Integration of wearable sensors into sensory room therapies for children with developmental challenges

by

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Abstract

Wearable sensor technologies are becoming powerful tools in healthcare and therapy, especially for children with disabilities such as autism or sensory processing disorders. These devices can track a person's heart rate, body temperature, movement, stress level, and even their location. When used in sensory rooms, special spaces designed to help children feel calm or focused, wearable sensors can make the therapy more personal and effective. For example, if a child is feeling stressed, the room's lights, music, or activities can adjust automatically to help the child feel better. This creates a smart, interactive space where therapy responds to the child's real needs in real time.

This report explores how wearable sensors can improve sensory room therapy by offering three key benefits: tracking where the child is in the room, monitoring their physical and emotional responses, and recording behavior for long-term review. Examples include a spinning toy with sensors for children who show repetitive behaviors, and GPS-based systems that track which therapy zones a child visits most. These technologies help therapists understand what works best for each child and plan better therapy sessions. The goal is to make therapy more responsive, safe, and tailored to the needs of each child.

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Introduction

The rapid growth of wearable technology has introduced new opportunities in personalized healthcare and therapy, particularly for individuals with developmental and sensory processing challenges. I chose this topic because children with autism and related disabilities often require continuous, adaptive support that traditional therapy environments alone may not fully provide. By integrating wearable sensors into sensory rooms, we can transform these spaces into intelligent, responsive environments that better match each child's unique needs and behaviors.

This work investigates how wearable technologies such as heart rate monitors, GSR sensors, GPS trackers, and motion detectors can enhance the effectiveness of sensory-based therapies. These tools allow therapists to collect real-time physiological and behavioral data, helping them understand how children respond to different stimuli and make data-driven adjustments to therapy. This combination of engineering and therapeutic design offers a promising direction for improving care and outcomes for children with complex needs.

The landscape of wearable innovations

In today's digital world, the meaning of "wearable" has changed a lot. It no longer just means clothes like fancy outfits or warm jackets for cold weather. Instead, it now commonly refers to images of smart accessories such as a smartwatch on a professional's wrist, a head-mounted display used by gamers, compact sensors on athletic gear, or smart clothing embedded with tracking technology for fitness purposes.

The traditional attributes of wearable clothing, focused on fashion and protection, have expanded to incorporate real-time functionality and mobility. Today's wearable devices enable continuous data processing and communication on the move. Whether it's someone checking emails while moving, a gamer playing online with others, a coach watching how a cyclist moves, or a runner tracking exercise and calories. These devices help people manage information easily in their daily lives. Just like clothes can be made to fit a person's size, style, or the event, today's wearable technology can also be changed for different uses, such as gaming, exercise, health, safety, or fun. These devices are now a big part of daily life and help us connect better with both the real and digital world. Many people, especially gamers, want technology that feels natural and easy to use. They like devices that react to body movements so they don't need to use a keyboard, joystick, or mouse [1].

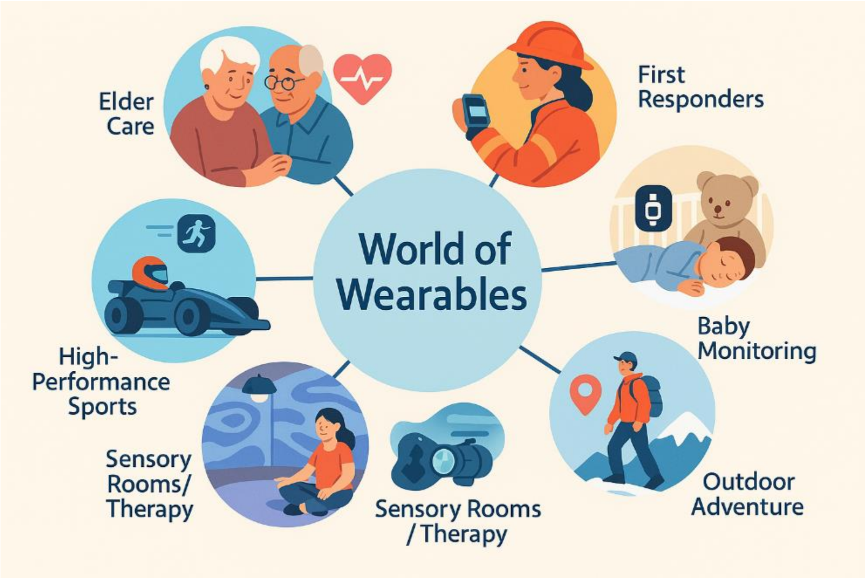

Figure 1. Landscape of Wearable Innovations (AI-generated image inspired by [1])

Figure 1. Landscape of Wearable Innovations (AI-generated image inspired by [1])

Wearable technology is becoming so relevant to all of us. Everyone should have basic understanding. This powerful technology has become so user friendly that we do not even realize how complex it is. Wearable technologies hold significant promise in advancing rehabilitation efforts, particularly for individuals recovering from strokes, anterior cruciate ligament (ACL) reconstruction, bone grafting, and other musculoskeletal injuries. These devices are very helpful for checking and improving orthopedic implants and assistive tools, especially during home-based rehabilitation without a doctor present [2]. Wearable sensors give continuous, non-invasive, and clear data about a patient's physical condition and recovery. This helps find possible problems with the implants, such as when parts stop working properly, and it also saves time during medical checkups in both supervised and unsupervised situations. There are many wearable devices sold today, but most are made for regular consumers and are not tested enough for medical use. This makes them less reliable for diagnosing or checking medical conditions. Unlike devices that go inside the body, wearable devices do not have problems like needing airtight packaging or using very little power. This makes them easier to build using ready-made parts. Because of this, they have developed quickly and are good options for use in healthcare. Still, some important steps are needed before they can be used everywhere. These include large clinical testing, simple ways to show data that non-engineers like doctors can understand, easy connection with healthcare systems, low cost, and designs that are comfortable and easy for patients to use.

Popularity of wearable technology

Wearable technology has become very popular in recent years. People use it for many things, like tracking their health, listening to music, and enjoying virtual or augmented reality. These smart devices, such as smartwatches, fitness bands, earbuds, and XR headsets, are part of a fast-growing electronics market. In 2024, about 560 million wearable devices are expected to be sold around the world. Earbuds are the most popular, with about 350 million units, followed by smartwatches, which are expected to make nearly $50 billion [3]. Wearable technology was first used in jobs like the military and healthcare, but now many regular people use it too. Apple is the top company in this market, mostly because of the Apple Watch and AirPods. Other companies like Fitbit, Beats, Huawei, and Xiaomi are also important. Since the market is still growing, wearable technology is expected to become even more common as more people want and use these devices [4]. A recent survey shows that about one in three Americans uses a wearable device, like a smartwatch or fitness band, to track their health and fitness. More than 80 percent of these users are willing to share their data with doctors to help manage their health [5]. Even though many people use these devices, they are not used much by people who have or may get heart disease. Fewer than 25 percent of these people use wearable technology [6]. Only 38 percent of people with heart problems use wearables often, compared to almost half of other adults [6]. These devices are more common among adults aged 18 to 49, people with higher income, and those with a college education. These results show that as wearable devices improve, especially those that check heart rhythm and work with medical data, we need better plans to make sure everyone can use them and get the health benefits [7].

The role of wearables

Wearable devices are made to do five main things: sense, process, store, send, and use data [8]. How they do each task depends on how and where the device is used, and what the person needs. For example, the device can process data on itself or send it to another place, like a control center. If a wearable sensor finds dangerous gas near a rescue worker, it can quickly send a warning, share the data with a remote team, and get a message back, like "put on your gas mask," which can help save their life. This idea also works in other areas, like video games, where players can change how they play based on real time updates.

Even though wearables are used in many areas, this text mainly looks at how they help in healthcare. These devices can check a person's health all day and over a long time, maybe even for their whole life, without causing discomfort.

Tracking personal health data over a long time can help find changes in the body early. This can lead to faster medical help and a better quality of life. While this part focuses on healthcare, the same ideas like real time sensing, reacting to the situation, and adjusting to the person can be used in other areas too. This shows that wearable devices can be powerful tools in many different fields.

Taxonomy of Wearable Devices

Wearable technologies can be grouped based on the types of sensors they use, how they send data, and what they are used for. Most wearable devices have advanced parts like processor chips, software, and sensors. These parts help them to keep checking the body, collect data, and send it wirelessly using things like WiFi, NFC, or mobile networks. These devices can be used for tracking health and fitness, watching the environment, checking daily activities, helping athletes improve, or even for medical use and early health checks.

