The SenseHB Network

Creating a Zero-Barrier Air Travel for People With Sensory Processing Disorder

Benjamin D. Fedoruk, Int. Mathematics and Computer Science at Ontario Tech University
Kai Fucile Ladouceur, Mechanical Engineering Technician at Confederation College
Alden O'Cain, Software Engineering at Ontario Tech University

Track 4
How might we help cognitively impaired and people with intellectual disability?

January 31, 2022

Abstract

Sensory processing disorder (SPD) is prevalent amongst a sizeable proportion of the population, afflicting at least 1 in 20 adults [1]. Cases of individuals having SPD appear to be trending upward amongst school-aged children, with 5-16% of these children being affected [2] – many of whom have other cognitive impairments (e.g., ASD and ADHD) [3]. These travellers have difficulty navigating airports, which can be attributed in part to audio stimuli. Sensory rooms currently in use provide a space for those experiencing a breakdown to remove themselves from stimulating situations, but are not proactive in the prevention of breakdowns. The SenseHB Network proposes a method which would pipe audio into noise cancelling headphones. This technology allows people who suffer from SPD to block out external audio stimuli while allowing them to be aware of important airport announcements, such as flight information. The SenseHB Network utilizes BLE to allow for zoned announcements and stronger signal connection. The hardware required to implement this technology is also currently widely available in most airports. The SenseHB Network provides an original, user-centric, executable, and usable solution to benefit travellers who suffer with SPD.

1 Background

1.1 Description of SPD

Individuals with cognitive impairments often go unnoticed in the realm of public transit due to the lack of visual indicators. Sensory overload – a type of cognitive impairment – is often overlooked since it is often exhibited in supplement to other cognitive impairments [3]. Sensory processing disorder (SPD) is a neurological disability which alters the ability of the body to receive messages through the senses. The condition is characterized by improper motor and behavioural responses to stimuli in the environment. Thus, affected persons are unable to filter out background sensory information, causing overwhelm and over-stimulation in spaces with many different noises, smells, and people [3, 4]. This over-stimulation of the individual's senses is known as sensory overload, and can often prevent people from going to places with loud background noises (e.g., airports), keeping them in their homes [5].

Currently, SPD is much more prevalent within children than in adults, with only 1 in 20 adults suffering from the affliction [1], compared to the 1 in 6 children being affected worldwide [3]. Within certain subgroups of the population such as those with autism, a history of prematurity, fetal alcohol syndrome, or Down syndrome, this number is over 80% [3]. Living with SPD can be difficult for those affected due to its all-encompassing and chronic nature. Regardless of therapy or age, the disorder is ever-present in the lives of those impacted by it [5]. The best way to support those with the condition is to identify the potential triggers of a sensory overload, and taking a preventative instead of reactive approach to addressing them. A reactive approach addresses the triggers after the overload has occurred, whereas a proactive approach anticipates the potential overload and takes measures to reduce the triggers that the individual would face [3]. Some of the methods associated with a proactive approach taken by individuals include wearing sunglasses or noise-cancelling headphones [3]. However, these are only methods which the individuals themselves can take and do not include those which can be implemented by mobility service providers to maintain utmost comfort for affected passengers.

1.2 Epidemiology of SPD

Ubiquitously, SPD is seen in individuals with autism spectrum disorder (ASD) [6]. Sensory overload, however, is a concern for many individuals with attention deficit hyperactivity disorder (ADHD), post-traumatic stress disorder (PTSD), obsessive-compulsive disorder (OCD), schizophrenia, Down syndrome, fibromyalgia, Tourette syndrome, chronic fatigue, and anxiety [7–15]. Other conditions, including misophonia and synaesthesia [16–18] – among others – occasionally face sensory overload. Thus, it is increasingly critical for mobility service providers, such as the air travel industry, to accommodate individuals with SPD.

Those impacted by SPD – such as an individual surveyed in Thunder Bay, ON – claim that air travel is an extreme difficulty for people who experience sensory overload. He goes on to describe

The recorded video associated with this paper can be found at https://youtu.be/63ebVLU4ssI.

the benefits of noise-cancelling headphones and wishes that established technologies in the air travel industry would permit the use of noise cancellation.

