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Hearing aid solutions for children with autism

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ABSTRACT

Children with autistic spectral disorder (ASD) have difficulty in processing sensory inputs, especially auditory inputs. There have been a number of technological solutions that have developed based on different approaches in the form of hearing devices, however, limitations include the inability to successfully allow, through whitelisting, important sounds such as fire alarms and the sounds of cars and car horns. This paper proposes a hearing device supported by an application as a solution for children with ASD, the device is based on blacklisting and whitelisting features that allow for a reduction in auditory input through a selective process and contributes to selectivity through whitelisting for safety purposes. The proposed device will reduce distraction associated with hyper-responsiveness to certain auditory inputs, such as those from teachers or working group members, and increase concentration in the child by having fewer distractions.

1. Introduction

Autism or autistic spectral disorder (ASD) is a neurodevelopmental disorder that is characterized by qualitative impairments in communication skills and social interaction (Carter, 2014). According to the STAR Institute, 75% of children with autism have "significant symptoms of sensory processing disorder." A sensory processing dysfunction can manifest in a variety of ways, including motor delays, language delays, strong sensory aversions or interests, and an inability to interact with objects or people. This research paper will explore the issue of auditory sensory processing disorder or aversion, with the aim of designing an original hearing aid solution, or specifically a headset, for children with autism. The paper will begin by introducing the topic and discussing the ways in which sensory aversion affects these children. The normal hearing principles for children will be outlined, and subsequently, the ways in which this differs for children with autism. The paper will then discuss the specific headsets currently on the market. The advantages and disadvantages of the current products will be assessed before, in the research design section, a new product will be introduced. It is hoped that the proposed design will overcome the current issues that children with autism face with their existing headsets.

2. Literature review

2.1. Reported findings of hearing differences in children with ASD

Early signs of autistic spectrum disorder (ASD) include auditory communication. Until recently, most evidence that describes sensory processing disorders came only from parental reports, videotape analysis, and first-hand accounts. Such findings, however, have consistently shown that children with ASD have a prevalence of finding difficulty in processing auditory sensory information. Further evidence shows that children with ASD have unstable neural responses to sound (Otto-Meyer et al., 2018). Fernández-Andrés et al. (2015) compared sensory processing children with and without ASD both at home and in the classroom and found that in the classroom environment hearing and touch were the most affected, they recommended reducing unpredictable auditory inputs in the classroom.

According to Bennetto et al. (2017), children who are later diagnosed are more likely than those who do not develop ASD to fail to respond to their name being called (Baranek et al., 2013). This hyporeactivity has a classic diagnostic consideration whereby children who may have seemed to be deaf in early childhood did in fact have autism (Wing and Wing, 1971). Studies with older children have

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similarly found atypical processing of auditory input, including the abnormal perception of speech and non-speech stimuli including pitch, in addition to the perception of more complex input such as speech with background noise to certain sounds (O'Connor, 2012). Underresponsivity has been reported in other studies (Baranek et al., 2013). In a review of developmental patterns in children with autism, Greenspan and Wieder (1997) showed that 100% of the 200 participants showed difficulty responding to auditory signals in one way or another. In contrast, Jones et al. (2009) found that enhanced frequency discrimination is only found in 1 in 5 individuals who have ASD, which was perhaps not as great as earlier studies suggested. However, according to their clinical study, auditory frequency discrimination is increased in subgroups of people who have ASD that share characteristic, which, they claim, suggest a specific phenotype involved. They also claimed that individual differences in auditory discrimination can have an influence on sensory behavior "modulating the degree to which sounds are detected or missed in the environment" (Jones et al., 2009). While researchers claim that hearing loss is not causative for children with autism, findings appear to support the claim that hearing-impaired children show deficits common to autistic spectral disorder, for instance, impaired emotion or issues with vocal recognition (Most and Michaelis, 2012).

It is possible to measure auditory perceptual processing through assessment of the ability to discern between pure tones that vary according to frequency, duration, or intensity. Those who have high-functioning autism are better at frequency discrimination and categorization (Bonnel et al., 2003). Most research draws on what is termed event-related potentials (or ERPs) and points towards the detection of neural frequency changes enhanced at the pre-attentive level of ASD (Kujala et al., 2007). Evidence of superior identification of memory for pitch provides evidence for enhanced frequency discrimination (Heaton et al., 1998), and enhanced sensitivity for the pitch of closely spaced notes (Heaton, 2005).