Examples of wearable devices include smartwatches, heart rate monitors, smart rings, smart clothes, and shoe insoles with sensors [9]. Each type senses certain body signs like heart rate, breathing, movement, sleep, oxygen level, or body temperature. For example, the WHOOP Strap 4.0 is good for sleep and recovery, and Athos smart clothes check muscle movement. Big devices like the Apple Watch Series 8 and Samsung Galaxy Watch 5 Pro can track many health and fitness things at the same time. This list shows that wearable technology has many uses, especially in sports and healthcare, where it helps people make better choices, avoid injuries, and track health in a personal way.

Wearable Technology in Disability-Oriented Therapies

In recent years, wearable sensors have become very helpful tools in therapy for children, especially those with disabilities. These devices can sense the child's body and behavior all the time without needing to touch or hurt them. They give real time feedback that helps doctors and therapists make better decisions, give personal care, and plan for long term treatment. In therapy, these sensors are useful for checking movement, finding unusual patterns, tracking progress, and helping children stay active through fun feedback. They are very useful for children with brain or development problems, like cerebral palsy or autism, where watching them outside the clinic can really help. Wearable sensors are also great for improving sensory therapy for children with autism and other special needs. They give clear and automatic data about social behaviors that are hard to see with just eyes. In the past, teachers or videos were used to watch how children act, but this takes a lot of time, needs training, and may miss small changes. These problems are even bigger in sensory rooms, where it is important to see the child's reaction right away to choose the right help. In a study by Douglas and others [10], they made a sensor system that could find out how close children with autism were to their friends and if they were facing each other while playing. The system used small ultrasound and radio tools to measure two things: how much time the children looked at each other and how close they stood. The results were close to what trained people saw in videos, with 83 percent match. This shows the sensors are good at catching real and useful social actions. Using these sensors in sensory rooms helps therapists see how children are connecting with others right away, without stopping their play. The sensors help find patterns like being alone or joining in more, which shows how well the therapy is working. Since the data are always being collected, therapists can see changes over time and change their plans to match what works best. The data also helps choose which children should play together or which room setup works best, instead of just guessing. In the end, wearable sensors in sensory rooms let therapists quietly and clearly see how children react to lights, sounds, or touch. This helps make therapy more personal, easier to measure, and more helpful for children with special needs.

Background

Sensory Processing Disorders in Children

Sensory Processing Disorder (SPD) is a brain condition where the child has trouble noticing, understanding, and reacting properly to things they see, hear, feel, taste, smell, or how their body moves. Children with SPD do not handle these sensory messages well and may act in unusual ways. They might overreact or not react enough to everyday experiences. This can make it hard for them to learn, control their emotions, talk with others, or do daily tasks.

SPD usually appears in three main ways. Some children are over-responsive. This means they feel things too strongly and may find normal things painful or too much, like loud sounds or certain clothes. Others are under-responsive. They may not notice things around them, like someone calling their name or a loud noise. Some children are sensory seekers. They want a lot of input and may move around too much, touch things all the time, or do unsafe things like bumping into furniture. Some children show more than one of these behaviors. SPD is very common in children with developmental disorders. For example, up to 90 percent [11] of children with autism have sensory issues. They may be very sensitive to small changes in noise or texture and have a hard time focusing when there are many things happening around them. These challenges can make it harder for them to talk, socialize, or stay calm. Many children with ADHD also have SPD. Studies show that more than half of children with ADHD have sensory problems. These issues can make them distracted, restless, or upset. For example, an under-responsive child may not notice things in class, while an over-responsive child may be bothered by classroom noise or lights. These problems can make learning and behavior harder to manage [12], [13].

Children with cerebral palsy (CP) may also have SPD, but it is not talked about as much. In CP, movement and coordination problems can come with unusual responses to touch or sound. These children might struggle with knowing where their body is or feel too sensitive to being touched. This can make it hard for them to do physical therapy or use tools that help them move, and it may also affect how they play with others. SPD can also affect families. Parents may feel stress when their child reacts in ways that are hard to understand or manage. They may not know how to create safe and calming spaces for their child. SPD is also linked to other health problems like poor sleep, eating issues, stomach pain, anxiety, or acting out. Even though SPD is common and causes many problems, doctors and schools often miss it. This is because there are no clear rules for diagnosing it, and the signs can look like other conditions. When SPD is not noticed early, the child may miss out on helpful therapy or get the wrong kind of support. Since SPD is often seen in children with autism, ADHD, and CP, it is important for parents, teachers, and doctors to work together. They should look for sensory problems early and choose treatments that fit the child's specific needs. When this happens, children can do better in school, enjoy daily life more, and build stronger relationships [11], [12].

Impaired Sensory Processing Systems in SPD

Children with Sensory Processing Disorder (SPD) often have problems with more than just one sense. Many of their body's sensory systems can be affected, which causes different emotional and behavioral reactions to the world around them. These systems include hearing, sight, balance, touch, taste, smell, and the ability to combine different senses at once.

The hearing system (auditory) may be very sensitive in some children with SPD. They may feel upset or scared by normal sounds like a phone ringing, a vacuum cleaner, or classroom noise. On the other hand, some children may not respond to sounds at all. They might not hear their name being called or may seem unaware of what is going on around them. The sight system (visual) can also be a problem. Bright lights or colorful rooms might bother some children. They may avoid eye contact or feel overwhelmed in places with lots of things to look at. Others may not notice what they see and ignore things that would usually catch a person's attention. The balance system (vestibular) helps with movement and staying upright. If this system does not work well, children may fall a lot, have poor balance, or feel scared when doing things like swinging or climbing. Some children may avoid these activities, while others may enjoy spinning or moving all the time because they need stronger movement input. The sense of touch (tactile) is another area that is often affected. Some children do not like being touched or hate certain textures, like scratchy clothes or sticky food. This is called tactile defensiveness. Other children may not feel pain, dirt, or changes in temperature. These issues can make it hard for them to dress, brush their teeth, or eat properly [14].

Multisensory integration is the brain's way of combining information from more than one sense at a time. Children with SPD often struggle with this. For example, a child might have a hard time watching a teacher, listening to instructions, and holding a pencil at the same time. This can make it hard to focus and learn.

Taste and smell can also be affected. Some children are very picky about food and cannot stand strong tastes or smells. They might gag or refuse to eat many foods. Others crave strong flavors or smells and seek them in unusual ways.

These problems do not happen one at a time. Most children with SPD have more than one sensory system affected. This makes it harder to understand what they need and how to help them. The mix of different problems also makes it hard to diagnose SPD. That is why doctors and teachers need to work together to figure out which senses are affected and what kind of therapy is best. When we understand how each child is affected, we can help them feel more comfortable, do better in school, and enjoy spending time with others [13].

Purpose and Development of Sensory Rooms

Sensory rooms, also called Sensory Adaptive Environments or multisensory rooms, were made to help children with autism who have special needs when it comes to sensing things around them. Many autistic children are either too sensitive or not sensitive enough to things like light, sound, touch, or movement. These differences can make it hard for them to feel comfortable, stay calm, or take part in daily life at home, school, or in therapy. The main reason for making sensory rooms is to help reduce stress, increase joy, and give children with autism a better chance to interact with others in a positive way. These children may get anxious easily, have trouble calming themselves, or avoid school and social situations because of how they react to certain sounds or feelings. Sensory rooms were created to help with these problems by offering a safe space with carefully chosen lights, sounds, and textures to help children feel relaxed and focused [15].

These rooms are built to fit different sensory needs by using special tools and equipment. These include things that help or calm the senses of sight, hearing, touch, balance, body awareness, smell, and a mix of senses at once. Sensory rooms can either calm the child or give them more stimulation, based on what they need. One of the first and most well-known types of sensory room is called a Snoezelen room. It was first made in the Netherlands [16]. The name comes from two Dutch words that mean “explore” and “relax.” These rooms usually have soft lights, bubble tubes, padded floors, textured objects, and calming music. At first, they were made just to help people relax and enjoy themselves. Now, many of these rooms also have fun, interactive tools that respond to how the child moves or behaves, making the room more helpful during therapy. Today, sensory rooms are used in many places like schools, hospitals, therapy centers, and group homes. They help children with autism handle their feelings, learn how to cope better, and improve how they talk and play with others. These rooms are becoming more popular because they can help children feel better, reduce their stress, and enjoy life more [17].

