RESEARCH OBJECTIVES

This research stems from the intersection between university studies about interaction design and a personal interest in accessibility issues. Strongly believing that design should aim to have a valuable impact on people's lives, the researcher has chosen to focus on a delicate but often neglected subject: hearing disability.

Hearing loss currently affects more than 1.5 billion people, representing 20% of the global population (World Health Organization, 2021, p. 28). This is a figure that underlines the strong impact that this deficit has globally, but to which not too much attention is paid.
The following thesis takes an all-round analysis of the topic of deafness, with the aim of creating greater awareness around this disability which is still characterized by stigma and preconceptions, that may distract from understanding the real needs of hearing-impaired people. In fact, this deficit implies in deaf people's specific needs in terms of interaction, which is necessary to be aware of in order to guarantee accessible experiences for them.
This led to the first research question: *"How does the current context respond to deaf people's needs in terms of interaction design to allow accessible experiences with their surroundings?"*
From this inquiry, it emerged various guidelines established in various fields, from physical space interaction to digital experiences in video games, which aim to ensure accessibility, emphasizing a focus on inclusivity.

In a context of increasing technological progress, it is also important to pay attention to the grade of accessibility of more advanced technologies such as VR, which are destined to become more and more widespread as the XR technology market is estimated to grow in terms of user penetration over the next few years (Statista, 2022), highlighting the relevance it could acquire in the future. In addition, one of the major uses of VR is currently for social purposes, a usage that could greatly benefit deaf people as it would represent an aid to overcome obstacles they have to face in real life when relating to others.
From this reflection, the second research question arises, with a very specific focus: *"What are the requirements for Social VR platforms to ensure deaf people with cochlear implants an accessible communicate with other individuals?"*.
The aim of the research is to provide accessibility guidelines that can assist designers and developers in the purpose of creating new designs and services able to include deaf people.

METHODOLOGY

To give structure to the design process, the Double Diamond model, created by the British Design Council in 2005, was used. This framework is structured in two main parts, where the first is dedicated to research, composed of Discover and Define steps, while the second is related to design, defined by Develop and Deliver steps.

The conducted experiment follows specifically the first Diamond of the model, placing the initial focus on the divergent step of Discover, where analysis of documentation and literature review was conducted.
In detail, a very extensive desk research was performed, covering several topics. Firstly, hearing disabilities were investigated in order to achieve a clear and solid overview of the topic from a medical and technological point of view, collecting supporting case studies.
Then, it proceeded to the investigation of deaf people's needs to effectively interact with physical space, exploring a project in this regard. Likewise, an analysis of how they relate to digital gaming experiences was performed, with particular attention to the guidelines that have been defined to ensure accessibility in this context.
Finally, the focus shifted to VR, initially investigating this technology at 360 degrees and then cutting the study more and more towards the topic of deafness and accessibility, comprehending its potential relevance on a social level.
Lastly, after highlighting the social opportunities offered by VR, the research was directed towards human-to-human interaction content, acquiring knowledge on the concept of interpersonal communication brought forward by Watzlawick and Ekman's universal emotions, representing the conclusion of the divergent phase.

A convergent process then began through the Define phase, where the aim was to define the problem.
The focus was placed on VR platforms for social purposes, and firstly, the researcher experienced a VR platform first-hand to get familiar with the platform's functionalities as well as to get insights about the accessibility of the app.
Afterward gathering insights, a field research phase was conducted, thus involving users: at first, digital ethnography was performed to comprehend what users think and write online about the analyzed VR platform, evidencing the main issues. Subsequently, an experiment with interviewees was conducted, structured in the form of semi-structured interviews through which users experienced a Social VR platform with a specific focus on human-to-human interaction.
Lastly, results were extracted, through which a clear definition of the problem to be solved arose, concerning accessibility in VR. Building on these insights, new requirements to make communication accessible for deaf people in social VR platforms were structured, representing a starting point for the Develop phase which aims to focus on and develop a solution in response to the identified issue.

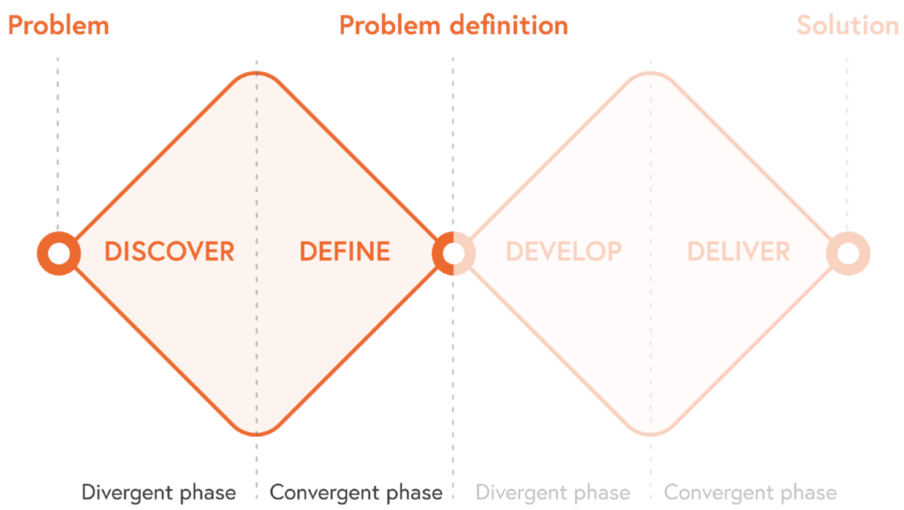


Fig. 1

Double Diamond process, where it's highlighted the steps conducted for this thesis

Source: Design Council

1

Hearing disability

The five senses - sight, hearing, touch, smell, and taste – have the role to collect information about the environment.
Each of them provides different stimuli to our brain, which interprets and combines them to reconstruct a complete picture of the surroundings.
Through our senses we establish a connection with the outer world, we interact with it and gain critical information for our survival.
Given their relevance in our existence, what happens in case of sensory loss?
This chapter explores the following topic, specifically the hearing sensory disability, starting with the analysis of the different types, degrees, and reporting the difficulties that hard-of-hearing have to face on a daily basis. Then, it explores the response of our brain in case of sensory loss and its subsequential reorganization, dealing with concepts of cross-modal plasticity and sensory substitution.

1.1 What is hearing loss?

The warning sound of a horn, the people's laughter, the harmony of a guitar strumming.
As humans, we rely on our hearing sense for vital reasons, from understanding what is happening around us to communicate with others. Nevertheless hearing is central to our survival, we are inclined to take it for granted, neglecting the several individuals in the world who suffer from hearing impairment.
Going in-depth, hearing loss my have different facets as it involved different types, as well as different degrees. This is also why approaches to this deficit can vary, going from using sign language to exploit hearing aids.

1.1.1 Definition and types of hearing loss

Hearing loss can be described as the condition in which the capacity of the individual to perceive sounds is reduced in comparison to the normal ability, equivalent to thresholds of 20 decibels up to 120 decibels in both ears, respectively corresponding to the sound of human breath and the police siren. It is considered disabling, a loss of 35 decibels or greater in the better ear, equal to the inability of perceiving sounds as the rustling leaves.

According to estimates, hearing loss currently affects more than 1.5 billion people, which consists of 20% of the global population, of whom 430 million have moderate or higher levels of damage in the better hearing ear (World Health Organization, 2021, p. 28). In Europe, 34 million people are currently living with a disabling hearing impairment, while in Italy the figure is around 5 million, according to Brunel University London (2018, p. 55). The geographical distribution is different all over the world and this data is attributable to region-related factors, such as healthcare access and high levels of noise exposure (GBD, 2019, p. 7), which add up to person-related characteristics that can alter the normal hearing mechanism, as aging and heredity.

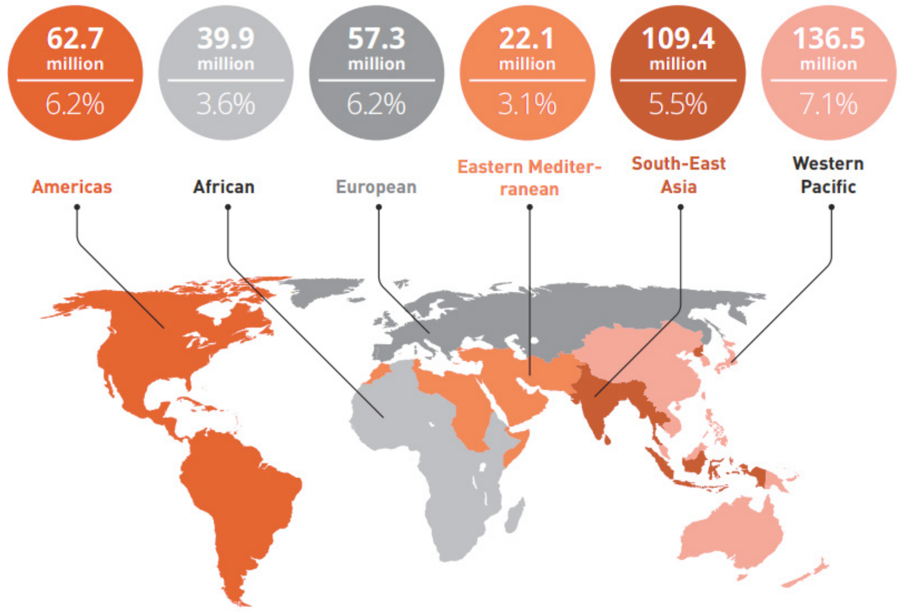


Fig. 2
Prevalence of hearing loss (moderate or higher grade) across WHO regions (not country boundaries), 2021
Source:
World Health Organization

The hearing disability is indeed determined by the improper functioning of one part of its complex system, which involves several steps:

1. Firstly, the sound is transmitted through the air as sound waves from the environment, which are gathered by the outer ear and sent down the ear canal to the eardrum.
2. The eardrum vibrates and sets the three tiny bones in the middle ear into motion.
3. The motion of the three bones causes the fluid in the inner ear, or cochlea, to move.
4. The movement of the fluid in the inner ear causes the hair cells in the cochlea to bend, which are responsible for changing the movement into electrical impulses.
5. These electrical impulses are transmitted to the hearing auditory nerve and up to the brain, where they are interpreted as sound (Better hearing, no date).

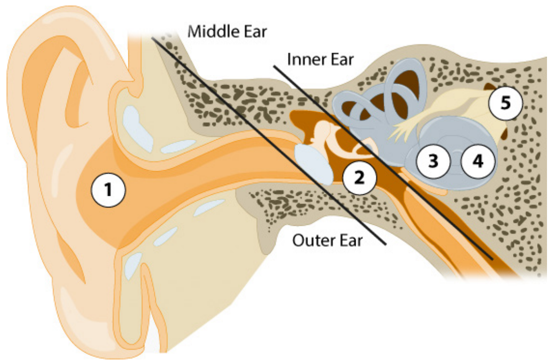
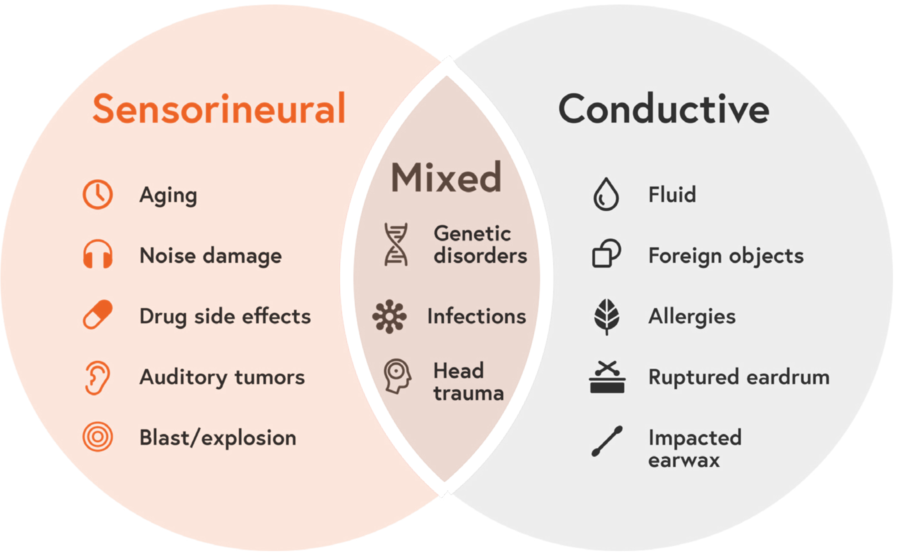


Fig. 3
Visual representation of the hearing mechanism
Source:
Hearing & Balance Center

The misfunctioning can be triggered by several factors, which are distinguished into three different categories: the sensorineural is the most common one and it involves a permanent disability due to damage to either the hair cells in the inner ear or the auditory nerve, which compromises the transfer of nerve signals to the brain.
The causes could be many, such as genetic syndrome, an infection passed from mother to fetus, or aging. A less common type is conductive hearing loss, where obstruction stops sounds from being conducted to the inner ear. It can be temporary or persistent depending on the causes, such as otitis or allergies. The last category is the mixed one, a combination of sensorineural and conductive loss, which is could be triggered by genetic disorders, infections, or ear trauma (Mroz, 2022).

Fig. 4
Types of hearing loss
Source:
Healthy Hearing



1.1.2 Grades of hearing loss

In order to establish the impairment severity, it's required to perform an audiometric measurement. It consists of a non-invasive hearing test, aimed to measure the person's ability to perceive different sounds in terms of loudness (intensity) and sound wave vibrations speed (tone). The detected hearing thresholds determine the individual's grade of hearing loss consisting of seven categories ranging from mild to complete, from a loss of 20 to 95 decibels or greater in the better ear (World Health Organization, 2021, p. 56). Different levels of severity imply varying difficulties for the involved individuals, from the inability to hear conversational speech to not perceiving most of the environmental sounds. The most severe form is the complete grade, with a threshold loss of 95 decibels or total, which implies the impossibility to hear speech, the surrounding noises, and that therefore has a strong impact on the quality of life of the affected people.

Grade	Hearing threshold in better hearing ear in decibels (dB)	Hearing experience in a quiet environment for most adults	Hearing experience in a noisy environment for most adults
Normal hearing	Less than 20 dB	No problem hearing sounds	No or minimal problem hearing sounds
Mild hearing loss	20 to < 35 dB	Does not have problems hearing conversational speech	May have difficulty hearing conversational speech
Moderate hearing loss	35 to < 50 dB	May have difficulty hearing conversational speech	Difficulty hearing and taking part in conversation
Moderately severe hearing loss	50 to < 65 dB	Difficulty hearing conversational speech; can hear raised voices without difficulty	Difficulty hearing most speech and taking part in conversation
Severe hearing loss	65 to < 80 dB	Does not hear most conversational speech; may have difficulty hearing and understanding raised voices	Extreme difficulty hearing speech and taking part in conversation
Profound hearing loss	80 to < 95 dB	Extreme difficulty hearing raised voices	Conversation speech cannot be heard
Complete or total hearing loss/deafness	95 dB or greater	Cannot hear speech and most environmental sounds	Cannot hear speech and most environmental sounds

Fig. 5
Grades of hearing loss and related hearing experience
Source: World Health Organization

So each grade involves diverse daily consequences for the hearing-impaired, who are also called with other specific terminologies based on sound threshold; the term "hard of hearing" delineates the condition of mild to severe/profound hearing loss, while "deaf" describes a severe or profound grade in both ears (DO-IT, 2022). Notable is that hearing impairment can affect just one ear, becoming a unilateral loss, or both ears called as bilateral.

Currently, nearly 60 million suffer from deafness, representing 0.8% of the hard-of-hearing globally, while 16%, more than 1150 million people, suffer from a moderate loss (World Health Organization, 2021, p. 58).
The prevalence of the higher grades of hearing loss increases with age, rising from 5.6% aged 50 to almost 60% at 90 years old (World Health Organization, 2021, p. 59). Although it is mainly affecting elderly people because of aging, this condition concerns 70 million children between 0–15 years old globally, mainly interested by a moderate loss (GBD, 2019, p. 7). While for the oldest the prevalent triggers are age-related factors, for the youngest the main loss causes are congenital and otitis. The occurrence of hearing issues at different stages of one's life entails different consequences and therefore a diverse impact; in the case of children, it is determinant for their growth since it can impact spoken language, cognition, social well-being, and isolation (GBD, 2019, p. 7).

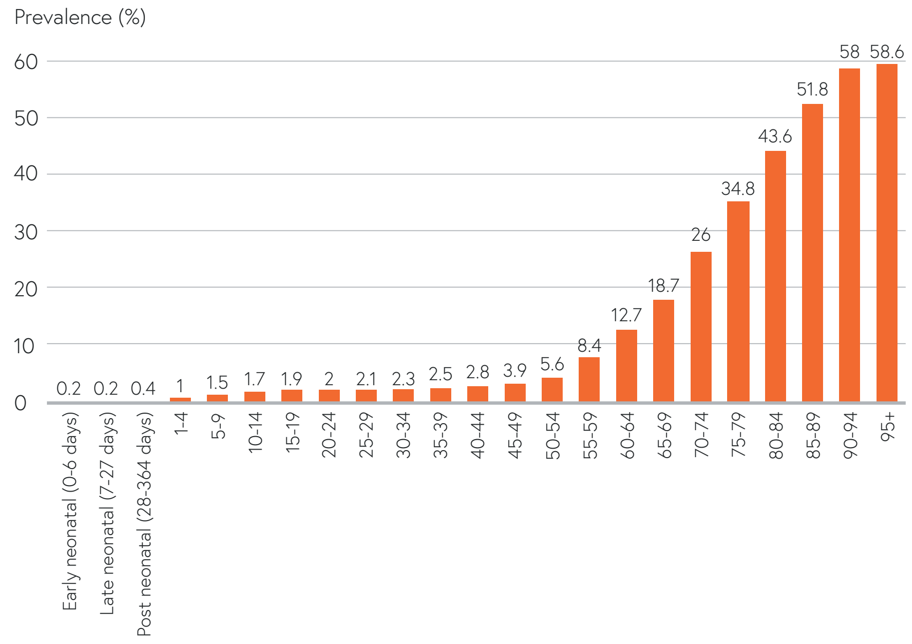


Fig. 6
Global prevalence of hearing loss (moderate or higher grade) according to age, 2021
Source: World Health Organization

1.1.3 Different approaches to hearing loss

Thanks to advancements in the medical field, hard-of-hearing can rely on technology aids, aimed to give enhanced access to information carried through sound and speech. Devices such as hearing aids and cochlear implants have the role to offer a better life quality for people with hearing loss who desire to improve their current situation.
In this regard, it's notable to say that deafness is not unanimously considered a condition that needs to be fixed (Mindess, 2014, p. 46).
A positive attitude towards deafness is quite typical and leads to the use of terminologies as "deaf gain", in order to highlight the change of perspective. Those who strongly believe in this ideology consider themselves as part of a Deaf[1] culture, composed of individuals who share the same beliefs, behaviours, and values regarding the signing approach. Indeed, Deaf culture revolves primarily around the use of sign language: it is a form of communication that conveys messages without sound, through the use of facial expression, body language, arms, and especially hands. It relies on the idea that *"vision is the most useful tool they have to communicate and receive information"* (Healthy hearing, 2019) and it allows the dialogue between signing Deaf.
According to United Nations statistics (2022), more than 70 million deaf people worldwide use sign language as their first language, where the most widely-used is American Sign Language (ASL). Globally it exists more than 300 distinct languages and most of them significantly vary from country to country. Hence, in order to communicate, signing deaf involve the use of their body without relying on their voice. Because of that, they have been improperly called for years as "deaf-mute", an obsolete term that was erased and replaced by the term "deaf" (Law No. 95/2006) in order to remark the integrity of their phonic capacity (Parlamento Italiano, 2006).
As a matter of fact, the reason why signing deaf individuals don't entail the use of spoken language is that, since they can't hear sounds, they cannot reproduce them.
However, a signing Deaf can also be bilingual and therefore master both signs and his or her country's spoken language. Indeed, signing is not the only modality through which hard-of-hearing can communicate, since the presence of another approach: oralism.

1 Deaf (upper case D) refers to people who are members of the Deaf community and who communicate almost exclusively with sign language, while deaf (lower case 'd') concerns people who have hearing loss who may communicate orally and may also be users of sign language.

Fig. 7
Two people conversing in sign language
Source: BeTranslated

Considered as a threat by the Deaf community, oralism focuses on reading speech cues and the involvement of voice to interact with others. Indeed, it is not based on sign language, but it takes advantage of sound as well of lip reading, regarded as "*a way for deaf of using their skills, knowledge and general awareness to be enabled to take part in the conversation*" (Hearing Link Services, 2022). Also known as speechreading, it is based on the visual interpretation of lips, tongue, and face movement, aimed to understand and then produce spoken language. Even though it is central for oralist hard-of-hearing, the estimates evidence that only around 30% of speech sounds can be correctly lip-read even in quiet environments (National Deaf Children's Society, no date). So relying only on the interpretation of lips movements is not enough for good verbal communicating skills and therefore it's required the involvement of hearing technology, such as hearing aids and cochlear implants, to increase the awareness of speech and noises.

Hearing aids are non-invasive wearable and electronic devices, which provide an overall improvement in communication ability since they allow deaf to perceive sounds in a clearer way.
Their role is to amplify the surroundings noises through simple steps:

- Firstly, a miniature microphone perceive a sound and convert it into a digital signal.
- This signal is processed, boosted and modified according to the hearing loss of the specific user.
- Finally, a miniature loudspeaker sends the processed sound to the ear (Hearing Link Services, 2022).

They are suitable for hard-of-hearing who experience mild to moderate loss degrees. Known also as acoustic prostheses, they are characterized by a wide range of different products and types in order to meet all the listening needs and lifestyle.

Fig. 8
Different types of acoustic prostheses
Source: Connect Hearing

Fig. 9
Person wearing acoustic prosthesis
Source: Fondo Sanedil

Another technological possibility is the cochlear implant, a surgically implanted electronic device which gives deaf the possibility to detect sounds as well as hearing aid. As opposed to acoustic prostheses, it acts as a substitute of one part of the auditory system, the cochlea, a component of the inner ear that translates acoustic information into electrical impulses for the brain.
This prosthetic device completely by-passes the normal hearing mechanism and directly stimulates the cochlea by sending electrical signals straight to the auditory nerve.
In order to work, an implanted and external device are both required. Starting from the external, a sound processor (A) has the role to capture the surroundings sound and turn it into digital code, which is transmitted through the coil (B) to the internal implant (C). The latter converts the digitally-coded sound into electrical signals. Then, they are sent to the electrode array in the cochlea (D), that stimulates the cochlea's hearing nerve fibers (E) which finally transmit the auditory information to the brain (Hearing Link Services, 2022).

Cochlear implants are suitable for individuals with profound or total loss, who have only a little or even no benefit with a conventional hearing aid. The bilaterally deaf person can choose whether to have cochlear implants in both ears or to continue using prosthesis in one of them.
Approximately more than 800,000 users worldwide benefit of a "bionic ear", as it is generally called by its patients (Carlyon and Goehring, 2021, p. 1).
Their age range is very difference, since it goes from children as young as 12 months born as deaf to adults who meet the proper hearing impairment

Fig. 10
Cochlear implant functioning
Source: Hearing Link Services

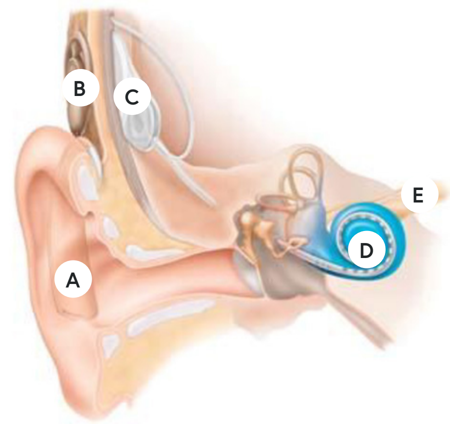


Fig. 11
Person wearing cochlear implant
Source: Hear and Say

requirements[2] (Cochlear, no date).
Depending on the age at which the device is implanted, its impact on deaf lives could change. As report by the National institute on Deafness and Other Communication Disorders *"when these children receive a cochlear implant followed by intensive therapy before they are 18 months old, they are better able to hear, comprehend sound and music, and speak than their peers who receive implants when they are older."* (National institute on Deafness and Other Communication Disorders, 2021).
Cochlear implants as well as hearing aids provide Bluetooth pairing functionality: by exploiting additional components related to the aids, they can be connected to other devices, such as TVs or headphones, for having direct access

2 According to Cochlear, cochlear implantation can be evaluated for individuals who meet the minimum age and/or weight requirements, have a moderate to profound sensorineural hearing loss in one or both ears, get limited benefit from wearing a hearing aid and have no medical contraindications. Moreover, they need to be motivated to follow scheduled rehabilitation sessions (Cochlear, 2017).

to the implant's sound processor and thus reaching a better sound quality.

As mentioned in the previous quote about intensive therapy, the potential benefit of technological assistive devices, as hearing aids and cochlear implants, are truly expressed when accompanied by an intensive speech therapy. This discipline deals with the diagnosis and treatment of communication diseases thanks to speech therapists, audiologists and other professionals. By starting a journey of rehabilitation, they aim to improve their patients' communication and spoken language. The therapy is addressed to both children and adults, whose benefits can vary due to age but also to individual aspects, such as motivation. Notable to clarify is that both of the above-mentioned technological devices, accompanied by speech therapy, do not lead to a total hearing reacquisition, but only to a partial gain. As a matter of fact, oralist hard-of-hearing can return to perceive sounds, but with some limitations since cochlear implants have a much smaller dynamic range than a normal ear.

Fig. 12
Speech therapy session with a child with a cochlear implant
Source: Keele University

Even though acoustic perception is very subjective, the sound reproduced by both hearing technologies is commonly considered as "metallic, electronic" and therefore not completely natural (Pisano, 2018).
A research conducted by the Sound and Vibration Research Institute reports that *"some people have described listening to music through an implant as listening to a piano played with a boxing glove: rhythmic information is good, but frequency resolution is poor, even sound separation is very difficult. We use harmonics to group sounds, but an implant user does not get good enough frequency resolution with electrodes, so picking out individual instruments from a mix is a real challenge"* (Pisano, 2018).

1.2 Daily impact of hearing loss

Hearing loss entails considerable consequences for hard of hearing on a daily basis. From hearing the public announcements of a train departure to communicate in a dimly lit room, they constantly have to face many challenges which can affect their life quality. They have difficulties at the cinema because of the absence of subtitles, or when talking to someone who is not completely within their visual range since it undermines the possibility to lip-read, resulting in miscommunication and therefore frustration. Hearing loss can compromise their daily activities and moreover it affects more than their ability to hear, having consequences on the health, psychology, and sociality of the individual.

1.2.1 Health consequences

Hearing sensory disability, as previously explained, is caused by the improper functioning of the hearing system which in turn could lead to the occurrence of other issues, seemingly unrelated to ears, such as vestibular disorder.
Manifested with symptoms of dizziness and vertigo, it is a dysfunction of the body's balance system which causes a loss of equilibrium, spatial orientation, and coordination of movements (Dougherty et al, 2023, p. 1). Because of anatomical connections inside the inner ear, hearing and vestibular systems are strictly interconnected and this is why as many as 30% of deaf people may have balance problems such as postural instability, the risk of stumbling, and falling (Berke, 2022). Children with congenitally severe hearing loss are likely to be affected by vestibular disturbance as well as individuals with cochlear implants, because of the electrical stimulation that can cause vertigo after surgery. Therefore, hearing loss can strongly impact on hearing impaired's relationship and perception of the environment and it consequently affects how they interact with the surrounding space.
In case of hearing loss, it is crucial to quickly intervene and not neglect this disease, otherwise it could lead to several health issues. In the past decade, it has become an expanding area of research on the correlation between untreated hearing loss and cognitive consequences. The Hearing Links Services reports that "*when hearing loss is unassisted, those with a mild hearing loss are twice as likely to develop dementia as people without hearing loss. Those with severe hearing loss are five times more likely to develop dementia.*" (Hearing Link Services, 2022).
There are various hypotheses on the mechanisms which link hearing loss to brain alterations, although the nature of this association is still unclear. According to Censis, hearing impairment increases the effort required to understand the context, which results in brain fatigue and can cause a subsequent reduction of attention for other tasks (Censis, 2018), while another supposition is that hearing loss involves a lack of stimulation of the five senses, that affects the brain's health.
The possibility of the occurrence of the above-mentioned cognitive issues can be averted by early detection of the hearing disability and immediate intervention through assistive technological aids (Censis, 2018).

1.2.2 Psychological and social consequences

The biggest challenge that deaf have to face on a daily basis is communication, which is our distinguishing trait as human beings that enables us to create meaningful relationships. According to Maslow's hierarchy of needs pyramid, the establishment of relationship bonds is one of our basic psychological needs, which makes us feel loved and as belonging to something (McLeod, 2023).

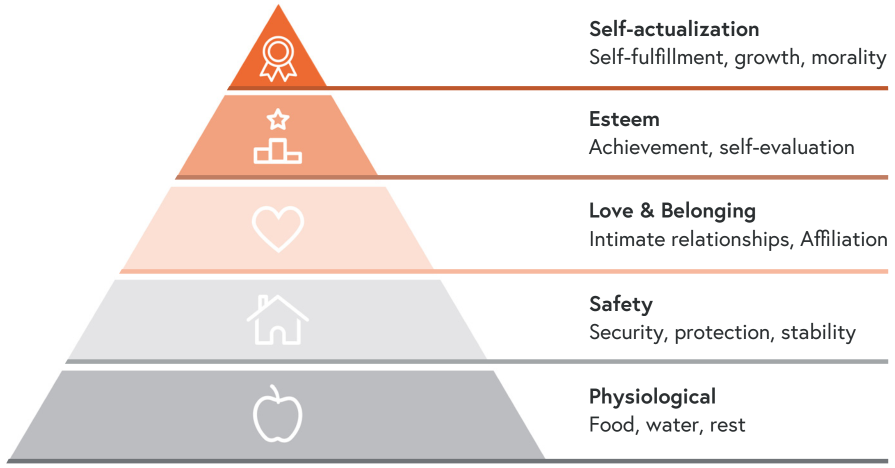


Fig. 13
Maslow's hierarchy of needs pyramid
Source: Multidisciplinary Digital Publishing Institute

If the ability to communicate is compromised, it can result in difficulties in interacting with others and therefore in psychological and social diseases, as for those affected by hearing loss.
"Acquired hearing difficulties are responsible for a high level of general psychological distress for a significant number of people, due in part to isolation, loneliness, and withdrawal" (Meadow-Orlans, 1985, cited in Committee on Disability Determination for Individuals with Hearing Impairments, 2004, p. 181).
As reported by Hearing Loss: Determining Eligibility for Social Security Benefits, their mental status is strongly affected by isolation, which can lead to the oc-

currence of psychological issues such as heightened anxiety, depression, and sleep disturbance. Moreover, the difficulties they may face when communicating with others can result in the development of personal insecurities; some express embarrassment and self-criticism when trying to comprehend spoken language, while others are used to criticize the sound of their own voice, which is a common behaviour among hearing-aid users (Committee on Disability Determination for Individuals with Hearing Impairments, 2004, pp. 180-181).
The communication barriers that daily challenge hard-of-hearing individuals create for them an emotional and psychological damage, which may also occur in a family context: 9 out of 10 deaf children are born to hearing parents (National Institute of Deafness and Other Communication Disorders, 2021) and because of that, they might sometimes feel excluded and not fully understood by their loved ones. Also, some of them have difficulties in admitting their hearing loss and end up having issues in accepting themselves, with consequences on a psychological level.

An important aid, which positively affects the social status of individuals-affected, is the cochlear implant as demonstrated by the experiment quoted by Dobie and Susan Van Hemel (Knutson et al, cited in Committee on Disability Determination for Individuals with Hearing Impairments, 2004, p. 181). The study conducted over 54 months, involved 37 post-lingually deafened adults with cochlear implants and evidenced a relevant improvement in measures of loneliness, social anxiety, paranoia, social introversion, and to a lesser extent depression after the bionic ear intervention. So, the exploitation of technological devices brings benefits for the hard of hearing lives firstly on an auditory level and consequently on a social perspective, giving them the possibility to interact with everyone, also with hearing people.
On the contrary, if hearing loss remains unaddressed, it entails impactful social consequences especially for babies since more than 80% of neuronal development takes place in the first three years of life (Istituto Superiore di Sanità, 2020). As a matter of fact, it can affect children's development of spoken language, cognition, and sociality with long-term effects on their entire lives (GBD, 2019, p. 7).

Over the past two years, another barrier has challenged the deaf's social skills even more, which is the usage of face masks against Covid-19. The following device has undesirable consequences as it creates communication obstacles for those affected by hearing loss. It prevents them from lip-reading and thus removes important visual support signals, that are crucial for them, especially in noisy places. It's the reason why, during the pandemic, many deaf people have requested the use of transparent masks, an initiative that unfortunately had not caught on. Therefore this new challenge increases the mental effort required to hear and interact with others, representing another factor that can compromise their psychological and social status (Amplifon, 2021).

Fig. 14
People speaking while wearing transparent masks, which allows the possibility to lip-read
Source: Health line

1.2.3 Discrimination issue: audism

Another factor that impacts hard-of-hearing lives is prejudice, which takes the name of audism when deafness-related. It is discrimination against hard-of-hearing and deaf individuals, based on their ability to hear.
The term audism dates back to 1997, when it was coined by Tom Humphries in his doctoral dissertation Communicating across cultures (deaf-hearing) and language learning, defined as "*the notion that one is superior based on one's ability to hear or to behave in the manner of one who hears*" (Humphries, 1977).
A distinctive attitude of discriminating people, defined as audists, is the belief that deafness corresponds to inferiority and consequently able-bodied people and their culture are superior. One of the behaviours regarded as discriminatory is related to a lack of effort in communicating with a deaf person as, for example, not paying attention to position themselves in the visual range of the other. Another prejudice is the idea that deafness prevents one from doing many everyday activities and that it represents a tragedy. These are just a few of the behaviours resulting from prejudice, which the most serious and alarming occurs in the workplace (Ai-media, no date).
As reported by the Deaf jobseeker and employee experiences survey (Totaljobs, 2016, p. 4), on a sample of 473 hard-of-hearing participants living in the UK, more than half have experienced discrimination due to their condition while at work. A worrying result of the questionnaire is that 25% of respondents had left their job as a result, as in the case of one respondent who recounted his experience: *"At interviews some employers have said that I am not suitable for the job because I need to be able to use a phone when out and about. Colleagues have often left me out of conversations or asked me to do a specific*

job to get me out of the way rather than talking to me" (Totaljobs, 2016, p. 21). To avoid these unpleasant situations, the ADA, Americans with Disabilities Act, was created and signed into law in 1990, which acts in the US against disability discrimination in various contexts, such as the office (Wikipedia, 2022). These episodes occurs also because there are still knowledge gaps in what the hearing community comprehends about deafness, sometimes due to a lack of interest which leaves room for biases.

Audism can also occur within a medical context, taking the name of institutionalism audism. This term was first used in 1992 in Harlan Lane's treatise Mask of benevolence, arguing that medical and educational institutions do not allow deaf people to express themselves on matters that personally affect them (Lane, 1992, p. 198).
An example on a medical level is the cochlear implant: a child exposure to surgery for acquiring hearing capabilities can be seen as discrimination against deafness. On an educational level, we can think about the oralist method, seen by Deaf culture as an obligation for deaf children to learn the spoken language to be integrated into the hearing culture.
Every person is different and the same applies to deaf people, who can freely choose how they communicate. For this reason, there are different, even conflicting, strands of thought between them. The unifying element is their need for greater inclusion given the many barriers still present in their everyday lives. Move towards greater accessibility is becoming a real necessity, especially in view of the World Report on Hearing predictions: according to their analysis, 2.5 billion people will be living with some degree of hearing loss in 2050, specifically predicting an high increase during the next three decades (World Health Organization, 2021, p. 139).

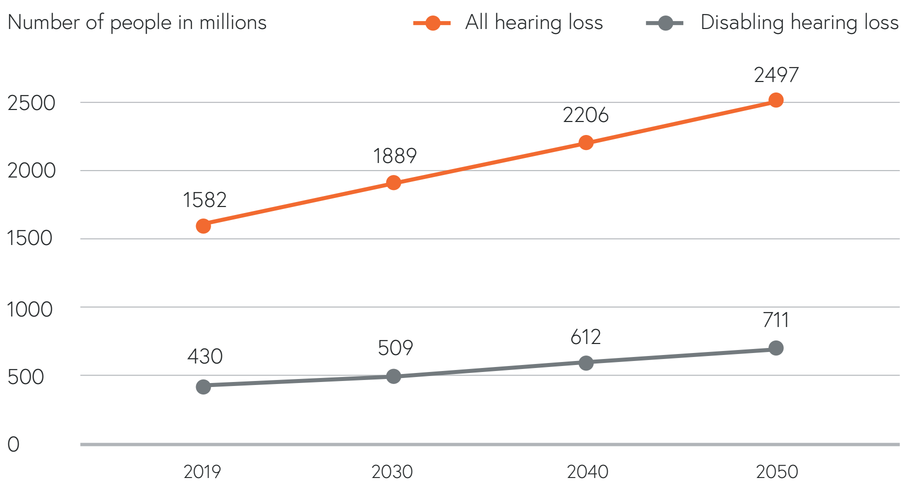


Fig. 15
Projected increase in prevalence of moderate and higher of hearing loss, 2019-2050
Source: World Health Organization

1.3 Cross-modal neuroplasticity in hard-of-hearing

As we enter the world, our brain and its structural interconnections change throughout the course of our existence as we acquire new abilities, such as learning how to speak or memorizing how to play an instrument.
Modifications at the cerebral level occur as well in case of a sensory loss, taking the name of cross-modal neuroplasticity. It corresponds to the brain's ability to reorganize itself and create new neuron circuits to compensate for the deficit. It is an adaptive phenomenon, in which portions of a damaged sensory region are absorbed by unaffected ones and acquire different functionalities (Benetti, 2017).
Regarding hearing loss, the reorganization interests the temporal lobe: a cerebral region dedicated to auditory stimuli processing and also responsible for spoken and written language comprehension, objects and faces recognition, declarative memory, and social perception. The following area deprived of sound stimulation does not remain inactive but assumes compensatory abilities in primarily two of the four remaining senses: sight and touch. This happens since visual and tactile stimuli, respectively processed by the occipital and parietal lobe, are further elaborated by the temporal one. As a consequence of this, the above-mentioned two senses result in heightened for individuals with hearing loss (Beltone, 2019).

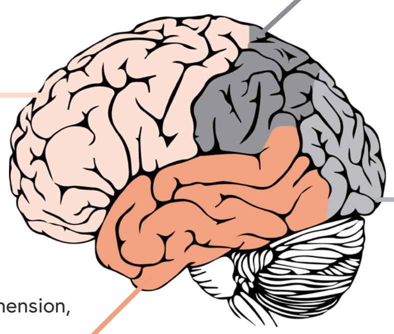


Fig. 16
Visual representation of the brain's lobes
Source:
CGS Psychology

Notable to point out is that neuroplasticity's effects vary person-to-person. The type of changes depends on the sensory experience and on the age since the capability to create new neural connections is elevated in young people and then decreases with age. Neuroplasticity may also compromise the effectiveness of hearing aids and cochlear implant treatments, if applied after the age of 4 in congenitally deaf children. This occurs since the temporal area will already be occupied by other functions compromising the recovery effectiveness (Cardon, Campbell and Sharma, 2012, p. 6).

1.3.1 Sight

The correlation between hearing loss and neuroplasticity has been the main subject of a few pieces of research, which explore visual ability enhancement in deaf individuals. As reported in the scientific paper PNAS, an experiment on 31 early deaf users evidenced the activation of the temporal lobe for visual face processing, through the exploitation of behavioral and multimodal neuroimaging measures (magneto-encephalography and functional imaging) (Benetti et al, 2017, pp. 2-4).
Therefore, the hearing-related cortex participates in face identity processing, contributing to the elaboration of relevant information for social interaction.

Deafness has been furthermore correlated with a heightened ability in perceiving motion, peripheral view, and visual attention, Audicus health company reveals. All the following data are referred to deaf individuals, while it remains untested for people with mild hearing loss, even though many scientists suspect a similar phenomenon (Audicus, 2021).
The aforementioned visual capabilities might be best conceptualized as an enhanced reactivity to visual clues. Micah M. Murray and Mark T. Wallace in The Neural Bases of Multisensory Processes explain that *"deaf individuals do not see better, but react faster to the stimuli in the environment"*, corresponding to a better attentiveness of sight-related stimuli (Murray and Wallace, 2011, p. 443). Since they cannot fully rely on their hearing, they are inclined to pay close attention to visual clues and therefore to metaphorically associate their eyes with hearing skills, as reported by the neuroscientist Christina Karns (Lewis, 2013).
A heightened vision can also involve the negative effect of light high sensitivity, which tends to interest more deaf-born children.

The following insights about cross-modal neuroplasticity effects have been furthermore explored by Canada's University of Western Ontario, which tested the current phenomenon on domestic animals. The research team performed behavioral tests with cats, demonstrative that deaf-born have better peripheral vision and motion-detection abilities than those with normal hearing. Moreover, in order to pinpoint which parts of the brain were responsible for the enhanced visual abilities, the scientists applied a surgical method called reversible deactivation, responsible for a temporary cooling of cerebral regions. By making inoperative the deaf cats' auditory cortex, the animals lost their peripherical vision advantage, evidencing that, as in deaf human beings, cross-modal plasticity leads to sight-related enhancement (Than, 2010).

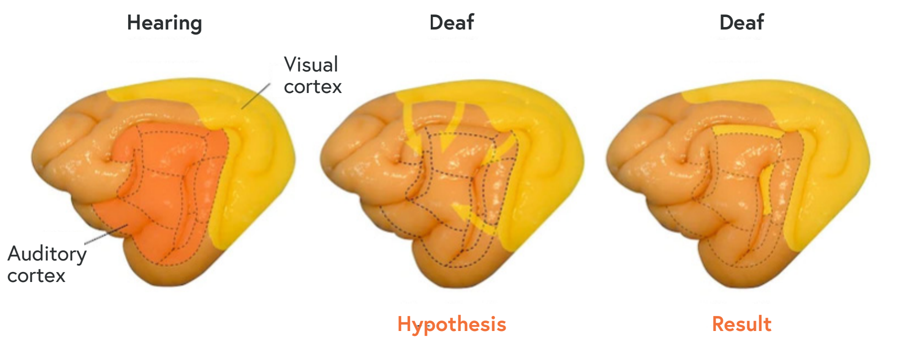


Fig. 17
Visual representation of the cat brain's visual cells migration to hearing region
Source: National geographic, in courtesy of Amee J. Mcmillan

1.3.2 Touch

Confirmation that cross-modal neuroplasticity also heightens the sense of touch comes from research at the University of Oregon. Their investigation set out to respond to an unanswered question: does deafness affect how the brain processes touch and vision together?
In order to do that, they involved 13 congenitally deaf and 12 hearing adults, who were required to wear a designed apparatus like headphones while inside an fMRI scanner. During the test, they experienced both tactile and visual stimuli: regarding touch, double puffs of air were located precisely on participants' faces, combined simultaneously with the visual stimulus of two brief pulses of light mounted directly below the air-puff nozzle.
Through the use of fMRI, changes in Heschl's gyrus brain activity of the participants, the primary site of the auditory cortex in the human brain, were measured during the study. The experiment showed that deaf individuals have greater brain activation in the temporal lobe in response to sight and touch clues than hearing ones, confirming the use of the auditory cortex for processing visual and tactile stimuli.
Moreover, deaf individuals have been part of a sensorial illusion: they perceived a double flash of light when in reality it was only a single pulse paired with double air puffs. Karns, one of the scientists, explained this phenomenon by saying that *"deaf people don't have sound, so they end up building a visual system that's more accurate"*, suggesting that, since they cannot rely on sound, they exploit tactile stimuli to improve the visual accuracy and understanding of the surroundings (Karns, Dow and Neville, 2012, pp. 2-8).

The performed test took advantage of a known perceptual illusion involving hearing people: the auditory-induced double-flash, a phenomenon in which a single flash of light, paired with two or more brief sounds, is perceived as multiple brief pulses by those with normal hearing capabilities. The University of Oregon researchers modified the following test for deaf individuals, by replacing auditory clues with tactile ones. As hearing was susceptible to the illusion thanks to the combination of visual and auditory stimuli, deaf people experienced the same circumstance but with touch and visual ones.
Interesting data emerged regarding different degrees to which deaf participants responded to the illusion: those with the highest level of brain activity in the auditory cortex during the experiment also had the strongest response to the visual impression. These insights support the thesis that the double-flash phenomenon is a consequence of cross-modal neuroplasticity in deaf people (Bates, 2012).
The experiment's findings about sight and touch connection are considered relevant for the deaf and for their daily lives. As reported on the National Institute of Health, *"if touch and vision interact more in deaf, touch could be used to help deaf students learn math or reading"* (Latham, 2012).

1.4 Sensory substitution for hearing loss: case studies

Our brain plasticity and its response to sensory deprivation represents an advantage for a mechanism called sensory substitution: it deals with the use of a sensory modality to supply environmental information normally gathered by another sense.
One of the first to really investigate this concept was the neuroscientist Paul Bach-y-Rita, who started his study on sensory substituting to treat those suffering from neurological disorders and then expanded the research field to blind people, as published in Journal Nature in 1969 (Cause Effect Psychology, no date).
In the following demonstrative paper, the neuroscientist exposed his experiment conducted on blind individuals: the participants were sitting on a modified dental chair with tactile sensors on its back, while a video was set up. When an object was framed by the camera, the following visual clue was transmitted to the users through tactile stimuli, by providing vibration into their backs thanks to a grid of solenoids placed inside the chair. After a training, blind people were pretty good at distinguishing which element was being recorded and what they were feeling through their bodies (TED, 2015).
Starting from that many modern incarnations of this research were performed, also treating other senses. Indeed, several studies explored the possibilities of sensory substitution for hearing loss.