The peripheral auditory system can be tested using what is known as otoacoustic emissions (OAEs): "Sound causes basilar membrane motion that results in voltage changes across cochlea outer hair cells causing them to change their length (due to the cochlear amplifier) and these length changes generate acoustic signals that can be recorded in the external ear canal (i.e., sound-evoked otoacoustic emissions)" (Bennetto et al., 2017). Measurement of the normal hearing process involves measuring a traveling wave that is enhanced using a local electromechanical amplification that is only present in cochlear outer hair cells. These hair cells are necessary for humans to distinguish between sounds where the frequency varies between 0.2 and 0.5 %. Damaged or less well-functioning hair cause impaired auditory tuning (Dallos, 1992). These hair cells are connected by neurons that originate in the area of the nuclei of the superior olivary complex which corresponds to the medial olivocochlear bundle (MOC), the activity of which is regulated by information that originates from the upper part of the brain. MRI imaged brains and autopsies from adults with ASD have been shown to have an absent or less developed olivocochlear region (Kulesza and Mangunay, 2008). More recently, Bennetto et al. (2017) revealed reduced cochlear responses at 1kHz for children with ASD however, they had comparable responses at 4-8 kHz frequency ranges to other children of the same age. They were able to use non-invasive measures and concluded that their methods may provide even more information about auditory processing deficits of ASD (Bennetto et al., 2017).

2.2. Auditory sensory processing disorder and how it affects children with ASD

Findings have suggested that physiological auditory impairments present in the brains of children with ASD lead specifically to an over-responsive or under-responsive type of sensory processing disorder. This subsequently leads to a lower threshold for sensory stimuli or input. This means that it is easy for such children to become overwhelmed, overstimulated, or irritated by an external stimulus. Oversensitivity or over-responsivity to a specific sensory input can affect a "child's willingness to play, explore, and feel safe or comfortable in his environment." McKernan et al. (2020) found that over-responsivity can predict amplitude discrimination in addition to the effect of adaptation for young people with ASD. This is often termed sensory defensiveness, as the child will defend themselves with a behavioral or emotional response, such as avoiding exposure to the sensory input. This is a physiological response that is referred to as "fight, fright, flight." As stated, this can have repercussions on their day-to-day life and engagement with the world around them.

The literature also supports the claims that atypical sensory experiences are commonly found in individuals with ASD. Ludlow et al. (2014) showed that children with ASD demonstrated significantly reduced mismatch negativity responses to words and pseudowords, furthermore, they tested the relationship between sensory processing and auditory processing and found that children with ASD showed more extreme sensory behaviors. As mentioned, they can result in significant distress and impairment, subsequently, this interferes with how the environment is processed by the brain negatively impacts adaptation. Parents and carers regularly report high levels of atypical sensory behavior such as placing hands over ears and a preoccupation with particular sounds (Baranek et al., 2013). Crucially, the literature also claims that sensory experience is paramount for the development of normal neuronal circuitry (Jiao et al., 2010). Where a child continuously blocks essential sensory inputs, they are more inclined to compromise normal neurodevelopment, this has implications for cognitive and social development (Dawson et al., 2007). It is not solely the children with ASD that are affected by difficulties in sensory processing, Suzuki et al. (2019) examined the association it had with the mental health of primary carers and found poor mental health outcomes.

2.3. Sensory headsets

Specifically, if a child is defensive or too responsive to auditory input, they may respond by covering their ears or are startled easily. This overreaction is manifest through a difficulty to self-regulate, meaning that a child may find no other way to block or avoid the sound other than the physical reaction. Auditory overstimulation or overload can occur in any environment and may make it difficult for a child to interact in a range of environments and contexts, such as at school. To address this, "sensory headphones," have been designed to help children manage the sensory input they receive and process.

Headsets are useful for children to wear in noisy environments, such as supermarkets or playgrounds, or in places where they need to pay attention to a single stimulus, for instance at school. They are also effective at altering the acoustics of echo-prone rooms such as cafeterias or sports halls.

Headsets are designed in a number of different ways. For instance, some work by blocking or canceling sound, and others by reducing it. Sound blocking and noise-canceling work by eliminating most of the auditory information the child is exposed to in any given environment. Some claim that this design may not be safe as the child may not be able to respond to what could be critical or important information, whether this is hearing their name being called or something more serious like an alarm or car horn. Furthermore, it could also compromise even further, the typical neurodevelopmental trajectory by not giving the brain a chance to develop its abilities in processing noise in challenging environments (Dawson et al., 2007). Rance et al. (2014) investigated listening devices that ameliorate auditory deficiency in children who have ASD, specifically, monaural and binaural processing skills were investigated to determine the effects of personal frequency modulation on listening ability, resulting in improved discrimination of speech in noise. While this device resolved hearing difficulties and improved social interaction, there was no consideration of whitelisting for safety purposes.

Instead, a noise reduction design helps to decrease the decibels that the ear has to process but it does not fully eliminate the noise. Such a design allows children to participate fully in what would otherwise be potentially loud environments or situations where there are a number of stimuli. It also means that they are aware of and interact to a greater extent with the environment around them. This has helped children to feel less alienated as a result of the device (Wang et al., 2013).

Other considerations in the design of a headset are the physical appearance and whether a child is comfortable with the positioning of the headset. For instance, some headsets are designed as an earphone to go inside the ear and others are designed as an earmuff to be worn over the ear. This may be more comfortable for some children but more visible. There are a variety of places that offer support for parents wanting to buy headsets. For instance, The Ear Plug Superstore provides a noise rating system that will help parents and children decide on where they will most benefit from using a sensory headset and what they want to get from it.