Therapeutic Goals of Sensory Rooms

Sensory rooms, also called Sensory Adaptive Environments, are special spaces made to help children with strong sensory, emotional, or behavior needs especially those with autism or serious disabilities [18]. These rooms are carefully designed to give children different types of sensory experiences, like light, sound, or touch, in a safe and controlled way. The goal is to help children feel calm, stay focused, and enjoy their time in the room. One of the main reasons for using sensory rooms is to help children feel more relaxed and less anxious. Some children get stressed or upset easily by things around them, like loud noise or bright lights. Sensory rooms use soft lights, quiet music, and gentle textures to help these children feel safe and calm. For example, a type of sensory room called the Snoezelen room was made just for this purpose. These calming spaces can help children go from feeling upset to feeling relaxed and ready to connect with others. At the same time, some children do not react much to sensory input and need stronger feelings to wake up their senses. These children may seem sleepy or uninterested. Sensory rooms help them by using music, lights, moving activities, and hands-on items to get their brains and bodies more active. This helps the child pay attention and take part in activities.

Sensory rooms also help children join in and feel more involved. Fun activities like dancing, playing with sounds, or looking at lights can help children move around more and talk to others. Instead of just watching, they start to take part, talk more, and connect with teachers or other children. Another important idea is called “participatory sense making” [19]. This means that children and others, like teachers or friends, can share a moment together using sounds, lights, and movements. This is very helpful for children who do not speak much, because it gives them a new way to share feelings and attention with others. These shared sensory moments can build trust and emotional closeness. Sensory rooms also let children make choices. They can choose what lights to turn on, what sounds to hear, or what textures to touch. This helps children learn to control their emotions and energy levels. Making choices gives them a feeling of independence and helps them become more confident. This is very different from classrooms where adults usually decide everything for the child.

These rooms can also help reduce challenging behaviors. When children get the kind of sensory input they need, they can focus better and show fewer signs of stress, like hand flapping or yelling. This means the room helps them feel better and act more calmly.

In addition, sensory rooms support the child's feelings and mental health. When children enjoy their time in these rooms, they feel seen, safe, and understood. This is very important for children who may not be able to speak. The room responds to them and their needs, not the other way around. It shows that every child matters and gives them a space where they can feel happy and at peace.

Types of Sensory Stimuli in Children with Autism or Disabilities

Children with autism often react differently to things they see, hear, feel, smell, or taste. These unusual reactions can make it hard for them to pay attention, stay calm, talk to others, or take part in daily life. To help with these problems, special rooms called sensory rooms, or multisensory environments (MSEs), were created. These rooms are made to give children a mix of sights, sounds, textures, smells, and movements to help them feel better and join in activities.

In a study by De Domenico and colleagues [20], a sensory room was set up with many tools that gave visual, touch, sound, smell, and movement input. The goal was to let children experience different senses at the same time in a fun and calming way. The room had colorful lights, bubble tubes, and projectors to catch the children's attention and help them look and focus better. Children could also use a tablet to change the colors and brightness, which gave them more control and comfort. The room also had soft things to touch, like a ball pool, smooth furniture, and soap bubbles. These helped children feel different textures in a safe way and slowly become more comfortable with touch. At the same time, soft sounds like ocean waves or birds were played in the background. These calming sounds helped the children listen better and feel more relaxed. They could also choose the type and volume of the sounds, which made the space feel more personal. Smells were added using scent diffusers with gentle scents like lavender or lemon. These smells helped children feel calm, especially those who do not like strong smells. For movement, the room had tools like a swinging chair, a water bed, and a swing. These helped children understand how their body moves, stay balanced, and manage energy levels. This made it easier for them to stay calm and focused. A big part of the room's success was that it let children choose how they wanted to use it. They were free to explore and interact in their own way and time. This helped them feel safe and confident, even if they were shy at first. The study found that this kind of sensory room helped children improve how they react to touch, smell, and taste. It also helped them feel calmer, join activities more easily, and show fewer hard behaviors. By using many senses together in a thoughtful way, the sensory room became a helpful space for learning, comfort, and growth for children with autism and other needs.

Evaluating the Efficacy of Combining Sensory Room and Traditional Therapy for Children with Autism Spectrum Disorder

Multisensory environments (MSEs), started in the 1960s [20]. They were made as calm therapy spaces for people with Autism Spectrum Disorder (ASD) and other learning or developmental conditions. These rooms were meant to give simple sensory experiences, like soft lights, gentle sounds, smells, and textures, without making the person do anything or follow instructions. The goal was to help people relax, feel calm, and stay in control of their emotions, especially if they were easily overwhelmed or had trouble with different types of sensory input.

Baillon and colleagues [21] explained that sensory therapy usually takes place in a quiet room where people can enjoy different sights, sounds, touches, and smells. These rooms do not ask people to think hard or behave a certain way. They are made to be peaceful and fun to explore freely, helping people feel safe and comfortable.

The rooms often have soft-colored walls, low lighting, and curtains that block outside light or noise. Some of the tools used include bubble tubes, fiber optic lights or curtains, mirror balls, projectors, and music players. For example, bubble tubes (as seen in Figure 2) light up, change color, and make bubbles rise, which can help a person stay focused or feel relaxed. When touched, the tubes also give off soft vibrations that many people enjoy. Other tools like scent diffusers, wall panels, or soft touch toys add to the experience. Seating is made comfortable with beanbags, soft mats, or padded benches so people can sit or lie down in a relaxed way. These rooms are made for free play and do not force people to do anything. This freedom helps children and adults feel more independent, safe, and in control. This is very helpful for people with autism, learning disabilities, or memory problems. Even though old-style sensory rooms do not use smart or digital tools, they are still popular because they are easy to use and work well. They are often found in schools, hospitals, therapy centers, and mental health units [22].

Figure 2. Bubble-tubes in a Multisensory Environment (AI-generated image inspired by [22]

Instrumented sensory rooms, also called smart sensory rooms, are new and improved versions of regular sensory rooms. They are made for children and people with sensory and developmental disorders like autism. These rooms use special technology so the child can control things like lights, sounds, colors, music, and vibrations. This makes the room more interactive and helps the child feel calm, focused, and in control.

In a study by Unwin et al [23], children who used these smart rooms were able to choose what kind of lights or music they liked. The study showed that when children had control over their environment, they paid more attention, moved around less, made fewer loud sounds, and behaved better compared to when the room worked on its own.

Another new idea is using Virtual Reality (VR) to make sensory rooms. Researchers created a VR sensory room called Evenness [24]. It let children wear a headset and use hand controllers to explore a relaxing space with lights, shapes, and sounds. This kind of therapy can be used at home, school, or clinics and is cheaper and easier to set up than regular sensory rooms. Some smart sensory rooms also use wearable sensors. These sensors can track things like the child's heart rate, body movement, or stress level. The room can then change the lights or sounds to help the child feel better. This way, the therapy becomes more personal and helpful.

Figure 3. User view of the Evenness VR Sensory Room (AI-generated image inspired by [24])

Benefits and Limitations of Traditional and instrumented sensory rooms

In recent years, sensory rooms have played a significant role in therapeutic interventions for individuals with communication disabilities. Traditionally, these rooms provided controlled environments where individuals could receive multisensory stimulation aimed at promoting relaxation, engagement, and in some cases, skill development. However, technological advances have introduced instrumented or virtual reality (VR)-based sensory environments, offering new opportunities and presenting novel challenges. This section compares the benefits and limitations of both traditional and instrumented sensory rooms, particularly in the context of communication disabilities. Traditional sensory rooms are physical spaces equipped with various stimuli such as soft lighting, textured surfaces, auditory feedback, and interactive sensory tools. These environments are designed to offer calming experiences, reduce anxiety, and support emotional regulation. For individuals with communication disabilities, these spaces can foster a sense of safety and engagement, promoting readiness for learning and interaction.

While traditional sensory rooms have been beneficial in many therapeutic settings, they are often limited by accessibility and scalability. These rooms require dedicated physical spaces, specialized equipment, and ongoing maintenance, which can be costly and restrictive for widespread implementation. Additionally, traditional sensory environments may not always offer opportunities for real-time tracking of user engagement or progress, limiting their effectiveness in structured skill-building interventions. In contrast, instrumented sensory rooms particularly those using immersive virtual reality offer simulated environments that replicate real-life scenarios in a safe and customizable manner. These environments can be tailored to individual needs and allow users to interact with computer-generated surroundings through head-mounted displays (HMDs), motion sensors, and interactive avatars. One of the most prominent advantages of VR-based sensory environments is their potential to simulate naturalistic communication scenarios. This allows users to repeatedly practice real-world skills, such as greetings, social turn-taking, and job interview responses, in a controlled and immersive setting. Research has shown [25] that VR interventions can support the generalization of learned skills from virtual environments to real-life interactions, making them highly valuable in communication therapy. VR environments also offer a high level of engagement and motivation, particularly for users with autism or acquired communication disabilities. Users often report enjoying the interactive and gamified aspects of VR therapy, which can enhance participation and adherence to intervention protocols. Furthermore, VR systems are increasingly portable and scalable, enabling access to therapy for individuals who may be geographically or physically limited from attending traditional therapy sessions.