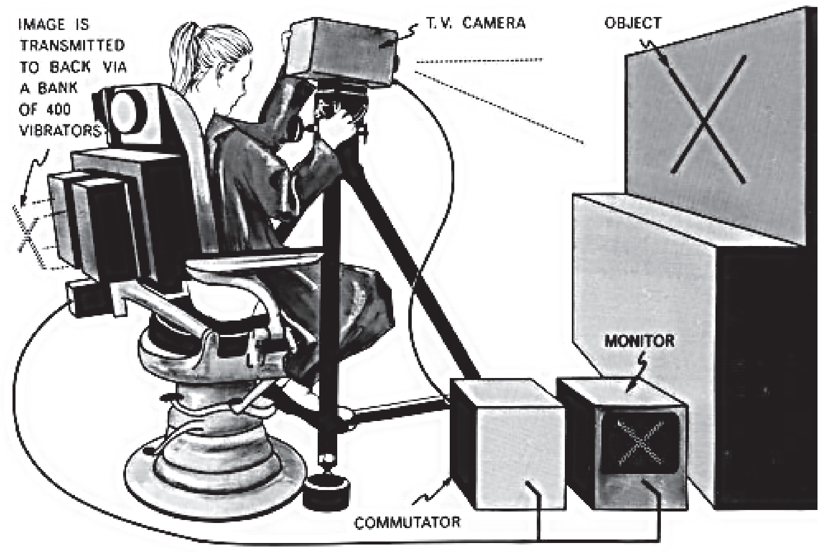
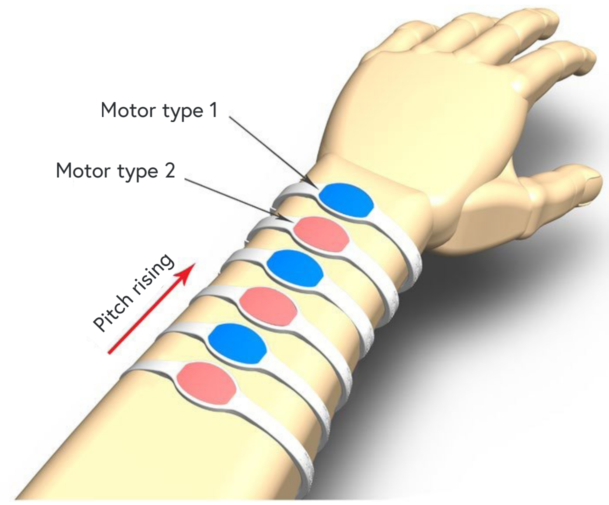


Fig. 18
Scheme of the experiment conducted by Paul Bach-y-Rita on blind people
Source: David Eagleman TED Talk

1.4.1 Haptic stimuli for enhanced pitch discrimination and intelligibility

The Southampton University researchers Mark D. Fletcher, Nour Thini, and Samuel W. Perry explored a new approach to provide auditory stimuli, focusing on enhancing pitch discrimination for cochlear implant users. As explained earlier in chapter 1.1.3, the bionic ear has some limitations related to severely impaired sound perception and its smaller dynamic range than a normal ear.
Starting from the analysis of previous studies, British scientists have found in haptic stimulation a way to answer these issues. The researchers involved have shown the effectiveness of augmenting hearing stimuli with haptic feedback in CI[3] individuals since tactile inputs improve speech understanding and melody identification.
After acquiring knowledge of the current state-of-the-art, the Southampton University researchers designed a wearable device named mosaicOne_B, which extracts pitch information from audio in real time and delivers it through haptic stimulation on the forearm. The vibrations are provoked by twelve motors, six along the top of the arm and six on the underside, where each motor represents a different pitch within a single octave.

Fig. 19
Schematic representation of the mosaicOne_B haptic stimulation device on the forearm
Source: Scientific reports



3 CI is the abbreviation for cochlear implant.

The device was tested with twelve normal-hearing users who listened to simulated audio of a cochlear implant and then responded to a specific task; after listening to two consecutive tone pitches, participants were asked to judge which interval contained the sound or vibration with the higher tone. This procedure was performed in three different conditions: audio only, haptic only, and the two of them combined.
The findings confirmed the role of touch as a substituting sense for hearing: thanks to the exploitation of mosaicOne_B, the participants listening to CI simulated audio were able to discriminate pitch differences at a similar level to normal hearing of able-bodied users. The following device has the potential to improve music perception, speech recognition, and speech prosody perception in subjects with bionic ears, proving to be effective even in environments with background noise (Fletcher, Thini and Perry, 2020, pp. 1-5).

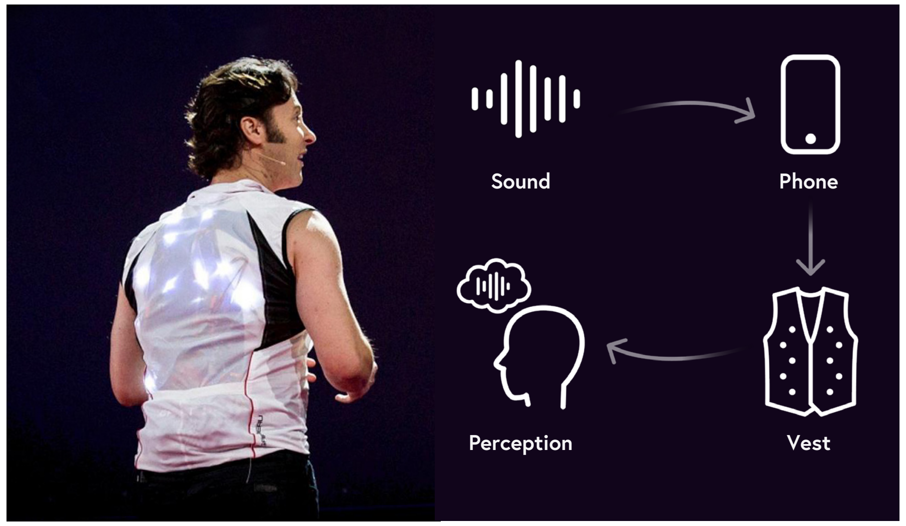
In fact, CI performs poorly in the presence of environmental noises due to its limited transmission of low-frequency sound information. Because of that, another study explored the possibility of vibrotactile stimulation to enhance speech intelligibility in multi-talker conditions.
The experiment followed a similar path to the above-mentioned one: eight able-bodied participants listened to a bionic ear simulated speech-in-noise through a small device placed on their fingertips which produced tactile stimulation in conjunction with the sound. The device converted sounds into tactile signals, through the exploitation of a computational algorithm. The test took place in two different moments, before and after a 3-day training regimen where participants were exposed to the simulated speech noise with both with and without concurrent haptic stimuli for 30 minutes.
The results indicate a performance improvement in sentence recognition after the training. Thus, the research confirms the central role of the sense of touch in the improvement of speech intelligibility in multi-talker noise, representing a great aid for deaf people (Fletcher, Mills, and Tobias Goehring, 2018, pp. 2-8).

1.4.2 Haptic stimuli in wearable devices

"Your brain doesn't know where the signals come from. It just figures out what to do with them" (TED, 2015). Through this sentence, the American neuroscientist, author, and university professor David Eagleman introduces his project on sensory substitution for the deaf. Presented at a TED talk in 2015, it is a wearable device that exploits the sense of touch, designed with his student Scott Novich.
The intention to enable deaf people to hear sounds takes shape in a vest, which exploits the use of portable computing technology and personal mobiles.

Its pretty simple functioning had been explained by the neuroscientist: *"As I'm speaking, the sound is captured by a tablet and it's getting mapped onto a vest that's covered in vibratory motors"*. Therefore, the environmental sounds are recorded by the personal device, which exploits Bluetooth to transmit information to the suit into haptic feedback. As Eagleman said during his speech, through this object *"I'm feeling the sonic world around me"* (TED, 2015).
Some tests were performed with deaf people whose results are very encouraging: after just a little time of training, people can start understanding the language of the vest. Talking about Jonathan, a test participant, after 8 hours of training in 4 days he was able to correctly identify all the words being said. This occurs because his brain is starting to figure out what the sensory data means, even if he is not doing it consciously. The neuroscientist affirmed that, after wearing the vest for about three months, the users may have the direct perceptual experience of hearing without any conscious intervention.

Fig. 20
Eagleman wearing his invented vest and a schematic representation of its functioning
Source: IDEA.TED.COM



The above-mentioned invention highlights once again the benefits of exploiting the sense of touch in deaf people. The device has the potential to become a game-changer, as it represents a non-invasive alternative to cochlear implantation for hearing the sound of the world.

Another creation that pursues the same aim was designed by Not Impossible Labs team, who shifted their focus to a more specific theme: music experience. Taking into account the difficulties deaf people have in enjoying live entertainment, they developed a haptic suit to make concerts more inclusive: it uses the sense of touch to make the deaf experience music through their skin.
The suit translates sound inputs into tactile ones through a software of twenty four points of vibration. This technology exploited by the vibrotactile wearable vest allows users to perceive sound waves of the music event.
Moreover, even though this device was designed for a specific target, it could address everyone since it has the potential to change the traditional way of

enjoying music. It would provide a new innovative experience for everyone and, from a deaf point of view, it would finally make live entertainment fully accessible also for them (Freethink, no date).

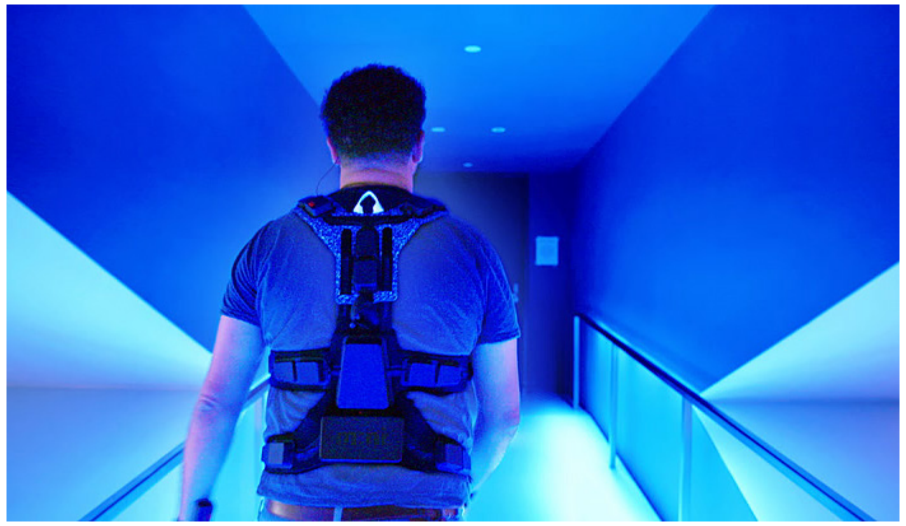


Fig. 21
Haptic suit designed by Not impossible Labs
Source: Freethink

1.4.3 Haptic and visual feedback in jewelry

As previously explained in chapter 1.3.2, sign and touch senses are relevant for deaf lives, especially when the two of them are concurrent. Based on this concept Quietude was born, a jewelry collection created by the Fab Lab of the University of Siena under the direction of Professor Patrizia Marti, with the collaboration of Glitch Factory, T4All, Siena Art Institute, and the University of Southern Denmark.
The project includes necklaces, bracelets, and rings designed for deaf women with the aim to integrate aesthetics with functionality. Made from recycled and environmentally sustainable materials, the accessories convert sound stimuli into tactile and visual feedback. Using specific technologies, they continuously detect environmental sounds and translate them into vibrations, lights, or changes in the shape of their components, informing the deaf about the surrounding noises. The following modality of use, defined as continuous listening, can provide a quality representation of sound as its different frequencies correspond to diverse intensities of light and vibration. The collection is accompanied by a smartphone application through which it is possible to record sounds of interest, which are then notified to the user in the preferred mode when the sound occurs again. Fundamental for this creation was the co-design methodology, where side-by-side researchers and deaf women designed the

final products (Università di Siena, 2021).
The following project aims to enhance the concept of diversity and to reduce the negative impact of disability, by considering users as people and not as disabled. Patrizia Marti, therefore, emphasizes a new concept of disability, by seeing it not as an obstacle but as a creative opportunity to experiment.

Fig. 22
Jewels of Quietude collection by Patrizia Marti
Source: Quietude

1.5 Conclusions

Deafness is a fragmented condition, more than one might think: going beyond common knowledge, it can affect different age groups and not just the elderly, there are different types and grades of hearing impairment, as well as different approaches to this condition.

Indeed two separate segments result from that consisting of signing and oralists hearing impaired, which differ in the way they receive information from the external world and communicate with others. On the one hand, signing individuals rely on hand gestures of sign language, on the other oralists imply the use of hearing aids and voice to interact with the outside world.

Due to their deficit, the subjects' brain reorganizes its connections, changing its structure and assuming compensatory abilities in sight and touch senses, which as a consequence may result heightened (Beltone, 2019). Because of that, the above-mentioned two senses were involved in virtuous experiments about sensory substitution, where users involved were able to comprehend information delivered by sound since it was transformed into visual and tactile stimuli.

Despite brain attempts to compensate for this loss and despite the projects developed in this regard, deaf people still have to deal with daily-basis obstacles, such as talking on the phone or being able to understand the speaker announcement at the train station.

This leads to consequences that go beyond their ability to hear, involving their health, psychology, and also sociality. Regarding the latter, hearing loss can lead to not being fully able to respond to our need as human beings to communicate and interact with others, which may result in serious consequences. Therefore, it's necessary to have fully accessible contexts and environments for deaf people, able to respond to their needs.

2

Physical space interaction

Although the world we live in has been conceived to be experienced visually, architect Hansel Bauman reports that *"at the same time, it is designed in such a way that assumes hearing as a central means of spatial orientation"* (Bauman, 2010, p. 10). For this reason, the absence of the auditory sense implies a different interaction of the hard-of-hearing with the surrounding space, even considering their heightened visual-tactile abilities. Therefore, it becomes relevant to take into consideration their specific needs in terms of space, lighting, and spatial disposition since the environment affects the physical, emotional, and social well-being of individuals.
Starting from these considerations, the project DeafSpace has been created by Bauman to define design guidelines to make architecture more inclusive and representative of the unique ways of being of the hearing-affected. The project stems from a redesign request to renovate with a more inclusive and integrative perspective the Gallaudet University, a private American university for deaf and hard-of-hearing students located in Washington. Observation and research were central to accomplish the redesign, where technologies such as GoPro cameras were involved to observe how deaf interact with the space and with others.
By taking into consideration all the possible approaches to deafness, the study explores five major points of intersection between deafness and the physical space, here explained.

Fig. 23
Images of the Gallaudet University interiors
Source: Excepcionales

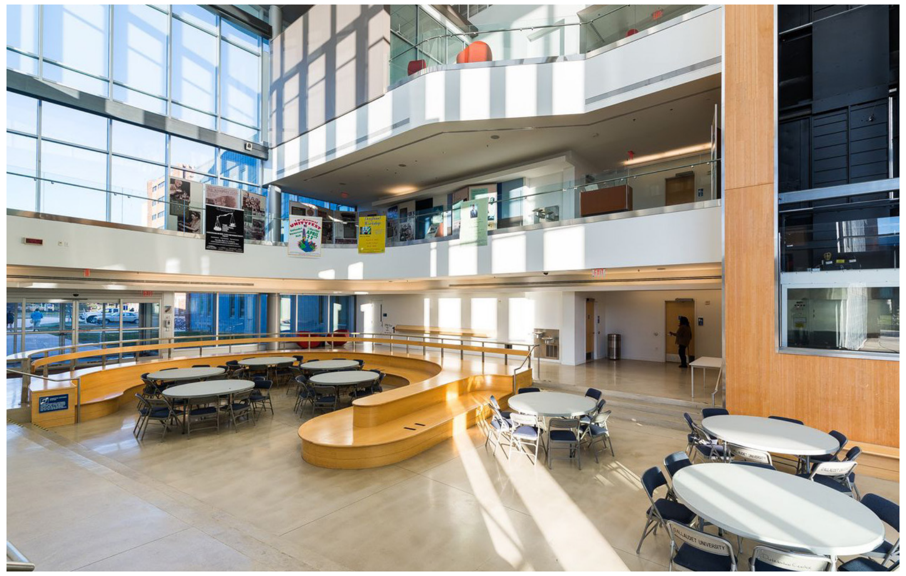
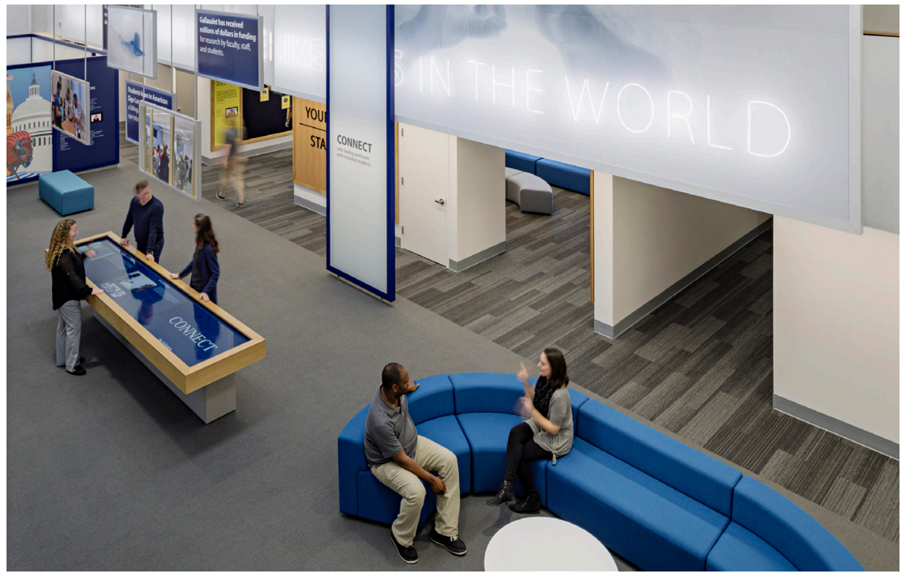


Fig. 24
Images of the Gallaudet University welcome center
Source: SEGD

Fig. 25
Images of the Gallaudet University communal area
Source: C&G Partners



2.1 Space and proximity

Being deaf implies specific proxemics requirements since a proper distance between individuals is necessary to allow the hearing-affected to correctly see the other individual and therefore understand what he or she is saying.
Because of the possible approaches to deafness, hard-of-hearing people have different needs while holding a conversation: talking about signing Deaf, it's fundamental the eye contact as well as facial and body movements, while for oralists may be crucial lip-reading. The absence of visual barriers across faces is fundamental for both cases, but signers require a more generous space around their arms to communicate comfortably and for seeing an answer in sign language in its totality. This leads to several architectural implications in terms of dimensions and space, defined as guidelines by architect Hansel Bauman.

In addition to emphasizing the importance of correct proximity, he highlighted the importance of providing a balance of enclosure and openness in physical environments, since too much enclosure creates feelings of isolation in deaf, while too little makes them perceive exposure which tends to reduce concentration and increase stress (Bauman, 2010, p. 28). Talking about openness, the visual control provided by open spaces brings in hard-of-hearing a sense of security and well-being.
Based on these theoretical considerations, it has been reconsidered the general layout of private and public spaces, so that occupants have a greater degree of enclosure behind them and face toward the most open area of the room, where are places the entries. The aim is to minimize the potential interruptions from behind and therefore to allow deaf individuals to be in total control of the situation (Bauman, 2010, p. 28).

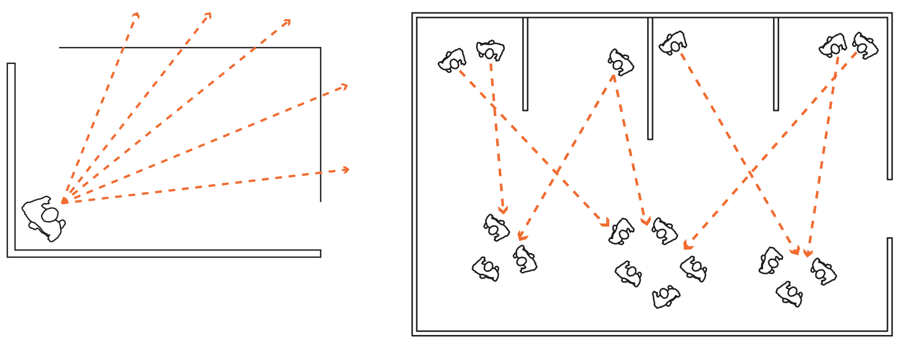
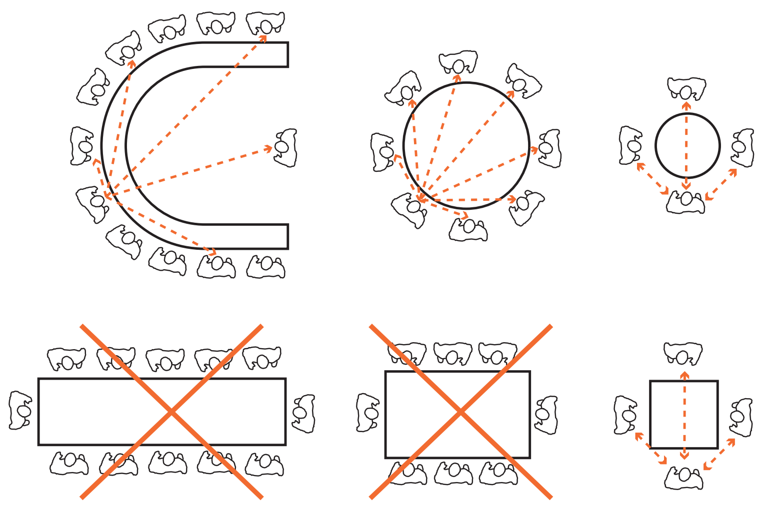


Fig. 26
Suggested layout for private and public spaces to have a trade-off between enclosure and openness
Source: DeafSpace Design Guidelines

The same objective is pursued in rethinking the gathering spaces since they have to be *"specifically designed to facilitate group gatherings, where participant's attention is primarily directed toward a dominant focal point such as a presentation, lecture or staged performance"* (Bauman, 2010, p. 30).
Therefore it's essential to direct attention toward the point of interest and guarantee legible communication between participants. This results in a careful selection of the furniture, avoiding the use of square or rectangular tables as they obstruct the view of faces and prevent eye contact with each occupant, with significant consequences for the deaf. The problem occurs in groups of more than four, getting worse the larger the group. Therefore, round and horseshoe-shaped tables represent the best solution since they ensure complete sightlines for deaf individuals (Bauman, 2010, p. 30).

Fig. 27
Round and horseshoes shaped tables are indicated for gathering spaces to allow equal visual access to all the participants
Source: DeafSpace Design Guidelines



This also applies to the design of classrooms, which should accommodate a horseshoe seating arrangement and a presentation space[4] located at the one open end, to allow equal visual access to all the occupants.
Talking about meeting rooms, the preferred choice for an inclusive social interaction is a single round or oval table for the gathering of moderate group size, with the presentation space located at the far end of the room. For a higher number of participants, instead, Bauman recommends two arched tables facing the center, which guarantee a visual focus both on each occupant and on the displayed presentation, located along the central axis of the room.

The re-thinking of the above-mentioned spaces aims to eliminate physical barriers that may hinder the sociability of deaf people and therefore encourage conversations and interactions, even in a casual manner. In this regard, visual connections are crucial since they allow hard-of-hearing to make initial eye

4 When talking about presentation space, Bauman is referring to an area that accommodates a lectern and or teacher's desk and projection screen with audiovisual systems controls. Screens should accommodate the simultaneous projection of visual displays and written text.

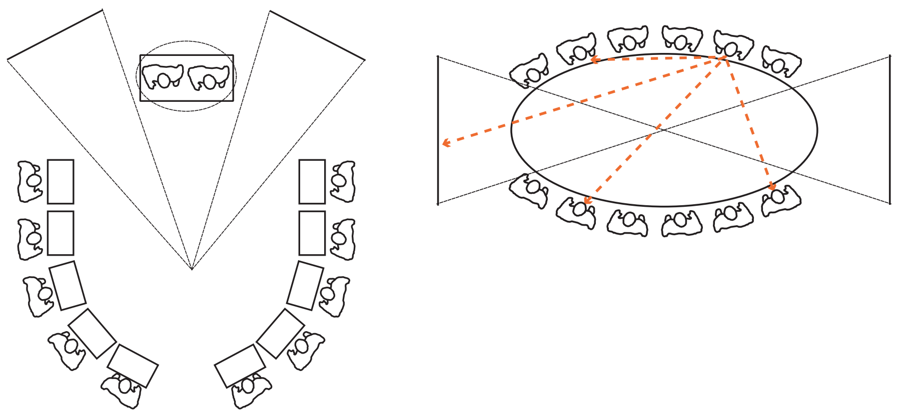


Fig. 28

Suggested layout for classrooms and meeting rooms to ensure equal visual access to all the occupants

Source: DeafSpace Design Guidelines

contact and understand the surrounding dynamics.
By focusing on the interior spaces of campuses and offices, Bauman designed a layout that can encourage interactions between occupants, deaf or non-deaf individuals: the rooms have transparent sliding walls and doors to see one's colleagues inside other rooms. This ensures a visual connection between the occupants and consequently an increasing possibility to start a conversation. In this regard, the presence of a central space becomes relevant, since it represents a place for interaction and meeting (Bauman, 2010, p. 35).

Whether in formal or non-formal venues, the use of moveable lightweight chairs is preferable as it ensures the possibility of moving them to include in the conversation all the participants and to easily accommodate new ones. Moreover, the seating should not have arms that may restrict the movements of the signing deaf (Bauman, 2010, p. 37).

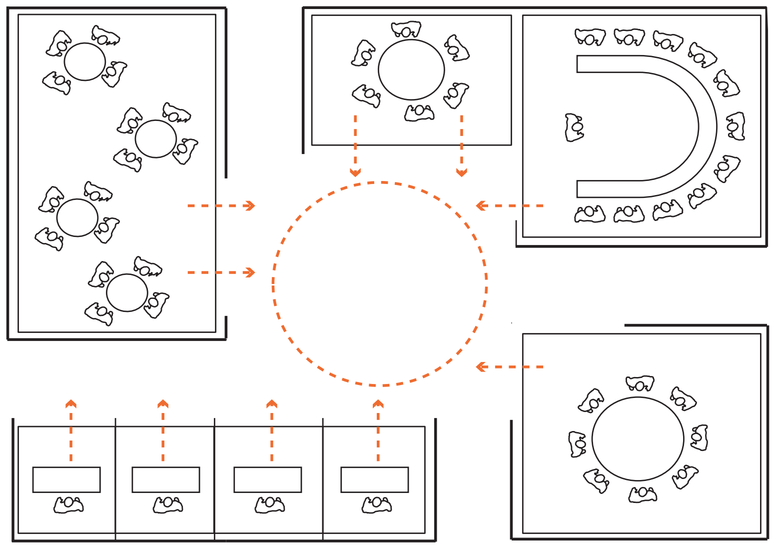


Fig. 29

Suggested layout for having connected interior spaces

Source: DeafSpace Design Guidelines

2.2 Sensory reach

Humans' ability to perceive and orient in space is enabled by the five senses' interrelation, called sensory reach (Bauman, 2010, p. 38). As previously explained in chapter 1.3, in the case of hearing disability, the brain compensates for this loss through the enhancement of the other senses, with the aim to extend the individual's sensory ability. As a result, vision and touch become fundamental means for hard-of-hearing to achieve a 360-degree perception. Bauman considered the heightening of these two senses to provide design guidelines representative of the unique ways of being of the hearing-affected.

VISION

Regarding vision, it represents their primary means of gaining information and therefore it becomes fundamental to enhance visual connections and to exploit sight-related cues, such as clear pathways and indications.
Transparency represents the main ally since it allows users to have visual access and to be in control of the surrounding context. Because of that, it's suggested the use of glass-made or open spots in hallways and corridors to make hard-of-hearing aware of the activities taking place throughout the building's rooms. When talking about transparency, it's equally important to take into consideration privacy concerns and to find a trade-off between them (Bauman, 2010, p. 44).

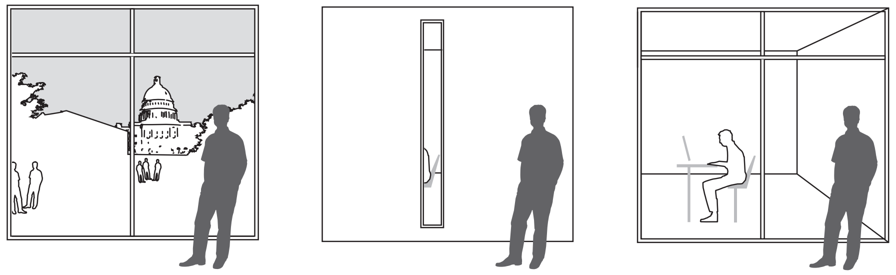
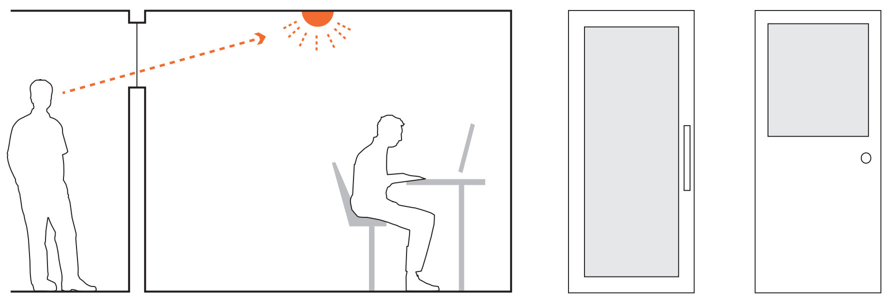


Fig. 30
Architectural suggestions to guarantee a trade-off between privacy and openness
Source:
DeafSpace Design Guidelines

Since privacy needs could be different based on the room's purpose, the visual access should be tailored, starting from the material's selection. Bauman proposes the use of glass, polycarbonate, and metal for the openings between rooms and interior-exterior space, to be selected based on the desired grade of isolation.
Glass provides the best level of openness and indeed its use is recommended for sidelites and transoms, elements that ensure quick clues of the activities taking place indoors (Bauman, 2010, p. 44).
See-through elements also ensure a reduction in barriers that may hinder communication and navigation. Indeed, they have the capability to encourage a connection between individuals and the physical space. An example is the glazed entrances in major buildings, which guarantee visual connections and

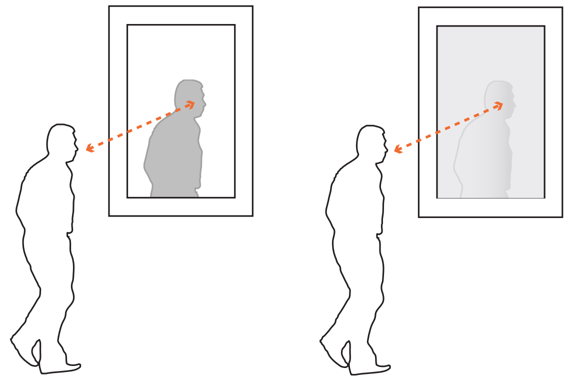
the comprehension of movements, traffic, and activities from the outside. Similarly, the exploitation of glass in elevators allows connection to adjacent places and in addition lessens the feeling of confinement and increases the perception of safety by the deaf (Bauman, 2010, p. 47).

Fig. 31
Suggested transoms and sidelites disposition to guarantee a visual access
Source:
DeafSpace Design Guidelines



Another central factor that contributes to provide essential information is reflection since *"it gives awareness of spatial depth, the dimension of space and activities that lie behind the viewer"* (Bauman, 2010, p. 50).
Reflective finish represents a significant tool for hard-of-hearing to extend their sensory reach and, because of that, care should be given to the materials applied: highly reflective ones can create undesired conditions such as glare and visual clutter, while it's preferable the exploitation of surfaces with muted reflections, as metals, which provide more subtle clues about the context activity (Bauman, 2010, p. 50).

Fig. 32
Surfaces with muted reflections are indicated since they avoid glare or visual clutter
Source:
DeafSpace Design Guidelines



The advantages of using reflective surfaces are evident when applied in closed environments: in moving spaces, such as corridors, they provide visual clues to activities happening in front of and also behind hearing-affected people, allowing them to have a 360-degree understanding. Therefore, reflection helps heard-of-hearing to understand the surrounding activities while being busy holding a conversation, for example.

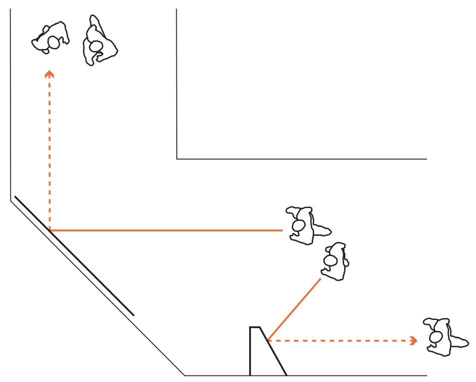


Fig. 33
Reflective surfaces allow deaf to avoid collisions and understand what is happening behind or in front of them
Source: DeafSpace Design Guidelines

TOUCH

Therefore, sight-related shrewdness can actually enhance the relationship deaf have with the physical space, especially when associated with the sense of touch. Indeed, sensing vibrations represents another way to experience the environment and receive indications about orientation. As an example, perceiving footsteps increases awareness of what is happening behind.
Given the importance of tactile stimuli in spatial interaction, it is necessary to take care of the level and type of vibrations of the room surfaces. In fact, uncontrolled vibrations can cause the opposite effect and lead to confusion in the hearing affected.
Therefore it's crucial the choice of floor and wall materials since they are responsible for the amplification or reduction of tactile feedback.
Based on the space purpose, the suggestions may change: for areas designed to encourage sociality, such as meeting rooms and classrooms, floor materials have to be capable to provide noticeable vibrations since it may help deaf people who want to initiate a conversation through a tap on the floor, for example. In contrast, in the case of spaces adjacent to privacy places, it is necessary to choose surfaces able to attenuate and isolate vibrations (Bauman, 2010, p. 53).

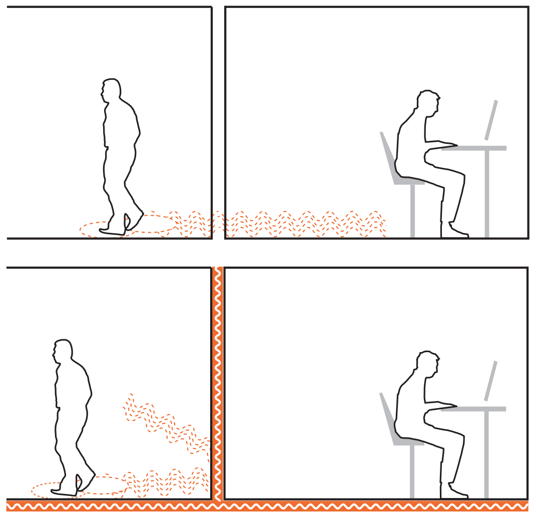


Fig. 34
The choice of interior materials must be well thought out as they are responsible for amplifying or reducing tactile vibrations
Source: DeafSpace Design Guidelines

2.3 Mobility and proximity for signing deaf

As explained above, body movements become fundamental for signing deaf to express themselves but also to understand others while conversing. In static circumstances, the flow of conversation is fluid and easy as opposed to in moving situations. As an example, in the case of a walk, signers holding a conversation run into risks of tripping, falling, colliding with others, or having obstructions. Minimizing physical dangers on their path becomes a necessity as well as ensuring the right distance between individuals to allow a smooth interaction.
Bauman investigated this intersection between mobility and proximity starting with providing guidelines about pathways and sideways: he identified the need to widen them to ensure the correct distance for communicating via sign language and the necessity to favour the use of soft angles, in order to avoid abrupt transitions and to allow pedestrians to see each other in advance (Bauman, 2010, p. 62).

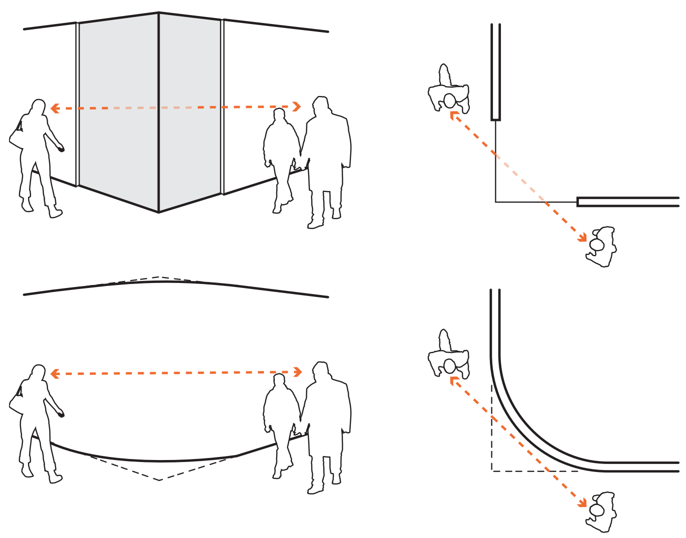


Fig. 35
Soft angles allow signing deaf to see others in advance and to avoid abrupt collisions
Source: DeafSpace Design Guidelines

With the same aim of eluding possible collisions, the architect suggested the provision of road signs and physical elements at the edge of the pavement in outdoor space. Instead, talking about indoor corridors in campuses and offices, it's indicated the provision of recessed spaces where individuals can carry on conversations outside the flow of traffic (Bauman, 2010, p. 60).
Another relevant factor to focus on is the entrance, which can affect non-fluent and segmented communication. Indeed, it is preferable to exploit automatic sliding doors or entries with holds open, as they allow uninterrupted movement during a signed conversation and create easy transitions between spaces (Bauman, 2010, p. 66).

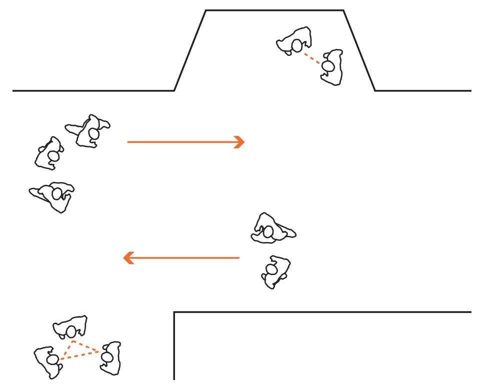


Fig. 36
Recessed spaces are used to carry on conversations outside of the traffic flow
Source: DeafSpace Design Guidelines

Thus, when walking while engaged in a signed conversation, hard-of-hearing employs cognitive effort to simultaneously hold dialogues as well as be in control of the route conducted. In this case, the heightened of their peripheral view comes to their rescue, allowing them to "read" the environment and respond promptly to circumstances changes.
To better orientate themselves they also use strategies, such as aligning themselves with building elements and following interlocutors that are able to maintain a safe and secure path of travel. According to Bauman, another useful clue is the use of repetitive and continuous elements in buildings, since they can strongly contribute to orienting a deaf person while busy interacting. One example is the use of horizontal indications, such as the floor base, which provides information about the continuity of space, representing a visual anchor (Bauman, 2010, p. 68).

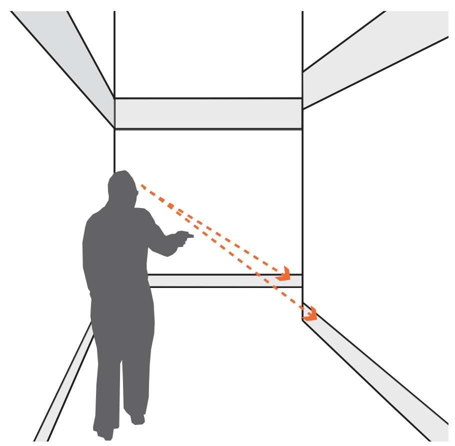


Fig. 37
Horizontal indications, such as skirting boards, give relevant visual clues about orientation
Source: DeafSpace Design Guidelines

In the external context, what can provide visual indications are the arcades, composed of the rhythmic placement of columns, which allow users to quickly and easily scan the environment and consequently recognize dangers. The same aim is pursued by continuous textures, such as brick coursing, window placement, and mullion patterns, that immediately allow the eye to identify

out-of-place elements and thus alert the individual.
Not only buildings can play this role, but also nature itself: the repetitive arrangement of trees, as well as lampposts, provides a visually recognizable and helpful reference for signing hearing-affected (Bauman, 2010, p. 69).

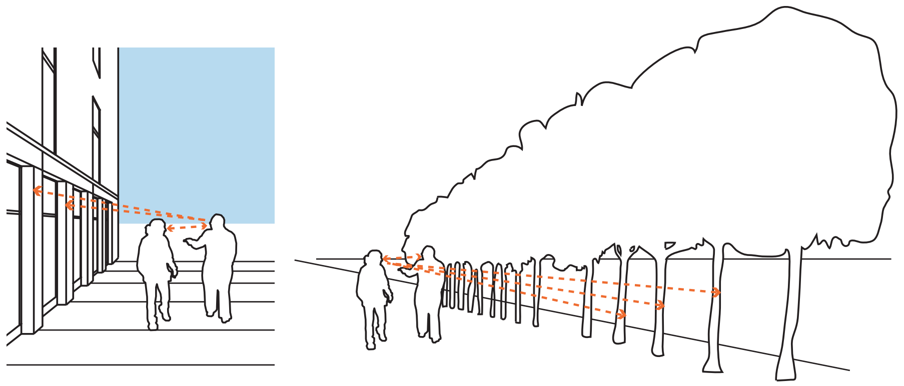


Fig. 38
Outdoor repetitive indications, as arcades or trees, give important visual reference about orientation in an outdoor context
Source: DeafSpace Design Guidelines

2.4 Light and color

Sight represents a central means for the deaf to learn about surroundings and communicate with others. This constant visual attention can lead to eyestrain, resulting in attention loss and fatigue. For this reason, it is important to design spaces by taking into consideration the correct use of light, colors, and textures, since their interconnection determines the individual's perception of spaces with consequences also on their sense of well-being. In regards to colors, they represent more than an aesthetic concern for hearing-affected, since tints can have an impact on orientation as well as on communication through sign language. When applied on surfaces, colors can indicate paths and thus ensure a better spatial orientation for deaf people (Bauman, 2010, p. 73).

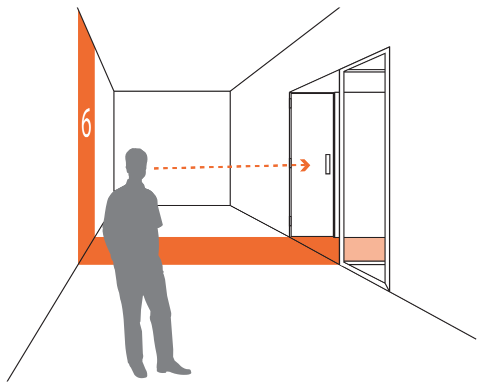


Fig. 39
Colors can be used to indicate paths and offer indication for a better spatial orientation
Source: DeafSpace Design Guidelines

On a social level, the use of dark colors contributes to create intimate atmospheres that can thus encourage social interactions.
Specifically, in the case of signers, the use of green and blue tones on a room's walls ensures a proper contrast between the subject and the background, as they are complementary to the pink of humans' skin. In addition, the two cool colors instill tranquility, creating restful environments both psychologically and physically. If dark tones represent an aid, on the contrary, light ones contribute to reflecting light and therefore they increase the occurrence of glare and reflections which can create visual confusion (Bauman, 2010, p. 73).

Another factor to take into account when designing physical spaces is the sunlight, which makes users see the surroundings but at the same time, if too intense and uncontrolled, causes orientation and communication difficulties for deaf individuals.
A relevant shrewdness is to prevent backlighting, as it impairs the ability to lip-read and communicate via sign language with consequences on the sociality of the hard-of-hearing. Hence, in indoor contexts windows behind people or focal points should be avoided as they cause a high contrast between the subject and the environment (Bauman, 2010, p. 74).

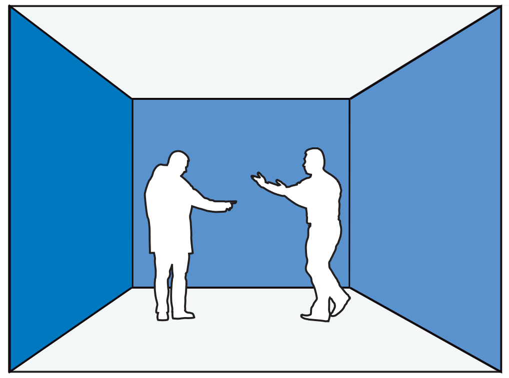


Fig. 40
The use of blue and green tones ensures a proper contrast between subjects and the background
Source: DeafSpace Design Guidelines

A balance of light levels is therefore necessary, which can be applied through the use of multiple light sources, such as the combination of a window with other openings since it reduces eyestrain.
Another method to counteract overly concentrated lighting is the exploitation of light shelves, which provide non-direct and non-blinding access to light thus ensuring smooth communication between subjects (Bauman, 2010, p. 75).