More recently, devices have been designed to accommodate more sophisticated software through the production of applications. These can tailor the individual requirements of a piece of hardware, offering more advanced services than simply noise canceling or noise reduction. Wang et al. (2013) for instance, proposed an interactive system for those with ASD to be able to focus on a preferred single auditory stream during a conversation. More recently, Winoto et al. (2016) designed an application that was based on a virtual reality simulation that interacted with the real world to create both an auditory and a visual aid for children suffering from both impairments. It worked by marrying the two stimuli in an interactive manner that strengthened both visual and hearing responses.

Finally, it is worth noting here that an alternative to headsets is the notion of auditory integration training (AIT) (Bérard, 1993). AIT typically includes a number of hours of exposure to music at a pre-described level of decibels. Treatment sessions are conducted over consecutive days or weeks, with the aim of exercising and toning muscles in the ear in order to enhance the ability to process sounds (Dominick et al., 2007). This is a method that is prescribed in the US despite insufficient evidence to support its efficacy (Kobari-Wright and Miguel, 2014). The following section will discuss a proposed new design for a headset that aims at combatting some of the issues described here.

3. Proposed design

The proposed design of the headset is a wireless noise-reducing earpiece that has the ability to be altered for the specific needs of the individual child. Moreover, the design consists of both hardware (earpiece) and software (an application). The application is intended to personalize the device in an original way, based on the concept of blacklisting and whitelisting.

The set will be based on the design of Wang et al. (2013) and will be composed of two noise canceling microphones mounted on the device which will sit in the ear and hook around the back of it, similar to some hearing aid designs. The audio stream will be picked up from the two microphones and converted into digital audio data. This data will then be inputted into the algorithms that will run on the application (the child will carry this around with them as it is designed to run on a mobile phone or small separate device if the child is too young to use a mobile phone). The earpieces will muffle extraneous noise and allows only the voice selected by the child.

The model also includes the design of software created and distributed through the use of an app. The application detects speakers and localizes them by using a speech processing algorithm. It will be designed to provide the child with a list of all recognized speakers and to let the user decide on which recognized voice it wants to focus on. This is similar in design to Winoto et al. (2016), who created a blacklisting mode, whereby if a user does not want to hear a speaker they had the option of adding the speaker to a blacklist. Then, whenever the application recognizes that a blacklist speaker is talking, it mutes the speaker. The same would work for 'whitelisting,' where if a voice from the whitelist is detected, it is outputted to the earphone. Whitelisting also includes important sounds such as fire alarms and sounds from cars and car horns, these sounds by default will be allowed and cannot be adjusted, due to safety reasons. The application will be able to store hundreds of voices and will learn more accurate recognition the more the application is used and the more it is exposed to a voice. The child will have the option to switch a speaker from blacklisting to whitelisting and vice versa, depending on the given situation, however, the whitelisting function that allows for sounds related to safety cannot be controlled by the child. The device will also work to muffle background sound; this can be lowered or increased easily enough using the application. This latter feature will be more effective in a classroom environment where instead of blacklisting individual peer voices, background sounds will be muffled, together with whitelisting the teachers' voice.

The hardware will be designed to be discreet, lightweight, and easy to remove. As it is wireless, it will be designed to work via Bluetooth to connect to the application. The device will be specifically suited for older children from 8 years of age and older. It is expected that the application feature can accommodate potential design features through software updates.

4. Impact on learning for the child

Based on similar designs outlined in the literature review and the research design/methodology, it is expected that the proposed headset will improve children's concentration in the classroom. By blacklisting and lowering background noise, it will be easier for the child to listen to the teacher's voice in class. Fewer distractions mean that the child can focus on the teaching content. The child is also able to alter whose voice the device focuses on at any one time, so during group work for instance, when classrooms are often noisy environments, again, the child can focus only on the students in their immediate environment or small group. This will have an impact on their ability to interact comfortably and contribute to discussions without being overwhelmed, as claimed by Winoto et al. (2016). A final impact based on Wang et al. (2013) study is that the child should have increased confidence and self-esteem, knowing that they are less likely to become overwhelmed or unable to take part in an activity due to noise. This again will have benefits for the learning process.

5. Conclusion

The causes and consequences of atypical sensory behaviors, together with their link to ASD still remain not fully understood. However, the current findings all suggest that differences in auditory information can result in atypical sensory experiences which become manifest in specific auditory sensory behaviors. Whilst many children with ASD suffer from an auditory sensory impairment, the specific nature of the impairment can differ greatly. This makes it difficult for auditory sensory headsets and earpieces to work efficiently for each individual's needs. The design described above uses downloadable software delivered through an application that can easily be adjusted on a smartphone or computer by a parent or child to meet their specific needs. It is proposed that the blacklisting and whitelisting feature will help make distinguishing voices much easier. The contribution that this design has over other designs is that it is able to allow important sounds such as fire alarms or car horns, thus increasing safety. This is something that cannot be controlled by the child. Finally, by operating via Apple or Android app stores, the device can be easily managed on a child's mobile phone or another wearable device without the need for extra equipment.

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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