However, instrumented sensory rooms also pose several limitations [26]. First, the complexity of the technology may present a barrier to some users, particularly those with intellectual or cognitive disabilities. Non-immersive VR environments, which rely on point-and-click interfaces, may be difficult to navigate without prior technical familiarity. Second, the use of VR can induce side effects such as cybersickness, disorientation, or fatigue, especially with prolonged use. These symptoms can limit the duration and frequency of VR therapy sessions.

There are also important ethical considerations associated with the use of immersive VR. These include concerns about user privacy, as VR systems may collect detailed biometric data such as eye movements, facial expressions, and body posture. Additionally, the simulation of disability experiences within VR for educational purposes may risk misrepresentation or oversimplification, raising concerns from the disability advocacy community.

Finally, despite growing interest in VR applications for communication therapy, the current body of evidence is still emerging. Studies tend to involve small sample sizes and limited follow-up, meaning that the long-term efficacy of VR-based sensory rooms remains to be fully validated.

Fundamentals and System Design of Wearable Sensors

Wearable sensors are becoming very useful tools in personal healthcare. They offer a new way to check health without needing to visit the clinic often. These sensors can track changes in the body in real time and are either noninvasive or cause very little discomfort. They work all day and help doctors and patients see early signs of health problems [27].

The first wearable devices, like smartwatches and fitness trackers, mainly measured simple things like heart rate, body temperature, and movement. But now, new types of wearables are being made that can check more complex things using body fluids like sweat, saliva, fluid between skin layers, and tears. These newer devices can look like skin patches, tattoos, contact lenses, films on teeth, or tiny needles. They are being used for health checks, treatments, and general wellness.

Wearable sensors are built from several important parts. First is the base material or substrate, which needs to be soft, strong, stretchable, and safe for the skin. Natural materials like cotton and silk are breathable and strong. Synthetic materials like PDMS and polyimide are used a lot because they can be easily shaped using modern tools like 3D printing. Hydrogels are soft and absorbent materials that work well with the skin. They are great for carrying medicine, collecting fluids, and even holding living cells. Other materials like metals and tiny materials such as graphene are used to add electronic functions like circuits and antennas, but they can be harder to use on skin for a long time.

The sensor part is the heart of the device. It includes special biological tools like enzymes or antibodies that react with the target chemical or marker in the body. When they react, they create a signal such as an electric or light signal that the device reads. The signal is often made stronger so it can be processed more clearly. Then the processing part collects the data, filters it, and sends it wirelessly to a phone or a cloud system where it can be analyzed in real time. Finally, the device needs power. Power can come from small batteries, movement from the body, or special energy collectors. All these parts together make a smart, small device that is comfortable to wear for a long time.

Figure 4 shows both the history and the design of wearable sensors. The top part shows how these devices have changed from the 1960s to 2020. It begins with early heart monitors like the Holter device and goes to new tools like sensors made with graphene, smart face masks used during COVID, and microneedle tools for checking or giving medicine. The figure also shows which devices are already sold and which are still in the lab.

The bottom part of the figure shows the key parts that make up a wearable sensor. This includes the types of materials used (natural, synthetic, hydrogel, and inorganic), how the device senses things (like detecting chemicals and sending signals), and the extra parts that store and send information. It also shows how the device collects fluids like sweat, tears, saliva, urine, or skin fluid. Overall, Figure 4 helps explain both the progress of these devices and how they work step by step.

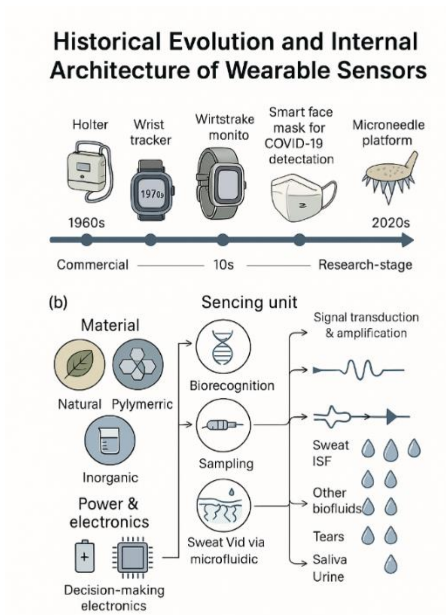

Figure 4. Timeline of Major Milestone in the Development of Wearable Sensors (AI-generated image inspired by [27]

Wearable sensor systems are made up of three main parts [28]:

1. Sensors and data collection: These are the tools that collect important health data like heart rate, breathing, body temperature, walking style, and posture.
2. Communication units: These parts send the data wirelessly to a mobile phone or a gateway device, which then sends it to a medical server.
3. Data analysis systems: These systems take the raw data and turn it into useful health information using signal processing, pattern recognition, and machine learning.

Thanks to new technologies like very small machines called MEMS, flexible electronics, and smart fabrics, all of these parts are now smaller and more comfortable. This makes it easier for people to wear them every day for a long time.

Wearable sensors used to only measure simple body signs. Now, they are smart systems that can understand more complex actions and health events. For example, they can detect if someone falls, follow how someone is doing during physical therapy, or keep track of symptoms in diseases that affect the brain or lungs.

These devices now work with mobile phones and cloud systems, so doctors can see the data easily and make fast decisions. Some clothes now even have sensors and wires built into them, making the systems very light and easy to wear. Wearables are often used together with sensors placed around the home, so monitoring can continue even when the person is not wearing the device.

Figure 5 shows a drawing of how a remote health monitoring system works with wearable sensors. In the picture, wireless sensors are placed on a person's body to collect data like heart rate, breathing, and how they move. The data is sent to a phone or access point, and then goes to a medical center through the internet. The system can quickly find emergencies, like a fall, and send an alert to doctors, family members, or emergency help services. This way, doctors can watch patients from far away and make health decisions when needed.

By combining wearable sensors with communication and data analysis tools, we can build a strong system for personalized, nonstop, and early healthcare support.

Figure 5. Illustration of a Remote Health Monitoring System Based on Wearable Sensors (AI-generated image inspired by [28])

Exploring the Connection Between Wearable Sensor Technologies and Sensory Room Design

Using wearable sensor technology together with sensory rooms is a new and growing idea that connects biomedical engineering and therapy. Sensory rooms are special spaces made to help people who have trouble with sensory input, brain conditions, or strong emotions. These rooms use lights, sounds, textures, and smells in a calm and controlled way. Wearable sensors are smart tools that can track body signs like heart rate, body temperature, movement, and stress levels all the time. When we use both of these technologies together, we can create a smart and helpful environment that changes based on what the person needs at that moment.

Wearable sensors are built using important ideas from engineering. They have soft materials that are easy to wear, parts that sense the body's signals, small systems to send the data wirelessly, and small batteries or power systems. All of this is designed to be light and comfortable so people can wear them for a long time. When these sensors are used in sensory rooms, caregivers and therapists can stop using one-size-fits-all methods and instead give each person a custom experience based on real-time data.

Most sensory rooms are set up with fixed lights, sounds, and textures that are chosen in advance. But if we add wearable sensors that measure how the person is feeling in real time, the room can change to fit their needs. For example, if a child starts to feel stressed or overwhelmed, the lights can dim or the music can change to something more calming. This is called a feedback system, where the body's signals help control the room's settings. It helps make the therapy more accurate and useful [29].

Bringing together wearable sensors and sensory room design is a step toward creating smart therapy spaces. These spaces help caregivers better understand what works for each person, adjust the environment to meet their needs, and support their emotions and senses in a clear and science-based way. As research continues in areas like brain science, rehabilitation, and how people use technology, this mix of sensing tools and sensory rooms is expected to improve how we give therapy and how we understand sensory challenges.

