Haptic Devices Designed for Hearing-Impaired People

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Haptic devices transmit information to the user, using tactile stimuli to augment or replace sensory input. People with limited sensory abilities, such as vision or hearing can receive supplementary information by relying on them.

haptic devices hearing impairment human–computer interaction

1. Introduction

Based on the number of people with a hearing loss greater than 35 decibels in their better ear [1], the World Health Organization has estimated that more than 5% of the world's population (around 430 million people) requires rehabilitation or treatment to deal with hearing impairment. However, this estimate increases to 1.5 billion when the number of people with a noticeable level of hearing is also taken into account [2]. In addition, it is estimated that this number could reach 2.5 billion people by 2050 [1].

Thus, given the high number of hearing-impaired people, efforts aimed at supporting the said population can positively impact a large part of the population, including those close to them. For example, parents of children with disabilities who receive support and have an action plan experience lower stress levels [3].

The World Health Organization has also estimated that the annual cost to the global economy due to the lack of proper care of the hearing impaired is 980 billion USD. These costs are transferred to the health sector (not including the cost of hearing devices such as cochlear implants), educational support costs, reduced productivity, and social costs [1]. In other words, efforts directed toward addressing the disability would not only benefit the concerned people but also their families and friends, as well as the society at large.

As Julia Taylor and Kellie Mote point out, accessibility refers to designing systems that allow everyone the same access and opportunities, regardless of their personal characteristics, ensuring that all can fully participate [4]. Therefore, accessibility is a step towards inclusion.

Certain technology tools for assistance can help people with hearing disabilities, thereby improving their accessibility and inclusion. One such example is the haptic technology, which consists of devices that apply tactile stimulation to the user. This technology allows deaf and hard-of-hearing (DHH) individuals to receive information through one of their fully functioning senses.

Aside from technology, policy implementation can also contribute to inclusion. In this regard, the United Nations has established a strategy titled “United Nations Disability Inclusion Strategy”. This strategy has four areas: leadership, strategic planning and management, inclusion, programming, and institutional culture [5].

The strategy aims to collaborate with people with disabilities in order to create an inclusive environment where they can integrate with both internal work of the parent organization and the external work of other organizations.

Haptic devices and technology play a key role in achieving the above strategy. In order to understand the relevance, it is important to first to know the difference between equality and equity. Paula Dressel states: “The path to equity will not be met by treating everyone equally. It will be achieved by treating everyone fairly according to their circumstances” [6].

This means that if you treat everyone equally, then individuals in disadvantaged situations will still be disadvantaged. For example, if a company offers video calling tools to all its employees to promote online meetings, a deaf employee will still be unable to hear their colleagues during such meetings, unless they have the option to transcribe the audio. Thus, to promote fairness, a deaf employee should receive support through a transcription tool.

Technology plays an important role in inclusion. It enables people with disabilities to fully participate in activities where they might otherwise be excluded from. People with partial or complete loss of one or more senses can better integrate into different activities by using devices that serve as sensory augmentations or substitutions, such as haptic devices.

In a previous study [7] the authors illustrated the potential of technology in promoting inclusion. Water polo is a sport played in a swimming pool, so athletes using hearing aids need to remove the device. As a result, they cannot hear the referee’s whistle during a match and have slower reaction times, which negatively impacts their team’s performance. To solve this problem, a waterproof haptic device has been developed that detects the sound of the whistle and translates it into vibrations in the athlete’s ear. If this device is available, offered and supported, water polo can become a more inclusive sport for hearing-impaired players.

People with disabilities face a variety of challenges that differ from those faced by the rest of the population. Technologies, including those mentioned above, are not intended to solve the entirety of their barriers. However, these devices can still be of substantial help in reducing the problems experienced during certain activities.

The Web Accessibility Initiative mentions three relevant aspects of accessibility [8]. First, it emphasizes that accessibility benefits people with or without disabilities. Second, it indicates that accessibility features are increasingly available in standard computing hardware, mobile devices, operating systems, web browsers, and various other tools. Lastly, it highlights that people perceive the world in a variety of ways, including touch, which is directly related to haptic technology. In addition, the Web Accessibility Initiative specifies that an accessible tool should be perceivable, operable, understandable, and robust [9]. Haptic devices provide increased opportunities to people with different disabilities by using touch as a communication channel, which differs from traditional media. For example, a device could increase its perceptibility by implementing tactile feedback. Similarly, devices that offers several options to communicate the same information, including the haptic channel, become more robust.

2. Hearing Impairment

Hearing impairment generally refers to a diminished ability to hear sounds and can range from barely perceptible noise to total deafness. It can originate from different areas, such as the conduction of sound to the inner ear, the perception of sound by the sensory cells of the cochlea, the processing of sound by the cochlear nerves, the auditory pathway, or cortical auditory centres [10].