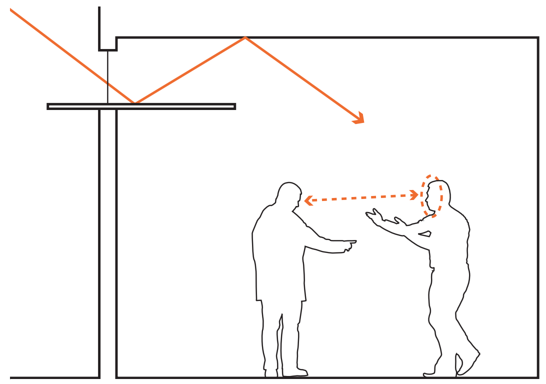


Fig. 41
Light shelves are a good method to bring light inside the building without being too concentrated
Source: DeafSpace Design Guidelines

One circumstance in which social interaction between deaf individuals is momentarily interrupted is when passing from an indoor to an outdoor space, where eyes have to readjust to different light intensities thus preventing the deaf person from using their sight for a few seconds. This is why it is important to provide elements that can accompany the sight re-adaptation, such as canopies, tree crowns, awnings, and elements that provide glare-free outdoor spaces in the shade (Bauman, 2010, p. 76).

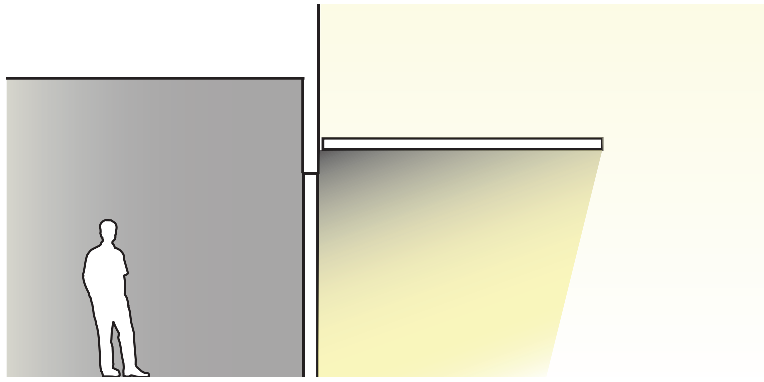


Fig. 42
Canopies accompany the sight re-adaptation from an indoor to outdoor space with different lighting
Source: DeafSpace Design Guidelines

Concerning artificial light, it is recommended to use diffuse and dimmable lights thus adjustable to specific needs. In the case of a presentation in an atrium, for example, the light source should focus on the presenters and the possible interpreters while diffuse dimmed lighting should be provided in the rest of the room (Bauman, 2010, p. 79).

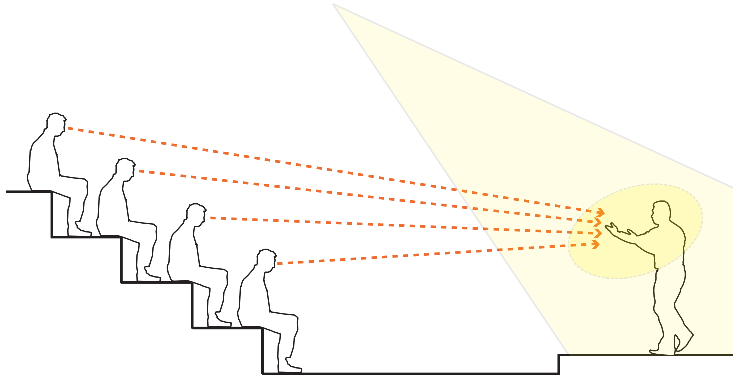


Fig. 43
Lighting for presentation space should focus on the presenters, while having a diffuse dimmed light in the rest of the room
Source: DeafSpace Design Guidelines

The importance of artificial light is evident in night contexts, where it plays a central orientation function for the visual-centered approach of the hard-of-hearing. Light sources must be used to indicate paths and illuminate buildings' entrances in particular while avoiding overhead lighting as it can obscure the individuals' faces and thus impair social interaction between them.

2.5 Acoustics

The space's acoustics can have an impact on the experience of oralist deaf individuals, which can be compromised by the presence of background noises. It may hinder orientation as well as social interaction, by causing disturbances and distractions originating from multiple sources, such as humming equipment, noise external traffic, and chatter.
It is therefore fundamental to avoid background noises, where sound reverberation represents one of the most impactful for hearing aids and CI users. The reason is that their technological devices amplify auditory signals, including possible echoes, which make speech unintelligible, particularly in collective situations. So ensuring a low level of sound reverberation becomes central, made possible through a careful design of spaces in terms of size and technological equipment.
To avoid background sound, Bauman also highlighted the importance of a correct building structure: spaces such as classrooms, where a high level of attention is required, should not be located next to noisy places such as roads or mechanical rooms to avoid sound interference (Bauman, 2010, p. 82).

2.6 Conclusions

Bauman provides recommendations for an accessible architectural and interior design able to meet deaf needs. He emphasizes the importance of designing buildings, interior design spaces, and flows with inclusion in mind.
Going into detail, his guidelines can be encapsulated in two themes. The first one is functional-related, such as using colored sections for indicating directions for orientation or having muted reflections on glass surfaces to avoid glare, where the aim is to create a space that is suitable for hearing-impaired individuals to interact with.
The other section is strictly about sociality, where concern as an example the use of round tables as opposed to square ones to ensure that deaf people can see all the involved participants or to have lighting that prevents backlighting as it hinders lip-reading, where the aim becomes more high-level. Indeed, the objective of all the several sociality-related recommendations is the creation of a physical space able to encourage interaction and communication for those suffering from hearing loss, evidencing the impact that an accessibility-oriented design could have on their lives.

3

Digital interaction

The digital advent has brought improvement in our lives, enhancing connectivity, sociality, and more. For deaf people the introduction of technological innovations has been life-changing, bringing a strong impact on a social, communicative as well as informational level, making deafness and its many facets known by the hearing community, often conditioned by bias and stigma.
The following chapter aims to recount the consequences of the digital advent on hard-of-hearing lives, by starting to analyze the positive impact that social media had on their lives.
However, the digital world still presents many accessibility issues for the hearing-affected, highlighted in the analysis of the current experience offered by video games. In response to that, several guidelines have been proposed to offer a more accessible and inclusive experience.

3.1 Social media

"I am a Deaf person and I feel like I'm equal to hearing people when I'm on the Web, there's no difference to us." (Valentine, Skelton and Levy, 2018, p. 11). With this sentence Gill, a deaf man, encapsulates what the Internet and especially social media represent for the deaf community: a means of inclusion that allows equal footing between deaf and hearing people.
In today's information age, the Internet has become a game-changer for the deaf community since it allows them to overcome barriers they have to face in real life. Before the widespread use of written online communication, it was frequent for the deaf to be left out of conversations and rely on somebody else to explain to them what has been said. They also could not rely on the technological innovation of the cell telephone since for them it only represented another obstacle.

The advent of the Internet, and then specifically social media, has enabled hard-of-hearing to break down these language barriers, providing them with the ability to converse with everyone in a simple and fluid manner through written text or visual content. This has contributed to greater integration and inclusion, partly fighting the social isolation from which they may suffer (see chapter 1.2.2). Therefore the web has the potential to enhance their well-being, as well as giving the opportunity to spread messages of awareness and advocate for social causes (Young, 2019, p. 33).

Fig. 44
Person using social media platforms
Source: Unsplash

Given the many benefits, the data could only show intensive use of the Internet by the hearing-affected: it emerged that out of 419 English deaf people involved in the survey, 79% of deaf people, especially oralist ones, are more likely to surf the net every day than the general population (59%) (Valentine, Skelton and Levy, 2016, p. 5). The questionnaire, which involved d/Deaf[5] individuals, highlighted that the reason why they stay online is mainly for looking for health information, jobs, online banking, emails, and chatting, recognizing in the online world a way to avoid possible discrimination (Valentine, Skelton and Levy, 2016, p. 7).

Regarding specifically online mediums, social media has opened opportunities for hearing people to learn more about the deaf world in all its facets. Examples of Instagram social platforms aimed to raise awareness on such issues are @thedeafsoul and @sordezine.

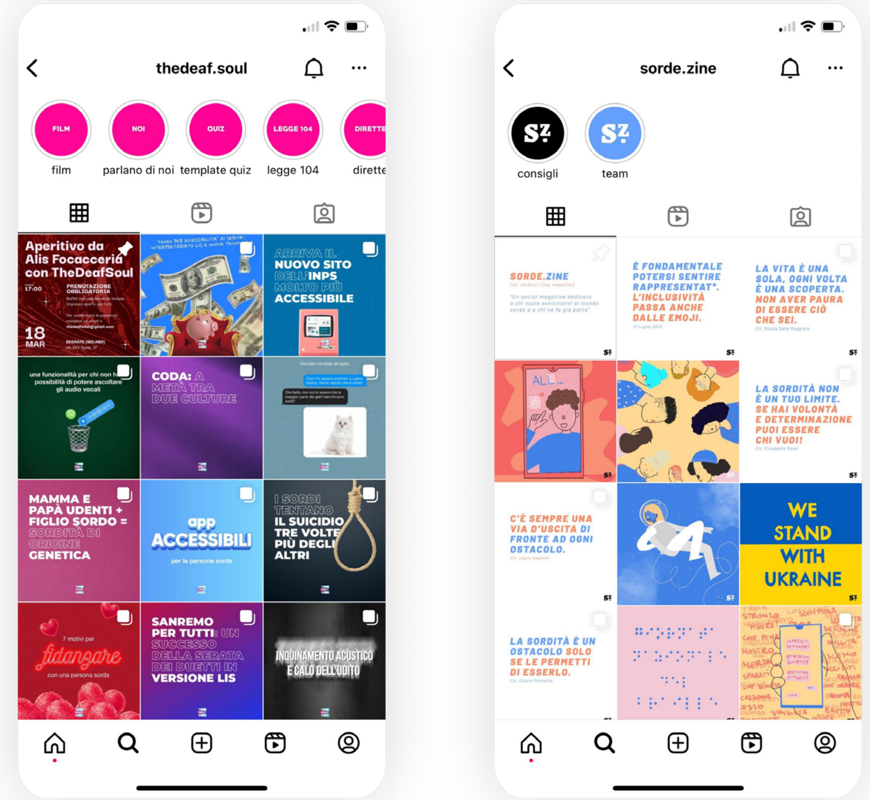


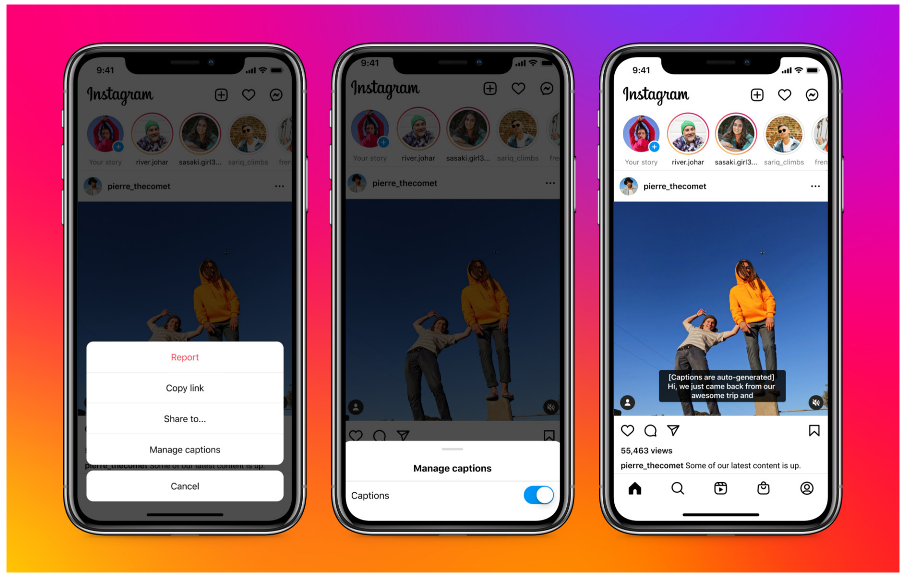
Fig. 45
Screenshots of @thedeafsoul and @sordezine Instagram pages
Source: Instagram

Hence, the social world through its visual approach has benefited the hearing-affected, however, it also has brought effects such as exposure to possible hurtful comments by the hearing community or tensions from the signing deaf,

5 The term d/Deaf is used to describe a sample of individuals who it's not known if they identify themselves as part of the Deaf community or not.

due to the lack of access to their preferred language. In this regard, given the lack of sign language translations, they rely entirely on written language, not only for chats but also as a support for audio content, useful for oralists too: on Instagram, deaf individuals can take advantage of auto-generated subtitles accompanying videos, a feature that was, however, not introduced until 2021.

Fig. 46
Screenshots of Instagram auto-generated subtitles
Source: Adam Mosseri



In conclusion, despite the possible threats and still present accessibility issues, digital channels have brought great benefits for deaf lives, as evidenced by the quote of Dan Gingiss: *"Social media has given the Deaf community the tools we need to mobilize, to reconnect, and organize, and perhaps most importantly, it's changed how the community is perceived by others"* (Gingiss, 2018).

3.2 Video games

Video gamers who are deaf or hard-of-hearing represent 10% to 20% of the 1.8 billion individuals who are part of the global gaming community (Titmus, 2023). This is a considerable figure, constituting only a part of the 400 million people with disabilities who play video games (Xbox Wire, 2021).
This sizable demographic is given by the multiple benefits they gain through playing, which emerged from the survey[6] conducted by APX (GDC Vault, 2019); the results showed that the motivation to play games stems from multiple factors: it allows disabled people to overcome the possible physical impairments they might have in reality, as well as divert themselves into new experiences. Through games, they also have the chance to acquire new skills and share culture with each other. Of all the benefits, the most impactful is the possibility to connect with other people and play together, which increases the fun and enjoyment of the experience and contributes to inclusion. For people with disabilities, video games represent a game-changer, as it provides the opportunity to spend time with people with whom they may have difficulties in real life.

Fig. 47
Person with disabilities playing a video game designed by The AbleGamers Charity institution
Source: Meuplaystation

Their motivations for playing are not far from those of able-bodied people, who do it for fun, relaxation, challenge, and for feeling as part of a community (Beeston et al, 2018, p. 11). Unlike them, however, disabled people have to face accessibility issues related to their constraints while playing: as evidenced by the questionnaire[7] from the disability equality charity Scope, 66% of impaired gamers face barriers, leading 40% of them to give up playing due to poor accessibility.
Another problem concerns assistive or adapted technologies, which can establish new obstacles due to their limited choice or availability, their high cost, and the knowledge required to set them up (Scope, 2020).

Specifically regarding deaf individuals, the issues they encounter concern subtitles, which allow hard-of-hearing to access audio content through written language. The related issue is the poor quality of captions in terms of visual contrast, text length, and wording of the sentence, creating great discomfort for the hearing-affected.
Another matter is linked to the use of visual clues to transmit information to the user, since their proper use is central for guiding the entire experience which otherwise could be instead compromised. Furthermore, the main concern they have to face while playing is the modality of the information delivery: given the ineffectiveness of sound stimuli, it is necessary to provide alternative modalities, involving the senses of sight and touch, which is not always guaranteed (GDC Vault, 2019).

What is unexpected about all these data is the slice of users involved: as reported in The AbleGamers Charity research[8], 41% of their active gamers turns on subtitles and 20% of them use recoloring options, but only 13% of the sample claimed to have hearing disabilities.
This proves, as reported by the vice president of The AbleGamers Charity Christopher Powder, that *"accessibility options are not only about disabilities, but it is about a broad part of designing games"* (GDC Vault, 2019).
Accessibility needs to be guaranteed to tailor the gaming experience to one's preferences and constraints but, however, it is not always ensured since video games do not have yet universal guidelines about accessibility.

6 The survey conducted by APX interested 122 people with disabilities (physical, sensory, or processing disabilities).

7 Conducted on December 2020, the survey involved a total of 1326 people comprising 812 disabled gamers and 514 non-disabled gamers.

8 The research was conducted on 397 active members with disabilities of the AbleGamers Charity, an American nonprofit organization dedicated to improve accessibility in video games.

3.3 Accessibility guidelines in video games

To ensure an accessible and inclusive video game experience, it is relevant to adopt a design methodology consistent with these goals. The AbleGamers Charity's President Mark Barlet describes Universal Design as a *"wonderful practice for most areas of digital media"* (Barlet and Spohn, 2012, p. 8): Universal Design, called also UD, is a design methodology aimed to make environments, services, and products usable by the highest number of people, regardless of their age, size, ability, or disability (Centre for Excellence in Universal Design, 2020). The pursuit is to obtain a single solution able to serve the most extensive possible user base, without added accommodations for all the different individuals' needs.
Barlet concludes his considerations by explaining that, for the virtuous goals of creating an experience widely accessible, UD's cannot be applied: its objective of creating universally usable solutions focuses on intercepting all the needs of the audience, but on average. Pursuing the concept of *"one size fits all"* therefore does not allow to respond to individual accessibility issues that people with disabilities, and in this case deaf, have to face while playing games.

Hence the need to adopt new approaches arises, which have to be capable to serve a full spectrum of people with diverse necessities. This may involve different solutions or processes for diverse groups of people, following a *"one size fits one"* approach. The mentioned concept is embraced by Inclusive Design, a methodology for creating solutions that understand and enable people of all backgrounds and abilities, which goes beyond the perceived average or typical user and considers specific cultural, social needs, and more (Joyce, 2022).

With this method in mind, several guidelines have been established with the virtuous goal of creating increasingly inclusive and accessible experiences for people with disabilities. They concern two categories: one is strictly functional, where recommendations are aimed to guarantee a tailored experience, while the other concerns sociality, where guidelines have the objective of ensuring a smooth and accessible social interaction between players, including those with hearing loss.

3.3.1 Functionality-related guidelines

In order to have a video game that meets deaf people's needs, it is first necessary to ensure that the offered experience is intuitive and it guarantees the necessary functionalities to set the game as one's prefers. Based on that, some recommendations have been defined.

3.3.1.1 Interface personalization

Having the possibility of customizing your interface is important to allow players to adapt the whole experience based on their specific needs and preferences. The following list includes guidelines concerning this field.

OFFER CUSTOM INTERFACE SETTINGS
The AbleGamers Charity has identified the possibility of customizing the game interface as one relevant functionality that has to be designed in video games. Since some players may have difficulties in interacting with the interface components due to their size, layout, and content, it is therefore essential to be able to modify the standard version of the user interface, so that they can efficiently interact with it (Accessible Games, 2022). This feature is particularly important for the deaf since they mainly rely on visual contents.
Another customization-related feature concerns visual clues and the possibility of changing the components' color for suggesting different information, as to specify which type of sound was reproduced.
Different opinions are interested in this functionality: on one side, Barlet and Spohn of the AbleGamers Charity reported that letting players change the preset colors would make it easier for them to establish what kind of sound is captioned, where it is coming from, and also to understand who is talking, with significant benefits on a social level. On the other side, Galitz states that excessive personalization can lead to improper usage of colors with negative consequences on the designed user experience, leading the gamer to be distracted (Costello, Lambert and Kern, 2019, p. 4).

MEMORIZE SET PREFERENCES
Ensuring the set preferences storage is also considered an important feature since it allows players to not re-enter their selections each time they start a new game session. Hardware can be shared between several players who may have different needs, so the settings must be saved within the player profile. This lets gamers take their tailored settings with them everywhere and live the

same gaming experience, no matter where they are. An example is World of Warcraft, where users can log into their account which carries all the set preferences (Game Accessibility Guidelines, no date).

Fig. 48
In World of Warcraft, users can log in to multiple accounts, where each of them saves the specific set of settings
Source: Game Accessibility Guidelines

3.3.1.2 Environment design

Another influential factor, to which game creators must pay attention, is lighting: in combination with sound, it establishes the atmosphere and the mood of the game's scene and thus determines the immersion of the player, which influences the engagement and judgment of the experience (Costello, Lambert and Kern, 2019, p. 5).

ENSURE A CORRECT ENVIRONMENTAL LIGHTING DESIGN
The involvement provided by sounds becomes useless when referring to the deaf and, consequently, visual elements turn out as even more relevant. For this reason, the digital environment lighting must be well designed to guarantee hard-of-hearing engagement that overcomes the lack of sound. De Jong states that lighting contrast and the use of different types and colors of lights can enhance the perceived immersion of the deaf. A good example is Dark Souls 3, where the lights create an evocative and spooky atmosphere able to capture the attention of the gamer (Costello, Lambert and Kern, 2019, p. 5).
Notable to say is that lighting design currently requires a significant commitment and effort, which may lead developers to find trade-offs.

Fig. 49
Dark Souls 3 is characterized by a composition of lighting able to create an immersive spooky atmosphere
Source: International Journal of R&D Innovation Strategy

3.3.2 Sociality-related guidelines

As emphasized in chapter 3.1, the greatest benefit that people with disabilities derive from the online gaming experience is the possibility to connect with other people and overcome the barriers they may have in real life. Recognizing the social relevance of video games, researchers, institutions, and foundations have defined several guidelines with the aim of ensuring a smooth and accessible social interaction for the hearing-affected.

3.3.2.1 Audio personalization

Developers need to pay attention to audio since oralist deaf take advantage of it with other clues coming via alternative modalities. Because of that, some shrewdness here described are required.

OFFER CUSTOMIZATION OF AUDIO SOURCES

The AbleGamers Charity suggests as a guideline the possibility of changing the sound settings to ensure that hearing-affected users can fully receive the information. In the case of people with unilateral deafness, changing the direction of sound is an important feature as they can direct the sound stimuli only into the hearing ear (Accessible Games, 2022). This setting is guaranteed in Diablo 3, where the mono switch makes sounds equally available from both the left and right sides of the headphones.
Another key functionality is the individual control of the different audio channels; background sounds contribute to the atmosphere and sense of immersion, but can create disturbances in understanding conversations with other players. For this reason, it is crucial to have the possibility to adjust the speech audio and background noise independently, allowing deaf players to set the volume of the different channels according to their own needs and preferences. In this way, they can receive information clearly and undisturbed, as the game Killer Instinct guarantees (Game Accessibility Guidelines, no date).

Fig. 50
Diablo 3 allows players to set the speakers in mono modality
Source: Game Accessibility Guidelines

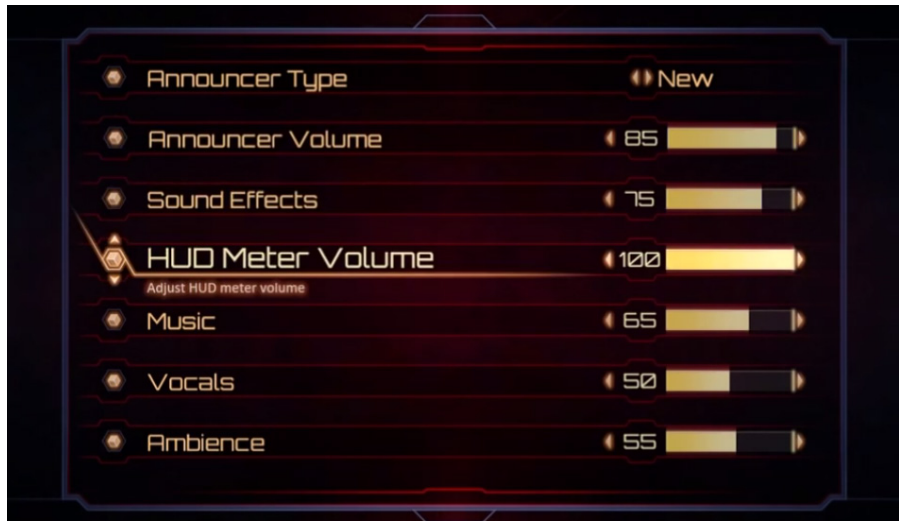


Fig. 51
Killer Instinct provides independent volume sliders
Source: Game Accessibility Guidelines

OFFER MATCHMAKING PREFERENCES FEATURE ABOUT THE INTERACTION MODALITY

While the above-described feature ensures that those with moderate or unilateral deafness can correctly understand sounds, it brings no benefit to signing deaf, whose social interaction is exclusively characterized by the use of body movements.
Due to their inability to hear sounds and their lack of vocal capabilities, a specific setting is required: a matchmaking preference feature, through which they can specify which mode they prefer to play with and thus only interact with people with the same playing needs. In Halo Reach, as an example, signing deaf players or anyone else who wishes can set they only want to play with users who communicate via keyboard, totally excluding the use of audio (Game Accessibility Guidelines, no date).

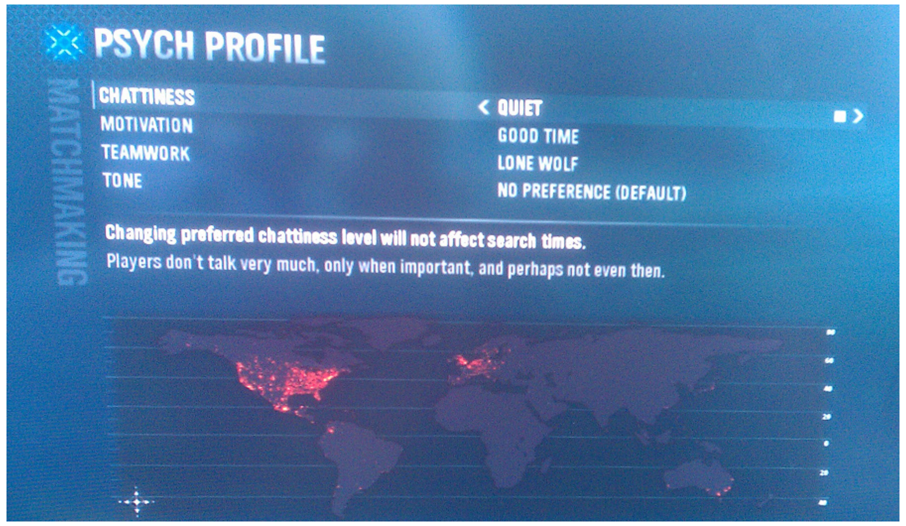


Fig. 52
In Halo Reach, users can indicate if they want to play only with players who use or don't use the voice chat
Source: Game Accessibility Guidelines

3.3.2.2 Alternative input modalities

Another issue deaf individuals have to face is the modality of receiving information. Video games, designed with the target of able-bodied people in mind, exploit sound stimuli not only to create an immersive atmosphere but also to provide essential clues to the game, such as the sound of an attack by an enemy. Conveying information through sound only represents an obstacle for people with hearing loss, as well as in general when in noisy environments or in other specific circumstances where the gamer cannot rely on audio. Therefore, some guidelines were created to stress this point.

PROVIDE ADDITIONAL FEEDBACK VIA ALTERNATIVE MODALITIES
The AbleGamers Charity as well as Game Accessibility Guidelines have stated the importance of providing a second channel through which to deliver gameplay clues.
For the deaf, audio information has to be conveyed also through additional channels, more specifically via visual or haptic feedback (Accessible Games, 2022). Good video game examples are Everybody's Gone to the Rapture, where a visual indication indicates the virtual elements that are emitting noises, and Fortnite in which the audio of a nearby survivor is also communicated by a text prompt and a visual cue (Game Accessibility Guidelines, no date).
With the introduction of alternative modalities to get clues, a fair experience among players is ensured since it avoids the presence of unfair advantages for hearing-affected individuals.

Fig. 53
Everybody's Gone to the Rapture provides a visual indication of the objects emitting sounds
Source: Gamersyde

Fig. 54
Fortnite indicates the closeness of another gamer through sound and visual clues
Source: Game Accessibility Guidelines

3.3.2.3 Subtitles and closed captions

A vital functionality for deaf people in the gaming experience as well as in digital-related situations is the exploitation of subtitles and closed captions, through which sound is transformed into a written form.
By analyzing the data of the online game Assassin's Creed: Origins, it emerged that roughly 60% of gamers turns on subtitles not only because of hearing issues but also for cognitive disabilities or simply because they are in specific circumstances where relying on audio is difficult (GDC, 2020). As reported by Mark Barlet *"[Closed caption] is an example of a feature for disabled gamers having value for non-disabled gamers"*, evidencing its profound impact and widespread usage by everybody (Barlet and Spohn, 2012, p. 28).

When talking about hearing-affected, it's required the exploitation of "closed captioning" instead of subtitles; in games, subtitles are used for translating into written text the speech coming from characters, while closed captions are intended for the hard-of-hearing audience since they report all audio information: dialogues, sound effects, background noises (Wallace, 2022).

Fig. 55
The difference between closed captions and subtitles
Source: Includification

Despite their relevance, subtitles and closed captions still have severe problems, which led researchers to provide recommendations.

PROVIDE A CORRECT USE OF CAPTIONS' FONT, DIMENSIONS, PUNCTUATION AND LENGTH

The accessibility specialist Ian Hamilton indicated a maximum of 2 lines per caption, 3 in exceptional cases, and no more than 38 characters per line in order to avoid an excessive amount of text which makes it hard to read (GDC, 2020). These indications are respected in Death to Right, as opposed to X-COM, which has very long texts that require a higher cognitive effort. Indeed, the shorter the text the easier it is for the player to understand the entire subtitle at a glance and quickly get back to the gameplay (Hamilton, 2015).

Fig. 56
X-COM represents a bad example of captioning since the not correct sentence length
Source: Game Developer

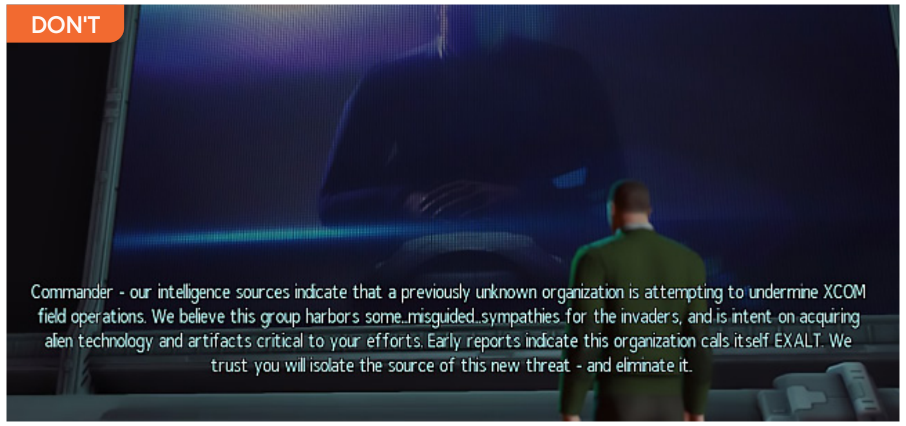
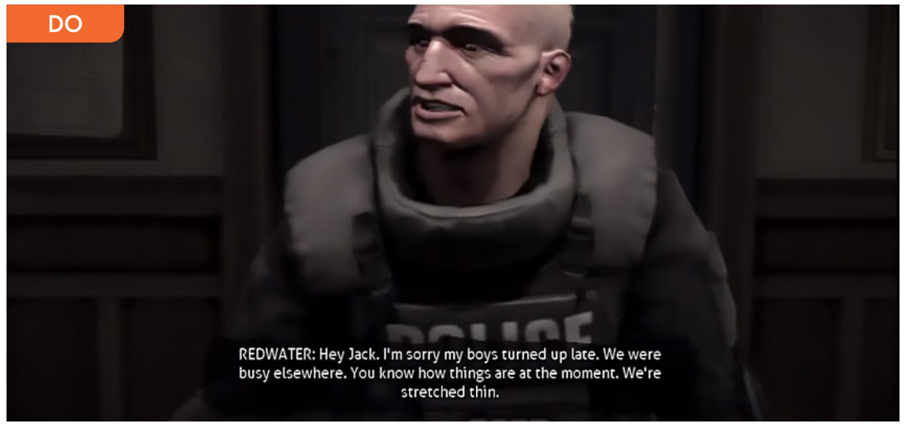


Fig. 57
Dead to Rights is a good example of captioning for the amount of text and the number of lines
Source: Game Accessibility Guidelines



To ensure optimal readability, the caption, in addition to containing a single and complete sentence, must also break at natural points simulating a real speech. As reported by BBC, the ideal line break corresponds to a piece of punctuation like a full stop, comma, or dash. While, if the break occurs in another part of the sentence, it's important to avoid splitting relevant parts of the sentence, such as the article with the noun or the pronoun with the verb (BBC, 2022).

DON'T

We are aiming to get a better television service.

DO

We are aiming to get a better television service.

Fig. 58
Subtitle example regarding breaking lines at natural points
Source: BBC: Subtitles Guidelines

Fig. 59
Yakuza 0 represents a bad example of line-breaks, since it separates the article with the noun
Source: Max Deryagin's Subtitling Studio

Fig. 60
In Knock II the sentence breaks at natural points
Source: Max Deryagin's Subtitling Studio

Another important factor that provides a clear and immediate understanding of the sentence is the typography: the choice of one font rather than another affects readability and consequently the user experience. In video games, the use of Sans Serif fonts is recommended because of their linearity and the absence of any peculiarities or grace, which makes them excellent for on-screen reading (Hamilton, 2015).
Some of the fonts suggested by BBC are Arial, Reith Sans, Verdana, and Tiresias Infofront (BBC, 2022).

Linked to the font selection, there is its size: it is suggested to present the text no smaller than 46px@1080p, with the possibility to change the dimension (Game Accessibility Guidelines, no date).
In this regard, it is also important to provide customization options for both the font, allowing the user to choose between predefined ones, and the size, providing the possibility of enlarging or shrinking the text. A good example of subtitles in a large and clear font is the video game Bertram Fiddle, where the sentence is highly readable also thanks to the excellent contrast with the black background (Game Accessibility Guidelines, no date).

Fig. 61
In Mass Effect: Andromeda the text is presented In a very small size, which compromises readability
Source: Max Deryagin's Subtitling Studio

Fig. 62
Bertram Fiddle displays the text in the recommended dimension to ensure a straight-forward comprehension
Source: Game Accessibility Guidelines

PROVIDE A CORRECT USE OF COLORS TO ENSURE LEGIBILITY
To ensure a straightforward understanding it's necessary to take into account also the use of colors: a white text juxtaposed with a black background box guarantees maximum intelligibility. The sentence has therefore to be against a dark solid or semi-opaque background, called letter boxing, ideally combined with an outline or shadow (Game Accessibility Guidelines, no date).
Other colours are not recommended, only to distinguish one speaker from another; for the hearing-affected, it can be complex to recognize who is speaking and therefore a visual indication of the character who is talking becomes fundamental for the experience. As reported by the BBC, the suggested tones in the captions aimed to indicate the players are in order of priority: white, yellow, cyan, and green (BBC, 2022).

PROVIDE VISUAL INFORMATION ABOUT THE DIRECTIONALITY OF SOUND
Other useful implementations are the floating text towards the side of the

speaker, indicating the name of who is speaking and representing the gamer's portrait. A combination of all these elements together guarantees a clear and straightforward understanding of the players the hard-of-hearing is playing with.
Another possible approach is an indication directly upon the person talking, as a speech bubble above their head (Game Accessibility Guidelines, no date) or, in the case of off screen-sound, a small arrow to the side of the subtitle that shows the direction from which it is coming from (Hamilton, 2015).

Fig. 63
Dream Chamber provides subtitles with name labels and the character's portrait
Source: Steam community

PROVIDE THE CORRECT POSITION OF SUBTITLES AND CAPTIONS

Talking about the position of the subtitle, it has to be by default in the vertical center and at the bottom, with a distance from the screen end. The caption doesn't have to collide with any of the user interface elements and therefore, in the case of scene components placed at the lower part, the subtitles have to be temporarily moved up to avoid overlapping (BBC, 2022).

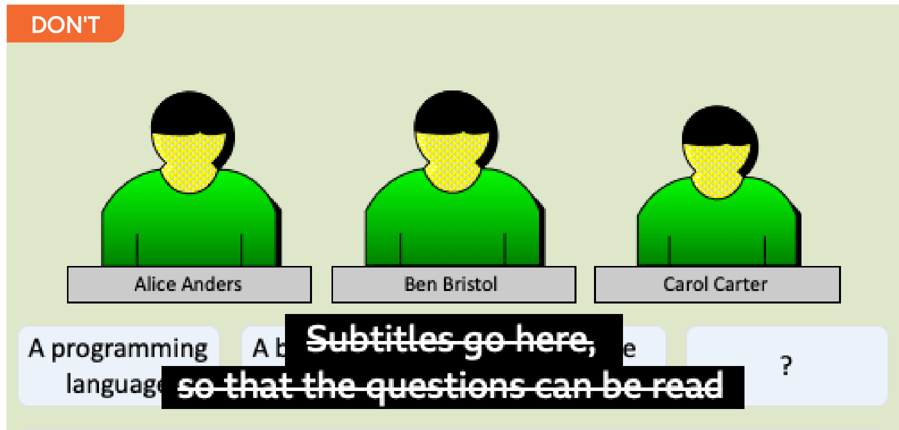
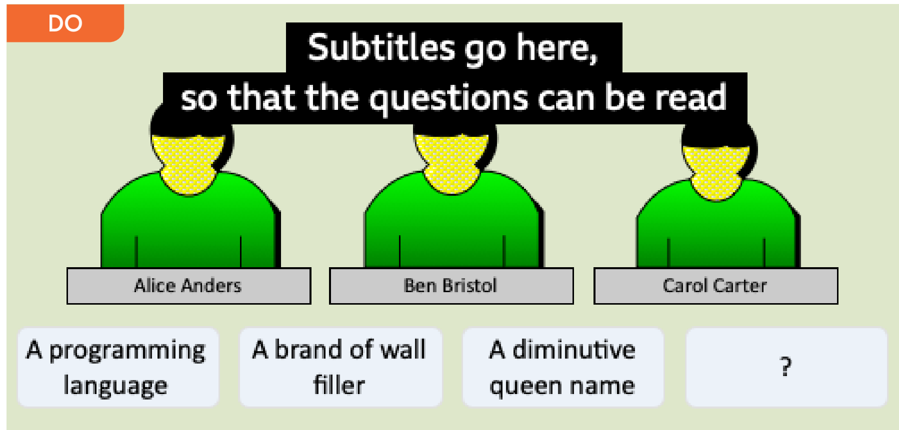


Fig. 64
The position of subtitles can impact the readability of the display interface
Source: BBC. Subtitles Guidelines



PROVIDE THE CORRECT VISUAL REPRESENTATION OF CLOSED CAPTIONS

Besides reporting the player's speech, when talking about hearing-affected it is required the use of closed captions for making them aware of all the sounds, including the background ones. Audio other than dialogues must be visually represented in a different way in order to have a clear distinction: in Portal 2, the significant scene noises are shown inside specific brackets (Game Accessibility Guidelines, no date).

Fig. 65
Portal 2 visually differentiates closed captions from subtitles to ensure a straightforward understanding
Source: Game Accessibility Guidelines

PROVIDE THE CORRECT TIMING TO ENSURE LEGIBILITY

The timing is another important factor to be considered and, according to BBC, the recommended subtitles speed is 160-180 words-per-minute (WPM) or 0.33 to 0.375 seconds per word (BBC, 2022).
In support of this recommendation, research conducted by the Office of Communications, also called Ofcom, highlights the necessity of not exceeding a threshold of 180 words per minute since it could potentially alienate a proportion of the deaf audience who struggle more with subtitles (Ofcom, 2005, p. 5).

Regarding the transition from one sentence to the following one, leaving a small gap of 100 to 200 milliseconds between captions that cover continuous dialogue ensures that the user's peripheral view recognizes the appearance of new visual stimuli (BBC, 2022).

ACCOMMODATE SCRIPTED AND LIVE CONVERSATIONS

In order to have an experience as faithful as possible to a real-life dialogue, the synchronization between speech, text appearance, and visual feedback is crucial. The text appearance when starting speaking should coincide with visual cues from the characters' faces or bodies, given the relevance of visual stimuli for hearing-affected.
In the case of live subtitling, another issue arises: live subtitles have limitations in conveying emotion and intonation of the speech. They only report the textual information excluding the mood and tone of the dialogue, with the risk of misinterpretation by hearing-affected players. The BBC has dealt with the definition of recommendations for broadcast subtitling, such as the use of capital letters to indicate shouted words or the exclamation mark for a sentence with emphasis (BBC, 2022).
Such indications, however, in addition to not being strictly designed for live captions, were designed specifically for television, while there are no specific guidelines for video games.
Indeed, in the world of online games, speech can be hectic, emotional, and involve the use of specific jargon, making accurate recognition extremely difficult. Therefore in the video games field, live subtitling still presents many issues despite being a feature that not only benefits the hearing-impaired.

OFFER CUSTOM CAPTIONS SETTINGS

For all these above-mentioned functionalities, it is necessary to ensure the possibility of customization: according to Game Accessibility Guidelines, the user has to be allowed to personalize his or her experience by choosing between different options for the text size, letter boxing opacity, font, and the possibility to include closed captions (Game Accessibility Guidelines, no date).
The video game Hitman follows the best practice of configurable subtitles, while Infamous First Light is a good example of easily turning on subtitles settings. Indeed, giving players rapid access to the activation of subtitles is fundamental to prevent players from missing relevant information, such as the introductory cinematic of video games. Therefore, a prompt to turn on subtitles before any sound is played or having captions turned on by default ensures an accessible experience for deaf players (Game Accessibility Guidelines, no date).

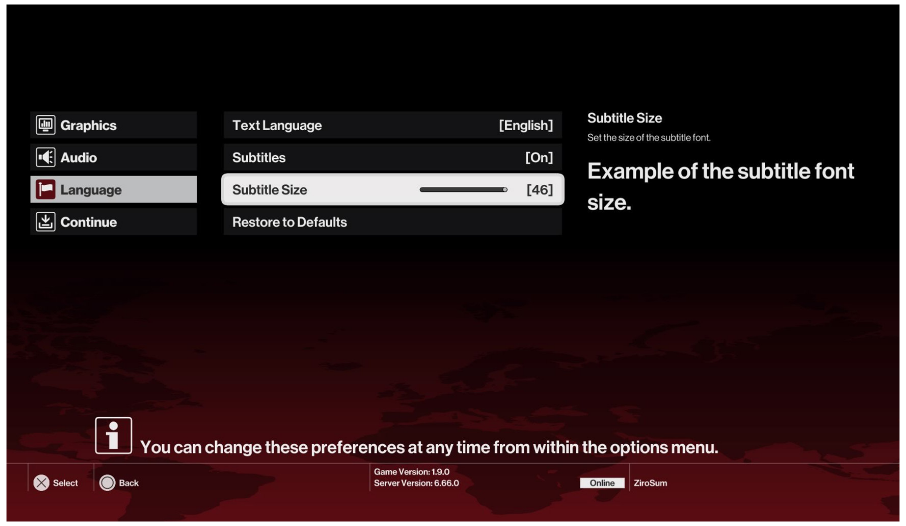


Fig. 66
Hitman gives users the option to configure subtitles size and see directly the preview
Source: Game Accessibility Guidelines

3.4 Conclusions

This chapter emphasizes the relevance of the Internet for deaf people in their everyday life, as it enables them to go beyond their physical barriers and socialize with others in a more frictionless way with respect to reality. Indeed, through social media they can interact with others in alternative ways, without the involvement of audio and voice. This is why social media represents a space where deaf users report to feel *"equal to hearing people"* (Valentine, Skelton and Levy, 2016, p. 11).

However, despite the importance of digital for their lives, not enough attention is still paid to their needs in terms of accessibility. This happens with video games, where socialization happens to take place, but where unfortunately hearing-impaired people still have to face accessibility issues. In this regard, many institutions have moved forward to combat these obstacles, where Game Accessibility Guidelines and the AbleGamers Charity stand out among the many bodies and experts who have provided recommendations.

There are several institutions that aim to overcome accessibility barriers while playing video games, assuming therefore that inclusiveness is a topic generally taken into account. Indeed at a practice level, people with disabilities still face accessibility issues when playing games, leading 40% of them to give up playing (Scope, 2020).

These alarming data underline that the current situation is still far from allowing the full inclusion of all individuals, regardless of possible impairments. Therefore, it emerges that accessibility is not considered central while developing a video game, consequently leading to the exclusion and marginalization of the deaf from the designed experience.

4

Digital interaction in Virtual Reality

Starting from the Internet invention, the digital world advance has led to the exploration of revolutionary new frontiers as early as the end of last century, including Virtual Reality.
Due to the limited technological resources at that time, it took several years to improve it and to make it ready for the general public. The real explosion occurred from 2015 to 2016, when the number of worldwide VR users went from 6.7 million to 43 million in the following year (Alsop, 2022). In 2019 there were over 171 million using VR in some way worldwide (Statista, 2022) and this figure has been increasing since then.
Despite this, the experience currently offered by Virtual Reality is still riddled with accessibility barriers (Stoner, 2022), evidencing a lack of attention to issues that may impair enjoyment by people with disabilities, including hearing-affected.
The following chapter provides an overview of Virtual Reality, including its main characteristics and application fields, with a focus on Social VR environments. It also evidences the central role of sound and therefore what parts of the experience are hearing-affected missing. Despite this limit that deaf people have to face, not so many guidelines embracing the concept of inclusion have been defined, evidencing that the opportunity of creating virtual accessible experiences is still under exploration.

4.1 Virtual Reality

"VR is not about simulating reality, really, but about simulating neural expectations" (Lanier, 2017). Through these words, the father of Virtual Reality Jaron Lanier described the aim of Virtual Reality: simulating how our brain perceives reality.
VR is a tridimensional artificial environment that is experienced through sensory stimuli, such as sight and sound, provided by a computer and in which one's actions have consequences on what happens in the environment (Tanni, 2020). The four primary elements of Virtual Reality are the simulated virtual world, the immersion aimed to make the experience closer to reality, the sensory feedback to recreate the human perception and finally the real-time interactivity between the user and the VR system (Engati, 2021).