Early Health Disorder Recognition via Wearable Devices

The use of wearable sensors for the early detection of health changes requiring medical attention is an area of increasing interest within wearable technology research. A notable application of this approach is in managing patients with chronic obstructive pulmonary disease

(COPD), where early recognition of exacerbation episodes typically marked by increased breathlessness, coughing, and changes in sputum is essential. Prompt detection and treatment of these events are critical to preventing deterioration, hospital visits, or emergency care. Remote monitoring systems are proving to be valuable tools for identifying early warning signs by tracking health trends that may indicate an impending exacerbation.

One method to detect such changes involves monitoring a patient's activity levels, as a noticeable decline could signal a worsening condition. For instance, Atallah et al. [30] developed a wearable ear sensor capable of detecting both physical activity types and their intensity using machine learning algorithms. Similarly, studies by Steele et al. [31] and Belza et al. [32] found a correlation between 3D movement data and various health indicators such as the six-minute walk distance, FEV1 scores, and quality of life assessments. Hecht et al. [33] introduced an algorithm to analyze minute-by-minute activity data from a single wearable unit, tested in a 14-day study involving 22 COPD patients. Their system included a compliance-check feature to determine whether the device was being worn. Interestingly, participants tended to increase activity during the initial days of wearing the sensor, suggesting that monitoring periods should be extended to avoid capturing short-term behavior changes caused by the awareness of being observed.

The combination of activity monitors and physiological sensors is especially promising. Studies by Furlanetto et al. [34] and Patel et al. [35] demonstrated that multi-sensor systems capable of tracking skin temperature, galvanic skin response, and heat flow—could more accurately estimate energy expenditure than standard step counters, particularly during slow walking. As wearable systems continue to evolve, integrating sensors for heart rate, oxygen saturation, and respiration, a more comprehensive health monitoring system for COPD patients becomes increasingly viable.

Wearable technologies have also been explored in the management of dementia, a cognitive condition affecting over 30 million people globally, with associated care costs exceeding $300 billion. Enabling patients to remain in their homes longer can significantly reduce the reliance on nursing facilities. Remote monitoring systems can assist by helping with daily reminders, detecting behavioral changes, and tracking medication adherence. In one example, Haiying et al. [36] developed a system that monitors sleep patterns using infrared and bed pressure sensors to assess cognitive impairment in early-stage dementia. Their findings indicated that those with mild dementia exhibited poorer sleep quality than healthy individuals. Other approaches include systems like the one designed by Jimison et al. [37], which used a modified computer game to detect early cognitive decline. Importantly, these systems must be non-intrusive and capable of passive data collection due to the patients' cognitive challenges. Hayes et al. [38] addressed this by designing a home-based monitoring setup using infrared motion and contact sensors, which were used to track activity in individuals with mild cognitive impairment. Their results revealed that these individuals had more variable daily activity patterns compared to those without impairments.

Applications of Wearable Sensors in Healthcare

A wide variety of physiological, motion and activity sensors, environmental interaction sensors and cognitive and behavioral monitoring sensors are now being integrated into sensory rooms to enhance their therapeutic impact.

1- Cardiac Arrhythmia Detection Using Wearable Sensors

Cardiovascular diseases (CVDs) are health problems that affect the heart and blood vessels. These diseases can lower a person’s quality of life and are one of the main causes of death around the world. Each year, about 17 million people die from CVDs, which is about 31% of all deaths globally [39]. It is very important to find and manage these diseases early. To do this, doctors check things like heart rate, heart rhythm, blood pressure, and the amount of oxygen in the blood. But the old ways of measuring these things do not always give real-time results and often need help from trained professionals. Thanks to new sensor technologies, we now have small, easy-to-use devices that can measure these important signs in real time. These tools are accurate, work without hurting the body, and can be used at home or anywhere [40]. Cardiac arrhythmias are problems with how the heart beats. They can involve changes in heart rate, rhythm, the place where the beat starts, how fast it travels, or the order in which the heart muscles contract. Some common arrhythmias include atrial fibrillation, ventricular fibrillation, and supraventricular tachycardia. These can be dangerous and may lead to heart failure or even death. Heart rate (HR) means how many times the heart beats per minute. For healthy adults at rest, this is usually between 60 and 100 beats per minute. Doctors often use an electrocardiogram (ECG) to check heart activity. The usual method involves gel-based Ag/AgCl (silver/silver chloride) electrodes placed on the chest and limbs. But these aren't ideal for long-term use because the gel can dry out or lose stickiness. The Holter monitor is another device that records heart signals for up to 24 hours. However, it uses several wires and electrodes, which can be uncomfortable and may disconnect during use. Thanks to new advances, dry electrodes that stick to the skin without gel have been developed. For example, Zhang et al. [41] created a fully organic, soft, stretchable dry electrode that stays attached to both dry and sweaty skin. It remains highly conductive even when stretched. As shown in Figure 6, this new dry electrode has lower contact impedance than standard gel electrodes. This means it picks up clearer ECG signals with less noise, both when the person is sitting still or moving.

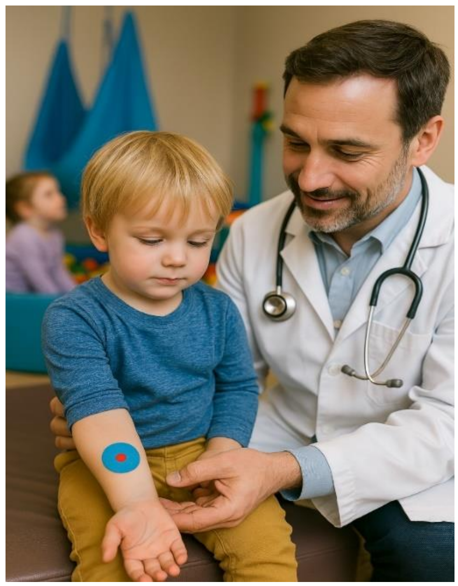

Figure 6. ECG Detection Using dry electrodes (AI-generated image inspired by [41])

In addition, electronic textiles such as sewable electrodes and signal wires made from carbon nanotube threads (CNTT) are being used in wearable health devices [42]. These materials are soft, lightweight, and breathable, making them very comfortable to wear.

They are also strong and durable, able to handle repeated stretching and even machine washing without losing the quality of the signals they collect. As shown in Figure 7, these features make them a great choice for long-term, everyday use in wearable technology.

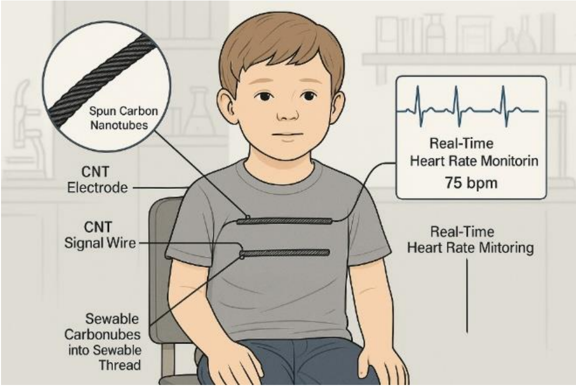

Figure 7. Heart Rate Monitoring with Carbon Nanotube Threads (CNTT) Textile (AI-generated image inspired by [42])

Besides sensors that are still in the experimental phase, wearable patch devices such as the Zio Patch from iRhythm Technologies and AT-Patch fromATsens, have received FDA clearance and are commercially accessible (Figure 8). Zio Patch has advanced algorithms for accurate arrhythmia detection and can store up to two weeks of data. AT-Patch shows high performance in gathering ECG signals from the heart, and its short-length electrode within the patch effectively reduces noise caused by body movement [43],[44].

Figure 8. Portable ECG Monitoring with Zio Patch (AI-generated image inspired by [43])

2- Galvanic Skin Response (GSR) Sensors

Galvanic Skin Response (GSR), also known as Electrodermal Activity (EDA) or Skin Conductance (SC), is a physiological signal that reflects changes in the electrical properties of the skin due to sweat gland activity. GSR is a valuable biometric tool for assessing emotional arousal, making it highly relevant in fields such as psychology, clinical therapy, usability testing, and biometric research. Emotional stimuli such as images, videos, sounds, or even thoughts can trigger subtle sweat gland responses, especially in areas like the palms and feet. These responses alter the skin's conductivity, which can be measured and analyzed to gain insights into a person's unconscious physiological state. Unlike other bodily reactions that can be consciously controlled, GSR is driven purely by the sympathetic branch of the autonomic nervous system, which governs involuntary functions such as sweating, heart rate, and blood pressure. This makes GSR a reliable, undistorted marker for detecting emotional arousal without interference from conscious behaviors. GSR offers researchers and clinicians direct access to subconscious processes that are often missed by behavioral observation alone [45].