Hearing impairment or hearing loss should be distinguished from other hearing disturbances such as hypersensitivity to sound (hyperacusis) or tinnitus, although these conditions can be caused by auditory loss itself [11].

Hearing loss implies that an individual is unable to hear as well as the average person, which is at least 20 decibels in both ears. It can be classified as, depending on its severity, into mild, moderate, moderately severe, severe, or profound hearing impairment [1].

Hearing impairment can be described through a variety of aspects. Depending on whether it affects one or both ears, hearing impairment can be unilateral or bilateral. Based on whether the person had already learned to speak before the hearing loss, hearing impairment can be pre-lingual or post-lingual.

In addition, hearing impairment can be symmetric or asymmetric depending on whether the hearing loss is the same in each ear. Moreover, it can be classified as either progressive depending on whether the loss increases over time or not. If the hearing loss is present at birth, it is said to be congenital, and if it appears at a later age, it is considered to be acquired [12]. From another standpoint, conductive hearing loss is present if sound conduction is impeded in some way through the external ear, the middle ear, or both. Sensorineural hearing loss is present if there is a problem with the cochlea or with the cochlea or neural pathway to the auditory cortex. Mixed hearing loss means both conductive and sensorineural loss are present.

Hearing loss can be caused by a variety of factors. On the one hand, hearing loss can be caused by temporary problems, such as wax build-up in the outer ear. Hearing loss due to eardrum ruptures caused by objects inserted into the ear, pressure, or sudden loud noises can heal over time if the loss is not severe. Ototoxic medicines, which can damage the ear, can result in temporary or permanent damage to the ears. On the other hand, constant exposure to loud sounds that damage the inner ear, as well as certain congenital or postnatal infections can cause permanent hearing loss. In addition, hearing loss can be hereditary or caused by conditions such as diabetes, high blood pressure, heart attacks, brain damage, or tumours [13].

3. Haptic Devices

Haptic devices allow for human–computer interaction through touch and external forces. Unlike traditional interfaces, such as visual screens and audio systems, haptic devices present mechanical signals that are perceived by human touch [14].

Haptic devices focus on tactile communication to transmit information, and these forms of information communication include the use of pressure, vibrations, and temperature [15]. In general, haptic devices work with the skin (the body's largest sensory organ), the musculoskeletal system, and other tissues. They send perceptual signals in the form of forces, displacements, or through electrical or thermal inputs to the user's skin and body. Specifically, the skin plays a critical role in perceiving and interacting with the environment [16]. Moreover, touch is an important aspect for human development [15].

Fleury et al. [17] present three general classifications of haptic devices. First, haptic devices can either be portable or anchored to the environment. They can also involve passive or active touch. Passive touch refers to the physical property of touching an object without exploring it; active touch refers to physically exploring an object through touch. Active touch is generated by the device using actuators and software, as most haptic devices use. Finally, the haptic device can either be in direct contact with the user at all times, intermittently, or be in indirect contact, as is the case with ultrasound.

Haptic devices can be further classified based on the type of their tactile interaction. As described in a previous study [18], there are a variety of tactile interactions, which are summarized below. Currently, there are no formal haptic device categories that correspond to different tactile interactions. Nevertheless, they can still serve as a broad classification tool.

- Vibration: applied normally or transversely to the skin's surface and can vary in frequency, amplitude, duration, or timbre.
- Contact/Pressure: an object can make contact with the body and then break that contact, alternating between these two states or varying the level of pressure.
- Temperature: changes in temperature, such as going from cold to hot, or from hot to even hotter.
- Geometry: shape, such as the curves or reliefs of an object.
- Texture: the sensation generated by touching certain surfaces, which may be smooth or rough, for example.
- Softness/Hardness: a material's resistance to pressure, such as when pressed by a finger.
- Electricity: electrical stimuli can be used to generate haptic sensations, known as electro-haptic stimuli.
- Friction: resistance to movement between two solid bodies whose surfaces are in contact.

4. Use of Haptic Devices for the Hearing Impaired

Sensory augmentation, as part of "hybrid biology", involves the addition of synthesized information to a person's sensory channel [19]. An example of sensory augmentation includes haptic devices, which transmit information through touch [20]. When external factors impact the information perceived through senses, people can use sensory augmentation. An example of this is the device shown in [21]; this device consists of a helmet for firefighters that uses vibrations to help them navigate in low-visibility areas.

Sensory substitution is a similar concept that is described as the use of one sense to provide environmental information that can normally be obtained from another sense [22]. Haptic devices can also be used here, as demonstrated in [23]. These devices use vibrations to alert people with hearing impairment about sounds coming from behind, such as greetings or calls for attention.

Compared to visual feedback, haptic feedback does not interfere with the user's view, and can be applied anywhere on the body [24]. As a result, haptic stimuli are considered to be relatively discrete. The haptic channel does not involve the user's vision and may be useful when someone is watching a movie in a foreign language. That individual either sees the movie or reads the captioning.

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