1.3 Current Supports in Air Travel

In spite of actions airports have taken to create a more accessible space for those with disabilities (such as implementing pre-boarding for passengers with disabilities or wheelchair access) [19], air travel can still prove challenging for travellers with SPD. To ensure the comfort of affected passengers, airports, such as the Philadelphia International Airport, have made strides by implementing measures to aid these passengers in the event of sensory overload [20]. Such measures include sensory rooms and training for employees to properly assist travellers suffering with cognitive or sensory disabilities [19].

Sensory rooms were developed as a method of providing a safe space where passengers can momentarily escape from the chaotic airport atmosphere. In addition to these rooms, airports have also implemented training programs for both employees and passengers with disabilities. Employees receive disability training which allows them to spot those with cognitive disabilities and make their experience more comfortable [19]. Furthermore, preparatory training for passengers consists of simulating the experience of being at the airport by guiding participants through the airport and boarding an out-of-service plane; this is all done while practicing social skills at the various stages of the process [19].

Despite the temporary positive impacts of such policies and measures, they are also limited in their impact. Notably, this limitation lies within an inability to consistently prevent over-stimulation through the implementation of barriers between the passenger and the sources of stimulation. Sensory rooms are only useful when the passenger is using them; upon inevitable departure from the room, the overwhelming environment returns. Assistance provided for affected passengers by trained staff is limited in efficacy due to an over-extension and a surplus of tasks. Training passengers with disabilities to successfully navigate airports may prepare passengers for the experience, but again does not prevent their senses from becoming over-stimulated through unforeseen circumstances (e.g. flight delays and passenger influxes).

Thus, a solution for preventing sensory overload must include the use of a barrier to shield passengers, thereby reducing the amount of stimulation they experience throughout their time on-site. Currently, there exists a method to shield affected passengers – the use of noise-cancelling headphones and sunglasses. However, these solutions are not immune to complication. While noise-cancellation technologies have been proven effective at providing safety to individuals affected by SPD, and recommended by health professionals [3], they unfortunately have the problem of preventing affected passengers from hearing important announcements such as flight departure times. Hence, it would be advantageous to create a solution which works in unison with noise-cancelling technologies while allowing users to continue to interact with the airport network.

2 Design Analysis

2.1 Description of the SenseHB Network

The proposed solution to solve the problem as described in previous sections is the SenseHB Network – a Bluetooth network to provide in-ear announcements to individuals who struggle with SPD. The solution would include a downloadable smartphone app-based interface for users to alter their connection to the network, including customization of announcement preferences and additional services. The network would be appended directly onto existing Wi-Fi hardware throughout the airports. Airports would have the potential for data collection, making an implementation of the SenseHB Network a valuable investment, beyond providing comfortable services to all customers. All data collection would be opt-in to promote privacy. The SenseHB Network would provide incentives to those who opt to provide data (this will be covered in further detail in a later section). Users should have access to a Bluetooth-enabled device and a set of headphones (potentially with noise cancellation). There is a potential, if feasible, for the airport to provide travellers who experience sensory overload with Bluetooth-enabled devices or noise-cancelling headphones, however this specific implementation detail is not in the scope of this paper. Every implementation of the Network will be tailor-fitted to the specific and unique local conditions of each and every airport.

The SenseHB Network would include three node types. Firstly, a single Management Node would be required, providing a core for server-side management and distribution throughout the wider system. Secondly, a series of Distribution Nodes should be spread throughout the airport to provide coverage to all airport areas, allowing the SenseHB Network to serve all of its customers. Thirdly, users' devices will be termed End Nodes. The flow of information for the SenseHB Network is visualized in Figure 1 in the form of a data-flow diagram (DFD). This DFD divides the flow into three key layers, each with it's corresponding nodes: the Management, Distribution, and End Layers.