The sympathetic nervous system triggers a fast response in the body known as the "fight or flight" reaction causing increased heart rate, blood pressure, and sweating during moments of stress or excitement. In contrast, the parasympathetic nervous system supports slower, calming processes like resting, digestion, and recovery, helping the body return to a relaxed state.

To understand how GSR works, it helps to learn a little about the skin. The skin is the body's largest organ and plays a big role in protecting the body, controlling body temperature, and helping us feel things. The skin has three main layers: the top layer is called the epidermis, the middle layer is the dermis, and the deep layer is the hypodermis.

The body has about three million sweat glands. These glands are mostly found on the hands, feet, face, and fingers. When we feel strong emotions like stress, fear, or excitement, a part of our nervous system called the sympathetic nervous system causes these sweat glands to become active. This sweating changes the way electricity moves across the skin. The skin becomes less resistant to electrical current, which means more current can pass through. This change is called skin conductance, and it is measured in a unit called micro-Siemens. This is the main idea behind GSR. It is linked to what is known as emotional sweating. This is different from sweating caused by heat. Emotional sweating happens when someone feels nervous, scared, or excited. Even if we do not see the sweat, the change in the skin's electrical signal can still be measured. Because people cannot control this kind of response, GSR is a good way to see how someone’s body reacts to emotional situations.

The sympathetic nervous system is the part of the body that controls the "fight or flight" response. When it is active, it increases heart rate, blood pressure, and sweating. The opposite system, called the parasympathetic nervous system, helps the body relax. Since GSR is only affected by the sympathetic system, it is very sensitive to emotional and mental changes.

Modern GSR devices are small and easy to use. They usually include two small metal parts called electrodes, which are placed on the skin to collect signals. There is also a small machine called an amplifier to make the signal stronger, and a digitizer that helps send the signal to a computer. These devices can be connected with wires or can use wireless connections like Bluetooth. Many are built into wristbands or skin patches. The best places to put the sensors are on the fingers, palms, or bottoms of the feet because those areas have the most sweat glands. Some devices need a special gel to help get a better signal, but others use dry sensors for more comfort and easier use.

3- Skin Temperature Sensors

Skin temperature (Tskin) is a critical physiological parameter reflecting the dynamic interaction between the human body and its environment. It plays a key role in thermal homeostasis, the body’s natural ability to regulate its internal temperature. Monitoring skin temperature is widely used in numerous disciplines, from exercise physiology and sports performance to clinical medicine and wearable technology. One of the most common and practical approaches to measuring Tskin is through contact thermometry a method that involves affixing sensors directly to the surface of the skin [46]. Contact thermometry operates on the principle of conductive heat exchange between the skin and the sensor. When the sensor is in direct contact with the skin, heat is transferred from the body to the sensor until thermal equilibrium is achieved. At that point, the temperature reading of the sensor approximates the skin's surface temperature. However, it is important to note that the temperature being recorded is not the direct temperature of the skin, but rather the temperature of the sensor itself after reaching equilibrium. Therefore, factors that influence the rate and stability of this heat exchange are critical to the accuracy and reliability of the measurement. A variety of sensor types are used in contact thermometry, each relying on different physical principles. Thermistors, for example, detect temperature by measuring changes in electrical resistance. Thermocouples utilize the Seebeck effect, generating a voltage based on the temperature difference between two dissimilar metals. More advanced digital options, such as iButtons, integrate the sensing element with built-in data storage and processing capabilities. These sensors vary in size, material, shape, and thermal properties, all of which influence how quickly they respond and how accurately they reflect true skin temperature. The popularity of contact skin temperature sensors in both research and real-world applications is due to several advantages. They are affordable, commercially available, and relatively easy to use. Their small size and robustness make them ideal for continuous measurements, and they can be applied to various body sites even under clothing or protective gear allowing for flexibility across different use cases. Despite these advantages, measuring skin temperature accurately with contact sensors poses several challenges. One key issue is that setup variables such as how the sensor is attached, the pressure applied, environmental conditions, and the specific sensor type can all affect the recorded temperature. For instance, using adhesive tape to fix the sensor can alter the thermal environment around the skin, potentially insulating the area and leading to artificially elevated readings. Similarly, the pressure exerted by the sensor on the skin can compress tissue and increase the local temperature reading, or if too light, cause poor thermal contact and reduce accuracy. Environmental conditions further complicate measurement. The ambient air temperature and airflow around the sensor can interfere with the heat exchange process. In cold environments, for instance, the skin may lose heat to the surroundings faster than the sensor can equilibrate, leading to underestimated values. High airflow or movement can also disrupt the thermal boundary layer around the sensor, introducing further variability. Another crucial factor is whether the sensor has had enough time to reach thermal equilibrium with the underlying skin. Until this equilibrium is achieved, the sensor may report transient values that do not accurately reflect the skin's steady-state temperature. These dynamic conditions highlight the need for consistent application and awareness of the time required for stable readings. There are also validity concerns surrounding contact thermometry. Because the sensor is physically attached to the skin, it can modify the microenvironment it is trying to measure. This disturbance can cause the temperature under the sensor to differ from the surrounding undisturbed skin. Such interference is especially significant in studies or clinical settings where high accuracy is required. Consequently, researchers and clinicians must evaluate whether a given sensor setup truly reflects the actual skin temperature or if the sensor's presence alters the measurement outcome. To overcome some of the limitations of contact thermometry, non-contact methods such as infrared thermography have been developed.

These techniques measure the electromagnetic radiation emitted by the skin and can provide temperature readings from a distance. While useful in some cases, non-contact methods have their own set of challenges, including sensitivity to movement, changes in skin emissivity, and reduced practicality in field or mobile conditions. Given all these factors, contact thermometry remains a widely used and practical solution for measuring skin temperature, especially in wearable devices and continuous monitoring systems. However, its effectiveness depends heavily on proper setup, calibration, and interpretation. To ensure accuracy, users must pay attention to sensor type, attachment method, pressure, ambient conditions, and the time allowed for thermal equilibrium. In conclusion, skin temperature sensors work by measuring the conductive heat transfer between the skin and a sensor in direct contact with it. The recorded temperature is influenced by the design and setup of the sensor, environmental factors, and how long the sensor has been applied. Despite its limitations, contact thermometry is a versatile and valuable tool for physiological monitoring, and with careful application, it provides reliable insight into human thermal regulation. As interest in wearable technology and personalized health continues to grow, the role of skin temperature sensors is expected to expand further offering new possibilities in healthcare, sports, rehabilitation, and beyond.

Feasibility of Wearable Physiological Sensors in Children with ASD

The adoption of wearable physiological sensors such as Galvanic Skin Response (GSR) or skin temperature monitors for children with Autism Spectrum Disorder (ASD) requires careful consideration of their unique sensory profiles. While these devices offer significant potential in tracking emotional and physiological states, assuming that children with ASD will readily tolerate wearing them is not always realistic. As highlighted in the study by Koo et al. [47], many individuals with ASD exhibit heightened sensory sensitivities, particularly tactile defensiveness, which can lead to discomfort or even rejection of wearable devices. These sensory issues often manifest as aversion to specific materials, device tightness, or sensations of pressure against the skin, making wearability a core challenge in technology design for this population.

To address these barriers, the design and implementation of wearable sensors must adopt user centered approaches that prioritize comfort, familiarity, and discretion. Participants in the Koo et al. study consistently emphasized the importance of soft, flexible materials and minimal bulk, preferring devices that could be integrated seamlessly into their daily routines. For example, accessories that resemble typical wearable items such as wristbands, watches, or even elements embedded within clothing were reported as more acceptable due to their resemblance to familiar, nonthreatening objects. These preferences suggest that wearable sensors designed to mimic favored personal items can reduce resistance and support voluntary engagement.

Furthermore, the use of hypoallergenic materials with soft textures and nonirritating finishes was identified as essential. Devices must be lightweight and free of rigid edges or seams to minimize tactile triggers. The preference for discreet, nonmedical looking devices also highlights the psychological importance of perceived normalcy, where children do not feel “different” or stigmatized due to visibly therapeutic equipment. In addition, the study supports the notion that presenting the sensor as part of a playful or imaginative experience may improve compliance. By framing the device as a “magic wristband” or a “superpower tracker,” caregivers and therapists can use storytelling to build positive associations, further reinforced by verbal praise or small rewards for consistent wear.

Although the study does not explicitly outline a protocol for gradual desensitization, the emphasis on customization and adaptation implies the value of slowly introducing wearables through stepwise exposure. Starting with allowing the child to visually explore the device, then physically handle it, and finally wear it for short periods before progressing to full session use can increase tolerance without causing sensory overload.