VR players can enter into altered situations and reality, living an illusion created by hardware and software capable of tricking our perception.
On the technical side, a VR system consists of a series of input tools, which take care of capturing the activities performed by the user, and output ones through which the individual receives information. Based on the different input and output channels, VR can be distinguished into different categories with a diverse degree of immersion.

4.1.1 Immersion

"VR creates in the user the illusion of being in an environment that can be perceived as a believable place with enough interactivity to perform specific tasks in an efficient and comfortable way. There are two main factors that describe the VR experience from the physical and psychological points of view: immersion and presence" (Gutiérrez, Vexo and Thalmann, 2008, p. 15).
As quoted, immersion is central in VR experiences since it determines the degree of engagement of the individual. Based on the different inputs and outputs involved, a classification was made on how much the user can perceive the simulated environment.
The three distinguished types of virtual reality are the following:

1. Non-immersive Virtual Reality: the degree of immersion is almost absent since the 3D simulated environment is accessed by the user through a computer screen. There is no sensory isolation and the ability to move in the environment usually relies on devices such as the keyboard, the mouse, or joysticks. A video game is a good example of non-immersive VR (Bardi, 2022).
2. Semi-immersive Virtual Reality: it's offered a partially immersed experience accessed through a computer screen, some type of glasses, or a headset.

For the simulation, there are exploited 3D graphics, high-resolution displays, powerful computers, and projectors. A common example is the flight simulator, through which pilots can train themselves (Engati, 2021).

3. Fully immersive Virtual Reality: it's the most realistic simulation where there's the involvement of sight, sound and even touch in some cases. Some experiments were made also involving olfactory sensations. VR technology commonly consists of headsets and sensory accessories such as controllers and motion trackers, which isolates the users from the real world. Based on 3D stereo vision, the headset uses two separate images, one for each eye, which allows the user to have a realistic representation of the ambient (Bardi, 2022).

4.1.2 Sense of presence

An important component to ensure the effectiveness of Virtual Reality is the so-called sense of presence, defined as a psychological perception of being in the environment in which the person is immersed. It's strictly interrelated with our consciousness: presence is achieved when the user is conscious, deliberately or not, of being in a virtual environment and therefore when the multi-modal simulations (images, sound, haptic feedback and more) are able to make the user process the environment as coherent (Gutiérrez, Vexo and Thalmann, 2008, p. 16).

The less the subject is aware of the mediation of the technological artifact, the greater it is the sense of presence felt in the virtual experience.

Based on different situations, one sensory simulation could be more relevant than another: as an example when simulating a surgery to train doctors, the tactile stimuli become central, while to recreate an orchestra, presence is achieved when the acoustics of the concert hall is correctly reproduced.

According to Biocca (1997 cited in Lee, 2006), three types of sense of presence can be distinguished: physical, social, and self-presence. Talking about physical presence, it's a subjective feeling of being physically located in a virtual environment, while the social one has been defined as the sense of being together with another individual, which could be real or simulated. The last type is self-presence, which is referred to the user's mental model of himself and the awareness of self-identity inside a virtual world.

4.1.3 Motion sickness

It's common while experiencing Virtual Reality to suffer from motion sickness: a feeling of dizziness, disorientation, or nausea that may affect a subject during or in the immediate aftermath of using a Head Mounted Display (HMD) in an immersive virtual environment. The cause is the dissonance of movements perception between various organs of our body, which send conflicting signals to our brain.

What can lead to confusion is receiving different input from three relevant systems for our perception, which are:

- Vestibular apparatus, which works as a movement sensor and therefore gives relevant information to our brain about the position and movement of the head.
- Sight, which creates images that are then calculated by the brain in order to understand the movement and position of objects.
- Somatosensory apparatus, which gains important clues about the movement of our body in space and about the external environment (Galdieri, 2019).

Therefore, as an example, if upon head movement the VR headset is not able to correctly represent this action, the eyes will then receive different feedback than they would expect, leading to motion sickness.

This problem is circumvented by offering 6 degrees of freedom headset, thus allowing each movement of the head in space to be possible. This is not the case with helmets with only 3 degrees of freedom, as they are only able to handle the rotation of the head, thus offering a limited experience (Galdieri, 2019).

Furthermore, the resolution of the lenses also matters, as a higher resolution leads to a better feeling of presence in the environment.

Since VR headset is still an evolving technology, it is recommended to use the headset not for an extended period of time, a maximum of two hours, to avoid the occurrence of motion sickness.

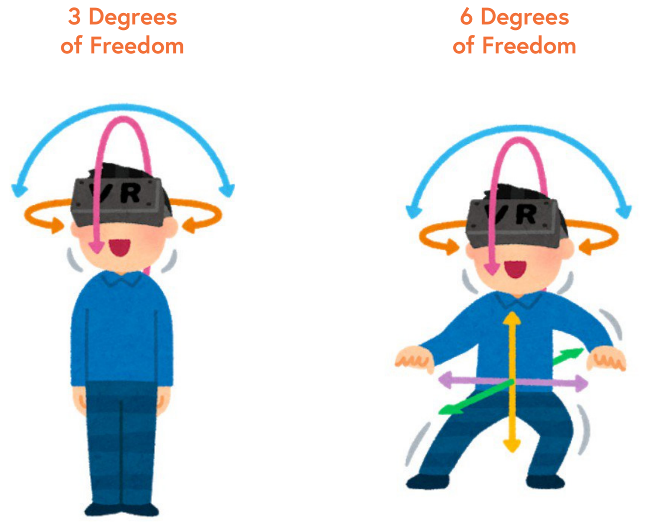


Fig. 67
Different between 3 degrees and 6 degrees of freedom headset
Source: Andren Joly

4.1.4 Current and future applications

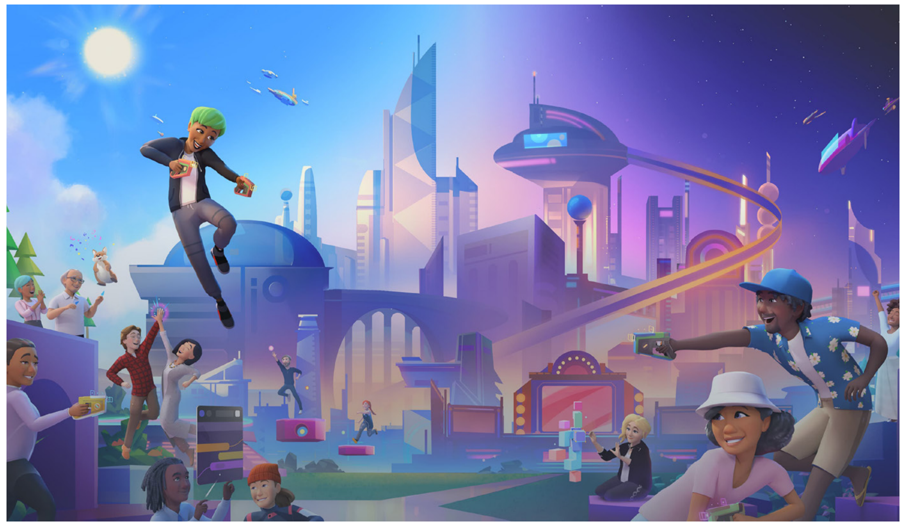
VR technologies are currently exploited in different fields and for different aims. Talking about the Automotive industry, companies such as BMW and Jaguar Land Rover have been using it for years to perform design and engineering reviews, while VR has been also involved in training, as in the healthcare field, where this technology can be used by doctors to better prepare themselves for surgeries.
Other fields of interest are tourism, real estate, architecture, and others where users can experience something before actually buying it. Its uses are endless, involving gaming, education, fitness, and even the metaverse.
Introduced for the first time in 1992, the term metaverse was originally coined within the science fiction novel Snow Crash by Neal Stephenson, where it was intended as an alternative world composed of avatars (Candolo, 2022). The term made a comeback in 2021 with Meta, which defines the metaverse as *"the next evolution in social connection and the successor to the mobile internet"* (Meta, 2023), which combines aspects of social media, online gaming, AR, VR and more to allow users to interact virtually (Folger, 2022) in an online, shared, persistent virtual place.
With this new advent, VR has also taken hold in new sectors such as retail, where users will be able to try on clothes digitally, or do virtual conferences, where people can connect with colleagues from anywhere to hold interactive and collaborative meetings.

Fig. 68
Walmart exploits VR to change the current grocery shopping experience
Source: The Verge

4.1.4.1 Social VR experiences

One sector considered to be expanding thanks to the advent of Meta is the Social one, where Mark Zuckerberg's company is designing a new way of relating and connecting with others, that allows people to live experiences together while being in different parts of the world. This could become the future of how we experience online information, where we currently interact in a two-dimensional format, through texts, visuals, 2D screens, and limited interactivity (XR today, 2022). In VR, this interaction could be substituted by a full immersion where users can together explore virtual worlds and live experiences such as meetings, games, concerts, fitness lessons, and so on, as they would do in the real world.
This specific type of environment is called Social VR, defined as virtual environments which are *"mediated by immersive technologies and taking place in predesigned three-dimensional virtual worlds where individuals, represented by an avatar, may engage in real-time interpersonal conversation and shared activities"* (Dzardanova, Kasapakis and Gavalas, 2018, p. 4).
It is therefore strictly based on the possibility of sharing a 'space' with other individuals, a concept embraced by Meta who designed Horizon Worlds, a social platform where users in an avatar version can communicate, collaborate, play with each other, and create new environments.
This social platform along with many others fulfills the users' desire for a more social virtual experience: in a survey run by GreenLight in 2018, 78% of 4217 VR users expressed their interest in interacting socially with other people in VR (Koetsier, 2018). The addition of social components also partly mitigates the possibility of isolation provided by purely immersive technology.
Social VR thus brings new value to Virtual Reality technology, which aims to have an impact on the interaction between individuals.

Fig. 69
Meta's Social VR app Horizon Worlds
Source: Meta



A relevant component inside Social VR apps is the avatar, a medium through which to communicate with others.
Professor Sylvia Xueni Pan at the University of London reports that using an avatar to interact with others counteracts our subconscious need of judging a book by its cover (TEDx Talks, 2022). Indeed, society and media had led us to create biases and prejudices towards others because of their appearance or other identifying characteristics.
In a VR world where users can show themselves as they prefer, the natural instinct to judge at first sight is therefore mitigated. Xueni Pan reports how several users in Social VR environments decide to show themselves in the form of non-human elements, such as chili peppers and mushrooms, creating a lot of amusement at first but also preventing others from judging them superficially. In fact, it becomes impossible to know at first glance the gender, age, and ethnicity of the person behind the avatar, thus leading social interaction to go beyond mere appearance.
Therefore, this brings benefits also for people with disabilities, as VR technology allows them to avoid prejudice from others and overcome the limits they have to face in real life. As summarized by the Professor, *"on these platforms, you have a more equal way of evaluating each other by the content rather than the packaging we are stuck with"* (TEDx Talks, 2022). Social VR, therefore, represents a way to go beyond: beyond prejudices, beyond one's physical limitations, where each individual can give vent to how they would like to be perceived by others.
Certainly, it's also important to make considerations about possible misuse s as a complete refuge from reality and its negative consequences. According to her studies, Xueni Pan explains that VR will not replace reality, but will be more of a place for us as humans to take a break from reality, enjoying an experience capable of revolutionizing the way we interact (TEDx Talks, 2022).

Fig. 70
Xueni Pan during her speech about the role of avatars in virtual experiences
Source: TEDx Talks

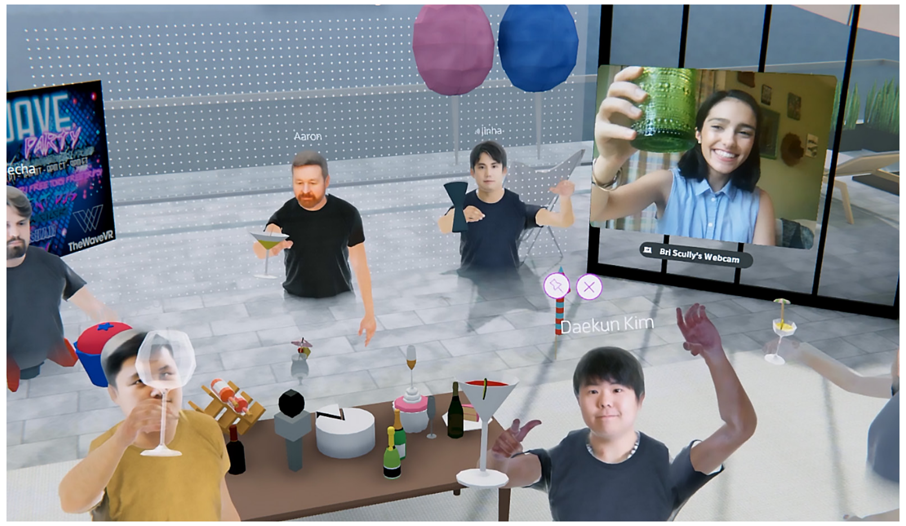
4.1.4.2 Avatar styles

Avatars are a key component in the majority of VR environments, especially Social VR ones, through which players are led to first-hand live experiences. The possibility of avatar representations are diverse based also on the different approaches and games' objectives: they can go from humanoid figures, such as robots, to non-animated objects. Indeed avatars can be categorized into three types: realistic, cartoon, and stylized.

REALISTIC

A realistic avatar offers many customization options so that the user can get as close as possible to his or her own appearance. However, VR technology still presents limits that can cause issues such as the "uncanny valley" effect, triggered by human representations with features perceived as artificial which makes the whole character seen as unbelievable or even uncanny. What widens the gap from reaching an acceptable realism is also the lack of tracking elements on body parts such as legs and even the face, which makes facial expressions look relatively rigid. Indeed, VR tracking is currently limited to arm and head movements, making facial expressions not yet virtualizable on a mass scale which is why many avatars may seem emotionless (Nguyen, no date).

Fig. 71
In spatial.io avatars exploit the participants' photos in order to embrace a realistic approach
Source: The New Real



Meta is moving towards increasing the level of realism through "Project Cambria", VR glasses intended as a next geneartion, which offer new features such as inward-facing cameras for the face and eyes. Through this additional tracking, eye movements and facial expression will be registered and transmitted to the avatar in real-time, increasing the credibility and the nature of virtual communication. Moreover, Cambria will offer improved gesture tracking, improving the authenticity of social interaction in virtual space (Nguyen, no date).

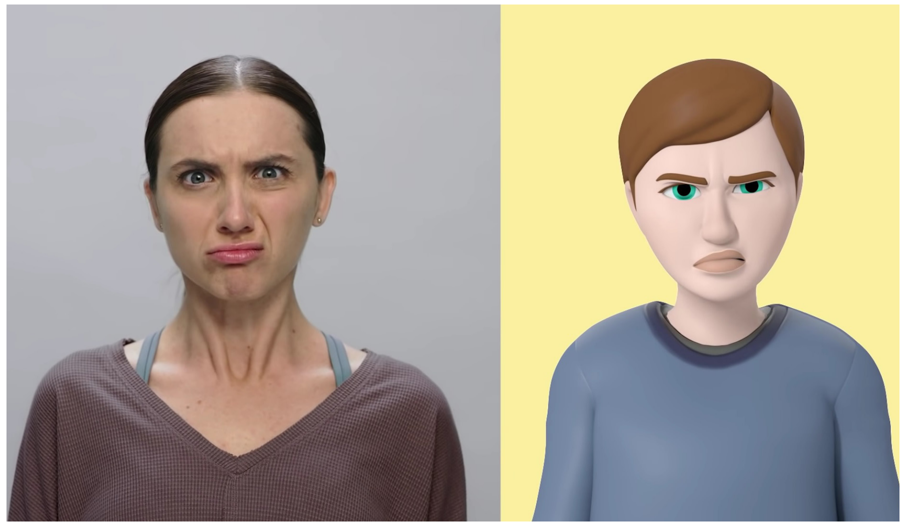


Fig. 72
Project Cambria headset will allow improvements in facial expression tracking
Source: Meta

CARTOON

A cartoon avatar doesn't have the aim to try to copy reality, but it still offers the possibility of individual design consistent with the style of the game.
The cartoon style doesn't work in any context: while presenting in a professional setting, it can make the circumstance seem less credible, therefore it may not be appealing to anyone. Also, as realistic characters, comic avatars are characterized by limited face mimics (Nguyen, no date).

Fig. 73
In ReadyPlayerMe a cartoony approach is embraced, but still remains consistent with human appearance
Source: VR Scout

STYLIZED

Stylized avatars still have humanoid features and can be customizable robots, sci-fi figures, and holograms. Because of their generic representations, they make virtual meetings appear less personal since it may be missing a point of reference, such as the face of other individuals (Nguyen, no date).

Fig. 74
In Holodeck, avatars are represented through impersonal sci-fi figures and abstracted humanoids
Source: The New Real

What differentiates the three approaches is the level of avatar fidelity, defined as *"its ability to mimic the real appearance and behavior of the player it represents"* (Mansour et al, 2006, p. 3), which is determined by two factors: visual fidelity and behavioral fidelity.

Visual fidelity is affected by the character's morphology and photorealism: the first one refers to the shape of the avatar and it ranges from humanoid to non-humanoid forms, while the photorealism concerns the level of visual details going from stylized to highly realistic shapes. Behavioral fidelity is the avatar's animation properties and it refers to the extent to which avatars and other objects in a virtual environment behave like their correspondents in the physical world (Mansour et al, 2006, cited in Swinth, p. 3).
The analysis conducted by the University of Louisville and Grand Valley State University researchers focused on analyzing the influence of visual and behavioral fidelity on the perception of social interaction in a Collaborative Virtual Reality Environment: a VR environment where participants can interact and collaborate with each other from different parts of the world.
The test involved 60 subjects who were asked to perform a task by taking joint decisions with another player. They were divided into three categories based on their randomly chosen condition: human avatar condition, non-human avatar condition, and object condition. During the test, each participant in all pairs was represented by the static avatar at one time and by the animated avatar the next time.
The results highlighted that players represented by animated human avatars experienced the highest perceptions of social interaction and behave as they would do in real face-to-face interaction. On the other hand, participants who were represented by the static object avatars perceived the lowest level of social interaction and they were not actively engaged in the interaction process with their partners as in the animated human condition (Mansour et al, 2006, pp. 5-7).
In conclusion, the research highlighted that avatars' morphology and level of

animation have a significant effect on the perceived social interaction while in a virtual environment and that a more realistic representation is responsible for reaching a higher level of social interaction between participants.
The authors suggested also the exploitation of human avatars in order to create warm relationships between the individual and his/her avatar and with other players. Moreover, they indicated that, in order to have a realistic and true-to-life interaction, it's relevant for characters to be able to convey also non-verbal communication behaviors, which is guaranteed in a realistic avatar representation (Mansour et al, 2006, pp. 7-8).

4.2 Role of sound in VR experiences

Just as in the real world, we experience VR environments through our senses, mainly through sight, tactile and auditory stimuli. Each of them contributes to make the experience credible for the individual who is enjoying it and thus increases their degree of involvement and immersion.
In the case of deaf people, however, the auditory stimuli are ineffective, and as a result, their experience is different from how the average. So, how compromised is VR experiences for people with hearing disabilities?

According to some VR creators, there's a boundary for deaf people, since on some platforms sound makes up 50% of the VR experience (Pagan, 2017). Audio is therefore a central component but, despite this, it is often taken for granted and only re-evaluated in its absence. According to sound designer Borghesi, however, it is important to bear in mind that *"an immersive sound design for the VR contributes to making the experience authentic"* (Borghesi, 2020), emphasizing the importance of sound in creating an experience with engagement and immersion. For this reason, audio within VR experiences is designed to be as faithful as possible to our everyday experience.

This is made possible by the use of spatial audio, which, by exploiting the position sensors of the headset, provides for a modulation of the sound intensity according to the user's position. Thus, a shift in position in the virtual space also corresponds to a change in the volume of the sound, in order to realistically represent if the user is getting closer or farther from the sound source (Bellanti, 2019). Our brain in real life is able to identify the origin of the sound source, thanks to three factors:

- The difference in time at which a sound reaches our two ears: even if it is imperceptible, a sound coming from the right will be perceived first by the right ear and immediately afterward by the left one, allowing our brain to understand which side the sound is coming from.
- Another factor that contributes to understanding the sound source position is the volume, defined as sound amplitude: if the sound comes from the right, it will be perceived at a higher volume by the right ear than by the left one.
- Finally, an not obvious element is the "pinna filter", which is related to the anatomy of our ears. Their very particular shape filters sound and allows our brain to understand whether they are coming from in front or behind us (Bellanti, 2019).

All of the following information is processed by our brain in the act known as "binaural fusion", whereby all signals received by our ears are processed into a single audio input, through which we acquire more information about the sound we have just heard.

This process is reproduced within VR through binaural audio, which is able to trick our perception and make us perceive noises in a similar way as in reality. Thus, the user immersed in VR will be able to perceive the audio associated with a precise position in space, even if he or she is actually in a VR environment. Thus, binaural audio, employed in virtual space together with spatial feedback, makes the experience responsive to the users' actions and increasingly believable to our perception.

On a high level, it's possible to say that sound is also able to influence and enhance the user experience. As evidenced by the designer Siddartha K, auditory stimuli play an important role in usability, as they are able to guide the experience and reassure users. As an example, sound provides feedback about doing something in the wrong or right way. It also has the ability to create empathetic connections: as reported by the designer, when hearing someone crying it's very likely that we will feel sad too. Moreover, as explained before, sound creates a context in terms of location and time, so it has the ability to provide clues about where the user is and when things will happen. It therefore can be considered as a component able to make the experience more real, since it's also able to create presence and engage users (Sid, 2022).
On a user experience level, sound therefore has multiple relevant functions, but what specifically is its role within a VR environment?
The sound designer Borghesi explains that audio stimuli in VR have multiple functions with an high influence on the overall experience. Sound allows the localization of events, as knowing where the enemy is coming from, and it triggers emotional reactions in response to circumstances, such as a consequence to a scream which put the user in a state of alert. Besides being responsible for making individuals perceive immersed and a sense of presence, sound is capable to create a suspension of disbelief, where the user temporalily accepts to believe in the imaginary world of the VR environment. This is possible through the design of an experience that has the aim to be perceived as authentic.
Sound also plays the role of complementing the message provided by images, allowing the visual part to take on the correct weight. An example given by Borghesi concerns the T-rex, which becomes huge ad heavy because its movements are associated with sounds defined as cannon shots (Borghesi, 2020).
In addition, audio, especially dialogue, allows the narrative to continue and to create storytelling, which contributes to increase immersion. It can be a voice-over guiding the experience as the dialogue between avatars in a social environment; in both cases, audio represents a crucial aspect.
An experiment study[9] performed by researchers at the Georgia Institute of

9 The experiment consisted of an exploration of a VR environment, where 322 subjects were involved. After the exploration, they were required to fill out two surveys, to respectively test the sense of presence and memory of objects in the environment. The results evidence that the concurrence of auditory, olfactory, and tactile stimuli increases the memory of elements in the tested environment, while it's not true for increasing the detail level of visual stimuli.

Technology also shows that sound plays an important role in enhancing not only the sense of presence, but also the memory of elements in the environment. The research, consisted of exploring an environment of VR twice: once without additional sensory clues and the other with them, consisting of additional visual, olfactory, tactile, and auditory clues. The results showed that the auditory stimuli, in conjunction with olfactory and tactile clues, concur to increase the user's memory of the space they are exploring, thus remaining more imprinted in the users' mind (Dinh et al, 1999, pp. 1-6).
Therefore, the benefits offered by sound are multiple and relevant in VR, as they determine the impact that the experience will have on the user. Many VR platforms bring the auditory component at the center of their offering, developing an experience characterized by the hearing sense, as the ones here discussed.

4.2.1 Anna Frank House VR

One relevant example is Anne Frank House VR, which aims to enable the visit to Anna Frank's house in a way never seen before.
The user can explore it in two different modalities, the first of which is the story mode where from the first experience it becomes evident the centrality of audio, which accompanies a few black and white images on a dark background, through which the salient moments of Anne's life are retraced. The story begins with her childhood, where the narrator's voice and background music instill tranquility and sweetness, while the tone becomes increasingly tense and inherently anguished as images of Hitler appear. Finally, it takes an increasingly sad and profound turn when the voice-over recounts the sacrifices made by the girl's family until the arrest. The music, therefore, changes tone according to the intent of the story, to allow the user to immerse himself in the situation being told and to empathize with the little girl's poignant story.

Fig. 75
The story mode of Anne Frank House VR platform
Source: Anna Frank House VR

This objective also persists in the second mode, the tour mode. In this case, the user is catapulted into the years of the Second World War inside the house where Anne Frank was hiding. The player can move freely around and listen to sentences extracted from her diary.
As one explores the house, the tense atmosphere of those years is perceptible, as a strident silence reigns which is aimed to recount her status as a refugee. The deafening stillness is unexpectedly interrupted by noises from outside such as the airplanes, whose intense and powerful sound shakes the walls of the house, instilling fear. Other perceptible noises that contribute to make the experience real are the sound of doors opening, the creaking of the floor, and the buzzing of people from the street. The experience becomes even more immersive when the user is asked to turn on the radio to hear the British radio message saying *"This is the day, the invasion has begun!"*.
In conclusion, the audio component in Anne Frank House VR achieves the intent of creating a gloomy and distressing atmosphere, feelings that characterize the little girl's diary. It is therefore a virtual experience that, if deprived of sound, would also be robbed of its emotional charge and its ability to immerse and engage the user. The virtual tour is available in multiple languages, including English, Dutch, Spanish, and Hebrew and it gives the possibility to activate subtitles in multiple languages.

Fig. 76
The tour mode of Anne Frank House VR platform
Source: Anna Frank House VR

4.2.2 The Assembly

Another VR platform that relies on hearing stimuli is "The Assembly", a VR game in which the user takes on the role of two individuals exploring a mysterious and morally ambiguous organization.
During this interactive story, the player discovers relevant information and shocking data as he or she moves through the organization's secret bunker, which has a sci-fi and futuristic setting. In these environments, the player is led to make difficult choices and overcome challenges. The two different characters he is interpreting are a newcomer going through initiation trials and then a veteran who's unravelling the conspiracy.
In both cases, the sound is crucial to the experience, especially the character's voice. Indeed, for the entire game the character talks a lot to himself, speaking his thoughts aloud, reasoning about his discoveries and the material he is exploring. The voice is realistic with a tone of voice capable of narrating different situations, from moments of tension to those of discovery.
The person wearing the headset, therefore, by listening to the speeches automatically made by the character, is able to understand his thoughts, emotions and thus identify with the role. The decisions that the person will be led to make are then influenced by these monologues, whereby the audio of the voice is decisive for the evolution of the story.

Fig. 77
The Aassembly VR game
Source: Steam powered

The user is alone within this environment, where he only has contact with other characters via radio, such as with an agent who gives the player directions via audio.
Concerning sound, a moment summarizing the centrality of audio is the scene where the player is asked to listen to a recorded message on the phone: at first the user is drawn in by the "beep" of the technological device and, once it has captured his or her attention, he is led to listen to the recorded message

in which Dr. Chavez reveals sensitive data that condition the prosecution of the story. In fact, after listening to it, the character responds by hinting that, thanks to this information, the situation is gradually becoming clearer.
In conclusion, the hearing sense plays a central role within the experience, as it is used as a means of communication with other virtual characters, to realistically reproduce the environmental noises, and above all to manifest the character's thoughts capable of influencing the players' future choices. The platform also provides the possibility of activating subtitles, the script of which, however, is only available in English.

Fig. 78
The Assembly VR game
Source: Steam powered

4.2.3 VRChat

Platforms where sound is not only important but underpins the whole experience are Social VR apps, where people can perform activities together and socialize by connecting from anywhere in the world. One of the most popular social platforms is VRChat, a multiplayer online platform created in 2014.

In VRChat, users in the guise of avatars can socialize with each other, meet new people while playing games, visit worlds, or even create new ones. Indeed, a part of the virtual worlds on the platform is created by the players themselves, which could be public or private, and that can be developed by using Unity 3D engine. During these last years, the platform has hosted many different events, concerts, and even festivals, where VRChat was exploited by Festival del Cinema di Venezia its section called Venice VR Expanded.
A distinctive element of this Social VR app is the wide range of already-created avatars that the user can wear, such as characters from video games, anime, or even inanimate objects. Going out of the box and having fun is at the heart of the experience, where there are many worlds through which users can go to the cinema, experiment with their artistic skills, or immerse themselves in games while being different from reality.

Fig. 79
Avatars in VRChat platform
Source: Steam powered

Concerning dialogues, users communicate with each other through the use of voice, which enables them to have immediate and direct interaction. Depending on their needs, players can switch their microphones on and off, which represents a well-recognized and familiar pattern. When one user communicates with another, the platform provides direct feedback on that action through a simulated lip-sync, whereby the opening and closure of the lips indicated that the user is producing sounds. This functionality still presents some limitations as it only represents the mouth's opening and closing, without faithfully reporting what is being said in the dialogue. Moreover, this feature has to be added manually for characters created ad hoc in Unity. Furthermore, non-human avatars, such as a robot, do not guarantee the presence of lips and consequently the possibility of having visual clues regarding the dialogue.
Instead regarding environmental audio, since many words have been waxed by the users themselves, they are not focused on providing environmental noises, which therefore makes the sound of voice even more central to the whole experience.

In conclusion, in VRChat the sound of voice characterizes and enables socialization between individuals, allowing them to share laughter, talk, and chatter. Indeed, the medium of voice has always been the method by which we as human beings relate to each other and this platform embodies the same concept by posing it at the center of its experience.

Fig. 80
Events in VRChat platform
Source: Meta Quest

Fig. 81
Worlds in VRChat platform
Source: Upload VR

4.3 Accessibility guidelines in VR experiences

From cultural platforms to gaming and social apps, hearing stimuli are relevant to create an experience able to immerse the player. The three platforms previously explained exemplify several VR experiences that deaf users experience differently, where they may have to contend with the limitations imposed by a not-fully accessible design and therefore not inclusive.
In addition to the ineffectiveness of sound, hearing-affected may also have to face another obstacle, related to the vestibular disorder. As reported in chapter 1.2.1, the improper functioning of the hearing system might lead to the occurrence of a vestibular issue, manifested through vertigo and dizziness which can become a real obstacle for deaf individuals while in a VR experience.
Indeed, in some cases these health consequences can contribute to the suffering of motion sickness while wearing a headset.
A demonstration is given by the deaf author Meryl Evans, who tested several platforms in order to give her feedback, including Anne Frank House VR. In that specific case, vertigo imposed her to do two separate sessions to get through the whole house tour, since captions were not designed consistently with deaf requirements: she reported that they were out of sync with the speaking voice and that they were presented in a scrolling modality. Indeed, for people suffering from vertigo, everything that minimizes motion could help, so it's suggested to not use roll-up captions but prefers to use pop-in ones since it gives users time to read at their own speed (Evans, 2021).
This is just one of the suggestions to keep in mind while designing an accessible VR experience for the hearing impaired. Some institutions have identified guidelines to make the enjoyment of VR experiences by deaf users possible. These guidelines are VR Accessibility Design guidelines by Meta Quest, Accessibility of Virtual Reality Environments by the Melbourne University, and XR Accessibility User Requirements (XAUR) provided by W3C, the acronym for World Wide Web Consortium which is the main international standards organization for the World Wide Web. Other entities have also taken an interest in VR issues such as Game Accessibility Guidelines and Xbox Accessibility Guidelines, which provide general game guidelines for non-immersive games but also include references to immersive Virtual Reality. Because of that, their recommendations overlap with the ones provided by VR-specific institutions.
In addition to institutions, some deaf VR users who are enthusiastic about VR have provided accessibility suggestions based on their personal experience and expertise.
The following chapters are a summary of all the VR-specific guidelines defined to ensure enjoyable VR immersive experiences for the hard-of-hearing.

4.3.1 Functionality-related guidelines

In order to create a VR experience intuitive and usable, it has been defined some functionality-related guidelines. They aim is to ensure deaf people the possibility of set the experience as they prefer based on their specific and personal needs in terms of interface, clues, and more.

4.3.1.1 Interface personalization

As for non-immersive game guidelines, interface personalization represents an important feature also in VR to ensure an enjoyable experience for everyone's needs.

OFFER CUSTOM INTERFACE SETTINGS
Meta Quest highlights the importance of offering customizable brightness settings, which is relevant for the deaf since they can regulate it to make sure to fully grasp central visual clues to compensate for the inability to fully rely on audio. Also for this reason, the visual component must fully respond to each player's needs, which may be different. For this reason, Meta Quest emphasizes the importance for the user to be able to customize the interface elements in terms of size, where the CTA necessary to proceed must stand out and be easy to find (Meta Quest, 2022).

OFFER VIEW RECALIBRATION
Being totally immersed within a virtual space can easily lead to the loss of reference points and thus to no longer finding the control menu, for example. In this regard, W3C has placed its attention on that, defining a guideline to ensure players can recalibrate their focus, view and zoom in an independent way (W3C, 2021). The Meta Quest 2 viewer ensures this by means of a specific button on the hand tracker, which allows frontal repositioning of elements in the interface (Meta Quest, 2022).

POSITION ELEMENTS IN THE INTERFACE BASED ON THEIR PURPOSE
Another interface-related guideline concerns the positioning of UI elements, that must be attached to a person's gaze. This ensures that a person does not lose sight of that components and, because of that, it is a useful feature for everyone since it allows to have visual elements always under control.
But as stated in the VR Accessibility Guidelines by Meta Quest, the positioning of such UI elements depends on the purpose: a menu may be responsive to the

gaze of the player, while other elements may be related to 3D components, as a button may appear above a door only if the user is close to it (Meta Quest, 2022).

4.3.1.2 Maximize comfort

Social VR experiences rely on Virtual Reality technology, which can lead to motion sickness. Because of that, some institutions provides guidelines to avoid the occurrence of this issue.

AVOID SICKNESS TRIGGERS

In XAUR it has been defined a guideline that avoids the occurrence of motion sickness for users with vestibular disorders, to which deaf people may be subject. In fact, certain types of interactions such as teleportation can easily trigger motion sickness for people suffering from this disease.
XAUR as well as the Game Accessibility Guidelines, therefore, indicate the need to have the ability to disable or even avoid interactions that can trigger such conditions, like teleportation movement, and also highlight that flickering images should be at a minimum or that can be easily deactivated (W3C, 2021).
Comfort is an important component for platforms and Oculus knows it. Indeed it provides an indication for each platform available in its store to inform the user about the comfort level offered. It's called comfort rating and it's composed of four evaluations, which goes from Comfortable to Reduced for apps considered with too intense motion and movements. This is useful for users to address their choice of which app to use.

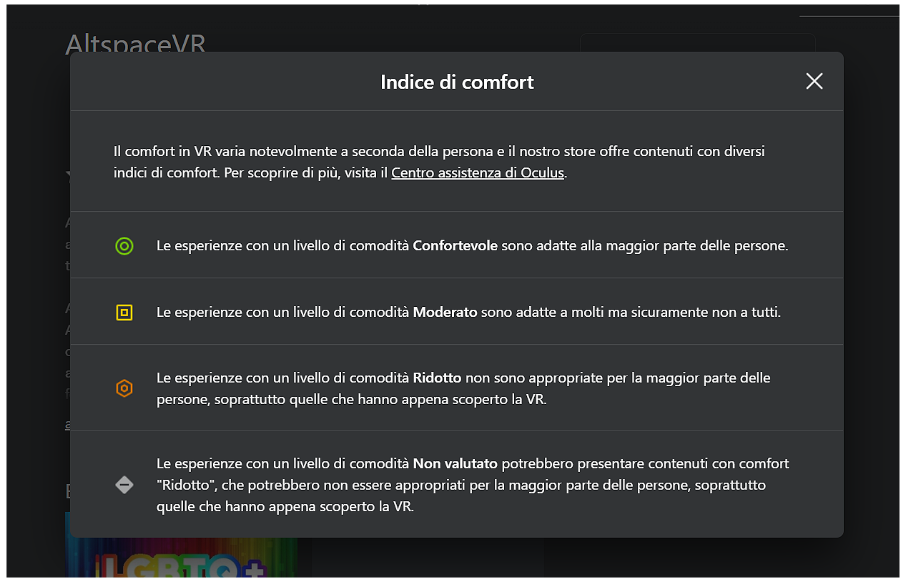


Fig. 82
The comfort index is an indication provided by Meta for the evaluation of apps available on Meta Quest store
Source: Meta Quest

PROVIDE COMFORT MODE

Another feature automatically activated by the platform that aims to enable comfort and minimize discomfort is the so-called comfort mode, a modality through which it's obscured part of the peripheral view while virtually moving within the space. As explained by Meat Quest, it's suggested to be implemented when moving via joystick or teleporting the player and its objective is to help the user to focus on what is really important and avoid discomfort (Meta Quest, 2022).

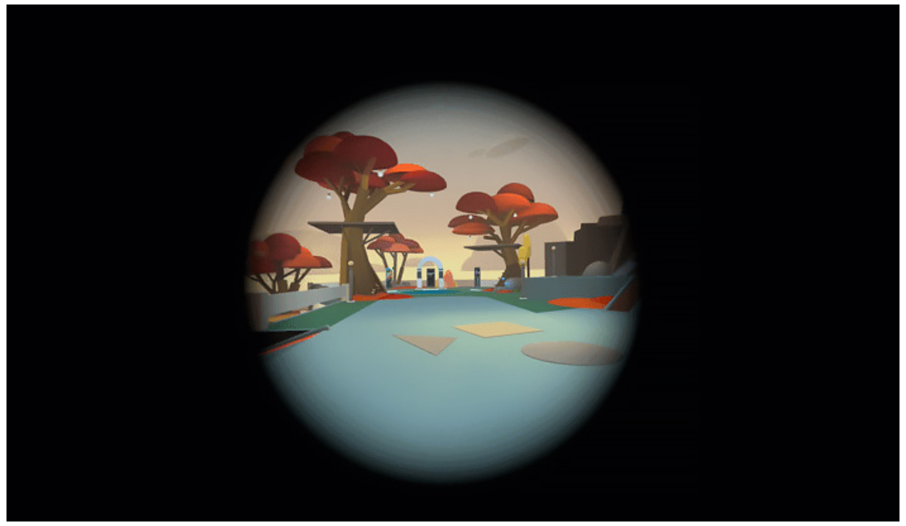


Fig. 83
Horizon Worlds provides a comfort mode while teleporting and moving around the space through controllers
Source: Meta Quest

4.3.1.3 Improve clues' clarity

Clearness is a key component of each experience and because of that, some guidelines have been provided to ensure it.

PROVIDE ADDITIONAL FEEDBACK VIA ALTERNATIVE MODALITIES

In VR Accessibility Design guidelines, Meta Quest highlights the importance of guaranteeing deaf users additional feedback via alternative modalities. This ensures clear reception of the message and, in order to do that, it is necessary to accompany audio stimuli with clues addressed to other sensory modalities, which are sight and touch. So as an example, when reaching the indicated destination, it is necessary to provide a vibration via the controller or a visual interaction in addition to sound, so that the successful task accomplishment is made clear.
It is also necessary to ensure that the user can always receive all the important information in the game and thus ensure that essential information, such as an indication of the direction in which one should move, is always located within the user's field of vision (Meta Quest, 2022).

PROVIDE IN-APP TUTORIALS
In order to ensure a clear and straightforward experience, it's relevant to ensure players the possibility to access tutorials where they can experience interactions for the first time. In accordance with the guidelines defined by Meta Quest, the tutorials have to be put at the start as a mandatory section and they have to include the elements and interactions that will be presented during the actual experience, going from visual clues to menu and buttons, as an example. Moreover, since it's a demo environment, users must have the chance to do and redo actions in order to familiarize themselves with it and gain confidence (Meta Quest, 2022).

INCLUDE GUIDING CHARACTERS
Meta Quest also focuses on the importance of having another character within the environment, represented physically or in the form of a narrator, who has the role of guiding and informing the user of his actions. Thus, for example, the other character can provide feedback on the success or failure of a required task, thus guiding the player in the accomplishment.
In the case of actions that may be complex, the physical presence of another character can help the player mimic or even shadow the movements of the other and thus make the experience more straightforward (Meta Quest, 2022).

4.3.2 Sociality-related guidelines

Similarly to non-immersive game experiences, it is extremely important to have design recommendations able to ensure effective social relations between users. To do so, guidelines related to social interactions were established, specifically concerning alternative input modalities, audio personalization, and subtitles.

4.3.2.1 Alternative modalities

As evidenced in previous chapters, deaf users require the presence of additional modalities of providing clues, which are through visual and tactile stimuli, to ensure the correct reception of information.

PROVIDE FEEDBACK VIA ALTERNATIVE MODALITIES
Providing additional clues through not only audio guarantees the correct reception of a message by deaf people. As expressed by Meta Quest, haptic feedback can be used to give additional clarity for alerting users of footprints near them or if an user is getting close to him to start a conversation. Meta suggests the use of tactile clues also to inform the player of a collision with objects, for giving hints about button clicks, but also for in-game sound as large crashes happening near the user. In the same way, visual stimuli have the role to make feedback or information clearer for the user, such as adding an arrow to indicate the element to interact with or inserting a visual clue to indicate that another character is talking to the user.
As reported in VR Accessibility Design, *"the more delivery methods you have to tell your narrative, the better the chances your user will follow along."* (Meta Quest, 2022).

PROVIDE INPUT VIA ALTERNATIVE MODALITIES
Meta Quest guidelines remark also the fact that voice input doesn't have to be the only means of controlling and performing actions, otherwise it would exclude players as deaf communicating via sign language or simply people who cannot talk at that moment. It's therefore necessary to provide alternative ways of communicating that do not rely on audio, such as via chat. Even though it represents a step forward to inclusion, there's still room for improvement for signing deaf who can't communicate through their preferred language, since it's still impossible for them to use sign language due to current technological limitations (Meta Quest, 2022).
Indeed as reported by W3C, in order to guarantee an experience suitable for

signing deaf needs, it's necessary to allow text, objects, and item descriptions to be presented to the signing player via a signing avatar, which therefore will be pre-recorded.
These videos where are required to be 1/3rd minimum of the original stream signing size, to ensure gamers to easily see and comprehend the message (W3C, 2021).

4.3.2.2 Audio personalization

Allowing audio personalization is an guideline for oralist deaf since it allows them to customize their experience based on their specific requirements and conditions. Indeed, deaf individuals using hearing aids and/or cochlear implants are still taking advantage of audio stimuli and therefore it's necessary to pay attention to the functionalities associated with it.

OFFER CUSTOMIZATION OF AUDIO SOURCES
It's necessary to ensure users the possibility of manually controlling the audio volume of different sources, allowing the player to prioritize the voice instead of environmental noises, as an example through a ducking technique that automatically decreases the majority of the mix to prioritize specific sounds like voice (Meta Quest, 2022).
Talking about unilateral deafness, in XAUR it's evidenced the necessity of providing mono audio customization, through which all sound information is reproduced on both sides so that the user can perceive the whole soundscape through either ear. Through this feature, audio is conveyed equally to both ears, allowing sound to be fully effective for the unilateral deaf. Because of that, sound can also be used associated with UI elements, such as when clicking on a button, to amplify their meaning and provided straightforward feedback on the action performed (W3C, 2021).

4.3.2.3 Subtitles and closed captions

An important component that allows socialization for people who cannot fully rely on audio is subtitles. Because of that, multiple guidelines are provided for this feature, following the one already provided by Game Accessibility Guidelines for non-immersive game experiences, even though there aren't currently captioning standards for VR. Meta Quest and W3C are moving towards this

goal through the recommendations they have defined.

PROVIDE A CORRECT USE OF SUBTITLES' FONT, DIMENSIONS, AND LENGTH
Meta Quest provides recommendations to ensure the correct use of subtitles, starting from the font selection. The suggested ones are Serif, Sans serif, and Monospaced ones, where Sans Serif ones represent the most legible.
Talking about dimensions, it is suggested to provide three font sizes: a smaller, a default, and a larger one, in order to meet all the users' needs. The default size is recommended to take up about 10% of the screen and then modify it based on the specific VR experience.
In order to make the conversation as similar as possible to hearing people, sentences as to be displayed in unison with the dialogue or as they are spoken, in blocks composed of two or three sentences and left-aligned to ensure better legibility. As reported in chapter 3.3.2.3, this length ensures the correct legibility for the user, without overloading him or her with too many words (Meta Quest, 2022).

PROVIDE VISUAL INFORMATION ABOUT THE DIRECTIONALITY OF SOUND
Elements that accompany subtitles representing an important component are visual indications, which can be arrows, bubbles, or even signals to direct players toward the source of a sound or elements to which the user has to pay attention. These visual signs can really contribute to the overall experience since they ensure that the deaf user is always aware of what is going on around him/her, such as social interactions. In fact, visual indications such as arrows can be exploited to indicate, for example, the character who is speaking. Their importance is summarized in the sentences provided by Meta Quest: *"If you can add visual cues to help the user locate audible events in the 360 world, the user will have an easier time navigating and understanding your experience"* (Meta Quest, 2022).