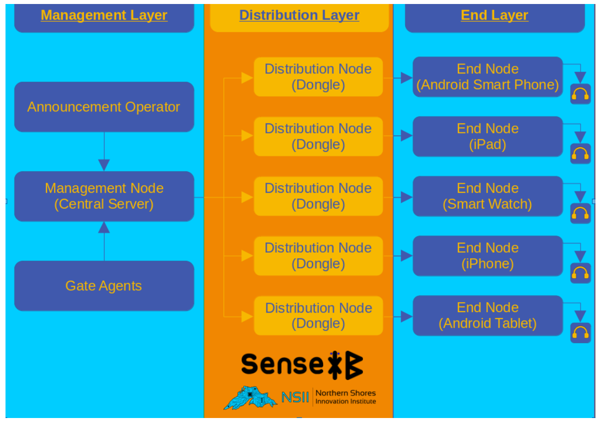

Figure 1: A DFD for the SenseHB Network

2.2 Ideal Bluetooth Technology

There are several key technologies that could be implemented. The three major, pertinent Bluetooth technologies are Classic Bluetooth, Zigbee, and Bluetooth Low Energy (BLE) [21]. For the SenseHB Network, the superior technology is clearly BLE. It offers various operational modes (as will be described herein) which are highly beneficial to the network. BLE also offers low power consumption compared to Classic Bluetooth [21, 22] – that is less taxing on the users' smartphones – as well as offers lower send times in comparison to both Classic Bluetooth and Zigbee [21] – which provides users with a seamless experience. There are several further areas of optimization which should be examined further to ensure a successful implementation of the SenseHB Network, including further research into the optimal use of the Bluetooth subband codec [23].

2.2.1 Operational Modes

The BLE Generic Access Profile (GAP) offers four key operational modes which make it an ideal candidate technology for the SenseHB Network [24]:

- central devices initiate and manage several connections to various other devices;
- peripheral devices are simple input devices;
- broadcasters can send out signals to an unlimited set of listening devices; and,
- observers can listen to any signals in their geographic area.

In the SenseHB Network, the users' devices use the Observer mode, while dongles use the Broadcaster mode. The Central/Peripheral pairing is not used for the network, as a Central device is limited to a mere nine Peripherals [21]. This implementation permits zoned announcements, as will be discussed herein.

2.2.2 Zigbee Transmitters

Although it is apparent that BLE is the optimal technology for the SenseHB Network, this does not necessitate exclusivity of the Bluetooth technology for all requirements of the network. Zigbee – a technology proven effective in smart home devices – provides an ideal technology to ensure fluid transmission between servers and dongles [21], or to permit information transmission between two distinct dongles, thereby allowing for a safeguard in the case of potential hardware failures. As such, alternative technologies – including Zigbee – should not be ruled out, as they may present benefits compared to using BLE exclusively.

3 Discussion

3.1 Value Proposition

Travellers with SPD undergo extended stress compared to travellers without SPD. Air travel proves especially challenging as airports contain numerous sources of over-stimulation, including: plane engines, crowded airport areas, announcement speaker systems, and lights. Passengers cannot easily control aural stimuli in these situations and are susceptible to experiencing a mental breakdown, which may involve shaking, crying, or loss of bodily mobility [3]. Undergoing a breakdown in a public setting can prove humiliating and debilitating, discouraging the use of air travel as a mode of transportation for those with SPD. Certainly, the potential of missed flights increases when travellers suffer such a breakdown. This has the further impact of causing undo expenses to airlines and airports as they oftentimes will provide accommodations to passengers and their families who have missed flights due to such breakdowns. Larger airports have tried to address the problem by providing sensory rooms for affected passengers, however as stated earlier, this kind of solution only provides momentary relief. With a sizeable portion of individuals being prone to sensory overload [3], travellers and airport administrators would benefit from having air travel that is more accessible. Barriers posed to travellers with SPD should be limited. All travelers should be able to travel safely and comfortably, regardless of ability. This is exactly what the SenseHB Network provides. It is a proactive solution which supplies constant relief for passengers with SPD without compromising their ability to interact with the airport network.

The Network permits passengers to use their noise-cancelling headphones to drown out external noise while still allowing for the reception of announcements and navigational directions. This is accomplished through the use of the user's smartphone. Airport and pilot announcements can now be heard through headphones, as they are piped directly into the mobile device. Upon testing and refinement, the SenseHB Network will significantly offset the frequency of aural over-stimulation, thereby increasing travel accessibility. An increase in travel accessibility will expand the market to new clientele who otherwise may have travelled at a reduced rate if at all.

Although this paper defines the SenseHB Network in an air travel context, it is not limited to the therein. This paper is focused on air travel, however there is the potential to make the Network deployable in several other contexts such as: train stations, bus terminals, educational institutes, and workplaces. The sheer number of global air travellers prove this implementation of the SenseHB Network to be highly beneficial. The goal of the novel SenseHB Network is to leverage technology to allow passengers who experience SPD to travel with fewer barriers.