Incorporating these design and behavioral strategies into the development of wearable sensor systems makes it more feasible to collect high quality physiological data in children with ASD. Such systems not only support individualized therapeutic planning but also respect the sensory needs and preferences of the child, ensuring that technology remains an enabler rather than a barrier to meaningful engagement.

4- Motion and Activity Sensors

Human motion disorders can arise from a wide range of causes, including musculoskeletal injuries, neurological impairments, and cerebrovascular events. These disorders often manifest through irregular movement patterns that may affect various parts of the body, such as the neck, shoulders, fingers, and limbs. To effectively detect and monitor these abnormal movements, on-site wearable sensors have emerged as a reliable solution. These devices offer an energy-efficient and cost-effective approach to motion tracking, facilitating early diagnosis, monitoring of disease progression, and enhancing rehabilitation outcomes.

4-1- Neck Motion Tracking

The neck and head are very important for keeping our posture straight and helping us move. Problems like forward head posture and long-term neck pain are becoming more common because people spend a lot of time sitting and using phones or computers. Doctors often check how well the neck can move to understand these problems better. Using sensors can help track neck posture, fix bad habits, and stop more serious spine issues from developing.

In 2022 [48], a new neck motion tracking system was created. It does not need a battery because it powers itself. The system uses special sensors called triboelectric sensors, which were placed inside a soft neck collar. These sensors create small electrical signals when the person moves their neck in different ways. The system then uses a type of computer model called a convolutional neural network (CNN) to understand and label the movements. As shown in Figure 9, the system could correctly recognize different neck movement types. This makes it a helpful tool for neck therapy and health monitoring.

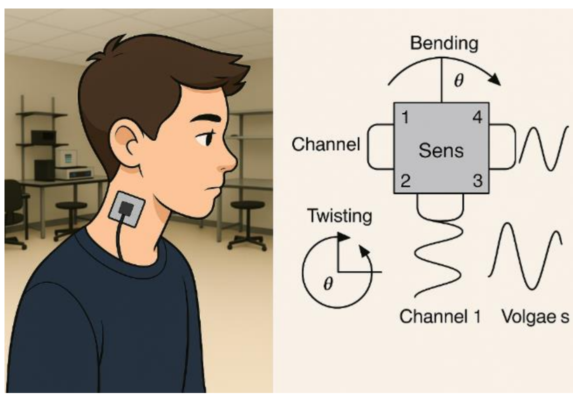

Figure 9. Neck Motion Sensor and Channel-Based Detection System (AI-generated image inspired by [48])

4-2- Shoulder Motion Tracking

Shoulder disorders, including frozen shoulder (adhesive capsulitis) and rotator cuff injuries, are also prevalent and contribute significantly to physical disability. These conditions are often linked to repetitive overhead tasks, heavy lifting, and awkward postures, especially in occupational settings. While physical therapy has proven effective for improving shoulder range of motion and reducing pain, excessive shoulder activity in the early post-operative period can increase the risk of rotator cuff re-tears in patients following surgical intervention [49],[50].

In response to this challenge, a flexible resistive sensor network was introduced in 2020, designed to provide precise and non-intrusive shoulder tracking. By applying principal component analysis (PCA) and neural network-based algorithms, the sensor system successfully mapped posture-related data into accurate motion classifications. As shown in Figure 10, the device is lightweight, flexible, and easily embeddable into wearable fabrics, making it ideal for continuous monitoring without restricting user movement an essential feature for effective rehabilitation [51].

This innovation allows therapists to monitor shoulder movements in real time, helping them better understand patient progress during recovery. The system can track complex shoulder motions such as abduction, rotation, and flexion, providing detailed feedback that was previously difficult to obtain outside of laboratory settings. Its non-invasive design improves patient comfort and compliance, making it suitable for long-term home use. Moreover, by integrating machine learning algorithms, the system can adapt to individual movement patterns, allowing for more personalized and accurate rehabilitation support.

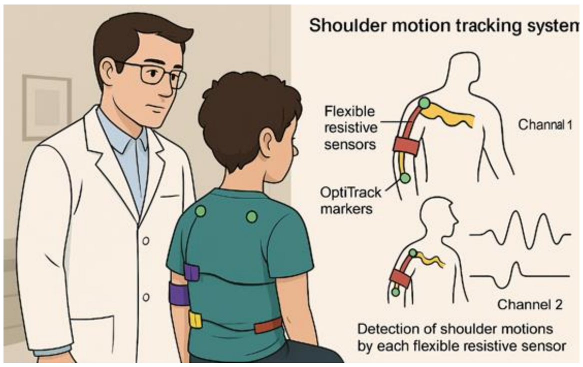

Figure 10. Shoulder Motion Tracking System Using Flexible Sensors (AI-generated image inspired by [51])

4-3 Finger Motion Tracking

Beyond the larger joints, finger movement tracking is critical for hand therapy and rehabilitation, particularly in patients recovering from injury, stroke, or motor control disorders. Accurate and objective tracking enables better customization of therapeutic exercises and progress assessment.

In 2020 [52], a cutting-edge electronic skin (e-skin) sensor system was developed that could detect dynamic finger movements remotely. When positioned on the wrist, the sensor detected five distinct finger gestures in real time by analyzing motion signals using a deep neural network. As

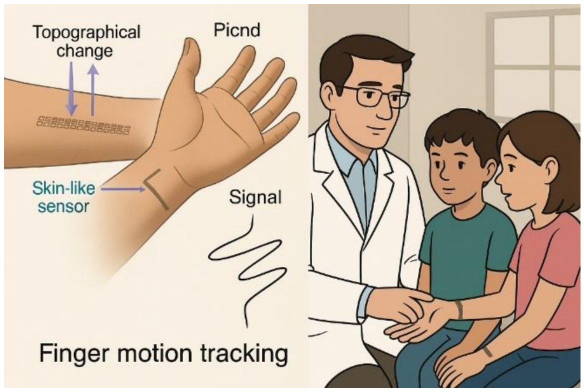

Figure 11. Finger Motion Sensor on Skin with Gesture Detection Illustration (AI-generated image inspired by [52])

illustrated in Figure 11, this innovative system allowed for continuous, non-invasive monitoring of fine motor functions, thus opening new pathways for remote rehabilitation and patient support.

5- Ultrasonic Sensors

Ultrasonic sensors emit a chirp usually between 23 kHz and 40 kHz, much higher than the typical audible range of human hearing at 20 kHz, hence the term ultrasonic. Using this chirp, they measure the amount of time it takes for the sound to bounce off an object. This is based on the same basic principles of echolocation used by bats to find their prey. As the speed of sound in air at room temperature is 343 meters per second, that time can be easily converted to distance, remembering that the ultrasonic chirp travels both to and from the object being sensed.

In recent years, the use of ultrasonic sensors in assistive technologies has gained substantial attention due to their low cost, reliability, and suitability for real-time obstacle detection. In the [53] study, a practical implementation of ultrasonic sensing is described for navigation assistance in individuals with visual impairment. This system integrates five ultrasonic sensors (HC-SR04), a Raspberry Pi 2, voltage dividers, and a Bluetooth headset into a wearable platform to help detect obstacles and provide auditory feedback to the user.

The core of this system relies on the basic working principles of ultrasonic sensors. Specifically, the HC-SR04 module emits a burst of ultrasonic sound at 40 kHz using its transmitter when it receives a short 10-microsecond pulse on its trigger pin. Once the sound waves hit an object, they are reflected back and received by the sensor's echo pin. The time taken for this round-trip is measured and used to calculate the distance between the sensor and the object. This calculation is based on the speed of sound in air, and the distance is obtained by dividing the total time by two and multiplying by the speed of sound. This time-to-distance conversion enables real-time measurement of the surrounding environment.