PROVIDE THE CORRECT POSITION OF SUBTITLES AND CAPTIONS
Another element to take into consideration when designing subtitles and closed captions is their location, where some additional reflections are required. If the above-mentioned subtitle guidelines are identical to those provided for non-immersive game experiences, this does not apply in this circumstance.
This is because, in a non-immersive space, it is just needed to place them at the center bottom, whereas in a 360 explorable environment this can lead to problems such as overlapping with UI elements.
In order to have effective use of subtitles and captions, Meta Quest suggests that developers start by spatializing them about an arm's length away from the user in virtual space and edit it based on the testing they would run with users.
Another recommendation that may have different options is speech bubbles containing text, which can be placed above or below characters who are speaking. Based on the specific circumstances, developers can design subtitles to be head-locked and therefore responsive to the head's movement or locked in space, meaning they stay in a fixed location. Meta Quest suggests

a combination of both: subtitles appear as locked in space, but when the user looks away it may render an arrow or visual clues indicating the sound source. According to Meta Quest, it enables players the agency to explore the space while still retaining the captions and subtitles in a legible location and, from the developers' side, it allows them to have control over the players' attention (Meta Quest, 2022).
Since experiences can be different, there's no strict rule to be applied, but testing with different locations and movements is required to find the most suitable solution.

PROVIDE A CORRECT USE OF COLORS TO ENSURE LEGIBILITY
Colors also represent a fundamental component, since they ensure legibility and a correct contrast. Following Game Accessibility Guidelines, the suggestions provided by Meta Quest are not different: lighted colors are preferred, so it's recommended to have black text on a white background. Indeed, it's necessary to also have a box or an outline that separates the subtitles from the background, which can then be easily read.

OFFER CUSTOM SUBTITLES SETTINGS
Finally, personalization options are required since it gives users the chance to make subtitles fit specifically to their needs and therefore players have to be quickly able to activate or deactivate them (W3C, 2021), or even personalize the settings of text colors and background, to guaranteed maximum usability for the players (Meta Quest, 2022).

4.3.3 Users' personal recommendations

In addition to the official standards set by institutions, deaf individuals passionate about VR highlighted what challenges they currently have to face while enjoying VR experiences. Then, they suggested recommendations to make VR more accessible based on their personal experience, evidencing that unfortunately, accessibility is still not a central point for this under-exploration technology.

4.3.3.1 User's feedback: Myles De Bastion

A VR user who identified accessibility guidelines is Myles De Bastion, an artistic director, musician, and designer who creates art installations. He's very enthusiastic about Virtual Reality even though he has to constantly face challenges due to his condition as signing deaf.
Because of that, he researched and experimented with many VR experiences to come up with a project which summarizes his personal accessibility suggestions. The project is Virtual Worlds Made Accessible Beyond Sound, a VR prototype that is part of his New Media Fellowship residency at Open Signal, created with software developer and engineer Genia Penksik in collaboration with the W3R XR Captioning Workgroup and CymaSpace.

Fig. 84
Myles De Bastion during his conference, explaining that VR is currently not accessible for deaf
Source: Open Signal

The focus of the developed prototype is to solve the design challenges of real-time captioning and sign language in digital 360° environments, recognizing in this technology a great potential for social interaction between avatars (Open Signal, 2021). The project starts from the designer's recognition of a lack of accessible technology in a world that increasingly relies on virtual spaces to interact in real-time, focusing on his condition as signing deaf.
He reports that the problem stems from the fact that big tech companies hardware and software developers that make VR typically do not consider users who may have different bodies, as people who do not hear and who therefore are not able to access VR technology (Open Signal, 2021).
Therefore he doesn't feel his dependency on accurate captioning and sign language as taken into account, since they unfortunately are not fully supported in VR.
To solve that, he carried out research that highlighted three major problems to be solved as they thread accessibility, which are: design and placement, unpredictability of conversations, and cultural access. For each of them, he has defined some recommendations, here explained.

HAVE RESPONSIVE CAPTIONS TO THE USER'S GAZE

Talking about design and placement, he evidences the necessity of captions to respond intelligently to where the viewer looks (Open Signal, 2021). As previously highlighted by Meta Quest guidelines, captions have to be responsive to the person's gaze in order for the player to not lose any written dialogue.

PROVIDE VISUAL INFORMATION ABOUT THE DIRECTIONALITY AND DISTANCE OF SOUND

Another issue that occurs with subtitles and captions is the lack of information about where the sound comes from and who is speaking, if not included in the user's view. This problem is called by De Bastion as directionality and distance of sound.
One solution could be to change the position of captions, from a fixed place as in non-immersive experiences, to above the person who is speaking, in the form of a bubble chat. The captions have to not be placed at the center of the sight line or below the person, since it may be blocking the view if the avatar would use sign language (Open Signal, 2021).
De Bastion highlights also the need for captions to be 3D spatial responsive and therefore be accessible from every perspective in the space, leading the subtitles to be called by him as environmental captions. So, regardless of how the user is looking at the speaker, he or she will still be able to read the captions above his head.

While looking around the environment without seeing the avatar who is speaking, the player has still to have access to the captions, which De Bastion displayed in the middle of the screen at the sight level. When going back to look at the character who is talking, the captions have to be automatically shifted back over the characters' heads (Open Signal, 2021).
When not looking directly at the avatar speaking, an issue occurs since there's

Fig. 85
Captions have to be 3D spatial responsive and be accessible from every perspective in the space
Source: Open Signal

no indication about where this sound is actually coming from. Because of that, the designer finds visual indications to be useful, such as a responsive arrow that moves on the edge of the captions box to provide information about the provenance of sound. There could be multiple ways to indicate where is placed the person who is speaking, or also include the avatar's name in the caption and exploit different colors to distinguish characters (Open Signal, 2021).
He finds the arrow he has developed to be improvable, since it may be bigger to be more clearer and could be linked to the attached line to the person who is speaking to easily track who is speaking while looking away, but it's considered as a good starting point.

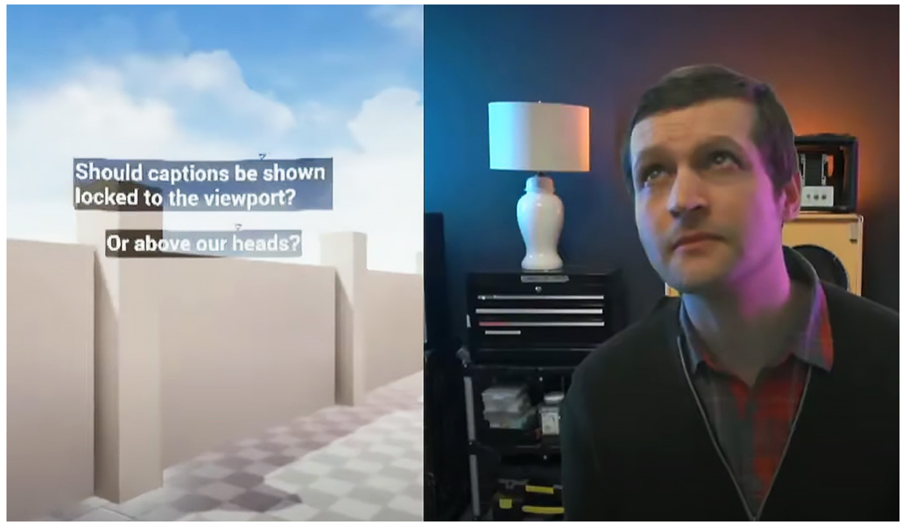


Fig. 86
Inserting an arrow in the captions box allows the user to know the directionality of that sound
Source: Open Signal

Talking about distance, De Bastion explains that, as the sound becomes wicker as the user moves away, likewise the captions box has to change its opacity (Open Signal, 2021). In fact, as the user goes further for the person speaking, the bubble chat above the characters' heads becomes increasingly opaque, until it disappears. In addition, the captions become smaller and smaller, as does the text within them when moving away from the avatar who is speaking.

ABILITY TO USE SIGN LANGUAGE

Cultural accessibility in VR space is even more limited for a particular segment: signing deaf, since VR headset technology has some limitations. One of them is related to hand shape which is fundamental for sign language. VR headsets such as Oculus Quest can recognize human hands and reproduce that virtually, but with some limits: when hands come into contact or overlap one another, they become indistinguishable and the contact part visually disappears. This can lead to loose important information because it can lead to misunderstanding the conversation due to current technological limitations.
Issues in sign language recognition as well as limits in facial representations represent barriers that this technology currently has for deaf and hard of hearing using sign language, making them marginalized in VR space.
Because of that, he remarks the fact that hardware and software developers must take active steps to make signing deaf equitable included (Open Signal, 2021).

VIEW YOUR OWN SIGNING CAPTIONS

One feature that De Bastion emphasizes as important as signing deaf is having the ability to view his own subtitles since automatic captions often have many errors. Therefore, the user has to be aware if their sign language has been translated into written text in the wrong way, in order to correct it afterward by repeating himself. According to him, these self-captions have to move with the user's virtual headset within the middle (Open Signal, 2021).

ACCOMMODATE LIVE AND SCRIPTED CONVERSATIONS

Another field of exploration is the unpredictability of conversations, which represents a real challenge for the deaf. Indeed, in virtual world as well as in real life, dialogues are unpredictable since they can involve a big number of participants, there could be background noises or even they could be in different languages.
In VR, conversations can be both live or scripted and, because of that, De Bastion highlights the necessity for this technology to accommodate both. Regarding scripted conversations, Unreal Engine systems support pre-recorded or scripted dialogues which can be made time responsive and therefore be displayed at the designed time and space.
It's even more relevant to support live conversations, made possible through automated speech detection, a technique that transforms speech into written text. However, it's really challenging since cloud services on which it relies on are expensive.
Because of that, he is exploring other options that do not rely on cloud computing. Anyways, he considers it a priority to enable scripted and live conversation captions in VR (Open Signal, 2021).

ACCOMMODATE CONVERSATIONS WITH A VARIABLE NUMBER OF ACTIVE SPEAKERS

The variable number of active speakers represents another challenge. Indeed, head-lock captions can overlap each other, making them obfuscate and impossible to read. The suggestion provided by the designer is to place the captions one above the other when this situation occurs, in order to avoid a layered visualization (Open Signal, 2021).
Moreover, multiple separate conversations can happen at the same time. If the user is close to both of them, in order for the user to distinguish them, De Bastion recommends using the opacity of the captions box to provide important clues: the darker the box is, the closest the user is to that conversation despite the other. Anyway, he recognizes that further development and research need to be done.

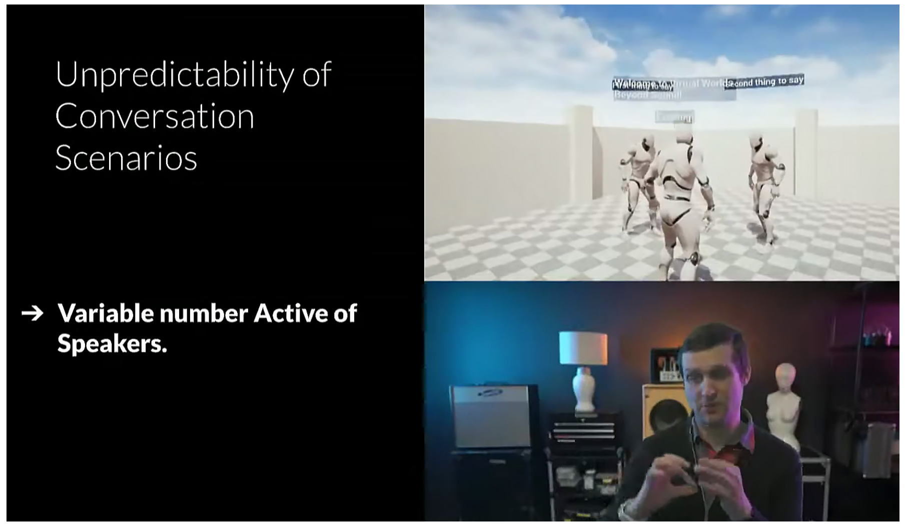


Fig. 87
De Bastion highlights the issue of having overlapping captions, which makes them impossible to read
Source: Open Signal

SUPPORT AUTOMATIC TRANSLATIONS BETWEEN DIFFERENT LANGUAGES

The last area identified where some problems occur is called by De Bastion as culture accessibility. He refers to the opportunity of VR to allow conversation with people talking different languages, explaining that with current developments in automated translations, there's the potential for automated language translation to allow conversation between people from diverse parts of the world (Open Signal, 2021). Even if it's possible, right now it's not implemented since the cost of cloud services for its functioning is currently expensive.

His project has the aim to evidence the challenges and provide solutions to them. It will be available as an app on Meta Quest once the initial development will be complete.

4.3.3.2 User's feedback: Merlyn Evans

Another player and VR enthusiast who decided to provide suggestions based on her personal experience with VR is Merlyn Evans, a professional speaker, accessibility marketing consultant, and writer who has a cochlear implant.
In order to recognize possible challenges for deaf users, she decided to test by herself several VR apps, by going from cultural experiences to social ones. Through Oculus Quest 2, she immersed herself in platforms such as AltSpace-VR, VRChat, Netflix, YouTube VR, and Anne Frank House. The aim of her experiment was to comprehend what Virtual Reality platforms need to do to improve their accessibility for deaf people with cochlear implants based on her personal experience and expertise (Evans, 2021).
The test resulted in a list of suggestions, here summarized.

PROVIDE AUTOMATIC CAPTIONS

She explained that she would like VR to be more like meeting platforms such as Zoom and Microsoft Teams and have the possibility to add the activation of automatic captions while having a conversation (Evans, 2021).

OFFER CUSTOM SUBTITLES SETTINGS

One current missing feature in the tested apps is the possibility of personalization of subtitles preferences, such as the sentence color background, and having these changes suddenly applied to all the apps that would be downloaded from the Meta Quest store (Evans, 2021). This would be a time-saving feature.

IMPROVE FILTERS BY ADDING CAPTIONS, COMFORT RATING, LANGUAGES, PLAYER MODE, AND ESRB[10] RATING

Meta Quest store currently do not provide a filter feature to scrape all the different app in their store, but they are only divided into "games", "app" and "entertainment" while having also a search bar. The offered voices are limiting since they do not offer the possibility for users to search apps based on their real needs, as for deaf to search for platforms with subtitles.
Instead Steam, another app store compatible with Meta Quest, offers the possibility of filtering based on the presence of closed captions, which makes it extremely useful for the hearing-impaired. However, some other points are missing, such as the comfort rating.

10 ESRB is an abbreviation used to judge app or games which summarized evaluated based on rating categories, content descriptions, interactive elements and rating summaries.

The comfort rating is an indication considered as central by Evans, which is provided by Meta Quest store in order to indicate the level of comfort offered by each available app. This information turns out to be significantly relevant for people suffering from vertigo, as Merlyn Evans. Indeed, as explained in previous chapters, it's likely for hard-of-hearing to suffer from vertigo. So, through the comfort rating, they can understand in advance which apps to avoid because they are too intense in terms of movement.

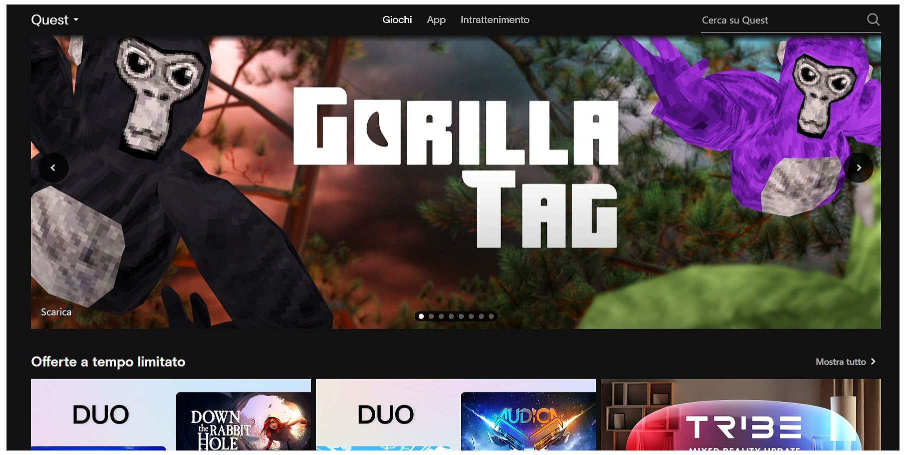


Fig. 88
Meta Quest store does not provide the possibility of using filters to scrape apps in its store
Source: Meta Quest

Since Steam does not provide this indication, during her test Evans had to spend additional time reading each app description in order to guess the level of comfort before actually buying the platform in question.
So, she recognizes the need to provide a comfort rating for each platform in each store available and to have a neutral third party create definitions and standards for comfort ratings in order to be fully impartial (Evans, 2021).

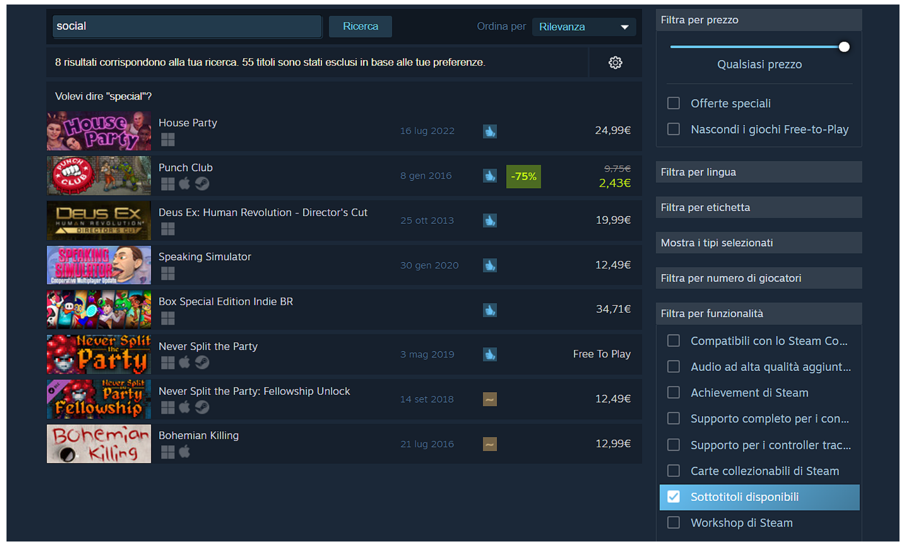


Fig. 89
Steam provides multiple filters, allowing users to insert their requirements while searching for new apps and games
Source: Steam

PROVIDE FEEDBACK VIA ALTERNATIVE MODALITIES AND INDICATE WHICH ARE THE OFFERED MODALITIES

As previously explained, providing alternative inputs and outputs additional to audio is crucial for the hearing-impaired. This concept is also remarked on by Evans, who highlights the need for app developers to indicate in the platform description whether the app gives instructions and feedback using audio, on-screen text, or both (Evans, 2021). This important information can make users aware of the input and output modalities offered in the specific app and therefore use this indication to decide if to download it or not.
She also states the necessity of avoiding making verbal communication the only means of input since it is marginalizing for a segment of the deaf community.

PROVIDE CAPTIONS IN A POP-UP AND HEAD-LOCKED FORMAT

As previously mentioned, it's very important minimizing motion and movements for people suffering from vertigo. Because of that, she indicates some suggestions to limit this issue starting with captions. She recommended using them in a pop-in format rather than in a scrolling one, since movements are restricted and therefore better for individuals with vertigo (Evans, 2021).
Going in-depth, pop-in captions give users time to look at the full video and read at their own pace, while keeping up with the audio. They are simpler and they limit movement more than scrolling ones, where each word appears on the screen in sync with the audio (Meryl K Evans, 2019).

Fig. 90
Merlyn Evans explaining the difference between pop-in captions (placed on the left) and scrolling (placed on the right)
Source: Meryl K Evans

Talking about subtitles and captions, Evans explains that, based on her testing experience, she finds head-locked captions to be preferable rather than fixed ones. This occurs because subtitles placed on the head of the speaker limit motions, while fixed ones, placed in a predefined part of the screen, upset her vestibular system (Evans, 2021). While performing her experiment, she recognized that not many platforms provided closed captions and the ones that have it may be improvable. This happened with YouTube VR, which offers closed captions but not of quality, since they have more than three lines of captions, all upper case and in scrolling format.

PROVIDE EASY ACCESS TO SETTINGS BEFORE STARTING WITH THE APP AND HAVE EASY-TO-FIND INSTRUCTIONS

Having an easy and direct access to settings allows hard-of-hearing to immediately turn on captions without starting the app. In fact, Evans explained that in the VR game Moss, she had to restart over the game after turning on the captions, which was frustrating for her.
Another easy-to-find functionality that needs to be provided is to easily access tutorials on how to use voice commands or hand tracking, for example (Evans, 2021).

REVIEW HEADSET DESIGN TO WORK BETTER WITH HEARING DEVICES

An issue Evans encountered in the first step of using the VR headset was related to its design, considered as not fully compatible with cochlear implants. Indeed, she had problems wearing the VR device since it dropped the bionic ear multiple times. She evidenced that Meta Quest offers an aid for those who are wearing glasses, but it doesn't happen also for those using hearing aids or cochlear implants. Because of that, she finds a gap in the device product design and asks for a review (Evans, 2021).

4.4 Conclusions

The accessibility guidelines have the objective of guaranteeing experiences equally enjoyable for everyone. They, therefore, aim to provide developers who are designing VR experience rules to guarantee the elimination of barriers that may exclude people with disabilities, such as deaf people.
The following analysis reported all currently available guidelines, of which, however, the researchers from the Stuttgart Media University pointed out an alarming fact: none of the presented list guidelines is exhaustive, as they found *"that there are some important rules missing in the relevant works that are included in other guidelines"* (Heilemann et al, 2021, p. 7).
Therefore, there is room for improvement, also because there are some current gaps. In some cases, guidelines are not strictly defined, such as the positioning of subtitles, where Meta Quest provides recommendations but leaves the final word to the developers and the tests they will have to carry out with users. Others recommendations are born for non-immersive gaming experiences and are applied in the same way in VR experiences, despite the fact that they may not be perfectly suitable for an immersive virtual experience.

But then the biggest issue is the lack of a single guideline list to refer to that covers all the rules defined. As evidenced in this chapter, recommendations are currently fragmented between various papers or websites and this can make the access, and the subsequent application of such rules, complicated for developers designing VR experiences.
Indeed, it is not surprising that currently there is a limited range of accessible VR games, as pointed out by the Stuttgart researchers, which could be attributed to a lack of awareness on these topics as well as a missing guideline list that covers the full range of accessibility needs of users (Heilemann et al, 2021, p. 3).
Therefore, this is a substantial problem that becomes more and more relevant assuming a hypothetical future scenario in which XR technologies will become increasingly relevant in our daily lives. Indeed as reported by Statista, its market is destined to grow since user penetration will be 28.8% in 2023 and is expected to hit 32.6% by 2027 (Statista, 2022).
For that reason, as reported in Accessibility Guidelines for VR Games, *"a comprehensive and widely acknowledged set of accessibility guidelines for VR games is needed in the future"* (Heilemann et al, 2021, p. 7), to ensure the full inclusion of people with hearing disabilities.

5

Investigation

In the previous section, the research has reviewed the impact of deafness on the lives of those affected, focusing also on the psychological and social consequences that can occur, including isolation, loneliness, and even depression. This happens because it becomes more complicated for the hearing-impaired to respond to a natural need for us as human beings: communicating and interacting with others.
With the intention of ensuring deaf people an accessible human-machine and human-human interaction, several guidelines have been established to design physical environments that encourage sociality as well as digital experiences that ensure accessible interaction for the hard-of-hearing. Similarly, the technology still under the exploration of Virtual reality is leading towards ensuring the possibility of unhindered socialization for deaf people, where Social VR platforms are the ideal environment in which to interact and meet new people.

This chapter aims to investigate what are the requirements for Social VR apps to offer an inclusive experience in terms of human-to-human interaction, that is able to meet specifically the needs of deaf people with cochlear implants. To do so, a Social VR environment, AltspaceVR, was tested by users, keeping a specific focus on interaction with other individuals.
Relevant considerations and insights emerged from the experiment on the potentials and current limitations of VR technology for human-to-human interaction in Social VR experiences.

5.1 Conducted process

Following the broad research phase about deafness, and physical and digital interaction as well as VR, it was conducted an experiment to analyze human-to-human interaction in Virtual Reality experiences. Its goal is to investigate what are the requirements for a Social VR app to meet the communication needs of deaf people who use cochlear implants. In order to reach this goal, the following steps characterized the performed experiment:

- It was first defined to focus on human-to-human interaction and, therefore, the mentioned topic was explored in depth through a desk research, representing the starting point for the next steps.
- Then, it was defined which VR platform to involve in the experiment phase. The selected one was picked from a specific category of Virtual environments, called Social VR apps, where dialogue is put at the center of the whole experience. Afterward, a specific environment was then defined: AltspaceVR, a social VR platform that made it possible to test interpersonal communication.
- The above-mentioned environment was first analyzed by the researcher to get familiar with the platform's functionalities as well as to understand the accessibility of the app, verifying which accessibility guidelines concerning deafness are currently met.
- Afterward, a field research phase was conducted, where users were involved. At first, it was performed digital ethnography to get insights about what users write online about the analyzed app, and, to understand if accessibility issues were reported.
- Subsequently, an experiment with interviewees was conducted, where the objectives were firstly defined, followed by the users' definition and the creation of a protocol, structured in the form of semi-structured interviews through which users had to experience the platform as well as answered questions about it.
Going into detail, during the experiment, the users participated in multiple conversations, at the end of which they had to indicate what they understood of the dialogue's content as well as the emotion intrinsic to the conversation.
- Then, results were extracted and valuable insights regarding accessibility emerged from the experiment.
- The outcome subsequently led to the definition of requirements to make communication accessible for deaf people in social VR platforms, structured in the form of guidelines.

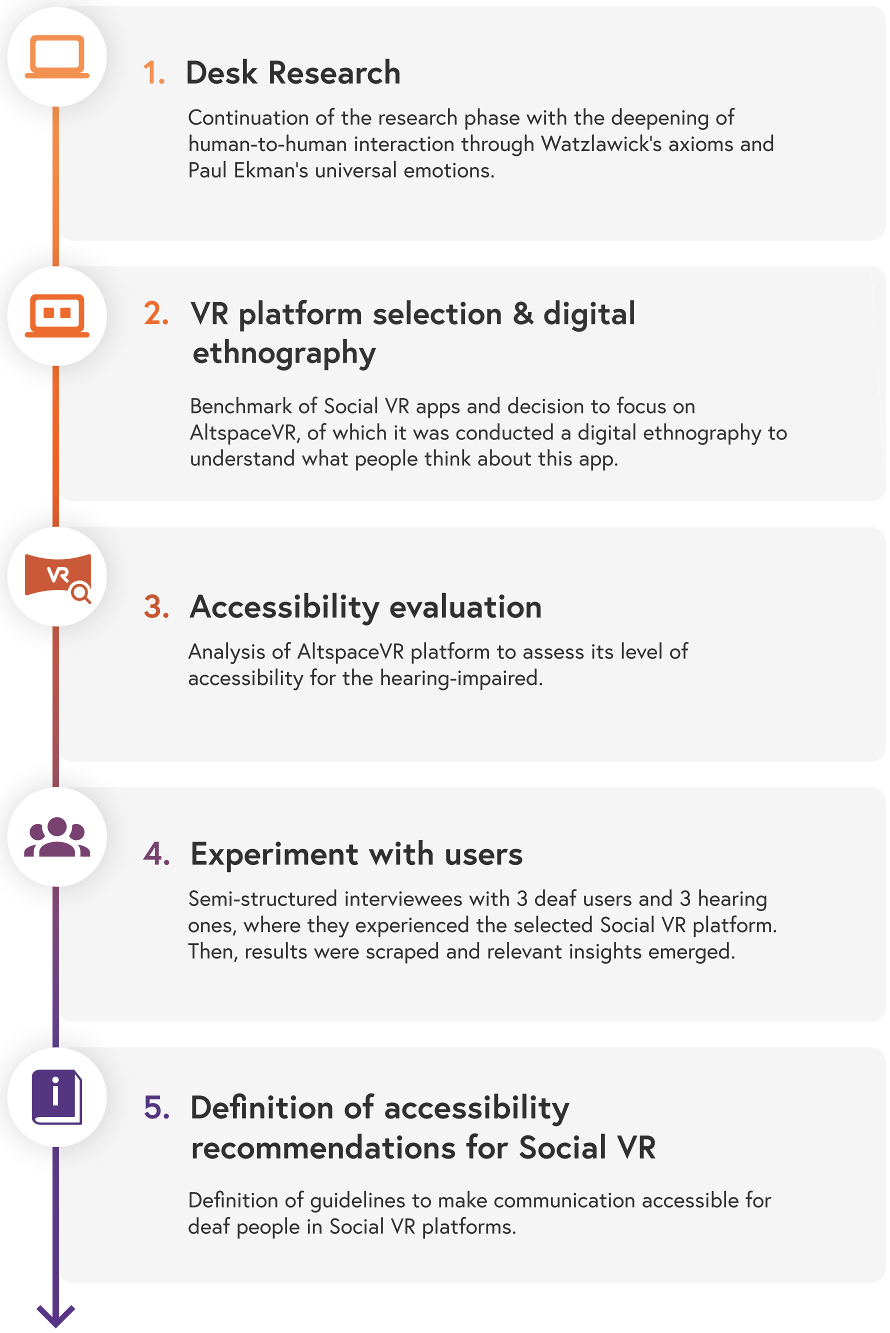


Fig. 91
Roadmap of the activities conducted during the investigation phase

5.2 Human-to-human interaction

With the aim of having a valuable impact, the experiment focused on a central component of our lives as well as of some VR experiences: communication between individuals. In some virtual platforms, users can interact with each other through the use of avatars and thus responding to the natural human necessity of socializing.
To understand how human-to-human interaction takes place within VR, it was first necessary to investigate how communication between people takes place in reality. For this reason, it was explored the concept of interpersonal communication through Watzlawick's axioms, deepened through Paul Ekman's studies about the relationship between facial expressions and emotions.

5.2.1 Interpersonal communication

Communicating can be defined as a need biologically embedded in us as human beings and that's why we perceive it as innate and natural to talk, socialize, and interact with others.
In terms of definition, we speak of communication when there is a message from a sender that reaches the receiver who consequently provides feedback, closing the circle. It's important for the effectiveness of the communication that the receiver recognizes that it is actually a message which is then interpreted accordingly to the context in which it is being said. Indeed, another relevant factor is the type of relationship in which the communication takes place: the message will be unconsciously interpreted by the receiver in a different way based on the relationship pattern that binds him or her to the person who uttered the message.
It's not hard to imagine that, it is very complex to be effective in communication. Indeed, psychologist Watzlawick explains that understanding the content of a message and therefore its effectiveness is something complicated since influenced by multiple factors, covered by Watzlawick's axioms: 5 principles that summarize the concepts characterizing interpersonal communication, listed below.

1. It's impossible to not communicate
With the first concept, the psychologist highlights the fact that mere presence is enough to communicate. Indeed, communication does not only occur through the official message but also through non-communication. For example, the

absence of an answer after a question also represents a message laden with meaning. So, everything becomes a message, what we say but also what our body and silence convey (Pillan, 2022).

2. Every communication involves a relationship (message and meta-communication, information, and command)

Within every communicative act, there are two levels: a content level and a relationship one that confers meaning on the former. The content is related to the transmission of messages and information, where the latter is understood as messages that are charged with novelty and that inform the user about something new.

If the content level concerns what is being communicated, the relationship instead indicates what bond is established with the addressed person. We, therefore, speak of meta-communication, understood as a passage of signals between receiver and sender conveyed on a non-verbal level, as body language, manner, tone of voice, and hence everything that accompanies the message and influences the interpretation of the content.

Conversation, therefore, takes place through different channels, including sensory ones. This non-verbal understanding occurs because interpersonal communication is a matter of perception, where our senses are optimized to pick up signals coming from the surrounding space (Pillan, 2022).

3. In every communication act, punctuation is connected to the relationship, and the interpretation of communication depends on the relationship between the communicating parties

There is no communication without punctuation, which reduces the possibility of misunderstandings and misinterpretations in both written and spoken language. The so-called act of "punctuation" is something natural for human beings which allows us to convey the message in a different way. It marks the rhythm and provides importance to the parts of speech, allowing us to distinguish the figure from the background. It, therefore, helps to achieve a correct interpretation of the message, which also depends on the pattern of interaction between two people. Indeed, the interaction pattern causes the punctuation of a message to be interpreted in one way rather than another (Pillan, 2022).

4. Communication can be analogue or digital

There are two types of communication, analogue and digital. Analogue communication is based on signals that do not need a learning process as it relies on people's natural ability to interpret emotions, such as a baby's cry. Digital communication, on the other hand, is based on a code that needs learning, such as the heart emojis, which represents a simplified version of our organ that is meant to instill affection. Analogue language is effortlessly understandable but is weaker in explaining the relationship between two individuals (Pillan, 2022).

5. Human interactions have a complementary or symmetrical nature

Interactions can have a different nature that is related to the organization model. An example of a symmetrical relationship is the one between students, who are on the same level. Whereas, for relationship between and professor and student, the interaction is asymmetrical because their roles are different: one teaches, the other learns. In the second case, their interactions have a complementary character since the behaviour of one compensated the other, who, however, don't have a level of superiority over the other (Pillan, 2022)

5.2.2 Expression of emotions

As Watzlawick made explicit, communication does not only involve the message itself but also much more, summarized by the term meta-communication which includes, for example, facial expressions and tone of voice that allow the emotions characterizing the dialogue to be recognized.

The psychologist Paul Ekman pioneered guidelines for the recognition of emotions through facial expressions.

As explained by him *"emotions are a process, a particular kind of automatic appraisal influenced by our evolutionary and personal past, in which we sense that something important to our welfare is occurring, and a set of psychological changes and emotional behaviours begins to deal with the situation"* (Paul Ekman Group, no date). Ekman explains that we feel many emotions, but only seven of these are considered to be universal, which are therefore visually comprehensible to all regardless of language, location, and ethnic differences since each of them is characterized by distinctive signals, physiologies, and timings (Paul Ekman Group, no date).

The seven identified universal facial expressions of emotions are: anger, contempt, disgust, enjoyment, fear, sadness, and surprise. For each of them, there are different muscles involved which made Ekman identify distinctive facial signals universally recognizable by the interlocutor of the conversation. It could be lips pressed tightly and the jaw clenching for anger, or the teeth exposed in a smile for expressing enjoyment. Notable to say is each emotion does not have to be considered separately, since one prevalent emotion may be composed of the sum of multiple emotions.

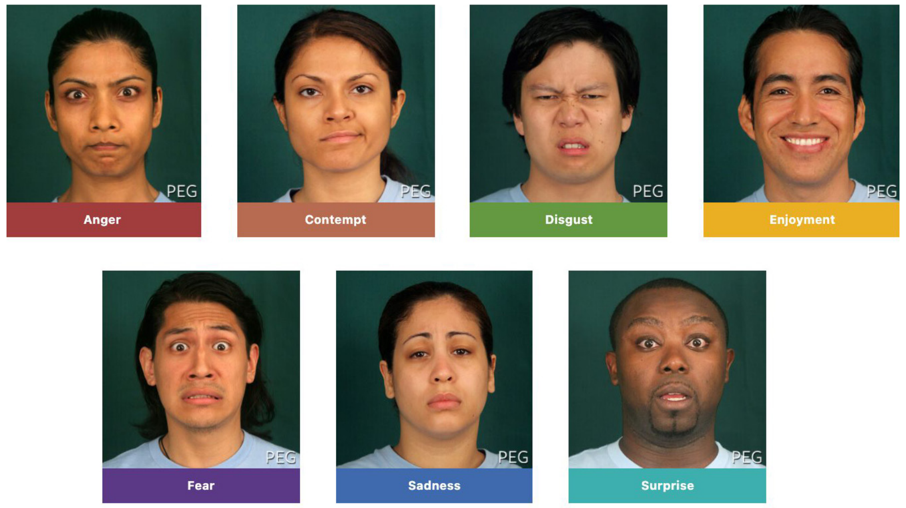


Fig. 92
Facial expressions of the 7 universal emotions defined by Paul Ekman
Source: Paul Ekman Group

5.2.3 Conclusions

Communicating is an intrinsic need in our human beings, which can be defined as complex since it is determined by multiple factors, but that, anyway, it's still perceived as natural and immediate. Within the real world, we have access to various clues that determine the comprehension of dialogue, but is this also guaranteed within a virtual experience?
In a VR experience, the interaction between two individuals takes place via the medium of VR technology, which could make the passage of information more complicated and could even lead to the loss of relevant clues for deaf people.

5.3 Experiment: environment selection and analysis

After the established focus on human-to-human interaction, it was decided to investigate the current state of the art of a VR platform and thus understand how dialogue is currently handled in a virtual environment.
So, the next step was the identification of a VR category to explore whose choice fell upon Social VR platforms, since they're the symbol of virtual socialization. Then, an investigation of available Social VR apps was conducted, where it was selected one of the most popular and widespread ones: AltspaceVR.
Subsequently, the researcher investigated the app through the Oculus Quest 2 headset and hand trackers. After understanding the functionality offered by the app, it was conducted a more in-depth analysis, in which it was checked whether the app met the VR accessibility guidelines recounted in Chapter 4.3. The analysis pointed out that there is currently room for improvement for AltspaceVR and it was therefore assumed that at the moment accessibility for deaf people is partly compromised in the analyzed app.

5.3.1 Selected environment: AltspaceVR

The experiment started with the decision of involving a VR environment where the element of socialization was a central factor.
Because of that, the choice fell on Social VR platforms, whose purpose is to allow users in the form of avatars to dialogue, socialize with each other, and live experiences together, such as playing games, attending concerts, and working. Statistics also evidence that it's an optimistic market environment since it's set to grow at a 14.1% CAGR between 2021 and 2027 (Market Insights Report, 2021) and therefore it is estimated that such platforms will be increasingly widespread. Horizon Worlds, RecRoom, VRChat are just some of the most used Social VR platforms, where it emerges AltspaceVR as the one with the lowest rating among the popular apps, and on which the experiment focused its research.
AltspaceVR is a social VR platform launched in 2015 and acquired in 2017 by Microsoft, of which it became part of the Mixed Reality division. In AltspaceVR users in the guise of avatars can socialize and communicate with each other in a cartoonish environment. The experience is highly customized: players can choose their appearance, from their body to their clothes and appearance.

Fig. 93
AltspaceVR's avatars using emojis reaction
Source: AltspaceVR

Once inside the platform, players can freely choose which events to attend, including concerts, and conferences, as well as the possibility of creating new events and worlds.
One example of an available event is the World Cup, through which users can see football matches via VR, or simply be immersed in a natural environment through the so-called Spring Campfire event. In each virtual event, there are moderators, who have the role to monitor the proper behaviour of users and proceed to expel them in case of inappropriate actions.

Fig. 94
AltspaceVR's Campfire event
Source: AltspaceVR

Gamers freely communicate with each other via real-time speech as they would do in real life, but here they can connect with people from different parts of the world. They can also decide whether to interact by switching the microphone on and off. The similarity to online calls is obvious, but in this case, the experience is more immersive and customizable, where the user has the impression of really being in a social context with other people.

Avatars can also communicate with each other via chat and via emojis reactions, able to quickly provide feedback. As in a real social context, avatars can make photos and take selfies, to have printed out the moments spent in the company of others.
Some additional feature has been inserted after some episodes of harassment, which made Microsoft decide to introduce a personal bubble, which creates a personal barrier to prevent avatars from getting too close to other characters.

In conclusion, AltspaceVR is a platform that well represents the category of Social VR experiences, since all the functionalities revolve around the possibility of socializing. It's also an environment where voice and audio are central for accomplishing tasks and for communicating and therefore it represents a suitable app for testing how accessibility for the hearing-impaired is actually handled.

On March 2023, AltspaceVR was shut down by Microsoft, since the company want to focus all its effort in terms of XR on a new platform called Microsoft Mesh. As reported, it's *"a new platform for connection and collaboration, starting by enabling workplaces around the world"* (AltspaceVR, 2023), thus maintaining the same socialization focus as AltspaceVR but for workplace purposes.

5.3.2 AltspaceVR: digital ethnography

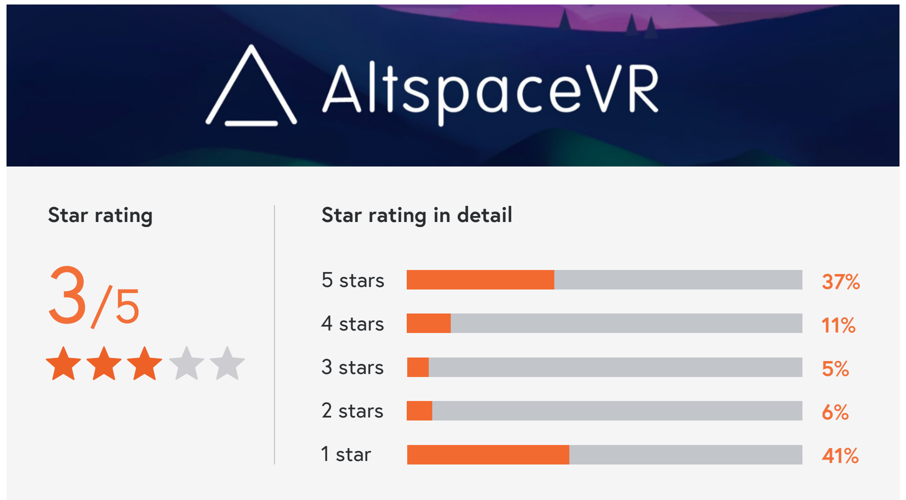
Before actually starting to analyze the platform, it was useful to understand the user's opinion about AltspaceVR, searching if some accessibility issues emerged. For this reason, the reviews of AltspaceVR on the Oculus Store were analyzed, where it emerged low rating in comparison to the major competitors. AltspaceVR has a rating of 3 out of 5 stars, while most of the most popular social VR apps have higher ratings, around 4 stars: RecRoom has a rating of 4.2 and 22 thousand reviews, while VRChat presents 4 stars and 18 thousand user ratings *(data as at January 22nd, 2023)*.

Looking more closely at AltspaceVR's rating, an alarming fact emerges: of the 1100 total reviews, 41% of users gave a negative rating, corresponding to 1 or 2 stars. At the same time, the 37% assigned 5 stars, thus considering the experience as extremely positive.
This discordance indicates that AltspaceVR's platform has split the users' opinions, leading them to have no middle ground.

Fig. 95
Table comparing the main Social VR platforms in the Meta Quest store *(Data as at January 22nd, 2023)*
Source: Meta Quest

Social VR app	Star rating	#N of reviews	Release date
Rec Room	★★★★☆	22 686	May 21st, 2019
VRChat	★★★★☆	18 565	May 21st, 2019
Alcove	★★★★☆	444	Aug 20th, 2020
vTime XR	★★★½☆	138	Nov 5th, 2020
horizon Worlds	★★★☆☆	3 221	Dec 9th, 2021
AltspaceVR	★★★☆☆	1 106	Sep 12th, 2019

Fig. 96
Data about AltspaceVR star rating on Meta Quest store *(Data as at January 22nd, 2023)*
Source: Meta Quest



To understand the reasons behind the rating, the reviews were analyzed and then clustered into different sections based on contents. First, they were filtered to include only those with a description, which were written between January 2021 and January 2023 to include a wide but more recent time span.
Starting with the negative ratings, 170 reviews with 1 or 2 stars in the indicated period covered the following topics:

REGISTRATION AND LOGIN ISSUES

This corresponds to the most highlighted issue, highlighted by 65 users corresponding to 38% of the ones giving 1 or 2 stars. The players point out the presence of an unnecessarily complicated registration process where verification on several devices is required, which involves having to take off and put back the headset. Other concerns are related to the username being considered erroneously invalid, problems with the user code, which expires after a very short time, and the automatic logout, which results in the user having to verify the login again. Currently, the registration and login process thus creates frustration, leading many users to give up and delete the application. Notable to say is that many players point out that such technical issues arose after Microsoft's acquisition of the platform.

> “ *I will just delete the app and use other social apps where I need that verification dance only once. It strikes me that Microsoft needs to make everything inconvenient and annoying.* ”

DISSATISFACTION ABOUT PROPOSED CONTENTS

18% of the ones giving 1 or 2 stars judged the contents available on the platform as boring and not very interesting. Indeed, concerning the events, many players negatively judged the lack of progress over the years, reporting that the contents have remained the same. Other concerns are related to the management of events and social interactions, where a moderator has the role to maintain a polite and respectful social environment. However, what users report is that bullying often occurs between participants, and sometimes the moderators themselves behave rudely for no apparent reason.

> “ *Should I even call it a game? It's just pointless, there is nothing to do in this platform.* ”

EXCESSIVE USE OF BANNING

Related to rude behaviour by moderators, it occurs the issue of being banned from events by them, was reported by 17%. They indicate that AltspaceVR staff have rudely banned many users, without even explaining, and often for no reason, in their opinion. In fact, some users were banned because they were considered to be excessively young and under the age of 13, which is the limiting age, when in fact they were within the permitted range.

> “ *I got banned for no reason: the app said that I'm under age even though I am over 20 years old.* ”

PRESENCE OF BUGS

13% reported the presence of bugs, which created frustration as some of them were blocked for the whole experience. In fact, many players report the loading failure of some pages, the disconnection from the account with the inability to log in again, the presence of glitches during the game as well as excessively long loading times. Bugs also affect audio and communication, where a few players reported having problems activating the microphone as well as deactivating it.

> “ *I'm very disappointed, it's really needed to work out the bugs. I feel like it would be a great app if functioning properly.* ”

INEFFECTIVE CUSTOMER SUPPORT

Due to the various problems above-mentioned, many users had to require customer service support, considered inefficient according to 11 users, corresponding to 6% of those who gave 1 or 2 stars. Going more in-depth, according to users the staff have response times considered as too long or even totally absent. Many problems, some even blocking the entire experience, were not resolved promptly, triggering users' anger.