In addition to travelers affected by SPD, the SenseHB Network would not be exclusionary. It could be easily provided as a luxury service for individuals who are not affected by SPD, to provide a more comfortable travelling experience. The SenseHB Network would enable these individuals to navigate an airport while listening to music or a podcast. This was previously infeasible, as passengers were forced to choose between listening to their media, or being alerted of potential, key flight information from an existing announcement system.

3.2 Optional Metrics and Analytics

3.2.1 Opt-In Structure

There exists an opportunity with the SenseHB Network to collect valuable user data, while maintaining privacy. User data that cannot be obtained from current records such as what path the traveller took through the airport and what stores they visited. This could be used to provide analytics to the airport that could be used to evaluate operations, for example how long a security screening process was took. These data provide incentive for administrators to consider an implementation of the SenseHB Network at an airport. Upon initial launch of the SenseHB application, an onboarding survey is presented to collect basic configuration settings. The application then modifies the tracked metrics according to the user's specified preference. A user of the Network will always have the right to opt-out of data collection at any given time. Provision of incentives (such as discounts on site or travel rewards points) encourages passengers to opt into having their data tracked. However, many of these minutiae should be varied based on the specifics of the implementation case.

Information that can be collected, includes but is not limited to: date, gate number, terminal number, seat number, travel class, airline name, departure airport, destination, boarding time, check-in status, and flight delays. Additional information can be obtained such as: arrival time at the airport, check-in time, and boarding time. Data collected from the application would focus on the perceived effectiveness of the solution by users. This data would be polls taken from users as to how they find the application and any potential recommendations they could have for software so as to ensure that solutions become increasingly tailored to specifically target the needs of the user base. Additionally, data could be used to determine how by this application has impacted those with SPD in their ability to go to the airport. This would especially be useful in determining the number of missed flights due to challenges.

3.2.2 General Location Tracking

The Distribution Nodes within the SenseHB Network would also be capable of tracking the geolocation of the user – a valuable insight that could be used by administrators to streamline their operations, make financial decisions, and determine if any changes are required to better serve passengers connected to the Network. Consent for this kind of tracking would be obtained through the use of a terms and conditions agreement that users can sign.

3.2.3 Zoned Announcements

Using geolocation services, the service is capable of providing zoned announcements – filtered announcements determined by the location of the Distribution Node to which the user's End Node is connected. Certain announcements may only be relevant for passengers within a certain radius of the source of the announcement, or may be meant for the area surrounding a specific gate (i.e. boarding calls). This reduces the overall volume of aural stimulation, ensuring that passengers only receive relevant announcements.

3.2.4 Navigational Assistance

The SenseHB Network provides navigational assistance for passengers traversing the interior of the airport through both audible, in-ear and visual, on-screen assistance. These assistance methods ensure comfort in travel for passengers during the boarding process. Additionally, this technology is capable of directing a passenger to an assigned seat on-board an aircraft. Navigational instruction, as described herein, removes a supplemental potential stressor for the traveller, which further increases comfort and ease of travel.

3.3 Impacts of Reducing Sensory Overload

By utilising the SenseHB Network, mobility service providers will be able to reduce the frequency of breakdowns caused by sensory overload. This would prove to be highly beneficial as at present, considering that there 5-16 percent of the population has SPD [25] it is reasonable to assume there are millions of individuals worldwide who are affected. Through the SenseHB Network, all parties involved will be satifisied with the results. Passengers with SPD and their families can now utilise air travel without fear of embarrassment and missing flights, and airlines and airports can profit from not having to spend their revenue on making accommodations.

3.4 Metrics for Success Determination

An implementation of the SenseHB Network would be classified a success or failure through surveys after the completion of their first segment of their voyage. Statistics regarding the frequency of breakdowns and their resulting missed flights, would prove beneficial in determining how to reduction in frequency of these incidents. Users who opt-in to provide additional data to the SenseHB Network would supply data regarding boarding times and delays. If the user opts to send additional data, it would also be possible to compare their actual boarding time to the expected boarding time and normal cut-off time for passengers boarding the aircraft. If the expected result is not achieved, secondary data would be used to modify the system, such as adding more user displayed airport information, distribution nodes or airport location data (e.g., restaurants, customer service kiosks).