> “ *It's pretty shameful that it's been 12 days since that user reported this login issue and I'm still experiencing it now.* ”

DISSATISFACTION ABOUT AVATARS' VISUAL APPEARANCES

The current visual appearances of avatars were judged negatively by 8 users, corresponding to 5%. They are generally dissatisfied with the current visual style, which is indicated as unrealistic, with customization limitations, and does not meet the players' tastes. Some of them also spoke of the limits given by facial expressions, seen as still very rigid and not able to represent how the player really feels.

> “ *For sure the avatars needs some work to look more human, they should also reconsider making them a little more realistic. I also want to tweak the avatar's face expression.* ”

What emerges from the analysis of the negative ratings is that players have currently to face many different issues concerning different parts of the experience, going from the login process to the visual appearance of the characters, causing a lot of frustration. Talking about people giving 3 stars, it only represents 5% of the overall given reviews, where they highlighted the same issues that were reported, such as problems with logins, bugs, and dissatisfaction with the experience offered. In this case, AltspaceVR is evaluated with 3 stars as the positive side is also taken into account.

In this regard, another perspective is given by the ones who gave a positive rating, where they consider only the positive impact that AltspaceVR had on them. From January 2021 till January 2023, 84 users gave a 5 or 4 stars review, which has been categorized into two sections, here explained:

APPRECIATION OF CONTENTS AVAILABLE

The majority of users, 52%, positively rated AltspaceVR for the variety of events offered, the possibility to let their imagination run wild by creating new worlds, and the impact it has on their lives. Indeed, according to many, the participation in these events allows users to experience different circumstances while having fun, ranging from karaoke activities to meditation, for example.

> “ *I think AltspaceVR through its events has created an amazing space for adults, which is educational, inspirational, spiritual, relaxed, and fun.* ”

GOOD ENVIRONMENT FOR SOCIAL INTERACTION

Regarding the other half with a positive rating, they really appreciated the social opportunities offered by the platform. 48% of users considered AltspaceVR to be an excellent social app, through which they could meet new people and make new friends. Dialogue with others also led to a share of knowledge, making these connections useful for learning new topics. According to many, the real social potential of AltspaceVR happened during Covid, since it allowed users to maintain a social life directly from home. Moreover, a few introverted users indicated that the app allowed them to manage their social anxiety.

> “ *This experience allowed me to connect through conversation about topics and subjects I want to learn and share about.* ”

AUDIO ISSUES

A proportion of users, therefore, judge the experience positively, as they recognize the achievement of the platform's high-level socialization goals.

Nevertheless, they also point out the presence of some technical issues which can hamper the experience, but they are inclined to consider only the positive impact of AltspaceVR. Talking about technical concerns, in addition to the aforementioned problems, a few users also mention audio-related ones: they report issues with audio and video synchronization and concerns about the current audio quality, considered in need of improvement.

> “ *The audio when talking with other people is not the best and is in drastic need of improvement. Moreover, video and audio are not in sync.* ”

This analysis, therefore, underlines that, while some recognize the social potential of AltspaceVR, the majority is nevertheless pervaded by a strong dissatisfaction caused by both technical problems and a sub-optimal user experience in terms of content and social interaction. The platform, therefore, has several areas for improvement, both in terms of usability and content.

No specific comment referred to hearing disability emerges, which was expected, but some highlighted issues may have an impact on deaf users: the limited facial expression of avatars as well as the suboptimal audio quality may have an impact on the experience lived by the hearing-impaired. These are problems that, combined with the above-mentioned problems, may hinder the experience for those suffering from hearing loss.

Therefore, after analyzing users' opinions of AltspaceVR, it was further investigated what obstacles deaf people have to face while in AltspaceVR, verifying which accessibility guidelines concerning the inclusion of deaf people are actually met.

5.3.3 AltspaceVR: accessibility guidelines analysis

After understanding the current offering and users' opinions, the researcher in the player's shoes experimented AltspaceVR by entering events and socializing with other users, exploiting Oculus Quest 2 and its hand trackers. This allowed her to familiarize with the platform and understand its content organization and information architecture.
This paved the way for a more in-depth analysis, which aimed to understand the current state of the art of AltspaceVR from an accessibility perspective: going into detail, it was analyzed which accessibility guidelines for VR, investigated earlier in chapter 4.3, are respected by the platform. In order to facilitate the comparison, it was maintained the same subdivision into functional-related guidelines and social ones, where the goal is to guarantee accessible social interaction for people with hearing disabilities.
Then the analysis was performed, which evidence the presence of some features consistent with some recommendations, while highlighting that a few important others are currently missing.

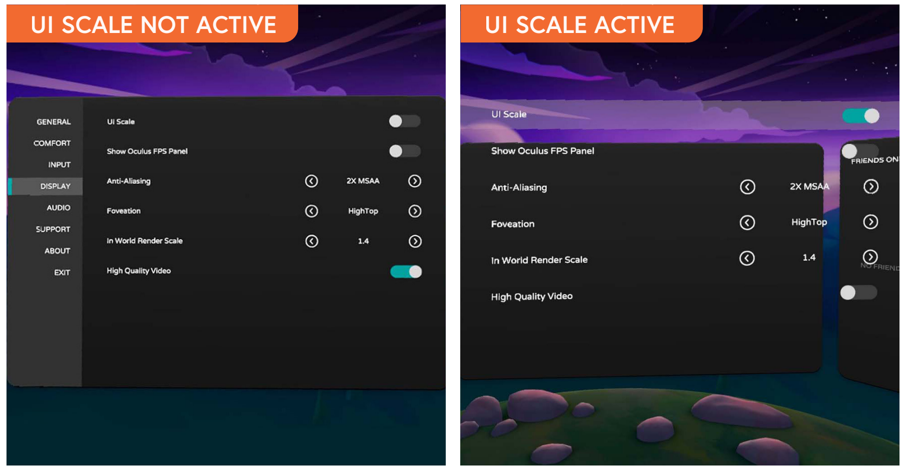
Fig. 97
Photo of the performed analysis through VR

5.3.3.1 Functionality-related: interface personalization

Regarding functional guidelines, offering the possibility of customizing the interface based on one own's needs is fundamental to ensure a good user experience. Here are the interface personalization guidelines which are respected in AltspaceVR platform.

OFFER CUSTOM INTERFACE SETTINGS
AltspaceVR platform guarantees the possibility of customizing the interface to suit one's needs. Thanks to the "UI scale" call-to-action in the interface settings, users can change the size of objects, fonts, and buttons, but through a single customization. Indeed, the activation of this function allows all elements to be modified together, without the possibility of intervening individually on each of them.
Moreover, the resizing has responsiveness issues, where the background rectangle has not a suitable size for the rest of the elements and therefore creates readability problems. This makes the guideline defined by Meta Quest about interface personalization not totally respected.

Fig. 98
AltspaceVR gives users the possibility to personalize the display interface by increasing the size of elements, even if there are issues
Source: AltspaceVR



POSITION UI ELEMENTS BASED ON THEIR PURPOSE
A guideline that is also respected is the positioning of UI elements attached to a person's gaze, which is a rule part of the VR Accessibility Design of Meta Quest. In AltspaceVR, when a player is inside an event, there are always available specific call-to-actions at the screen bottom in a responsive way to the player's point of view: they are the menu, which allows the user to exit the environment as well as activate the microphone or take photos, and the world editor, which displays information on the event and participants. These two elements are permanently positioned at the sides of the screen and follow the user's movements, allowing the user easy and intuitive access to the app's functionalities.

Fig. 99
AltspaceVR provides CTA attached to a person's gaze on the low part of the screen
Source: AltspaceVR

5.3.3.2 Functionality-related: maximize comfort

As previously explained, it's relevant for platform's developers to ensure good comfort to avoid issues such as motion sickness. AltspaceVR includes only the comfort mode feature.

PROVIDE COMFORT MODE

AltspaceVR takes into account the comfort of its platform, by including a feature that is directly activated by the platform in specific contexts. It's the so-called "comfort mode": it is a modality through which it's obscured part of the peripheral view while virtually moving within the space. Its objective is to help the user to focus on what is really important.
Therefore, each time the user indicates through the tracker's joystick that he or she wants to move, a part of the field of view is obscured to reduce motion discomfort, respecting the accessibility rule defined by Meta Quest to offer a "comfort mode".

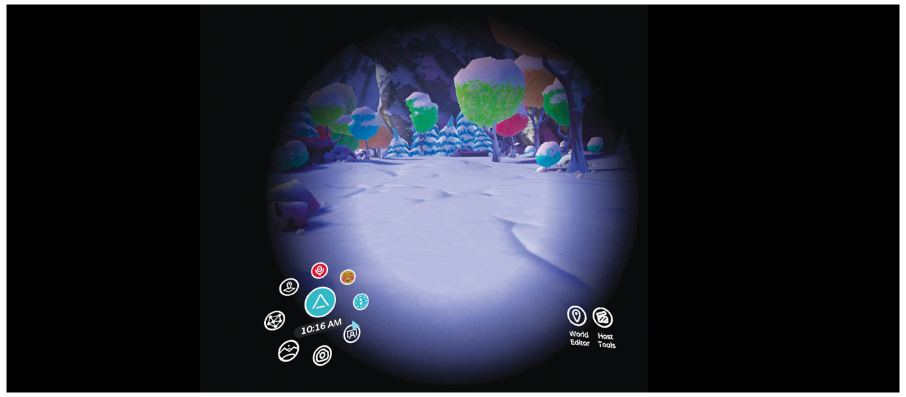


Fig. 100
The app automatically activates the comfort mode visualization when the user decides to move around in the virtual space
Source: AltspaceVR

5.3.3.3 Functionality-related: improve clarity

Clarity is a key component in experiences since it has an impact on the overall judgment of the offered experience. Therefore, guidelines regarding this field are present in AltspaceVR.

PROVIDE ADDITIONAL FEEDBACK VIA ALTERNATIVE MODALITIES

As remarked in the VR Accessibility Design guidelines by Meta Quest, it is necessary to guarantee deaf users additional feedback via alternative modalities to ensure clear reception of the message. Within AltspaceVR clarity is improved by inserting hints at a visual level: as an example, the visual sign "Follow the arrow" appears at the same time as sound to indicate the appearance of a new arrow to follow in the environment. The presence of a visual clue ensures that the message reaches deaf people or those who cannot rely on sound. Within AltspaceVR, haptic feedback is also used for additional clarity but mainly to provide the output of button clicks. In fact, their use is quite limited in the platform: when a button hovers, a slight vibration provided by hand trackers is emitted in addition to the sound or when an object is grabbed, sound feedback is also associated with visual and haptic feedback. Meta Quest, on the other hand, suggests the use of haptic clues also for greater purposes, such as alerting users that an avatar is approaching or colliding with objects in the virtual environment. Therefore, the use of the following clues could be improved and made more relevant to the experience offered by AltspaceVR.

Fig. 101
Additional feedback via visual and haptic modalities are provided by AltspaceVR as clues combined with audio stimuli
Source: AltspaceVR

Providing alternative clues is therefore relevant for deaf, even though audio can still be effective for deaf with hearing aids and mainly to unilateral deaf, who are affected by deafness only in one ear. So, it's still useful for them to remark the meaning of elements through sound, as indicated by Meta Quest guidelines and as respected by AltspaceVR. In the social app, audio is exploited to amplifies some elements' meaning and make them more remarkable: a prime example is the photographic camera, through which players can take photos of the virtual environment. The picture countdown is associated with sounds, at the end of which the typical noise associated with the camera clicking is reproduced. This is an example of a good use of sound combined with other stimuli, able to create consistency with the real world and provide a straightforward feedback consistent with the users' mental models.

Fig. 102
When taking a photo while immersed in a VR environment, AltspaceVR provides visual and sound feedback of the action performed
Source: AltspaceVR

PROVIDE IN-APP TUTORIALS

Finally, to ensure a clear and simple experience, AltspaceVR offers users the possibility to access tutorials as soon as logged in, which experience things for the first time. In accordance with the guidelines defined by Meta Quest, the in-app tutorials allow the user to familiarize with the different functionalities of the platform: as an example, in the analyzed app he can play with the control menu when using the tracker buttons or play with items inside the space. The user can also re-access the tutorials at any time via quick access from the home page and try out the various actions again.

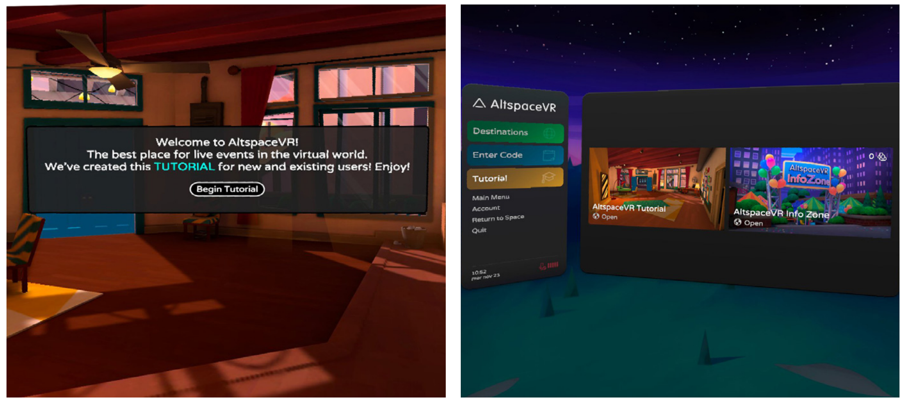


Fig. 103
In-app tutorials provided by AltspaceVR allow users to familiarize with the technology and the platform
Source: AltspaceVR

5.3.3.4 Sociality-related: alternative input modalities

At the level of social guidelines, the respected rules are exclusively focused on audio personalization and alternative input modalities.

PROVIDE ADDITIONAL FEEDBACK VIA ALTERNATIVE MODALITIES

Providing additional stimuli via sight or tactile clues is fundamental for the deaf and AltspaceVR follows this concept but in a very limited way. It offers visual feedback to indicate that the character is talking, through a bubble chat that appears on his or her head. The indication that the character who is talking becomes clear, even though the message of the conversation is still accessible only through audio due to the lack of automated captions.

Fig. 104
When an avatar is talking, a bubble chat appears on his or her head to inform the player that a conversation is taking place
Source: AltspaceVR

USE MULTIPLE DIVERSE INPUTS SIMULTANEOUSLY

Regarding the latter, AltspaceVR follows the Meta Quest guideline according to which voice input doesn't have to be the only means of controlling and performing actions, otherwise, it would exclude deaf communicating via sign language. In Microsoft's platform, it is therefore also possible to communicate via written chat and emojis reaction, but these still have limits due to a narrow choice. Anyways, it certainly represents a step forward toward the inclusion of signing deaf since it offers multiple visual ways to interact, but there's still room for improvement since they cannot currently use hand gestures to communicate due to the current technological limitations.

Fig. 105
AltspaceVR offers access to alternative input modalities which are the chat and emoji reaction, allowing users to communicate also via non-vocal clues
Source: AltspaceVR

5.3.3.5 Sociality-related: audio personalization

Talking about audio personalization, AltspaceVR provides shrewdness, here explained.

OFFER CUSTOMIZATION OF AUDIO SOURCES
The platform offers users the possibility of manually controlling the audio volume of different sources, allowing the deaf to prioritize other users' voice instead of environmental noises, for example. The reference guideline is the one of Meta Quest, which, however, talks about ensuring the presence of an automatic audio reduction called the ducking technique, which is not present in AltspaceVR. Ducking is a technique where the volume level of the specified audio is automatically reduced when a previously indicated second audio is present, whereas in the AltspaceVR platform it must be managed manually.

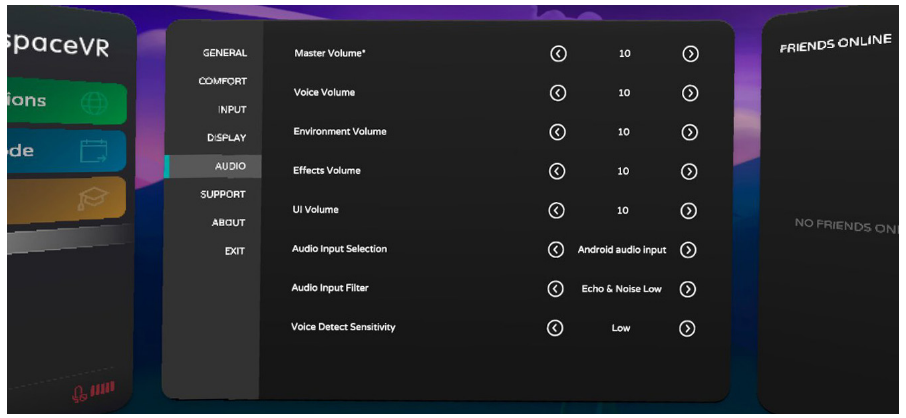


Fig. 106
Audio volume of different sources can be manually managed according to one's preferences
Source: AltspaceVR

Another relevant feature ensuring accessibility while communicating is the customization of mono audio: directly in the Meta Quest viewer settings, mono audio sound can be customized to ensure that all sound information is reproduced on both sides, respecting the guidelines defined in the XR Accessibility User Requirements. This rule ensures the inclusion of people with unilateral hearing loss, who therefore rely on audio through only one of the two ears. The definition of this preference within the device itself is also maintained within the Social VR app.

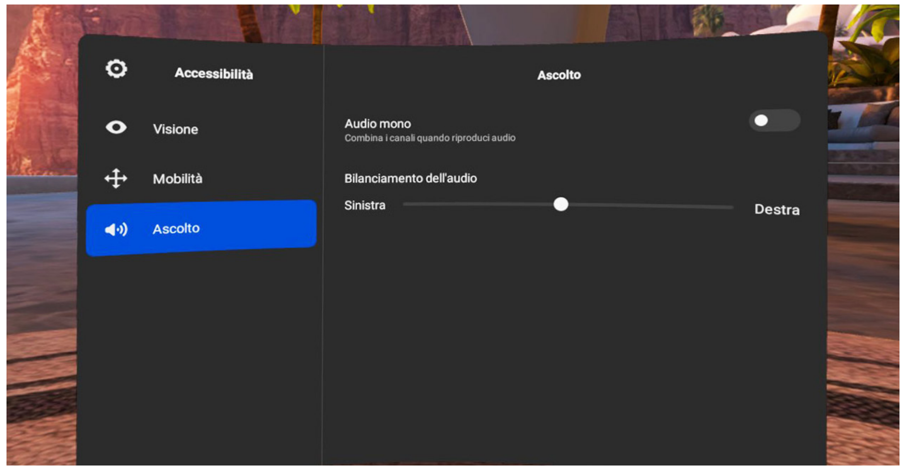


Fig. 107
In Meta Quest users can set their preferences in terms of mono audio
Source: Meta Quest

5.3.4 Conclusions

AltspaceVR is a platform that meets some of the currently established accessibility guidelines but there is room for improvement to make it fully accessible to people with hearing disabilities.
From a functional point of view, several guidelines have been introduced to ensure good usability of its platform but it's not happening on a social level. Indeed, some sociality-related guidelines are not fully respected, while others are totally discarded.
One of the guidelines whose absence resonates the most is certainly the current lack of one central feature for deaf people: the presence of automatic subtitles, which are even more fundamental within a platform that is based on dialogue and conversation. AltspaceVR therefore currently has a big gap, on which, however, progress was being made: automatic subtitles in beta version were introduced in the platform in 2021, which also offered automatic translation between different languages. However, they were suddenly removed after only a few months, thus excluding deaf people from its platform again.

In conclusion, the following comparison analysis with VR accessibility guidelines showed gaps in AltspaceVR, especially from a social point of view, which can impair the human-to-human communication experience by deaf people.

Fig. 108
AltspaceVR introduced for a few months 2021 a beta function which allowed users to exploit automatic subtitles during conversations
Source: Equal Entry

5.4 Experiment interviews

Investigating the accessibility guidelines respected, was useful to gain a general assessment about the platform level of usability and accessibility from a theoretical point of view. Then, users were directly involved through semi-structured interviews with the aim of investigating in detail a specific part of the experience: human-to-human interaction.
The structure of the experiment was approached in several stages: firstly the high-level objective of the experiment was identified, and then they were selected the users to be involved, corresponding to three able-bodied and three deaf users with cochlear implants. Subsequently, the protocol was structured through which individuals were required to experience the app, with a focus on communication between avatars, and then answer questions about it.

5.4.1 Objectives definition and users identification

In the first phase of the experiment, the high-level goal to be achieved was defined, which are: investigate which are the requirements for Social VR platforms to meet the communication needs of deaf people using cochlear implants.
The aim of the experiment is therefore to understand how the experience of communication between avatars is currently experienced by deaf people while immersed in the AltspaceVR platform, and to understand whether there are currently any particular problems and limitations that may even be blocking for the accomplishment of this task by deaf individuals.

Performing a test that could emphasize all the needs of people with different types of deafness is utopian and improbable since, as pointed out in Chapter 1, the approach to deafness may be different depending on the single individual: signing deaf communicate exclusively through sign language while oralist ones use hearing aids and/or cochlear implants, and for this reason, their experience, as well as their needs, may be different.
For reasons of time, the experiment focused on investigating communication needs only for one single approach to deafness, involving those who use cochlear implants. The reason for this choice stems from a strictly personal and emotional need, as the researcher's sister falls into the above-mentioned category.

Six users were involved in the experiment: three able-bodied individuals and three deaf users aged between 21 and 29, so as to have a greater probability of having users with the same level of technology and previous experience with VR. Talking about deaf interviewees, they all have a cochlear implant on just one ear, and have undergone bionic ear surgery at different ages, going from when they were 7 years old to 18, to understand their difference in terms of accessibility needs. One of the deaf users also wears a hearing aid on the other ear.
The decision to involve hearing people stems from the need to understand whether the approach as well as the lived experience is different between deaf and able-bodied. Moreover, this comparison is useful to distinguish whether the occurrence of any problems during the experience is caused by general usability issues, which affect the experience of both hearing and deaf people, or whether they are only limiting for people with hearing disabilities.

Fig. 109
Information about deaf and hearing interviewees involved in the experiment

DEAF INTERVIEWEES

Name: Francesca **Age:** 21 **Location:** Merate (LC)	**Name:** Ludovica **Age:** 25 **Location:** Milano	**Name:** Chiara **Age:** 29 **Location:** Milano
Relevant information: • Born into a hearing family. • Profound deafness in both ears since birth. • First 19 years with hearing aids, and 2 years with cochlear implant in one ear and hearing aid in the other.	**Relevant information:** • Born into a hearing family. • Profound deafness in both ears since birth. • First 7 years with hearing aids, then 18 years with cochlear implant in only one ear.	**Relevant information:** • Born into a hearing family. • Profound deafness in both ears since 1 y.o. • First 24 years with hearing aids, which were used sporadically. Then, 5 years with cochlear implant in only one ear.

HEARING INTERVIEWEES

Name: Francesco **Age:** 25 **Location:** Paderno d'Adda (LC)	**Name:** Alessia **Age:** 24 **Location:** Robbiate (LC)	**Name:** Gaia **Age:** 24 **Location:** Verderio (LC)

5.4.2 Interview structure

Starting with the definition of the experiment objectives as well as the involved users, the researcher proceeded with the drafting of the protocol, structured as semi-structured interviews. It is characterized by 4 distinct sections with different objectives, where the focus of the experience turns out to be the third part, which is about human-to-human interaction between the interviewee and the researcher in the guise of avatars. To make their virtual interaction possible, two Meta Quest 2 VR headsets equipped with special hand trackers were used. Going into detail, the sections characterizing the protocol are here explained.

5.4.2.1 Introduction questions

The first phase is the experiment introduction, in which the objective as well as the structure of the whole interview was explained to the user.
The purpose of this first part is to familiarize with the user and put him at ease through simple questions about himself, aimed at understanding his general technological level as well as his current knowledge in the field of VR. In fact, it is important to involve individuals with the same technological level in terms of previous experience with the Internet and VR experiences. Some of the questions also aimed to understand the user's propensity to use social platforms as well as their current motivation and interest in social VR platforms. During this introduction, it was also emphasized that the focus is not on testing the individual's skills but rather on understanding the challenges and limitations of the platform in question.

5.4.2.2 Creation of the avatar

The second step takes place within the VR platform AltspaceVR, where the user is asked to customize his avatar.
The purpose of this first activity is to allow him/her to become familiar with the app as well as with VR technology. For this reason, there was first a brief explanation of how the technology works and then the user was asked to wear the Meta Quest 2 visor and hand trackers to perform the action.
The objective of the task is the investigation of how users decide to represent themselves in a virtual world, whether faithfully to reality or differently, and for which reason. It also serves to understand their level of satisfaction with the virtual representations and whether they encounter any limitations that prevent them from achieving the desired result.

5.4.2.3 Human-to-human interaction

The third step represents the core of the experience, where the focus is on the investigation of human-to-human in the AltspaceVR platform. On a practical level, in this phase of the experiment, the user and the researcher are connected in the same virtual environment in the form of avatars, hypothesizing a scenario in which they use AltspaceVR to spend time together as they are located far apart. To simulate this circumstance, they are located in different isolated spaces in order to only have the possibility to communicate via VR.

While immersed in the virtual environment, the researcher will tell the interviewee stories structured in three separate dialogues, each lasting a few minutes, at the end of which the user will answer questions about them.
These dialogues are intended to simulate a normal conversation that can take place within the platform and, for this reason, in the three dialogues, the researcher will talk about three different TV series that she has recently watched, whose plot and personal impressions are told to the interviewee. This specific topic was chosen because it's of interest to her and which she would also talk about it in reality.

Each of the three dialogues is characterized by a different content as well as by different moods: each of them is perceived and therefore consequently narrated by the researcher with a different attitude and dominant emotion, which for the three dialogues respectively are joy, disgust, and fear. These emotions were selected from Ekman's seven universal emotions, the reason for which is explained in the following paragraphs.

Thus, the only action the respondent has to perform during this phase is to follow and pay attention to the researcher's avatar during the three dialogues, in order to answer subsequent questions that have a well-defined high-level purpose: to investigate the current effectiveness of dialogue in AltspaceVR in terms of verbal and non-verbal communication. In a nutshell, the aim is to investigate whether, by means of VR technology and the use of avatars, the user is able to understand the content of the communication and distinguish the mood characterizing the researchers during the three different dialogues.

To do this, five questions are asked at the end of each dialogue, in which as explained before the contents as well as emotions are different.

QUESTIONS ABOUT DIALOGUES CONTENT

The first three questions focus on the content, where the user is then asked to recount what had been said in the conversation and whether he encountered any problems in understanding it, in order to check whether there had been a correct comprehension.

QUESTIONS ABOUT DIALOGUES EMOTIONS

Instead, the other two questions focused on investigating which emotions and moods emerged from the dialogue according to the user.
To do this, two measurements were created ad hoc to help the user distinguish which emotions the researcher's avatar expressed.
The table represents a combination of the Likert scale and Ekman's 7 emotions. All 7 emotions are included because, as stated by the psychologist, a prevailing emotion may include or be the sum of others. If deemed necessary, the user may indicate other emotions.
The interviewee is asked for each emotion to indicate how much that emotion emerged during the dialogue in their opinion, where 0 indicates not at all while 4 means it was dominant. As an example, if he associates the emotion sadness with the score 4, it means that this emotion was significantly present in the dialogue according to him. After completing this question, it will be possible to understand whether the user recognized the correct emerging emotion and whether he perceived others.

Next, the experiment deals with understanding which element of the communication contributed to the respondent's understanding of the emotion of the researcher while speaking. Here again, the user is shown an ad hoc measurements that again makes use of the Likert scale through which he has to point which elements contributed to the understanding of which emotions were emerging. The items proposed in the table are the following: speech content, tone of voice during the speech, facial expressions of the avatar speaking and its body language during each dialogue. If the user deems it necessary, he can also indicate other components not present among those mentioned. Thus, for each voice the respondent indicates from 0 to 4 how much a specific element, such as the tone of voice, contributed to comprehend that the predominant emotion was sadness according to him, as an example.
This table makes it possible to understand what elements each user relies on to analyze the emotional state of the avatar and, above all, to reason about hypothetical differences between hearing and deaf people.

For each of the three dialogues, the same five questions were asked. Concerning them, as mentioned above, they focus on three different emotions such as joy, disgust and fear, the choice of which is not random but based on which emotions are the most widely recognized according to a research here mentioned.

Indeed, a test[11] conducted by several researcher in the field of Psychiatry, Behavioral Sciences, Neurosciences and mathematics, evidenced that the emotions which facial expressions were the most recognized are joy as the first one, followed by fear and disgust (Granato et al., 2018, pp. 9-10).
For this thesis, it was therefore decided to focus on these three emotions as they are the easiest to be recognized and thus not add degrees of difficulty by involving emotions that are also more difficult to recognize in real life.
As preparation for the three dialogues, the researcher investigated the mentioned emotions further through Ekman's research, where he highlighted which facial, sound, and body signals are representative of which emotion. This information represented a bis knowledge for the three dialogues conducted during the experiment and are here explained.

ENJOYMENT

Enjoyment is the most recognized emotion, where a smile represents a clear signal of a person's happiness which is expressed through a smile (Granato et al, 2018, pp. 9-10).
However, there are different types of smiles and some of them do have not the same aim of expressing joy. In order to distinguish a genuine one, Ekman suggests relying on the Duchenne Marker, where some distinctive signals where distinguished as the skin above and below the eye is pulled in towards the eyeball, the cheeks are pulled up, the crows' feet wrinkles may appear at the outer corner of the eye socket, and the eyebrows move down very slightly (Paul Ekman, 2019). Therefore, while experiencing true enjoyment the eyes are narrowed and there is wrinkling around the eyes, the cheeks are raised, and lips are pulled back to expose the teeth in a smile.
Feelings are also expressed through voice and in this case joy may be signaled with a sigh of contentment, squeal of joy, excited exclamation or shout, or laughter. In terms of body language, the posture may be different based on the happiness state, it can be either upright and elevated or still and relaxed (Paul Ekman Group, 2019).

11 The test involved 204 Caucasians subjects. It was shown to them a series of images, created by starting from the canonical emotions of anger, disgust, joy, neutral, fear, surprise, and sadness. Starting from that, it were created nine series of images, which were composed by 19 frames, where the first ones where two canonical emotions and the others were born by the gradual merging of them. The subjects had selected the image on the right or on the left according to which they identify as the central image in the series, and therefore identify which emotion they find as prevalent in the merged one.

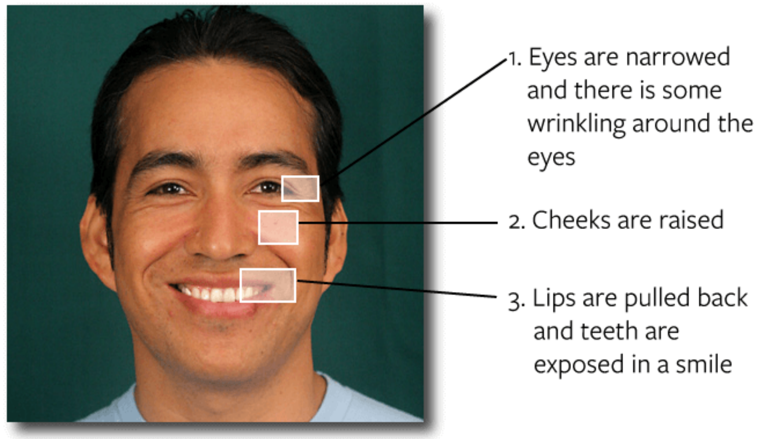


Fig. 110
Facial expressions of enjoyment
Source: Paul Ekman Group

DISGUST

As Ekman highlighted, we can feel disgusted by something we perceive with our physical senses, by the actions or appearances of people, and even by ideas. The distinctive sign of disgust is the wrinkling of the nose, accompanied by a "yuck" or "ew" sound, choking, and gagging.
Common sensations include revulsion in the mouth, throat, and/or stomach, and nausea, or physical repulsion, while in terms of posture, this feeling often leads to physically turning the head or body away from the source of disgust and often to cover the nose/mouth and hunching over when associated with nausea (Paul Ekman Group, 2019).

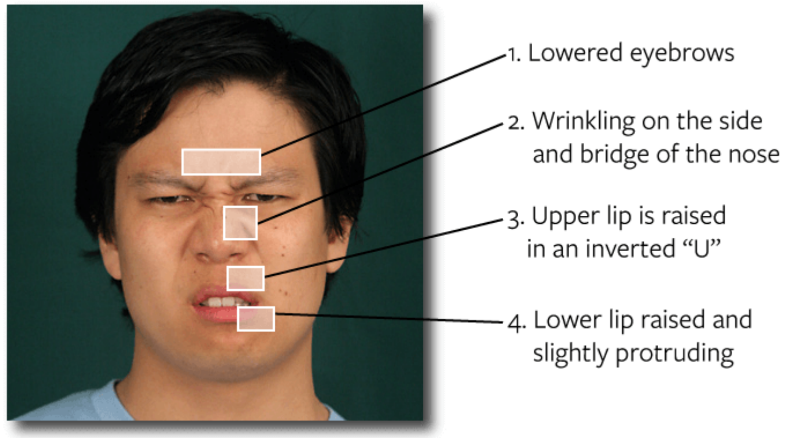


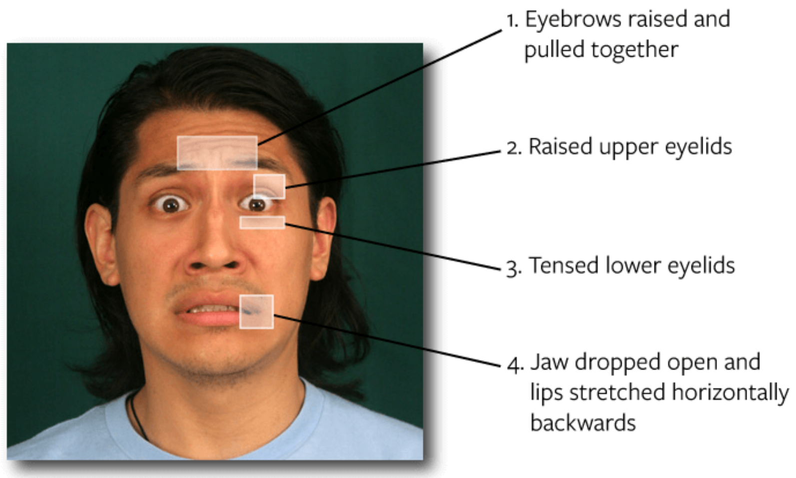
Fig. 111
Facial expressions of disgust
Source: Paul Ekman Group

FEAR

Fear arises with the threat of harm and it's something confused with surprise because of similar facial expressions: both are characterized by raised eyebrows, but eyebrows associated with a fear feeling are straighter and more

horizontal. Moreover, the upper eyelids results raised while the lower ones are tensed. The jaw is dropped open and lips stretched horizontally backwords.
In terms of vocal expression, the voice often has a higher pitch and more strained tone, and the person may also scream, while common sensations may include shortness and trembling or tightening of muscles in the arms and legs. The posture associated with fear is very distinctive and can either be mobilizing or immobilizing, freezing or moving away depending on the circumstances (Paul Ekman Group, 2019).

Fig. 112
Facial expressions of fear
Source: Paul Ekman Group



5.4.2.4 Final questions

Finally, in the last phase of the protocol, semi-structured questions are asked in order to understand the user's overall evaluation of the experience offered by AltspaceVR in terms of social interaction. The objective is to understand whether the following virtual communication mode is judged positively or negatively, why, and what can be improved.
In this regard, a specific question was asked to investigate in detail whether the respondent considered the implementation of additional functionalities to improve the current human-to-human communication via AltspaceVR to be necessary and thus to understand what he considered to be the requirements at the communication level to meet his needs. To help the interviewees in their reasoning and reflection, some features, such as automatic subtitles and a more realistic representation of the avatar's facial expressions, were indicated by the researcher to start a discussion and stimulate reflection.
Then, the final questions concluded the testing session, through which it was investigated the respondents' interest and motivation in using the AltspaceVR platform to communicate with other users.

Experiment protocol

Fig. 113
Protocol of the conducted experiment

1. Introduction questions

Hi! First of all, thank you for taking the time out of your day, it means a lot to me. Let me briefly tell you the reason for this test: I am developing a thesis on the topics of Virtual Reality and hearing disability. In particular, I am investigating what are the requirements for a particular type of Virtual Reality, called Social VR, to meet the needs of deaf people in terms of communication in a virtual environment.
I will involve both deaf and hard of hearing people for this experiment in order to understand how both experience dialogue within this virtual space.

The test will be structured in 3 parts: in the first phase I will ask you some general questions about yourself to get to know each other better, in the second phase we will live together a Virtual Reality experience within a Social VR app, while in the last phase I will ask you some final questions. Remember that there are no right or wrong answers and that we are not testing you but the platform in question, so feel free to say whatever you want, without feeling judged. If you have any doubts/difficulties/questions, interrupt me at any time.

1.1 General information about the interviewee

I will therefore proceed by asking you some general questions about yourself and your relationship with technology:

- [FOR DEAF ONLY] How long have you been deaf? What assistive devices do you use?
- How would you define your relationship with technology?
- What digital tools do you most use?
- Do you use any social networks? Which ones?
- How do you use social networks? For which purpose?
- Have you ever had an experience in Virtual Reality? If yes, which one?
- What do you think about Virtual Reality? What about the metaverse?
- Are you familiar with the term Social VR?
- What do you think about it? Do you know and have you ever used any Social Virtual Reality platform?

2. Creation of the avatar

Now we proceed to the second phase of the test, where we will enter a Social VR platform, which is called AltspaceVR. This is a social VR app where users can participate in events together, share experiences, and socialize with each other. So now we will continue our chat on this platform.

2.1 Create your avatar

As a first step, create your avatar and customise it as you prefer. The appearance you select will be how others will see you within the virtual platform. While doing this task, please think aloud about what are doing and what you are thinking.

- What look have you chosen for your avatar?
- What do you like about your avatar? Is there anything you don't like?
- Do you find the use of the avatar useful and interesting? Why?
- Do you feel comfortable using this technology? Are you having difficulties?

3. Human-to-human interaction

Now we will connect together within the platform.
Imagine then that we have decided to use AltspaceVR to be able to chat and spend time together assuming that we live far away from each other.
Within the platform, I will tell you 3 different facts, divided into 3 different dialogues. At the end of each dialogue, I will ask you to take off your headset to answer questions about the experience you just had. So, what I ask you to do is to follow and pay attention to my discourse.
I will proceed by moving to the other room thus simulating being located far from each other.

3.1 Dialogue

the following steps were applied to all three dialogues

Now I will tell you one story, and then I will ask you some questions after that. So let's put the headset on.

Now that we have finished with the dialogue, I will ask you some questions about it.

- Were you able to understand what I just told you? What did you understand?
- Did you have problems understanding what I was saying? If so, which ones?
- On an emotional level, how would you describe the attitude/state of mind of my avatar during the dialogue?
- What emotions emerged during my dialogue?
  To help you, I will name the seven universal emotions - for each one you will have to tell me how much in your opinion that emotion emerged from my dialogue from 0 to 4. 0 means that emotion did not emerge at all, while 4 means that it was dominant.
  Please think aloud while filling it.

Sadness	0	1	2	3	4
Disgust	0	1	2	3	4
Enjoyment	0	1	2	3	4
Fear	0	1	2	3	4
Anger	0	1	2	3	4
Contempt	0	1	2	3	4
Surprise	0	1	2	3	4

0 - Not at all
1 - A little
2 - Enough
3 - Very much
4 - Definitely

- Which elements of the dialogue allowed you to understand what were the emotions felt by my avatar?
  Let's analyse them one by one on a scale of 0 to 4, where 0 means that they did not contribute at all, while 4 means that it was crucial. Were there other elements that helped you? Please think aloud while filling it.

Speech content	0	1	2	3	4
Tone of voice	0	1	2	3	4
Avatar's facial expressions	0	1	2	3	4
Avatar's body language	0	1	2	3	4

0 - Not at all
1 - A little
2 - Enough
3 - Very much
4 - Definitely

4. Final questions

Now we will end the test with final questions where you can give your feedback on the experience you have just had.

- How would you rate the following mode of communication? Positively, negatively? Why?
- Did you find it difficult to understand the mood of the person you are conversing with through the avatar?
- What do you think could be improved/what would you change?
- In your opinion, to effectively communicate with other avatars via this platform, would it be useful to have other functionalities?
  To help you reason about it, here there have been proposed some features. You can also propose other ones.

Automatic subtitles	Written chat
Emojis	More realistic representation of avatar's facial expressions
More realistic representation of avatar's body language	Can you think of anything else?

- Imagine you own a VR headset (if you don't already have one): would you be interested in using Social VR platforms?
  - If yes: When do you imagine you would use it? For what reasons? Do you think it would benefit you?
  - If not: Why would you not use it?

That's it! Thank you very much for your time.

5.5 Experiment results

Following the definition of the interview protocol, the experiment took place with the six users. The experiment raised relevant data regarding many aspects of the VR experience, from the preferred mode of representation through avatars, to the degree of accessibility of the social VR in question, to highlighting common and divergent patterns between hearing and deaf people.
Notable to say is that the experiment was carried out within a closed environment characterized by silence and the absence of noise to avoid distraction. This means that, in the case of the occurrence of disturbing noise, the results of the experiment could instead be difference and go worsen.

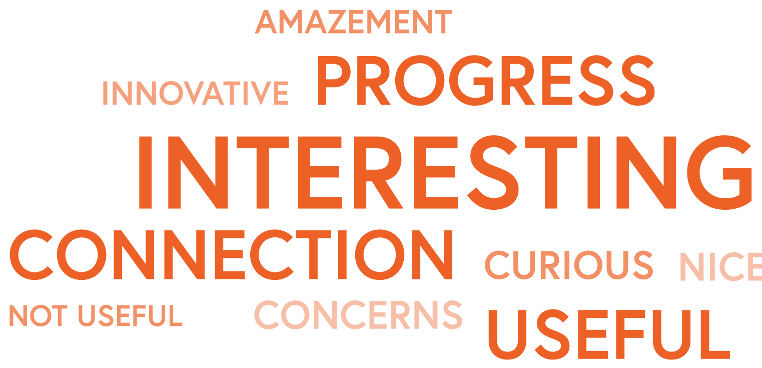
Fig. 114
Photos of the conducted experiment

5.5.1 Initial Social VR perception and evaluation

Before starting the VR experience, questions were asked to get to know the interviewee more in-depth. From the first considerations regarding their relationship with technology, it emerges for both hearing and deaf people a very good relationship with it and, above all, a strong use of social platforms, mainly for the purpose of interaction and connection with other people, highlighting the relevance of sociality in their lives.

With regard to VR, only a minority of the respondents, two out of six, have had a brief experience with this technology in the past. Nevertheless, it is perceived extremely positively by all respondents, seen as innovative and with possible useful purposes.
The use of Social VR was also seen as very intriguing, despite the fact that nobody knew about this concept before the experiment. Five out of six deaf and non-deaf users perceive Social VR as a virtual meeting and a socializing place that allows people from all over the world to connect, thus seeing the potentiality of creating great value.

Fig. 115
Word clouds about initial perception of the metaverse and Social VR platforms by deaf interviewees, with related quote



“ *I would be very interested in using Social VR platforms, I like the fact that it connects real people. It makes me very curious!* ”
- Ludovica, deaf interviewee

> *I think it's nice to be able to connect with other people who are far away.*
>
> - Gaia, hearing interviewee

Fig. 116
Word clouds about initial perception of the metaverse and Social VR platforms by hearing interviewees, with related quote

Following pre-navigation questions, the respondents familiarised with the platform by creating their avatars. Five out of six users decided to represent themselves similarly to reality but were not happy with it. In fact, two out of three deaf users and three out of three hearing ones stated that they were not satisfied with the result obtained, due to the lack of available choices that limited customization and therefore did not allow them to achieve a satisfactory representation.
In spite of this, they unanimously find the use of the avatar interesting and useful, defined by a deaf interviewee also as *"useful to socialize in a virtual way, since the avatar can give more help in doing so"*, thus imagining it as a potential help for their inability to rely on audio.

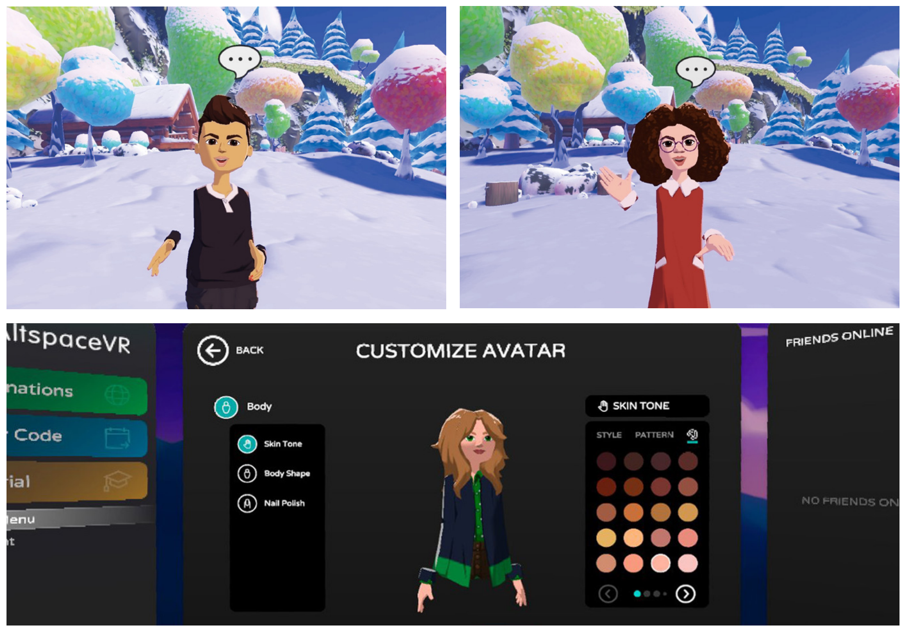


Fig. 117
Avatars created by three interviewees and screenshot of the interface related to the avatar's creation

From this first task of VR use, an initial obstacle for deaf people emerges: three out of three users had difficulty wearing the headset with the cochlear implant, as the back strap of the device caused the cochlear implant to detach, forcing respondents to spend time figuring out how to position the two devices to ensure the correct function of both technologies.

Fig. 118
Photo of a deaf interviewee wearing the headset

5.5.2 Dialogues

During the central phase of the experiment, the respondents joined an immersive experience in AltspaceVR, where the researcher in the guise of an avatar recounted three different facts, where the predominant emotion was different each time. Each speech was characterized respectively by the emotion of joy, disgust, and finally fear.
Relevant data emerged, underlining differences between hearing and deaf people with regard to understanding the content, and recognition of the associated emotions and components that enabled them to recognize what mood was prevalent.

Fig. 119
The avatar created by the researcher, with which respondents interacted

5.5.2.1 Understanding dialogues content

DEAF INTERVIEWEES
It emerged unanimously that all participants with hearing disabilities had serious difficulties in understanding the content of the speeches, stating in most cases that they did not understand anything at all.
Two out of three users stated that in two dialogues they were able to extrapolate words from which they tried to assume the content of the speech incorrectly. This is obviously a frustrating situation, which led one respondent to state that she was experiencing anger because of this situation: *"I couldn't understand anything, it made me a little angry that I couldn't understand the content!"*.

Fig. 120
Visual representation of the responses given by deaf users about the ability to comprehend the dialogues' content

Were you able to understand what I just told you?

"I was able to understand a few words, but then I lost the thread of speech" - Francesca

"I did not understand anything at all." - Chiara

Ludovica, a deaf respondent, states that she does not use this mode at all, because of the effort required.
The other modality for the devices of new generation involves the use of an add-on component to be attached to the device that allows the device to be connected to the implant via Bluetooth. However, this is a device that has to be bought separately and for a cost that is not affordable for everyone, around 300 euros. This creates obstacles that lead deaf people to use the bionic ear without additional components, despite a sub-optimal sound quality. For this reason, Francesca, who could use this mode, does not use it, due to the lack of this component and the fact that she uses the hearing aid in the other ear, so the difference in sound between the two devices would be even more noticeable.

Due to the impossibility of using sound, the appearance of another avatar within the empty virtual space was experienced, by two out of three users, as a moment of agitation and fright, precisely because it was unexpected and without any indication of another person entering the environment.

HEARING INTERVIEWEES
The outcome for hearing people, on the other hand, is easy to guess: three out of three were able to fully understand all the speeches, without any difficulties. Therefore, they were able to perfectly summarise the content of the dialogues.

Fig. 121
Visual representation of the responses given by hearing users about the ability to comprehend the dialogues' content

Were you able to understand what I just told you?

"I understood everything about the dialogue" - Gaia

5.5.2.2 Understanding emotions related to dialogues

DEAF INTERVIEWEES

With regard to the recognition of emotions, there were different outcomes according to the different dialogues.
In the first dialogue associated with enjoyment, the emotion was correctly identified by three out of three users in a fairly dominant manner.
As shown in Chapter 5.5.2, this is the most easily recognized emotion by humans (Granato et al, 2018, pp. 9-10) and this is also confirmed in the following experiment. According to two out of three respondents, the emotion of joy was accompanied by the presence of another positive emotion, which is surprise, linked to the fact that the speaker was telling something new and thus was positively surprised within the story.

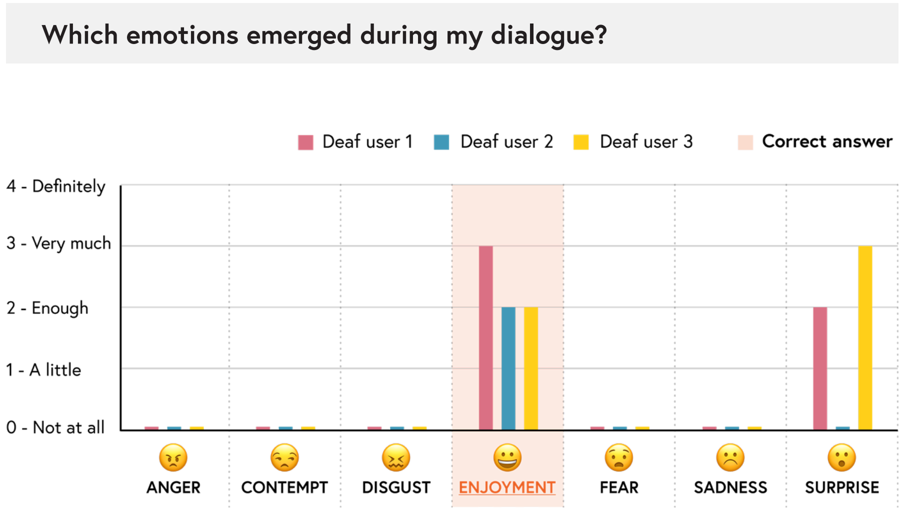


Fig. 122
Visual representation of emotions recognized by deaf users in the first dialogue

Concerning the other two dialogues, where the predominant emotions were respectively disgust and fear, the results become more intricate.
Concerning the speech on disgust, three out of three did not identify the presence of this emotion in the dialogue at all. On the contrary, two out of three detected the presence of joy, describing the speaking avatar's attitude as *"friendly, smiling, calm"*, due to its static facial expressions, which were always smiling and positive.
At the same time, however, they perceived the attitude as tense, due to the influence of the tone of voice. This denotes confusion in the perception of emotions due to the reception of conflicting messages from different aspects of verbal and non-verbal communication.

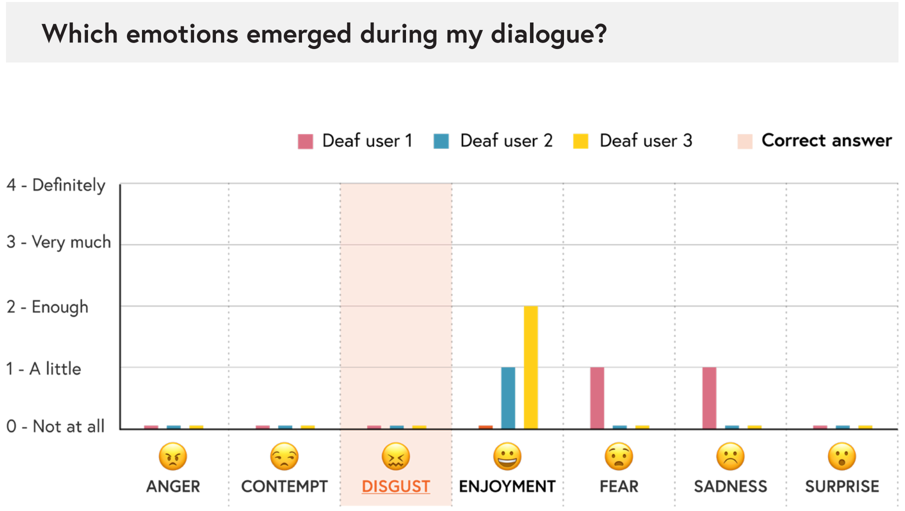


Fig. 123
Visual representation of emotions recognized by deaf users in the second dialogue

Similarly, the dialogue related to fear created divergent responses, where the emotion in question was not properly identified. A tense state, agitated but at the same time also joyful, was recognized, as it was stated that the emotion of enjoyment was mildly present. As with the dialogue on disgust, the static smiling facial expressions had an influence on the assessment of the dominant emotion.
This is an alarming finding, as it leads the deaf person to completely misunderstand the other person's emotion and thus probably not know how to interpret the information he/she can take in from the interaction.

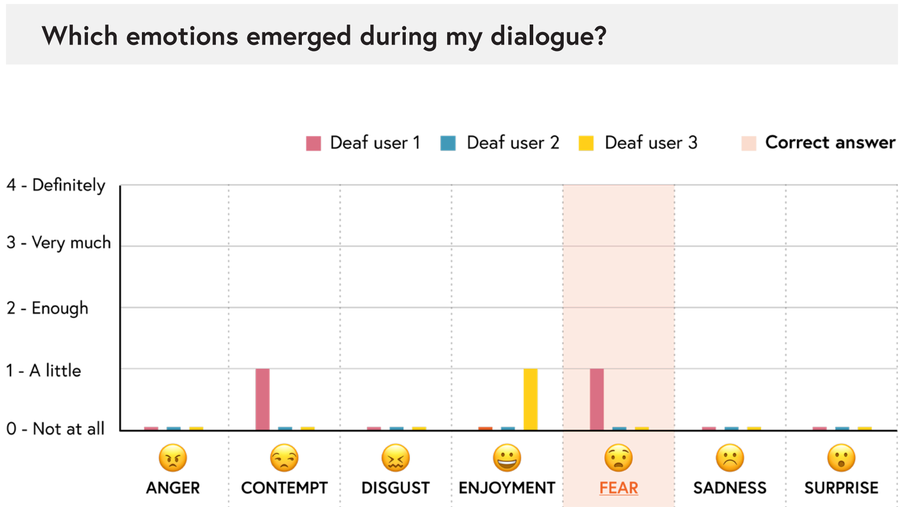


Fig. 124
Visual representation of emotions recognized by deaf users in the third dialogue

Regarding the elements considered as useful in recognizing what the avatar's attitude was, no clear-cut figure emerges either, where the evaluations were in general very low and therefore poorly impactful.

For enjoyment, the tone of voice emerged as a fairly relevant component in understanding what the other's attitude was, as did body language, precisely because joy-related movements were defined as large and excited. On the other hand, the content was declared as quite useful, but only for the fact that two out of three users were able to recognize a few words, as well as the facial expressions, which were considered static and therefore not central but capable of conveying joy.

Which elements of the dialogue allowed you to understand what were the emotions felt by my avatar?

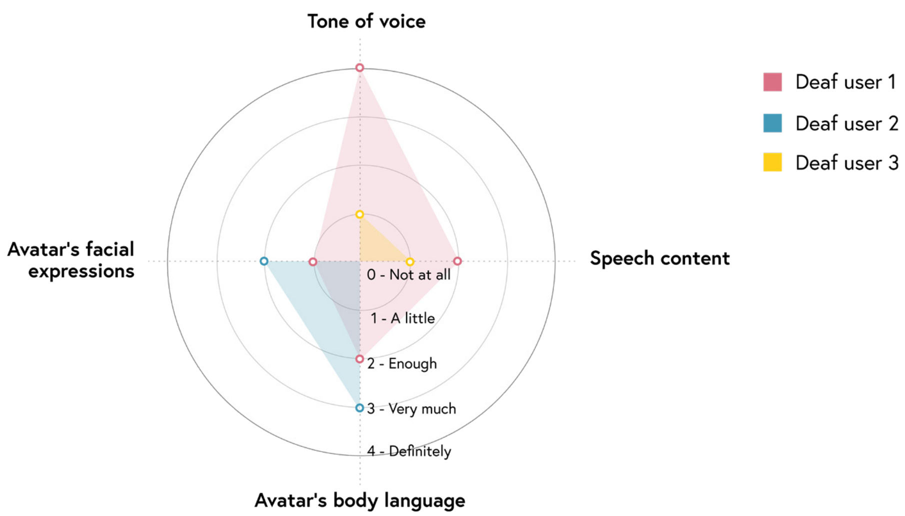
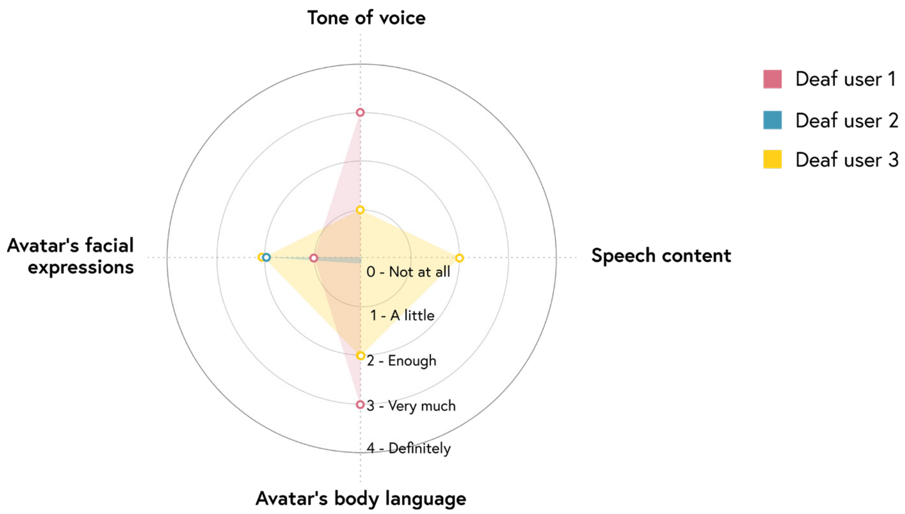


Fig. 125
Visual representation of dialogue elements that enabled deaf users to recognize emotions in the first dialogue

Facial expressions were also recognized as quite relevant in the dialogue regarding disgust, defined as neutral and thus easily associated with emotions of tension, but at the same time wrongly seen as positive and smiling.
The tone of voice divided the respondents. According to one out of three, it was absolutely relevant to convey tension, as recounted by Chiara: *"although I did not understand the content of the speech, from the tone of voice I could perceive hesitation"*. For the other two, however, it did not provide relevant information on the attitude of the speaking avatar.
The body language is reported to provide help in understanding the emotion, since staying still and the reduced movements conveyed a perception of tension.

Fig. 126
Visual representation of dialogue elements that enabled deaf users to recognize emotions in the second dialogue

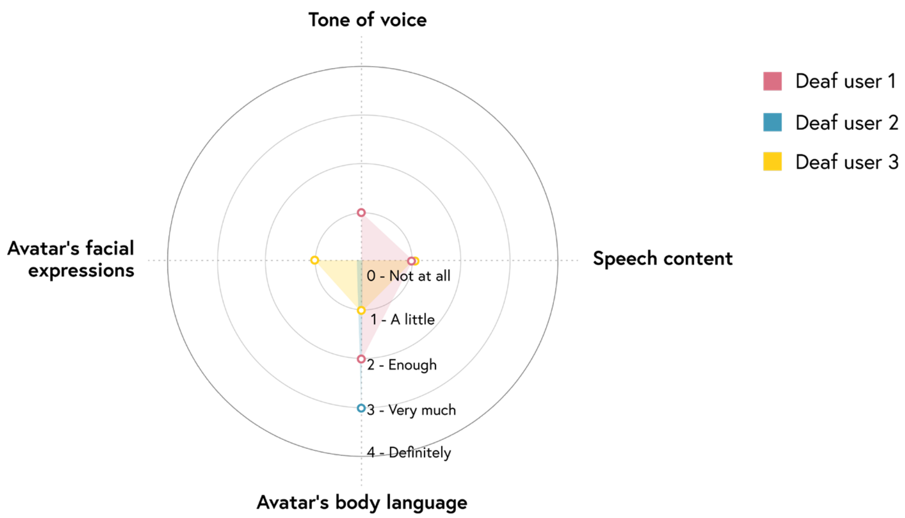
Which elements of the dialogue allowed you to understand what were the emotions felt by my avatar?



In contrast, in the dialogue pertaining to fear, body language was considered important, where gesticulation conveyed agitation and thus it was assumed that an emotion associated with tension was present.
The content and tone of voice were indicated as not very relevant, just as facial expressions, which were considered generally not useful since always static and positive.

Fig. 127
Visual representation of dialogue elements that enabled deaf users to recognize emotions in the third dialogue

Which elements of the dialogue allowed you to understand what were the emotions felt by my avatar?



What emerges is a not clear-cut pattern, which is may due also to the different therapeutic paths taken by the three interviewees.
In fact, the three deaf interviewees present a different age at which the implant was implanted, a different frequency and modality in which speech therapy was carried out, and a different use of aid devices, which therefore affect the deaf person's ability to hear and interpret dialogues. This is why one deaf person is different from others, also in terms of the elements on which they base their interpretation of emotions.
Certainly, what emerges from the experiment is an approach based on intuition and hypothesis by deaf people, whereby they hypothesized what was the predominant emotion based on the understanding of a single element, such as a specific hand movement as well as the understanding of a specific word. It turns out to be a risky approach, which can lead to mistakes, but which they continue to do because there are currently no tools through which they can understand dialogues with certainty. That is why they have to rely on assumptions, at the risk of misunderstanding and even being excluded from conversations.

HEARING INTERVIEWEES

Concerning hearing people, they had no difficulties understanding emotions. Three out of three recognized the emotion of joy as absolutely dominant in the discourse, again confirming that joy is the most recognizable emotion (Granato et al, 2018, pp. 9-10).

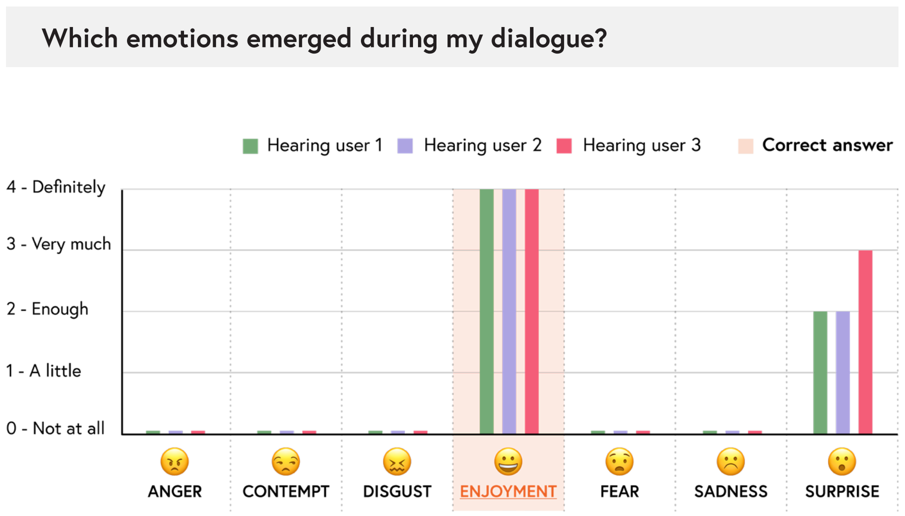


Fig. 128
Visual representation of emotions recognized by hearing users in the first dialogue

Regarding disgust and fear, they were recognized, but in co-presence with other emotions: the interviewees state that disgust was accompanied in a less dominant way by emotions of fear and contempt, recognized through the speech content, as well as in an extremely low way by enjoyment and surprise, due to the smiling facial expressions of the avatar.

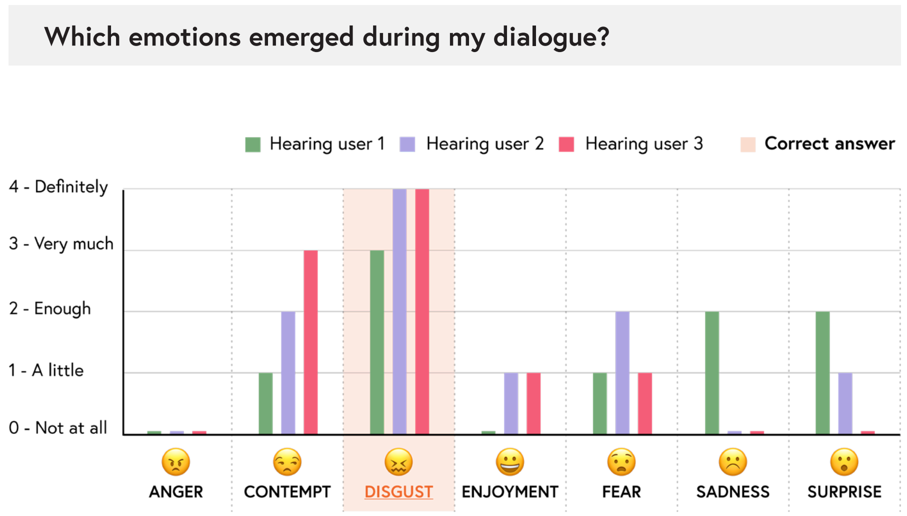


Fig. 129
Visual representation of emotions recognized by hearing users in the second dialogue

In the third dialogue, fear is correctly recognized dominantly, but in co-presence with positive emotions such as enjoyment and surprise, considered as fairly present in the speech also here due to visuals and to the tone of voice. Only one hearing user out of three did not recognize the presence of fear.
Thus, the influence of the visual component also emerges in the hearing interviewees, who recognized the presence of emotions associated with a positive mood also in the last two dialogues. But, as opposed to deaf users, they were able to receive information not only through their eyes but also via audio, which allowed them to identify correctly which were the dominant emotions in the conversation.

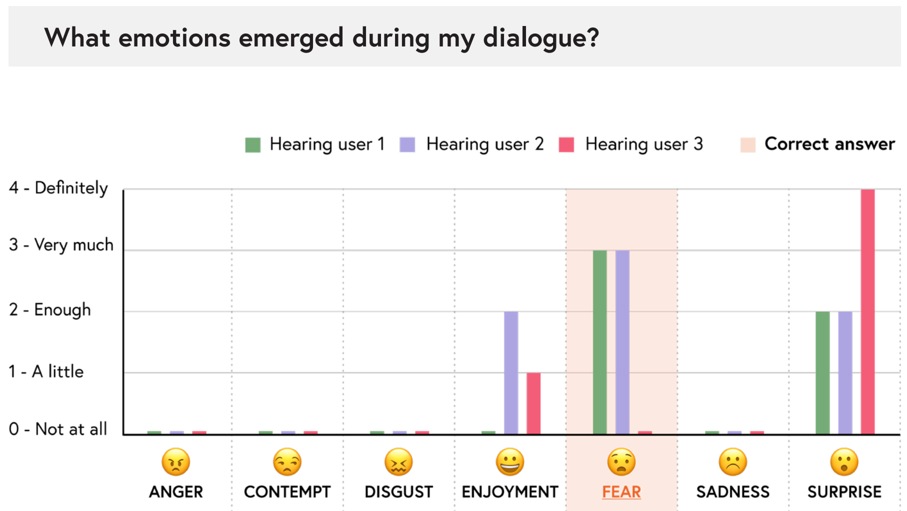


Fig. 130
Visual representation of emotions recognized by hearing users in the third dialogue

With regard to the components that allowed them to understand what the dominant emotion was, a clearer pattern emerges in hearing people: the tone of voice turns out to be on a general level the component they relied on primarily to understand the avatar's attitude, as well as the content of the discourse itself, through which they understood the mood and content.
Body language gestures are also seen as relevant, as they can reinforce the perception of a given emotion in combination with other components, such as the tone of voice.
Finally, facial expressions were rated as irrelevant, precisely because they are static, always positive, and often create discordance with the content of the speech. Regarding the speech related to disgust, one interviewee evidenced how the positive visuals almost led him astray, causing confusion: *"[The avatar] even looked pleased. This almost made me doubt whether in your speech was emerging disgust since from your expression you looked amused".*

Which elements of the dialogue allowed you to understand what were the emotions felt by my avatar?

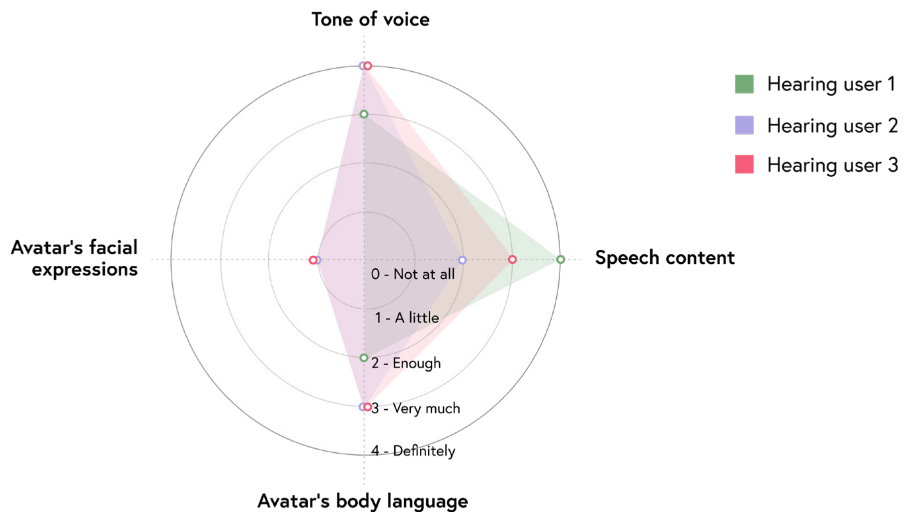


Fig. 131
Visual representation of dialogue elements that enabled hearing users to recognize emotions in the first dialogue

Fig. 132
Visual representation of dialogue elements that enabled hearing users to recognize emotions in the second dialogue

Which elements of the dialogue allowed you to understand what were the emotions felt by my avatar?

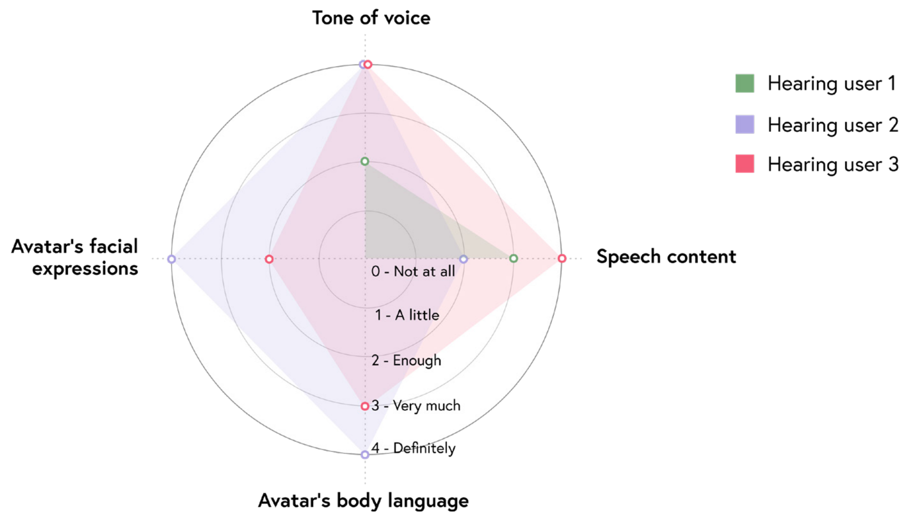
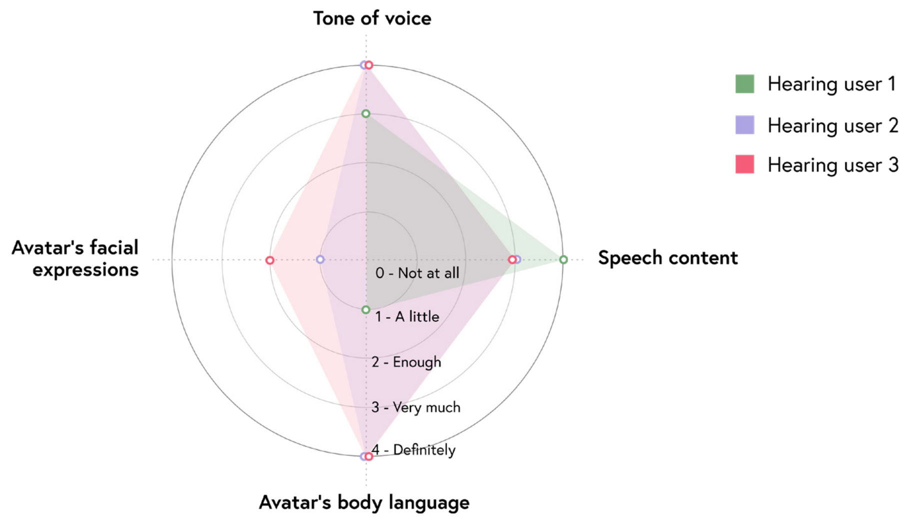


Fig. 133
Visual representation of dialogue elements that enabled hearing users to recognize emotions in the third dialogue

Which elements of the dialogue allowed you to understand what were the emotions felt by my avatar?



5.5.3 Final Social VR perception and evaluation

Following the human-to-human interaction experience in VR, the respondents were asked post-navigation questions, from which relevant insights emerged.

DEAF INTERVIEWEES

If the initial positive evaluation given by hearing people on Social VR remained unchanged after the VR experience, this is not the case for deaf people.
In fact, after wearing the headset, they judged the communication experience in the AltspaceVR platform as negative, as all three respondents recognise the lack of tools that could make the experience accessible to deaf people: first of all, the absence of automatic subtitles and facial expressions and therefore a realistic labial.
In fact, these shortcomings made it complicated for them not only to understand the content but also to recognize the emotions present in the conversation, making it an experience full of obstacles and barriers.
The words and quotes given here bear witness to this:

DIFFICULT EXPERIENCE PARTIALLY POSITIVE
NOT INTERESTED SOCIALIZATION
IMPROVABLE
FUN
BEAUTIFUL ACCESSIBILITY BARRIERS
ABSENCE OF RELEVANT FEATURES

Fig. 134
Word clouds about final perception of the metaverse and Social VR platforms by deaf interviewees, with related quotes

> *Labial, facial expressions, body language: there is still a lot to do in this regard. I couldn't tell if you were smiling, if you were serious, if you were raising your eyebrows.*
>
> - Ludovica, deaf interviewee

> *Facial expressions were the same. It's different for us from the hearing, they understands what is being told, whereas we are good at noticing facial expressions and labial, which were, however, absent.*
>
> - Chiara, deaf interviewee

This is why they declare the need for additional functionalities to improve accessibility at the level of human-to-human interaction.
They consider it absolutely and unanimously necessary to have more realistic facial expressions, able to reproduce lips movement and not only simulate the opening and closing of the mouth. In fact, they are currently very rigid, unable to simulate facial movements and thus to make the deaf understand speech content but also associated emotions.
Secondly, they consider the presence of automatic subtitles to be crucial, as they are more relevant if one is unable to read lips. In fact, their expectation was the appearance of automatic subtitles within the cloud that is solely responsible for indicating when a person is speaking, thus creating a mismatch of their expectations.
With a lower priority, they all felt that a more realistic representation of the body would be useful, as they felt that it only needed to be more detailed, such as the definition of the hands, and to ensure more fluid movements, but they thought that currently the result was already good.
Another feature that could be useful is written chat, which they obviously feel would require more effort and time, but that they would use in situations where they cannot communicate verbally or to warn the person in front of them of their condition before interacting verbally.
They unanimously consider the use of emojis not useful for communication purposes, as it would be a more aseptic and cold conversation.

Fig. 135
List of features proposed to be added in the platform and deaf users' considerations

MUST-HAVE
REALISTIC AVATAR'S FACIAL EXPRESSIONS
Recognized as necessary the reproduction of lips and facial movements.

MUST-HAVE
AUTOMATIC SUBTITLES
Considered as crucial due to the impossibility to read the avatar's lips.

NICE TO HAVE
WRITTEN CHAT
Identified as useful for specific situations or to warn others about their condition.

NICE TO HAVE
REALISTIC AVATAR'S BODY LANGUAGE
Considered as nice to have a more detailed representation of body movements.

NOT RELEVANT
EMOTICONS
Recognized as not useful for communication purposes.

An alarming finding that emerges from the following analysis is the loss of interest in these types of VR at the end of the experience, precisely due to a lack of accessibility, leading deaf respondents to state that they would only use it if some features were integrated to make the experience truly inclusive.

> *It would be a waste of time to use it and then not understand anything of the dialogue, I would invest my time if there was easier communication for me as a deaf person.*
>
> - Ludovica, deaf interviewee

HEARING INTERVIEWEES

Regarding hearing individuals, their final assessment remains positive, with three out of three stating that they are interested in using the platform as it is for social interaction purposes, especially to communicate with people far away from them and thus associating the platform with a great social value of connection.

What emerges from hearing interviewees is also for them the desire for more realistic facial expressions, not because of the need to read the lips as for the deaf, but to have a representation of emotions that is also readable on the avatar's face, and not only through content and tone of voice.

Fig. 136
Word clouds about final perception of the metaverse and Social VR platforms by hearing interviewees, with related quote

> *It was a positive experience, very fascinating! The only thing is that there weren't facial expressions to understand the avatar's emotions, which is a minus.*
>
> - Francesco, hearing interviewee

This is obviously more of a nice-to-have feature, rather than one that is vital for understanding the conversation. The same applies to the use of subtitles, where three out of three said they would use them in case they had to talk with a foreign person.

Two out of three, on the other hand, would use emojis as Instagram reactions, to communicate quickly but would use them in specific situations and sporadically.

On the other hand, they do not see a need for a more realistic representation of body language, where the current level is considered to be satisfactory.

The same applies to the introduction of a written chat, as they consider that the writing mode provided in AltspaceVR, which involves typing letter by letter without prompts, may make the writing process time-consuming and thus lead them to use mobile apps if their intent is to communicate via written messages.

Fig. 137
List of features proposed to be added in the platform and hearing users' considerations

NICE TO HAVE
REALISTIC AVATAR'S FACIAL EXPRESSIONS
Considered as nice to be able to read emotions also through face expressions.

NICE TO HAVE
AUTOMATIC SUBTITLES
Recognized as useful to be able to speak with foreign people.

NICE TO HAVE
EMOTICONS
Useful to communicate quickly but would use them sporadically.

NOT RELEVANT
REALISTIC AVATAR'S BODY LANGUAGE
The current level of realism is considered as satisfactory.

NOT RELEVANT
WRITTEN CHAT
Considered the writing process as time-consuming.

5.5.4 Conclusions

The experiment made it possible to gather relevant insights regarding the platform in question but, especially, on the needs of deaf people compared to hearing ones. In fact, the involvement of hearing people made it possible to understand that the experience was usable by able-bodied individuals, who didn't have any problems understanding verbal and non-verbal dialogues, thus enabling the player to have a positive experience,although some improvements would be necessary to offer an optimal experience.
This, however, is not the case for deaf people, who had to face various obstacles, which created an absolute difficulty in understanding the content, but also in perceiving the emotions felt by the avatar with whom they interacted.

Therefore, the platform lacks the necessary features to make the experience inclusive to deaf people, such as realistic labial and subtitles. Due to the lack of the means they normally rely on in reality to interpret speech, they were led to rely heavily on the visual component, which however bring them to misunderstand the dominant emotions in two conversations out of three, due to the avatar perpetually smiling and with a positive expression. In fact, this led them to general confusion and disorientation that did not allow them to identify elements of the discourse on which to focus in order to understand its content and the associated emotions.
Therefore, they were led to hypothesize and find strategies to extrapolate information relevant to understanding the content and dominant emotion. This is an instinctive method that could cause misunderstanding of conversations and thus be excluded from them. This difficulty leads to generating negative emotions such as anger, and frustration, which underline a problem that needs to be solved to ensure a better experience and well-being for deaf people when immersed in Social VR apps.

The involvement of AltspaceVR allowed the understanding of the level of accessibility of a platform with one of the most negative ratings in the Oculus Store but, specifically, it had the role of a medium to comprehend the requirements for Social VR apps to be accessible to deaf people in terms of human-to-human interaction.
To do so, in addition to analyzing data from the experiment, it was also taken into account insights from the analysis of the accessibility guidelines for video games, VR platforms, and user recommendations concerning VR experiences. From this, a list of guidelines was defined with the intention of covering all aspects of avatar interaction in Social VR platforms.

6

Final output

The insights gained from the analysis of the accessibility guidelines for video games, VR experience, and user recommendations, integrated with the results of the experiment conducted with users, led to the final output: the definition of accessibility recommendations aimed to cover all aspects of human-to-human interaction in Social VR platforms.
The goal is to provide accessibility rules that enable a fully inclusive experience for deaf users with a cochlear implant.
The experiment also emphasized some aspects that require further iterations in order to achieve an increasing degree of definition of the guidelines and to reach the high-level goal of guaranteeing accessibility for a broader hearing-impaired audience and in different types of VR experiences.

6.1 Recommendations for accessible human-to-human interaction in Social VR

Through the process of Discover and Define of the Double Diamond, recommendations aimed at ensuring a human-to-human interaction in Social VR were then defined. To structure the following list, the researcher started with the analysis of the guidelines defined by the institutions and from the user feedback, in chapters 4.3.2 and 4.3.3. This research highlighted the fact that these guidelines are not exhaustive as the experiment revealed that the specific needs of deaf users are not taken into account by the official guidelines.
The following chapter, therefore, summarises all the recommendations to be taken into consideration to ensure an accessible human-to-human interaction for deaf users with cochlear implants, where for each recommendation it's indicated the source: for example, whether it stems from the official guidelines, whether from user recommendations or whether it comes from the conducted experiment. The identified guidelines are as follows:

Fig. 138
List of recommendations to ensure accessible human-to-human interaction in Social VR

ALTERNATIVE INPUT MODALITIES
- Provide smart written chat
- Include filters in the VR store about offered interaction modalities
- Provide information about one's preferred modality of interaction

ALTERNATIVE FEEDBACK MODALITIES
- Provide feedback about avatars' status in the virtual environment

AUDIO PERSONALIZATION
- Offer audio customization settings

CLUES' CLARITY
- Provide in-app tutorials about social interactions between avatars
- Provide easy and constant access to chat messages

REALISTIC AVATAR'S REPRESENTATION
- Provide realistic facial expressions and labial
- Provide realistic avatar's body language

AUTOMATIC SUBTITLES
- Provide accessible subtitles in terms of characteristics & position

PRODUCT DESIGN
- Provide accessible headset in terms of product design

PROVIDE ALTERNATIVE INPUT MODALITIES

Provide smart written chat

Problem

The mere presence of communication via voice is limiting for deaf people, as they may find it difficult to receive the message as well as they may prefer not to use voice to interact with others due to specific circumstances or because of their own preferences. In fact, they may wish not to have to communicate verbally and not to receive messages via audio when, for example, they are in a noisy room where they would not be able to distinguish sounds or when they are in situations where they cannot make noise, which is a situation common not only for deaf people but all players.
Talking about deaf players, as reported in chapter 1.2.2, some of them state that they experience discomfort because of their voice, which may lead them to not want to interact vocally (Committee on Disability Determination for Individuals with Hearing Impairments, 2004, pp. 180-181).

Solution

Voice input doesn't have to be the only possible way to interact with others. Therefore, it is necessary to provide an alternative modality: written chat. Chat has the role of additional functionality to communicate with others, in case one prefers not to use voice to interact in a virtual space.

Notable to say is that the chat did not emerge from the experiment as an easy-to-use modality in a virtual space, precisely because it would require a lot of effort in typing via the headset according to the deaf people, who, hover, consider this functionality as extremely helpful for communication. Instead, hearing people find the chat as not necessary in a Social VR interaction.

In order to be able to build a bridge between deaf and hearing people, it is essential that chat has smart features that make it easier and faster to use, which are as follows:

- Provide intelligent word suggestions: providing tips on words to type based on the letters selected helps speed up the process of typing words, which is now done letter by letter and which due to the constant moving of the head could cause motion sickness in the long run.
- Provide voice recognition: users can use the headset's microphone to state the message they want to send, which is then transformed into written form. This represents a modality of creating an input that is useful in cases where the person wants to communicate verbally but sends the message to the other person in a written form.
- Ensure keyboard Bluetooth pairing: have the possibility of connecting the VR headset via Bluetooth to a keyboard ensure the possibility of easily communicating in written form by typing directly into a physical keyboard.

Possible threats

The possible threats regard the feasibility of implementing word suggestions, which needs to be further verified.
Talking about voice recognition, this is a feature already provided by Meta Quest, but it currently has limitations: it is only available in the US and English is the default language.
While regarding the keyboard pairing, this is a feature already offered by Meta Quest, but that is currently only available in the Oculus Home and therefore not included within the apps downloaded from the store. For this reason, there is a need to improve this functionality at the feasibility level to ensure the implementation of a smart chat.

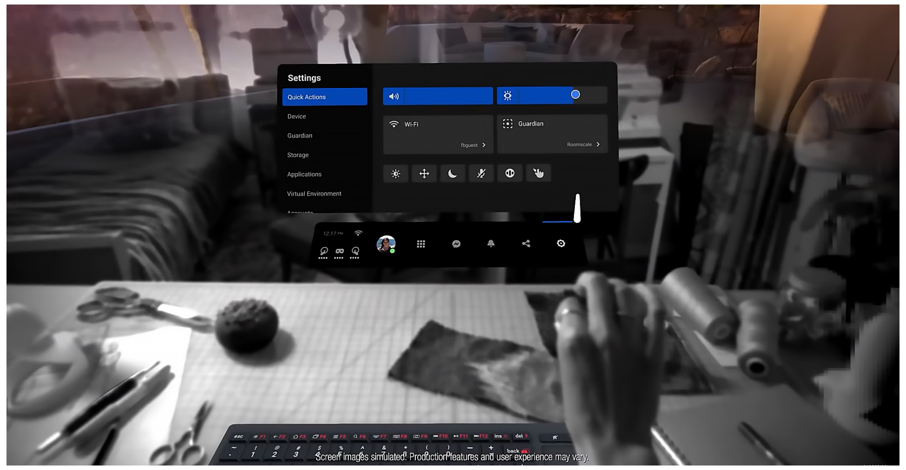


Fig. 139
The keyboard Bluetooth pairing is a functionality offered by Meta Quest but only available in the Home
Source: Virtual Reality Oasis

Source

The above mentioned guidelines emerges from the experiment results, where deaf users considered the chat as useful but too effort-consuming as it is now.

PROVIDE ALTERNATIVE INPUT MODALITIES

Provide information about one's preferred modality of interaction

Problem

Users connected in the same virtual environment may have different communication needs, such as they prefer to communicate via voice or via chat. This may happen because of the circumstances in which they find themselves, e.g. they may be unable to speak as they find themselves in a space where they have to be silent, or because they have a personal preference to interact via a specific modality, such as via chat because they wish not to have an initial verbal approach. The problem is that other users are not aware of the preferred modalities of interaction of other players.

Solution

It is necessary for each avatar to be associated with additional information related to his/her preferred mode of interaction, where the purpose is to inform other avatars who wish to interact with him or her.
Within the virtual space, when clicking on the avatar in question, additional details about the avatar may appear, such as his or her name, and also information about his/her currently preferred mode of communication, as an example a simple indication as *"John78 is available to talk via chat"*.
This "status" can be changed over time and has the role of providing indications to others about which mode they should use to communicate with that user, whether by audio or instead by chat.

Source

The experiment emphasized this requirement, as one deaf user stated that she would use the chat to inform other avatars about her condition and thus her preference to use this medium instead of voice. The relevance of this guideline is also emphasized by Game Accessibility Guidelines in chapter 3.3.2 about sociality-related guidelines, but not by Meta Quest and W3C.

PROVIDE ALTERNATIVE INPUT MODALITIES

Include filters in the VR store about offered interaction modalities

Problem

Meta Quest store does not provide the possibility to use filters to scrape apps available on its store. On the contrary, Steam store provides the possibility to use multiple settings, but without giving the possibility to filter apps by the modalities of interaction provided in the app. This leads users to go by trial and error and even to download or even pay for apps in order to access them, with the possibility of finding out which modality of communication is provided only by using it first-hand.

Solution

It's suggested to insert in VR stores an additional filter that concerns the presence of specific modalities of social interaction. Thus, by means of this functionality, the user has the possibility of viewing only those apps that, for example, provide his preferred input modality of interaction, such as via written chat. This saves him/her time and avoids unpleasant situations of frustration and anger due to the lack of accessibility in the experience.

Source

This guideline stems from the user recommendations of Merlyn Evans, who emphasizes the importance of providing information in advance about the features provided in the app. Thus, if, as emphasized by the above-mentioned recommendations, multiple modalities of interaction are expected, it is relevant to provide this information also directly in the store.

PROVIDE ALTERNATIVE FEEDBACK MODALITIES

Provide feedback about avatars' status in the virtual environment

Problem

When interacting with others, the user is immersed in a virtual environment that is dynamic since its status may change over time. This is referred to the fact that more people may join in the event, just as others may leave. As in real life, for deaf people there are moments of scare or surprise at the arrival of new avatars, since they may appear without warnings from the VR system.

Solution

It is necessary to provide the player with information on the status of the virtual environment in terms of updates of appearance and abundance of avatars in the environment, with the aim to keep them informed of what is happening around them. This information must be provided through multiple modalities, with the use of sound accompanied by a visual clue.
For example, a few seconds before the arrival of a new avatar in the environment, an indication may appear in the top right-hand corner *"John78 is joining the event"* accompanied by an appropriate sound, which remains viewable for a few seconds, and then disappears or can be removed directly by the user.

Possible threats

A possible threat is understanding how to manage this visual element at a UI level, since the simultaneous appearance and abundance of many users it may overfill the interface, taking away space from other relevant information.

Source

This recommendation stems from the experiment, where deaf users declared to have been frightened by the unexpected arrival of the other avatar. No official guidelines about VR are provided about this topic, while Game Accessibility Guidelines remarks on the relevance of this feature in video games.

AUDIO PERSONALIZATION

Offer audio customization settings

Problem

For oralist deaf, audio is still a relevant component. Often, however, the co-presence of many sounds can lead them to not distinguish the voice of the person they are conversing with, as might happen within a virtual environment.
Moreover, in the case of unilateral deaf people, they may have difficulty understanding the sound in its totality due to the spatial audio mode used in VR, which reproduces audio accordingly to the position of the sound source with respect to the user.