3.5 Candidate Airport Criteria

Spending the time and money to implement this system may not be suitable for every airport; for example, some smaller, local airports do not have the flights, size, complexity, or integrated announcement system to make this worthwhile. At a minimum, the annual traffic through the airport would likely have to be 5 persons per year, or greater. If there are 100 persons on board a commercial flight on average, a candidate airport should have a minimum of 50 civilian flights per year. Alternatively, some larger international airports may be too complex to test this technology. However, once the proof of concept has been achieved, these complex airports would be a prime candidate for a deployment of the SenseHB Network because of their high passenger traffic, and complexity. Beyond airport's size, there would also need to be a historical track record of these problems existing operationally: passengers having public breakdowns, causing delayed and/or missed flights.

3.6 Proof of Concept

Implementing a proof of concept at two Canadian airports of medium size, the SenseHB Network can avoid the outcome of a stranded passengers at the destination airport. A sample route is from Hamilton, ON to Calgary, AB – two medium-sized airports in which the SenseHB Network can be promoted and made available to their passengers. Domestic routes within Canada are encouraged to avoid barriers in implementing the system at international airports such as different langauges, cultures and customs.

4 Conclusion

4.1 Originality

While the technology behind the SenseHB Network is not novel, the implementation of this in airports is. To date, no company has proposed to use Bluetooth technology in this manner. While there certainly have been those who researched and demonstrated the potential of having this kind of network in airports, none have gone so far as to implement their ideas.

4.2 User-Centricity

The SenseHB Network is effective because it solves the problem of sensory overload among those afflicted with SPD and has a broad application to the general public without sensory disorders. Anyone going through airports will be able to take advantage of this network and thus will be able to receive flight updates through their headphones so that they will never have to fear missing an announcement again.

4.3 Execution

The execution of the SenseHB Network is also a significant benefit of this paper as it utilizes accessible and affordable technology. Additionally, its implementation utilizes the existing infrastructure within airports, as well as technology that is commonly used by individuals afflicted by SPD, to further reduce the cost of the network.

4.4 Usability

The SenseHB Network offers a solution that mobility service providers like airports would greatly benefit from. By implementing this technology, airports will be less likely to encounter passengers breaking down to sensory overload, which frequently causes the passenger to miss their flight and force the airport to cover additional accommodations for passengers. This leads to significant costs incurred by the airport for each passenger. The reduction in these events lead to a more pleasant experience for all persons moving throughout the airport.

4.5 Future Areas of Research

Some potential future areas of research stemming from this initial paper include:

- the efficacy of the SenseHB Network upon collection of substantial data;
- methods to give increased autonomy in airports to those impacted by SPD;
- methods to connect radios used by staff to the network so as to allow them to talk to those with noise-cancelling headphones without causing them to remove their barrier from audio irritation;
- a modified device which runs the software through the sound systems within cars and personal vehicles, while reducing wind buffeting;
- the implementation of similar systems within other modes of public transit such as buses and metro lines;
- measures to address other senses such as vision or touch; and,
- approaches to making navigation of airports easier and faster for those with cognitive disorders.

Acknowledgements

The authors acknowledge the assistance in ideation provided by Dr. Alaa Khamis, and the editorial assistance provided by Harrison Nelson.

References

[1] Lucy J. Miller and Doris A. Fuller. *Sensational Kids: Hope and Help for Children with Sensory Processing Disorder (SPD).* Penguin, 2007.

[2] Aviva Yochman, Osnat Alon-Beery, Sribman Ahuva, and Shula Parush. Differential diagnosis of sensory modulation disorder (smd) and attention deficit hyperactivity disorder (adhd): participation, sensation, and attention. *Frontiers in Hum Seurosci*, 7(862), 12 2013.

[3] Michele Kong and Megan A. Moreno. Sensory processing in children. *JAMA Pediatrics*, 172(12):1208–1208, 12 2018.

[4] Janice Rodden. Sensory Processing Disorder: Overview and Facts, 11 2020.

[5] Alex Rice. Sensory processing disorder (spd). 8 2020.

[6] Elysa Jill Marco, Leighton Barett Nicholas Hinkley, Susanna Shan Hill, and Srikantan Subramanian Nagarajan. Sensory processing in autism: A review of neurophysiologic findings. *Pediatr Res*, 69(5 Pt 2):48R – 54R, 5 2011.

[7] Ahmad Ghanizadeh. Sensory processing problems in children with adhd, a systematic review. *Psychiatry Investig*, 8(2):89–94, 5 2011.