Solution

The solution is giving the possibility of manually controlling the audio volume of different sources, whereby in Social VR apps it is necessary to separate the voice of the avatars from background sounds. Regarding unilateral deafness, providing mono audio customization is necessary, to ensure the reproduction of all the sounds present in the environment in both ears. This ensures a better enjoyment of the audio of the conversation and thus a more fluid and enjoyable interaction.

Source

These are both guidelines already existing, respectively provided by Meta Quest and by W3C.

IMPROVE CLUES' CLARITY

Provide in-app tutorials about social interactions between avatars

Problem

For a first user of the platform, it is necessary to start by familiarising with it to understand the organization and how to interact with it. In Social VR platforms, communication turns out to be the central action, so users may need to get at ease with this function before being in a real situation within a virtual space, where they may have problems or not know which are the possible modalities of interaction to communicate with others.

Solution

It is necessary to include demo environments that have the function of tutorials where the person, in addition to becoming familiar with the platform, has the opportunity to get to experience all the possible modes of human-to-human interaction intended in the platform: voice input and microphone on/off, use of written chat, use of emojis if present, and more. In order to do this, a fictitious character can be present in the tutorial, who will speak to the user, asking him to interact with him through the different modalities, in order to prepare the user to interact in the real virtual space with other avatars.

Possible threats

The effort required in the creation of a tutorial with a fictitious character able to provide clues based on the users' actions needs to be evaluated.

Source

This guideline stems from the experiment, where users discovered all the modes of communication only at a later stage. Meta Quest provides official guidance in regard to in-app tutorials, where the player can experience interaction with the platform. Such guidelines are unsatisfactory for Social apps, as they exclusively regard the human-machine interaction, such as how to select a specific call-to-action, and not focusing on human-to-human interaction.

IMPROVE CLUES' CLARITY

Provide easy and constant access to chat messages

Problem

Written chat represents an alternative modality of interaction besides the voice. The use of written chat to communicate involves sending and receiving of messages by different users, which must be managed by the platform to be easily accessible by the player and to be straightforward in informing him/her about the receipt of new messages.

Solution

It is necessary to provide the chat feature as fixed and constant CTA in the display. This allows an easy and constant access to this feature through which the player can send and receive messages.
The chat icon has to include information on the received number of message and to provide visual feedback on the receipt of new ones, such as a change of number in the counter, the display of a message preview, a visual micro-animation, or feedback at a tactile level.

Possible threats

A possible threat is to understand which is the best way to inform about the status of messages in order not to create overlap with other UI elements in the display.

Source

The experiment revealed the potential relevance that written chat can have.

REALISTIC AVATAR'S REPRESENTATION

Provide realistic facial expressions and labial

Problem

The rigid and static facial expressions of the avatars create a great obstacle as they prevent deaf users from relying on the observation of face and thus not being able to understand the attitude and also lip-reading, creating difficulties in understanding the speech content.

Solution

The implementation of more realistic and similar-to-reality facial expressions represents an absolute priority for deaf users. The facial representation has to be responsive to facial movements, of the lips, of the eyes, and of the entire face. This would allow the reception of information about the conversation on a verbal as well as emotional level.

Possible threats

The realization of increasingly realistic avatars could lead to the uncanny valley effect, where the avatar is perceived as disturbing because it is realistic but perceived as artificial. Meta is already working on the implementation with Project Cambria which aims to improve facial expressions through VR, but it may take a long time given the effort required to achieve an optimal result.

Source

This guideline stems from experiment results, where deaf interviewees stated that they needed more realistic facial expressions to lip read. Moreover, facial expressions represent a visual clue that deaf people relied on during the experiment, which highlights their relevance.

REALISTIC AVATAR'S REPRESENTATION

Provide realistic avatar's body language

Problem

The current level of realism of the avatar body and hand movement is not fully appreciated, as it is seen as very rigid and approximate, and therefore limited in conveying useful information about the conversation.

Solution

It's necessary to provide more fluid and detailed avatar's body movements, such as adding arms, which are not depicted in AltspaceVR, and provide more detail in hand movements. The aim is to allow the user not to visualize the avatar as a robot, but as an actual virtual representation of the person they are conversing with.

Source

This recommendation represents a non-primary priority and stems from the experiment, where deaf people stated that they find as quite useful to have a more fluid and detailed body language.

AUTOMATIC SUBTITLES

Provide accessible subtitles in terms of characteristics & position

Problem

As the experiment revealed, deaf users have difficulty in understanding what the other avatar is saying. Due to their condition, they cannot therefore exclusively rely on sound to receive information and thus to socialize with others.

Solution

It is essential for deaf people to introduce automatic subtitles that convert into text live conversations, which have to meet the following requirements for achieving optimal readability and accessibility:

CHARACTERISTICS

- Use of a font that guarantees high readability, such as Serif, Monospaced ones, and San Serif, where the latter is recommended.
- The default font size is recommended to take up about 10% of the screen and then modify it based on the specific VR experience (Meta Quest, 2022).
- Prefer a sentence length of no more than 2-3 lines (Meta Quest, 2022).
- Use text with a solid background, which has to provide a high level of contrast, by using respectively white for the text and black for the box below.
- Ensure a correct timing of appearance and disappearance of captions that are synchronized with the speech and that allows reading.
- Offer the possibility of translating foreign languages into the default language according to the preferences set in the subtitle settings.
- Provide custom settings to change font sizes, where three fonts are provided (small, default, bigger) and give the possibility to change fonts from the pre-set ones.
- Easily access the settings to be able to activate or deactivate subtitles, via a fixed CTA placed on the display interface.

POSITION

- It's recommended the use of speech bubbles, whereby subtitles are placed above the head of the avatar that is speaking, in head-locked mode.
- Subtitles have to be 3D space responsive, and therefore be readable and accessible from every perspective and responsive to the eyes' gaze of the player, for him to always be in control of the situation.
- Subtitles have to be consistent with the closeness or distance to the avatar who is speaking: as the audio fades away when the user is getting further to the avatar who is speaking, in the same way, subtitles have to gradually disappear. Therefore, the subtitles background will become increasingly lighter as the user will move away from who is speaking until the subtitle is no longer displayed.
- When not visually framing the people's talking, the subtitles need to be presented at the eyes' gaze in the middle of the screen. To be clear for the deaf person, they have to include also the name and face of the avatar, for him or her to understand who is actually talking. Moreover, an arrow indicating the provenance of sound and, therefore, where the user is located is necessary.

Possible threats

Live subtitles are made possible by automated speech detection, which transforms speech into written text, which may require a lot of effort in terms of technological implementation.
An obstacle that may arise with live subtitles is the efficiency of the technology, which may have issues that make the display and thus comprehension slow. Moreover, another problem concerns the mode of appearance, where the pop-in mode is normally suggested for subtitles, which allows the sentence to appear all at once and thus the person to read at their own speed. In contrast, in the case of live conversations, the used mode is scroll-up captions, where therefore one word will appear at a time, which may be causing a dizziness effect for deaf people.
Another issue relates to timing, where the speed of the conversation might be too fast to allow for accessible reading in terms of timing.
In addition, the experiment did not allow testing of subtitles as they are not provided; therefore, the testing of these features is required to define in detail what the requirements are.

Source

This represents a compilation of the recommendations provided by various institutions, Meta Quest, W3C, and Myles De Bastion's user's recommendations, thus representing an overview of the points emphasized by each.

ACCESSIBLE PRODUCT DESIGN

Provide accessible headset in terms of product design

Problem

The current product design of the headset is unable to fully accommodate hearing aids, as the back strap sits exactly on top of the aid, causing it to fall off. This can lead to the hearing person having to spend time figuring out how to position both devices so that they do not hinder each other.

Solution

The recommendation is to revise the VR headset design to work better with cochlear implant and hearing aids, and thus not have difficulties when using VR for being scared that the aids might fall off.

Possible threats

It is seen as an activity requiring high effort since it concerns the physical design of a product already in production

Source

This suggestion stems both from Merlyn Evans' user feedback as well as from the experiment, where the difficulty of wearing the headset without hindering the proper functioning of the cochlear implant emerges.

6.2 Future developments

The final output of this research and experimentation represents a starting point for ensuring the accessibility of deaf individuals in VR experiences. In fact, it emerges as necessary to carry out further rounds of interviews with a higher sample of users, where to test these suggestions and gather feedback through multiple iterations.
Hence, it would be required to create a prototype of a Social VR environment in which all the above-mentioned recommendations and guidelines are implemented, in order to gather user feedback to make suggestions more detailed and gather possible new ones. Therefore, it would be required to proceed with the following phases of the Double Diamond, Develop and Deliver, to create a solution embracing all the identified guidelines and test it.
Furthermore, during the experiment with AltspaceVR, it was not possible to test subtitles as they were not present; further tests would allow this aspect of the experience to be tested as well.

Performing multiple iterations and testing would also allow an understanding of which features are must-haves, and which others represent a secondary priority. This would be extremely relevant for developers, who would then have an indication of which features to prioritize and what to focus their efforts on.

The need for additional exploration also emerges from the interviewees themselves. Indeed, the experiment concerned exclusively deaf users with cochlear implants, who, as pointed out in Chapter 1.1.3, have a specific approach to deafness, different from the one of signing deaf or even those wearing hearing prostheses. Their needs are different, and this would require specific testing to highlight the specific obstacles they have to face in a Social VR environment and thus their different needs in terms of accessibility.

Another important aspect is the fact that the experiment focused on one specific type of VR experience: Social VR. VR platforms have different purposes, not only socialization, but also games, entertainment apps, learning apps, and much more. For this reason, it would be necessary to understand though testing whether these guidelines designed for Social VR are applicable to other types of VR and thus are equally effective. If this is not the case, it would be necessary to define new guidelines according to the different needs of the diverse types of VR experiences.

In conclusion, this research represents a starting point for the intersection between VR and hearing disability, since it is a topic that needs to be explored more in order to ultimately validate the accessibility guidelines.

Conclusions

Through the process carried out in this thesis, the research questions posed in the initial phase were answered.
With regard to the first of them, concerning how the current context responds to the specific needs of deaf people at the level of interaction, it was possible to finalize the research thanks to the presence of numerous research and literature regarding deafness in all its aspects, from the more strictly medical aspect to a more social one and so on. The investigation showed that various institutions and experts have established accessibility guidelines so that the external environment can be inclusive toward deaf people. This is certainly a positive fact, which underlines the intent to ensure inclusion and highlight a general focus on disability issues.

Concerning the second question, related to the accessibility in VR, the results are not so positive. Guidelines have been established to offer inclusive experiences in VR which, however, as pointed out by Stuttgart Media University, are not comprehensive and complete (Heilemann et al, 2021, p. 7). This lack even led some individuals to independently define recommendations to highlight what are their current barriers.
The performed experiment has the intent to respond to this gap and highlight which are the missing guidelines at the level of human-to-human interaction
In order to gain relevant insights from the experiment, two measurement methods were created: the first one aims to help the respondent recognize what the other person's emotions and attitude were during the conversation, and the second one to allow him/her to identify which elements in the conversation were relevant to distinguish the speaker's attitude, such as identifying the relevance of facial expressions, tone of voice and so on. Both models included the Likert scale to assign scores to the various items.
These two tools played a central role in the experiment, allowing for the collection of both qualitative and quantitative data, which enabled a straightforward comparison of the deaf respondents' experience with that of the hearing ones. This allowed the understanding of the impact of the lacking of accessibility.

In addition to this testing, the following measurements could be reused in future iterations of the project, where the next step would be the creation of a Social VR prototype in which the guidelines defined in Chapter 6 would be integrated. Then, the prototype would be tested and the use of the same experiment's protocol would be suggested to allow an easy comparison of the level of accessibility that emerged from the experiment carried out in the thesis with hypothetical subsequent iterations. This comparison would highlight the degree of improvement in the level of accessibility of the experience between the first testing and the following ones.

The performed experiment turns out to have a very specific structure because of the specific target audience of the thesis, which is why it would not be scalable in the way it currently is. However, its human-to-human communication approach could be useful for other VR-related experiments that focus on the communicative aspect and deal with accessibility issues, but for other disabilities. For example, in the case of testing with visually impaired people, the structure of the experiment could be a starting point for creating an experiment specifically tailored for blind people, therefore allowing to understand what the accessibility problems are at the communicative level for other disabilities.

Beyond disabilities, this thesis experiment could also be functional for other contexts in which VR is already in use, as in Air France, Airbus, and Boeing, where VR is used to train new workers to operate machinery without jeopardizing the integrity of the equipment or endangering the individual (Christiansen, 2020). This is the current exploitation of VR but, hypothetically imagining that this technology could be increasingly more integrated into workplaces in the future, it may also be used for collaborative aim between workers for certain tasks, as an example. However, the environment in which they are working is that of the factory, characterized by loud noises from the various machines, which could therefore hamper the fluidity of communication among employees. For this reason, performing an experiment such as the one recounted in this thesis could be valuable to understand whether the conversation is accessible under these circumstances and what the workers' needs might be to communicate and understand the dialogue in a clear and accessible manner.

This example concerns the momentary inability to rely on hearing, which raises the topics of permanent and momentary disability. Indeed, notable to remark is that disabilities could have different duration of time, where a momentary one may correspond to a broken arm as well as an ear infection in the case of hearing, as an example, thus circumstances that would make it impossible to rely on one sense for a defined period. It is important to design in an accessible way for the possible occurrence of these episodes as well since an accessible design would make the experience inclusive even for those living a temporary issue, but becoming also relevant because of the increase in expectations about the increasing number of people who will be experiencing hearing loss. As reported in chapter 1.2.3, the World Health Organisation has pointed out that in 2050 2.5 billion people will be living with some degree of hearing loss, corresponding to nearly 1 in every 4 people (World Health Organization, 2021, p. 141).

In conclusion, there's still room for improvement in allowing accessibility in Virtual Reality for deaf users, which results in being currently excluded from the social experience. Paying attention to accessibility problems and responding promptly to them is an increasingly urgent action to be taken into account.
Indeed, this thesis also aims to push others to conduct a further investigation about hearing disabilities as well as other pathologies, in order to gain insights about the level of accessibility provided for individuals affected by other disabilities, with the high-level objective of making our society more inclusive.

Bibliography

Accessible Games (2022) *Accessible Player Experiences* (APX) [online]. Available at: https://accessible.games/accessible-player-experiences/#access-patterns (Accessed: 1 July 2022)

Ai-media. (no date) *What is Audism? 5 Examples to Learn and Avoid* [online]. Available at: https://www.ai-media.tv/ai-media-blog/what-is-audism-5-examples-to-learn-and-avoid/ (Accessed: 10 April 2022)

Alsop, T. (2022) 'Forecast for the number of active virtual reality users worldwide from 2014 to 2018', *Statista*, 8 February [online]. Available at: https://www.statista.com/statistics/426469/active-virtual-reality-users-worldwide/ (Accessed: 16 July 2022)

Amplifon. (2021) *Coronavirus: mascherine trasparenti per non udenti* [online]. Available at: https://www.amplifon.com/it/news/mascherine-coronavirus-per-non-udenti (Accessed: 29 May 2022)

AltspaceVR. (2023) *AltspaceVR will shut down on March 10*, 2023 [online]. Available at: https://altvr.com/ (Accessed: 5 January 2023)

Bardi, J. (2019), 'What Is Virtual Reality: Definitions, Devices, and Examples', *3D Cloud*, 26 March [online]. Available at: https://www.marxentlabs.com/what-is-virtual-reality/ (Accessed: 25 July 2022)

BBC (2022) *Subtitle Guidelines, BBC* [online]. Available at: https://www.bbc.co.uk/accessibility/forproducts/guides/subtitles/#Subtitle-Guidelines (Accessed: 10 July 2022)

Barlet, M. C., Spohn, S. D. (2012) *Includification. A practical guide to game accessibility*, 1st edn. Kearneysville: The AbleGamers Foundation

Bates, M. (2012) 'Super Powers for the Blind and Deaf', *Scientific American*, 18 September [online]. Available at: https://www.scientificamerican.com/article/superpowers-for-the-blind-and-deaf/ (Accessed: 30 May 2022)

Bauman, H. (2010), *DeafSpace Design Guidelines Volume 1*. Working Draft 11 August 2010, Washington: Gallaudet University

Beeston, J., Power, C., Cairns, P. & Barlet, M. (2018) 'Characteristics and Motivations of Players with Disabilities in Digital Game', *Cornell University* [online]. Available at: https://doi.org/10.48550/arXiv.1805.11352 (Accessed: 25 June 2022)

Bellanti, E. (2019) 'Che cosa è l'Audio Spaziale (...e l'audio binaurale)?', *Wonderland Production*, 23 December [online]. Available at: https://www.wonderlandproduction.com/che-cosa-e-laudio-spaziale-e-laudio-binaurale/ (Accessed: 8 September 2022)

Beltone (2019) *Does hearing loss heightened the other senses?* [online]. Available at: https://www.beltonepa.com/blog/does-hearing-loss-heighten-other-senses (Accessed: 14 May 2022)

Benetti, S., Van Ackeren M. J., Rabini, G., Zonca, J., Foa, V., Baruffaldi, F., Rekz, M., Pavani, F., Rossion, B. & Colligon, O. (2017) 'Functional selectivity for face processing in the temporal voice area of early deaf individuals', *PNAS*, vol. 114 (no. 31) [online]. Available at: https://doi.org/10.1073/pnas.1618287114 (Accessed: 14 May 2022)

Benetti, S. (2017) 'La plasticità celebrale nelle persone sorde', *UniTrentoMag*, 19 October [online]. Available at: https://webmagazine.unitn.it/ricerca/28579/la-plasticit-cerebrale-nelle-persone-sorde(Accessed: 12 May 2022)

Berke, J. (2022) 'Deafness and Balance Problems in Infants and Children', *Very well health*, 1 June, [Online]. Available at: https://www.verywellhealth.com/deafness-and-balance-problems-1046328 (Accessed: 28 May 2022)

Better hearing. (no date) *How Hearing Works* [online]. Available at: https://betterhearingct.com/how-hearing-works (Accessed: 01 May 2022)

Borghesi, M. (2020) 'The importance of audio in Virtual Reality', *Vajont VR Devblog*, 21 July [online]. Available at: https://vajont.artheria.it/en/the-importance-of-audio-in-virtual-reality/ (Accessed: 7 September 2022)

Candolo, T. (2022),'Il metaverso', *Copernico*, 10 January [online]. Available at: https://www.copernicosim.it/il-metaverso/ (Accessed: 30 July 2022)

Cardon, G., Campbell, J., Sharma, A. 'Plasticity in the Developing Auditory Cortex: Evidence from Children with Sensorineural Hearing Loss and Auditory Neuropathy Spectrum Disorder', *J Am Acad Audiol*, vol. 23 (no. 6) [online]. Available at: https://doi.org/10.3766/jaaa.23.6.3 (Accessed: 5 June 2022)

Carlyon, R. P., Goehring, T. (2021) 'Cochlear Implant Research and Development in the Twenty-first Century: A Critical Update', J*ournal of the Association for Research in Otolaryngology*, vol. 22 [online]. Available at: https://doi.org/10.1007/s10162-021-00811-5(Accessed on: 16 May 2022)

Cause Effect Psychology. (no date) *Neuroplasticity – The Story of Paul Bach-y-Rita* [online]. Available at: https://www.cepsychology.com.au/neuroplasticity-the-story-of-paul-bach-y-rita/ (Accessed: 7 April 2022)

Censis. (2018) *I problemi di udito in Italia: ampiezza e complessità del fenomeno* [Online]. Available at: https://www.censis.it/welfare-e-salute/sentirsi-bene/i-problemi-di-udito-italia-ampiezza-e-complessit%C3%A0-del-fenomeno(Accessed: 23 May 2022)

Centers for Disease Control and Prevention. (2022) *Types of Hearing Loss* [Online]. Available at: https://www.cdc.gov/ncbddd/hearingloss/types.html (Accessed: 30 May 2022)

Centre for Excellence in Universal Design (2020) *What is Universal Design* [online]. Available at: https://universaldesign.ie/what-is-universal-design/ (Accessed: 30 June 2022)

Christiansen, B. (2020) 'The Use of AI and VR In Maintenance Management', *engineering.com*, 13 January [online]. Available at: https://www.engineering.com/story/the-use-of-ai-and-vr-in-maintenance-management (Accessed: 10 February 2023)

Clason, D. (2019) 'The importance of Deaf culture', *Healthy hearing*, 24 December [online]. Available at: https://www.healthyhearing.com/report/52285-The-importance-of-deaf-culture#:~:text=Understand%20that%20Deaf%20people%20listen,is%20a%20sign%20of%20respect (Accessed: 30 May 2022)

Cochlear. (no date) E*ssere un candidato ad un impianto Cochlear™*, [online]. Available at: https://www.cochlear.com/it/it/professionals/candidacy-considerations/cochlear-implant-candidacy#:~:text=L'impianto%20cocleare%20pu%C3%B2%20essere,una%20o%20entrambe%20le%20orecchie (Accessed: 20 May 2022)

Committee on Disability Determination for Individuals with Hearing Impairments (2005), *Hearing Loss: Determining Eligibility for Social Security Benefits*. Washington (DC): National Academies Press

Correll, R. (2022) 'Challenges That Still Exist for the Deaf Community', *Very well health*, 1 June, [Online]. Available at: https://www.verywellhealth.com/what-challenges-still-exist-for-the-deaf-community-4153447 (Accessed: 3 April 2022)

Costello, R., Lambert, M. & Kern, F. (2019) 'How Can Accessibility for Deaf and Hearing-Impaired Players be Improved in Video Games?', *International Journal of R&D Innovation Strategy*, vol. 1 (no. 1) [online]. Available at: http://doi.org/10.4018/IJRDIS.2019010102 (Accessed: 3 July 2022)

Deaf websites. (2013) *Audism* [online]. Available at: https://www.deafwebsites.com/deaf-culture/audism.html (Accessed: 8 April 2022)

Deaf websites. (2013) *Deaf Culture* [online]. Available at: https://www.deafwebsites.com/hearing-loss/high-low-frequency-hearing-loss.html (Accessed: 30 May 2022)

Deaf websites. (2013) *Learn Sign Language* [online]. Available at: https://www.deafwebsites.com/education/oralism.html (Accessed: 12 May 2022)

Deaf websites. (2013) *Oralism* [online]. Available at: https://www.deafwebsites.com/education/oralism.html (Accessed: 11 May 2022)

Deaf websites. (2013) *What is a Cochlear Implant?* [online]. Available at: https://www.deafwebsites.com/hearing-aids/cochlear-implant.html (Accessed: 10 May 2022)

Dinh, H. Q., Walker, N., Hodges, L. F., Chang Song and Kobayashi, A. (1997) 'Evaluating the importance of multi-sensory input on memory and the sense of presence in virtual environments', *Proceedings IEEE Virtual Reality* [online]. Available at: https://ieeexplore.ieee.org/document/756955 (Accessed: 26 September 2022)

DO-IT. (2022) *How are the terms deaf, deafened, hard of hearing, and hearing impaired typically used?* [online]. Available at: https://www.washington.edu/doit/how-are-terms-deaf-deafened-hard-hearing-and-hearing-impaired-typically-used#:~:text=%22Deaf%22%20usually%20refers%20to%20a,adequate%20assistance%20to%20process%20speech (Accessed: 12 May 2022)

Dougherty, J. M., Carney, M., Hohman, M. H. & Emmady P. D. (2023) 'Vestibular Dysfunction', *StatPearls Publishing*, 1 March [online]. Available at: https://www.ncbi.nlm.nih.gov/books/NBK558926/ (Accessed: 1 March 2023)

DTE staff. (2021) 'Every 4th person to suffer hearing loss by 2050: WHO', *DownToHeart*, 2 March [online]. Available at: https://www.downtoearth.org.in/news/health/every-4th-person-to-suffer-hearing-loss-by-2050-who-75718 (Accessed: 26 April 2022)

Dzardanova, E., Kasapakis, V., Gavalas, D. (2018) 'Social Virtual Reality', *Encyclopedia of Computer Graphics and Games*, 16 March [online]. Available at: https://doi.org/10.1007/978-3-319-08234-9_204-1 (Accessed: 26 August 2022)

Engati (2021) *What is Virtual Reality?* [online]. Available at: https://www.engati.com/glossary/virtual-reality (Accessed: 20 July 2022)

Evans, M. (2021), 'Accessible Virtual Reality: Advice from a Deaf Person on How to Make It Better', *Equal Entry*, 21 September [online]. Available at: https://equalentry.com/accessible-virtual-reality-deaf-advice/ (Accessed: 5 October 2022)

Fletcher, M. D., Thini, N. & Perry S. W. (2020) 'Enhanced Pitch Discrimination for Cochlear Implant Users with a New Haptic Neuroprosthetic', *Scientific Reports*, vol. 10 (no. 10354) [online]. Available at: https://doi.org/10.1038/s41598-020-67140-0 (Accessed: 8 April 2022)

Fletcher, M. D., Mills, S. R. & Goehring T. (2018) 'Vibro-Tactile Enhancement of Speech Intelligibility in Multi-talker Noise for Simulated Cochlear Implant Listening', *Sage Journals*, vol. 22 [online]. Available at: https://doi.org/10.1177%2F2331216518797838 (Accessed: 8 April 2022)

Folger, J. (2022) 'What Does Metaverse Mean and How Does This Virtual World Work?', *Investopedia*, 5 August [online]. Available at: https://www.investopedia.com/metaverse-definition-5206578 (Accessed: 3 August 2022)

Freethink. (no date) *This haptic suit lets you 'hear' music through your skin* [online]. Available at: https://www.freethink.com/hard-tech/haptic-suit (Accessed: 12 April 2022)

Galdieri, R. (2019) 'Cos'è il motion sickness VR', *player.it*, 8 July [online]. Available at: https://www.player.it/speciali/386296-vr-e-motion-sickness-cosa-ce-da-sapere.html (Accessed: 26 July 2022)

Game accessibility guidelines (no date). *A straightforward reference for inclusive game design [*online]. Available at: https://gameaccessibilityguidelines.com/ (Accessed: 5 July 2022)

GBD 2019 Hearing Loss Collaborators. (2021) 'Hearing loss prevalence and years lived with disability, 1990–2019: findings from the Global Burden of Disease Study 2019', *The Lancet*, vol. 397 (no. 10278) [online]. Available at: https://doi.org/10.1016/S0140-6736(21)00516-X (Accessed: 30 May 2022)

GDC. (2020) *Subtitles Are Changing, Don't Be Left Behind* [online video]. Available at: https://www.youtube.com/watch?v=fVFgSkZtCio&t=1462s (Accessed: 6 July 2022)

GDC Vault. (2019) *Accessible Player Experiences: A New Approach to Data Informed Design for Accessible Games* [online video]. Available at: https://www.gdcvault.com/play/1025719/Accessible-Player-Experiences-A-New (Accessed: 23 June 2022)

Gingiss, D. (2018) 'How Social Media Became a Game-Changer for the Deaf Community', *SocialMediaToday*, 9 January [online]. Available at: https://www.socialmediatoday.com/news/how-social-media-became-a-game-changer-for-the-deaf-community/514223/ (Accessed: 16 June 2022)

Granato, P., Shreekumar, V., Godefroy, O., Van Gansberghe J. and Bruyer, R. (2018) 'Measurement of the Ability to Recognize Facial Emotions over the Adult Lifetime in a Supra-Normal Sample', *iMedPub Journals*, vol. 4 (no. 3) [online]. Available at: https://clinical-psychiatry.imedpub.com/measurement-of-the-ability-to-recognize-facial-emotions-over-the-adult-lifetime-in-a-supranormal-sample.php?aid=23879 (Accessed: 9 January 2023)

Gutiérrez, M. A. A., Vexo, F. & Thalmann, D. (2008) 'Stepping into Virtual Reality', *Springer* (edn. 1), 29 March [online]. Available at: https://doi.org/10.1007/978-1-84800-117-6 (Accessed: 24 July 2022)

Hamilton, I. (2015) 'How to do subtitles well – basics and good practices', *Game developer*, 15 July [online]. Available at: https://www.gamedeveloper.com/audio/how-to-do-subtitles-well-basics-and-good-practices (Accessed: 8 July 2022)

Hear-it. (no date) *Hearing loss in Europe* [Online]. Available at: https://www.hear-it.org/hearing-loss-in-europe (Accessed: 25 May 2022)

Hearing Link Services. (2022) *Cochlear implants* [online]. Available at: https://www.hearinglink.org/your-hearing/implants/cochlear-implants/ (Accessed: 10 May 2022)

Hearing Link Services. (2022) *Deafness & hearing loss facts* [online]. Available at: https://www.hearinglink.org/your-hearing/about-hearing/facts-about-deafness-hearing-loss/ (Accessed: 30 May 2022)

Hearing Link Services. (2022) *What is a hearing aid?* [online]. Available at: https://www.hearinglink.org/your-hearing/what-is-a-hearing-aid/ (Accessed: 10 May 2022)

Hearing Link Services. (2022) *What is lipreading?* [online]. Available at: https://www.hearinglink.org/living/lipreading-communicating/what-is-lipreading/ (Accessed: 11 May 2022)

Heilemann, F., Zimmermann, G. and Münster, P. (2021) 'Accessibility Guidelines for VR Games - A Comparison and Synthesis of a Comprehensive Set', *Front. Virtual Real*, vol. 2 [online]. Available at: https://doi.org/10.3389/frvir.2021.697504 (Accessed: 6 October 2022)

Hoffman, M. F., Quittner A. L., Cejas, I., (2015) 'Comparisons of social competence in young children with and without hearing loss: a dynamic systems framework', *J Deaf Stud Deaf Educ*, vol. 20 (no. 2/April 2015) [online]. Available at: https://doi.org/10.1093/deafed/enu040 (Accessed: 6 April 2022)

Humphries, T. (1977) *Communicating across cultures (deaf -hearing) and language learning*. Ph. D. Thesis. Union Institute & University Ohio. Available at: https://www.proquest.com/openview/45c15e2d0846222f89c5a88ba615ac99/1?pq-origsite=gscholar&cbl=18750&diss=y (Accessed: 2 June 2021)

Istituto Superiore di Sanità. (2020) *Salute del bambino: l'importanza dei primi anni di vita nello sviluppo fisico e mentale* [online]. Available at: https://www.epicentro.iss.it/materno/linee-guida-oms-sviluppo-bambini-2020 (Accessed: 13 May 2022)

Joyce, A. (2022) 'Inclusive Design', *Nielsen Norman Group*, 30 January [online]. Available at: https://www.nngroup.com/articles/inclusive-design/ (Accessed: 25 June 2022)

Karns, C. M., Dow, M. W. & Neville, H. J. (2012) 'Altered Cross-Modal Processing in the Primary Auditory Cortex of Congenitally Deaf Adults: A Visual-Somatosensory fMRI Study with a Double-Flash Illusion', *JNeurosci*, vol. 32 (no. 28) [online]. Available at: https://doi.org/10.1523/JNEUROSCI.6488-11.2012 (Accessed: 4 April 2022)

Koetsier, J. (2018) 'VR Needs More Social: 77% of Virtual Reality Users Want More Social Engagement', *Forbes*, 30 April [online]. Available at: https://www.forbes.com/sites/johnkoetsier/2018/04/30/virtual-reality-77-of-vr-users-want-more-social-engagement-67-use-weekly-28-use-daily/?sh=60060e2818fc (Accessed: 30 August 2022)

La Nazione. (2018) 'Gioielli per i non udenti: così trasformano i suoni in luci e vibrazioni', *La Nazione*, 9 March [online]. Available at: https://www.lanazione.it/siena/cronaca/video/gioielli-sordi-1.3776764 (Accessed: 20 April 2022)

Lane, H. L. (1992) *The Mask of Benevolence: Disabling the Deaf Community*. 1st edn. New York: Alfred a Knopf Inc

Lanier, J. (2017) *Dawn of the New Everything: Encounters with Reality and Virtual Reality*. 1st edn. New York: Henry Holt and Company

Latham, R. (2012) 'NIH study shows the deaf brain processes touch differently', *National Institute of Health*, 10 July [online]. Available at: https://www.nih.gov/news-events/news-releases/nih-study-shows-deaf-brain-processes-touch-differently (Accessed: 8 June 2022)

Lee, K. M. (2006) 'Presence, explicated', *Communication Theory*, vol. 14 (no. 1) [Online]. Available at: https://doi.org/10.1111/j.1468-2885.2004.tb00302.x (Accessed: 30 July 2022)

Lewis T. (2013) *Do Deaf People Really Have Superhuman Vision?*, [Online]. Available at: https://www.livescience.com/41521-deaf-people-superhuman-senses.html (Accessed: 29 May 2022)

Mansour, S., El-Said, M., Rude-Parkins, C. and Nandigam, J. (2006) *The Interactive Effect of Avatar Visual Fidelity and Behavioral Fidelity in the Collaborative Virtual Reality Environment on the Perception of Social Interaction*, Stevens Point: World Scientific and Engineering Academy and Society

Maryville University. (no date), *3 Hearing Loss Types: Effects and Common Treatments* [online]. Available at: https://online.maryville.edu/blog/hearing-loss-types/#effects-of-hearing-loss (Accessed: 3 April 2022)

Max Deryagin's Subtitling Studio. (2017), *What Video Game Subtitling Got Wrong In 2017* [online]. Available at: https://www.md-subs.com/what-game-subs-got-wrong-in-2017 (Accessed: 12 July 2022)

McLeod S. (2023) *Maslow's Hierarchy of Needs, Simply Psychology*, 10 March [online]. Available at: https://www.simplypsychology.org/maslow.html (Accessed: 10 March 2023)

Meredith, A. M., Kryklywy, J., McMillan A. J., Malhotra, S., Lum-Tai, R. & Lomber, S. G. (2011) 'Crossmodal reorganization in the early deaf switches sensory, but not behavioral roles of auditory cortex', *PNAS*, vol. 108 (no. 21) [online]. Available at: https://doi.org/10.1073/pnas.1018519108 (Accessed: 15 May 2022)

Merlyn K Evans. (2019) *To highlight or not to highlight the captions?* [online video]. Available at: https://www.youtube.com/watch?v=m_UsLynsEJc (Accessed: 12 October 2022)

Meta. (2023) *What is the metaverse?* [online]. Available at: https://about.meta.com/what-is-the-metaverse/?utm_source=about.facebook.com&utm_medium=redirect (Accessed: 10 August 2022)

Meta Quest. (2022) *Designing Accessible VR* [online]. Available at: https://developer.oculus.com/resources/design-accessible-vr/ (Accessed: 5 October 2022)

Mindess, A. (2014). *Reading Between the Signs: Intercultural Communication for Sign Language Interpreters*. 3rd edn. Boston: Nicholas Brealey

Mittnacht, V. (2021) 'Do Hearing Impaired People Use Other Senses Better?', *Audicus*, 8 October [online]. Available at: https://www.audicus.com/do-hearing-impaired-people-use-other-senses-better/ (Accessed: 17 May 2022)

Mortaloni, A. (2021) 'Xbox Celebrates Global Accessibility Awareness Day', *Xbox Wire*, 20 May, [online]. Available at: https://news.xbox.com/en-us/2021/05/20/xbox-celebrates-global-accessibility-awareness-day/ (Accessed: 10 June 2022)

Mroz, M. (2022) 'Types of hearing loss', *Healthy Hearing*, 20 December [Online]. Available at: https://www.healthyhearing.com/help/hearing-loss/types(Accessed: 04/05/2022)

National Deaf Children's Society. (no date) *Lip-reading* [online]. Available at: https://www.ndcs.org.uk/information-and-support/language-and-communication/spoken-language/supporting-speaking-and-listening/lip-reading/ (Accessed: 10 May 2022)

National Institute of Deafness and Other Communication Disorders (2021) *Cochlear Implants* [online]. Available at: https://www.nidcd.nih.gov/health/cochlear-implants (Accessed: 13 May 2022)

National Institute of Deafness and Other Communication Disorders (2021), *Quick Statistics About Hearing* [online]. Available at: https://www.nidcd.nih.gov/health/statistics/quick-statistics-hearing#2 (Accessed: 13 May 2022)

Nguyen, H. (2021) 'Avatar types for virtual reality and augmented reality', *The New Real* [online]. Available at: https://www.nmy.de/en/blog/vr-avatare/ (Accessed: 1 August 2022)

Ofcom (2005) *Subtitling – An Issue of Speed?*. London: Ofcom

Open Signal. (2021) *Virtual Worlds Made Accessible Beyond Sound: Presentation and Q&A with Myles de Bastion* [online video]. Available at: https://www.youtube.com/watch?v=9l4aDH7HY3U (Accessed: 10 October 2022)

Pagan, E. (2017) 'The importance of sound in Virtual Reality', *University of Silicon Valley*, 18 July [online]. Available at: https://usv.edu/blog/virtual-reality-vr-sound-importance/ (Accessed: 3 September 2022)

Parlamento Italiano. (2006) 'Nuova disciplina in favore dei minorati auditivi', *Gazzetta Ufficiale* (n.63), 16 March [online]. Available at: https://www.parlamento.it/parlam/leggi/06095l.htm (Accessed: 20 May 2022)

Paul Ekman Group (no date) *What is disgust?* [online]. Available at: https://www.paulekman.com/universal-emotions/what-is-disgust/ (Accessed: 10 January 2022)

Paul Ekman Group (no date) *What is enjoyment?* [online]. Available at: https://www.paulekman.com/universal-emotions/what-is-enjoyment/ (Accessed: 10 January 2022)

Paul Ekman Group (no date) *What is fear?* [online]. Available at: https://www.paulekman.com/universal-emotions/what-is-fear/ (Accessed: 10 January 2022)

Paul Ekman Group (no date) *Universal Emotions* [online]. Available at: https://www.paulekman.com/universal-emotions/ (Accessed: 17 November 2022)

Pavani, F. & Bottari, D. (2012) 'Visual Abilities in Individuals with Profound Deafness A Critical Review' in editor Murray and Wallace, *The Neural Bases of Multisensory Processes*. Boca Raton (FL): CRC Press/Taylor & Francis, Chapter 22

Pillan, M. (2022) 'Comunicazione interpersonale' [Lecture], *099660: Processi e metodi di produzione di artefatti comunicativi*. Politecnico di Milano. 22 September. Available at: https://politecnicomilano.webex.com/recordingservice/sites/politecnicomilano/recording/87ff7d291c74103bab6f00505681f679/playback (Accessed: 5 November 2022)

Pisano, P. (2018) 'Come si sente con l'impianto cocleare', *Impianto Cocleare*, 17 June, [Online]. Available at: http://www.impiantococleare.info/soluzioni-contro-sordita/impianto-cocleare/cosa-possono-fare-gli-impianti-cocleari/ (Accessed: 16 May 2022)

QY Research. (2021) 'Global Social VR Market Size, Status And Forecast 2021-2027', *Market Insights Report*, 12 July [online]. Available at: https://www.marketinsightsreports.com/reports/07073049782/global-social-vr-market-size-status-and-forecast-2021-2027/inquiry?Mode=VIIIXX (Accessed: 29 November 2022)

Santos, T. G. T., Ramos Venosa, Luiz Lopes Sampaio, A., (2015) 'Association between Hearing Loss and Vestibular Disorders: A Review of the Interference of Hearing in the Balance', *Scientific Research Publishing*, vol. 4 (no. 3/May 2015) [online]. Available at: http://dx.doi.org/10.4236/ijohns.2015.43030 (Accessed: 28 May 2022)

Scope. (2020) *Accessibility in gaming report* [online]. Available at: https://www.scope.org.uk/campaigns/research-policy/accessibility-in-gaming/ (Accessed: 27 June 2022)

Sherman, C., (2019) 'The Senses: Hearing', *DanaFoundation*, 21 August [online]. Available at: https://dana.org/article/the-senses-hearing/ (Accessed: 22 May 2022)

Shield, B. (2018) *Hearing Loss – Numbers and Costs. Evaluation of the social and economic costs of hearing impairment. A report for Hear-It AISBL*. London: Brunel University London

Sid. (2022) 'The influence of sound design in UX', *Medium*, 28 January [online]. Available at: https://uxdesign.cc/the-influence-of-sound-design-in-ux-d4c910e25ef2 (Accessed: 10 September 2022)

Statista. (2022) *AR & VR - Worldwide* [online]. Available at: https://www.statista.com/outlook/amo/ar-vr/worldwide (Accessed: 20 October 2022)

Stoner, G. (2022), 'VR Is Here to Stay. It's Time to Make It Accessible', *Wired*, 1 March [online]. Available at: https://www.wired.com/story/virtual-reality-accessibility-disabilities/ (Accessed: 18 July 2022)

Tanni, V. (2020) 'Virtual Reality' [Lecture], *051475: Digital art*. Politecnico di Milano. 19 December. (Accessed: 10 June 2021)

Than, K. (2010) 'Why the Deaf Have Enhanced Vision', *National Geographic*, 12 October [online]. Available at: https://www.nationalgeographic.com/science/article/101011-deaf-enhanced-vision-brain-health-science (Accessed: 3 April 2022)
Thompson, S. (2022) 'VR Applications: 23 Industries using Virtual Reality', *Virtual Speech*, 1 March [online]. Available at: https://virtualspeech.com/blog/vr-applications (Accessed: 20 August 2022)

Titmus, D. (2023) *Accessibility For All Gamers* [Online]. Available at: https://vitac.com/accessibility-for-all-gamers/ (Accessed: 4 January 2023)

TED. (2015) *Can we create new senses for humans?* [online]. Available at: https://www.ted.com/talks/david_eagleman_can_we_create_new_senses_for_humans (Accessed: 11 April 2022)

TEDx Talks. (2022) *Social Interaction in the Era of Virtual Reality | Sylvia Xueni Pan | TEDxGoodenoughCollege* [online video]. Available at: https://www.youtube.com/watch?v=rh6e-mW_y5E (Accessed: 1 September 2022)

Totaljobs. (2016) 'Deaf jobseeker and employee experiences survey', *Totaljobs* [online]. Available at: https://www.totaljobs.com/advice/deaf-jobseeker-and-employee-experiences-survey-2016-research-conducted-by-totaljobs (Accessed: 10 April 2022)

United Nations. (2022) *International Day of Sign Languages*. 23 September [online]. Available at: https://www.un.org/en/observances/sign-languages-day#:~:text=Sign%20languages%20unite%20us!&text=According%20to%20the%20World%20Federation,than%20300%20different%20sign%20languages (Accessed: 15 May 2022)

Università di Siena. (2021) *Benvenuti al Fab Lab - Patrizia Marti* [online video]. Available at: https://www.youtube.com/watch?v=B9pjT6MjjCk (Accessed: 12 June 2022)

Valentine, G., Skelton, T. & Levy, P. (2018) *The Role of the Internet in D/deaf People's Inclusion in the Information Society*. Sheffield: The University of Sheffield

W3C. (2018) *Web Content Accessibility Guidelines (WCAG) 2.1* [online]. Available at: https://www.w3.org/TR/2018/REC-WCAG21-20180605/ (Accessed: 14 July 2022)

W3C. (2021) *XR Accessibility User Requirements* [online]. Available at: https://www.w3.org/TR/2021/NOTE-xaur-20210825/ (Accessed: 5 October 2022)

Wikipedia. (2023) 'Deaf culture', *Wikipedia*, 4 march [online]. Available at: https://en.wikipedia.org/wiki/Deaf_culture#Characteristics (Accessed: 5 March 2023)

Wikipedia (2022) 'Americans with Disabilities Act of 1990', *Wikipedia*, 7 March [Online]. Available at: https://en.wikipedia.org/wiki/Americans_with_Disabilities_Act_of_1990#Title_I%E2%80%94employment
(Accessed: 8 April 2022)

Wikipedia. (2023) 'Sensory substitution', *Wikipedia*, 27 February [online]. Available at: https://en.wikipedia.org/wiki/Sensory_substitution(Accessed: 5 April 2023)

World Health Organization (eds.) (2021) *World report on hearing*. Geneva: World Health Organization

XR Today. (2022) 'Why is the Metaverse Important?', *XR Today*, 11 March [online]. Available at: https://www.xrtoday.com/virtual-reality/what-can-you-do-in-the-metaverse-2/ (Accessed: 22 August 2022)

Young, H. J. (2019) *The Implications of Social Media on Communication Within the d/Deaf Community*. Utah: Utah Valley University

List of figures

Acknowledgements

Colgo l'occasione per ringraziare le persone che hanno fatto parte di questo percorso.

Alla **prof.ssa Pillan**, per avermi guidato in questi mesi con costanza e dedizione.

Alla mia **famiglia**, per essere un punto di riferimento costante e senza di cui non sarei arrivata dove sono oggi. In particolare ringrazio mia sorella **Francesca**, a cui è dedicato il mio elaborato di tesi.

A tutti i miei **parenti**, per il supporto continuo e l'affetto incondizionato.

A **Gaia** e **Alessia**, compagne di vita che da sempre rappresentano per me un punto fermo che non si allontana mai.

A **Mariella** e **Silvia**, preziose compagne di avventura con cui ho condiviso questi anni universitari, e che ora costituiscono una parte importante della mia vita.

A tutti gli **amici** e **amiche** che ci sono sempre stati anche da lontano.

Ed infine a **Francesco**, il mio più grande sostenitore che mi ha supportato e sopportato ogni giorno, rappresentando per me un porto sicuro.

L'augurio che faccio a me stessa è quello di continuare a crescere tramite nuove esperienze e di raggiungere nuovi traguardi, lavorando per ciò in cui credo e rimanendo sempre fedele ai miei valori.