[8] Maria Panagiotidi, Paul G. Overton, and Tom Stafford. Multisensory integration and adhd-like traits: Evidence for an abnormal temporal integration window in adhd. Master's thesis, University of Sheffield, College Road, Stoke-on-Trent, Staffordshire, ST4 2DE, UK, 2017.

[9] Kevin Clancy, Mingzhou Ding, Edward Bernat, Norman B. Schmidt, and Wen Li. Restless 'rest': intrinsic sensory hyperactivity and disinhibition in post-traumatic stress disorder. *Brain*, 140(7):2041–2050, 7 2017.

[10] Arash Javanbakht, Israel Liberzon, Alireza Amirsadri, Klevest Gjini, and Nash N. Boutros. Event-related potential studies of post-traumatic stress disorder: a critical review and synthesis. *Biol Mood Anxiety Disord*, 1(5), 10 2011.

[11] Patricia Gruner and Christopher Pittenger. Cognitive inflexibility in obsessive-compulsive disorder. *Neuroscience*, 345:243–255, 3 2017.

[12] Premysl Vlcek, Petr Bob, and Jiri Raboch. Sensory disturbances, inhibitory deficits, and the p50 wave in schizophrenia. *Neuropsychiatr Dis Treat*, 10:1309–1315, 7 2014.

[13] Michelle G. Newman, Sandra J. Llera, Thane M. Erickson, Amy Przeworski, and Louis G. Castonguay. Worry and generalize anxiety disorder: A review and theoretical synthesis of evidence on nature, etiology, mechanisms, and treatment. *Annu Rev Clin Psychol*, 9:275–297, 2013.

[14] Andreas Hartmann, Yulia Worbe, and Kevin J. Black. Tourette syndrome research highlights from 2017. *F1000Res*, 7(1122), 9 2018.

[15] Simon Morand-Beaulieu, Julie B. Leclerc, Philippe Valois, Marc E. Lavoie, Kieron P. O'Connor, and Bruno Gauthier. A review of the neuropsychological dimensions of tourette syndrome. *Brain Sci*, 7(8), 8 2017.

[16] Jamie Ward, Claire Hoadley, James E. A. Hughes, Paula Smith, Carrie Allison, Simon Baron-Cohen, and Julia Simner. Atypical sensory sensitivity as a shared feature between synaesthesia and autism. *Sci Rep*, 7(41155), 3 2017.

[17] Jennifer J. Brout, Miren Edelstein, Mercede Erfanian, Michael Mannino, Lucy J. Miller, Romke Rouw, Sukhbinder Kumar, and M. Zachary Rosenthan. Investigating misophonia: A review of the emprical literature, clinical implications, and a research agenda. *Front Neurosci*, 12(36), 2018.

[18] Fabiola Atzeni, Rossella Talotta, Ignazi F. Masala, Camillo Giacomelli, Ciro Conversano, Valeria Nucera, Bruno Lucchino, Cristina Iannuccelli, Manuela Di Franco, and Laura Bazzichi. One year in review 2019: fibromyalgia. *Clin Exp Rheumatol*, 37 Suppl 116(1):3–10, 2 2019.

[19] US Government Accountability Office. Passengers with disabilities: Airport accessibility barriers and practices and dot's oversight of airlines' disability-related training. pages 27–28, 4 2021.

[20] Mary Flannery. Quiet room opens at philadelphia international airport. 8 2018.

[21] Reshma Ann Mathews. Smart airport with universal announcement using bluetooth low energy. *IJIRAE*, 2(2), 2 2015.

[22] Philipp H. Kindt, Daniel Yunge, Robert Diemer, and Samarjit Chakraborty. Energy modeling for the bluetooth low energy protocol. *ACM Trans. Embedd. Comput. Syst.*, 1(1), 01 2020.

[23] Christian Hoene and Mansoor Hyder. Optimally using the bluetooth subband codec. *IEEE Local Computer Network Conference*, pages 356–359, 10 2010.

[24] Carles Gomez, Joaquim Oller, and Josep Paradells. Overview and evaluation of bluetooth low energy: An emerging low-power wireless technology. *Sensors (Basel)*, 12(9):11734–11753, 08 2012.

[25] CHADD. New research in sensory processing dysfunction. 9 2017.