The HC-SR04 sensor operates at a 5V logic level, whereas the Raspberry Pi 2 GPIO operates at 3.3V. To ensure compatibility and protect the Pi, a simple voltage divider circuit is used between each sensor's echo pin and the Raspberry Pi's input pin. This divider is constructed using a 1kΩ resistor in series with a 680Ω resistor, effectively bringing down the 5V signal to a safe level for the 3.3V input. The Raspberry Pi 2 plays a central role in this system. It triggers each ultrasonic sensor sequentially, measures the echo pulse width, and calculates the distance. These measurements are compared to a predefined threshold. If an obstacle is detected within this threshold, the system determines which sensor has reported the shortest distance and maps it to a corresponding direction such as "object front," "object hard left," or "object slight right." These messages are sent as audio cues via Bluetooth to a headset worn by the user. If no obstacles are detected within the threshold, the system remains silent, reducing unnecessary feedback and improving user experience. Field tests were conducted using this system to evaluate sensor accuracy and user navigation paths. The HC-SR04 sensors demonstrated high accuracy, with less than 2% error when detecting common materials such as aluminum, plastic, and styrofoam at distances up to 3 meters. Navigation trials revealed that users could follow relatively safe paths using the audio cues, with only minimal deviation from an optimal route. Travel times remained reasonable and consistent, indicating that the system successfully aids blind users in navigating unknown environments without requiring physical tools like white canes. This project illustrates the effectiveness of ultrasonic sensors in real-time environmental monitoring and user feedback. The combination of inexpensive hardware, Raspberry Pi-based data processing, and clear audio outputs offers a scalable and customizable solution for visually impaired individuals. It also opens pathways for extending the same principles into other contexts, such as sensory rooms for children with complex needs, where motion-triggered audio or light feedback could enhance therapeutic experiences.

In summary, children with sensory processing difficulties especially those with autism, ADHD, or cerebral palsy face a wide range of challenges that affect their behavior, learning, and emotional well-being. Sensory rooms have emerged as effective environments to support these children by providing tailored multisensory input that promotes relaxation, engagement, and self-regulation.

Whether calming or stimulating, these rooms are designed to match each child's sensory profile, helping them participate more fully in daily activities and therapeutic programs.

With recent advances in wearable sensor technologies and interactive systems, it is now possible to enhance sensory rooms by making them more responsive and personalized. The following section presents three implementation scenarios that demonstrate how wearable sensors, smart toys, and real-time monitoring systems can be used together in sensory environments to support children with complex needs more effectively.

Implementation Scenarios

In this literature-based report, three key ideas were used to explore how wearable sensor technologies can be used in sensory room therapies for children with complex needs. First, the use of PCB-based instrumented toys plays an important role in targeted sensory engagement. These toys have built-in sensors that can detect how a child interacts with them. For example, by tracking repetitive movements and give feedback that supports positive sensory responses. Second, location and movement tracking through wearable GPS or Bluetooth-enabled sensors allows caregivers and therapists to monitor where children are in the room, helping to ensure safety and better understand their behavior in different parts of the space. Third, real-time monitoring of physiological signals such as heart rate or galvanic skin response gives immediate information about the child's emotional or stress levels. This allows the sensory environment to be adjusted right away to better meet the child's needs. These three ideas guided the selection of research studies and the analysis in this report.

Idea 1: PCB-Based Instrumented Toy for Targeted Sensory Engagement

Recent advancements in sensor-based interactive toys have shown promising potential for early screening and behavioral assessment in children with Autism Spectrum Disorder (ASD). Mehralizadeh et al. [54] introduced a sensorized toy car equipped with a custom PCB integrating an ESP8266 microcontroller, an ADXL345 accelerometer, and magnetic shaft encoders to capture multimodal interaction data such as movement patterns and wheel rotations. This system was designed to detect specific ASD-related behaviors like repetitive actions and obsessive attention to rotating objects. The toy wirelessly transmitted real-time data to a remote application, enabling therapists and researchers to analyze behavioral responses across different states of play. Through a combination of acceleration and wheel rotation features, the system achieved a classification accuracy of up to 85.56% in distinguishing between children with ASD and typically developing peers. The authors emphasized the advantages of such low-cost, non-intrusive tools that can be used in natural environments like homes or clinics without requiring expert operation. This study supports the viability of using embedded systems in sensory toys to provide both therapeutic feedback and quantitative assessment, making it highly relevant to the development of custom PCB-based interactive devices for targeted sensory engagement and adaptive therapy.

Building on the idea of using wearable sensors in sensory therapy, a new and exciting tool is the sensorized spinning disk station. This device is designed to be used in sensory rooms, especially to help children with autism who often show repetitive spinning behaviors. Spinning objects can be very appealing to some children with Autism Spectrum Disorder (ASD), and this device gives them a safe and interactive way to explore that interest while also helping therapists learn more about their behavior.

The spinning disk is made using a custom PCB that includes key components such as:

- Rotary encoders that measure how fast and how often the disk is spun.
- An ADXL345 accelerometer that senses how the child moves their hand or how hard they press.
- An ESP32 microcontroller that sends the collected data wirelessly to a computer or tablet used by the therapist.

The disk can be placed on a table or attached to the wall. When a child interacts with it, it gives immediate feedback like changing lights (RGB LEDs) or gentle vibrations. These reactions can be customized. For example, if a child spins the disk quickly, the lights might get brighter, or the vibration might stop when the spinning slows down. This helps keep the child engaged and lets the therapist adjust the settings to meet the child’s needs.

In a sensory room, the sensorized spinning disk offers several important benefits:

- Supports sensory exploration by making the environment more engaging and interactive for children.
- Monitors repetitive behaviors, including the frequency and duration of spinning activity.
- Provides real-time feedback that adjusts based on the child’s interaction, such as changing light intensity or vibration levels.
- Collects long-term data, including average spin speed, session duration, and return frequency.
- Tracks therapeutic progress by comparing behavior patterns across multiple sessions.
- Serves as a calming tool for children who find spinning and vibration soothing and comforting.

The data collected is very useful. It can help therapists understand if the child is more sensitive (hyper-responsive) or less sensitive (hypo-responsive) to certain types of input, such as light, touch, or body movement. This allows the therapist to plan better, more personalized therapy.

Therapists can also use this data to show parents or caregivers how the child is doing in therapy. They can explain how much the child is engaging, what sensory activities help most, and how the child's behavior is changing over time. Overall, the sensorized spinning disk is not just a fun toy it's a smart tool that brings play, therapy, and science together to support children with complex needs in a meaningful way.

Given that the report theme relates to wearable devices utilized in therapeutic environments such as sensory rooms, a valuable extension to the spinning-disk idea would be to integrate a wearable component such as a wrist-worn physiological sensor (heart rate or skin conductance monitor). This wearable would communicate with the spinning disk station in real time, allowing the system to respond not only to the child's physical interaction with the toy, but also to internal physiological states. For instance, if the wearable detects rising anxiety levels while the child is interacting with the disk, the system could automatically trigger calming stimuli such as softer lighting, slower vibration patterns, or soothing audio cues. This bioresponsive feedback loop further personalizes the therapeutic experience and gives therapists an additional layer of insight by correlating sensorized play behavior with emotional or autonomic responses. Such integration reinforces the potential of combining wearable and embedded systems to create a richer, adaptive sensory therapy environment.

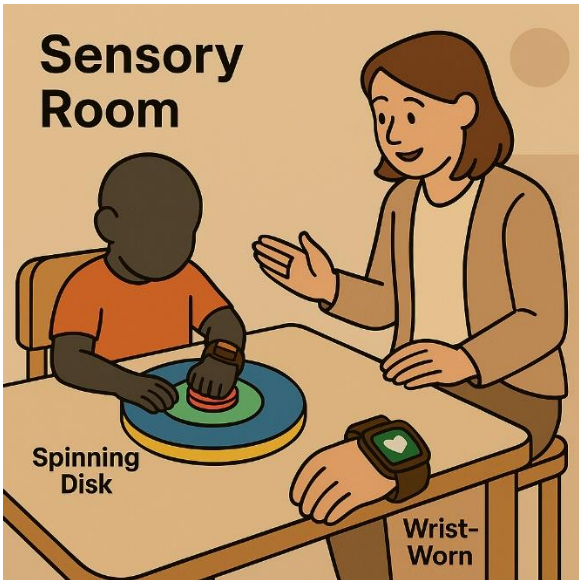

Figure 12. Child engages with ASD therapy disk (AI-generated image inspired by [54])

Linking Ayres Sensory Integration Theory to PCB-Based Instrumented Toys in Sensory Room Therapies

Ayres Sensory Integration (ASI) is a foundational theory that explains how the human nervous system takes in, organizes, and responds to sensory information from the environment to support meaningful behavior. Developed by Dr. A. Jean Ayres [55], this theory is based on the idea that the brain organizes itself, and that combining information from different senses is essential for skills like attention, emotional control, body movement, and learning. ASI focuses especially on three sensory systems that are very important in childhood development: the vestibular system (movement and balance), the tactile system (touch), and the proprioceptive system (body position and pressure). The theory highlights that active, engaging, and well-matched sensory experiences help the brain adapt and grow through a process called neuroplasticity.

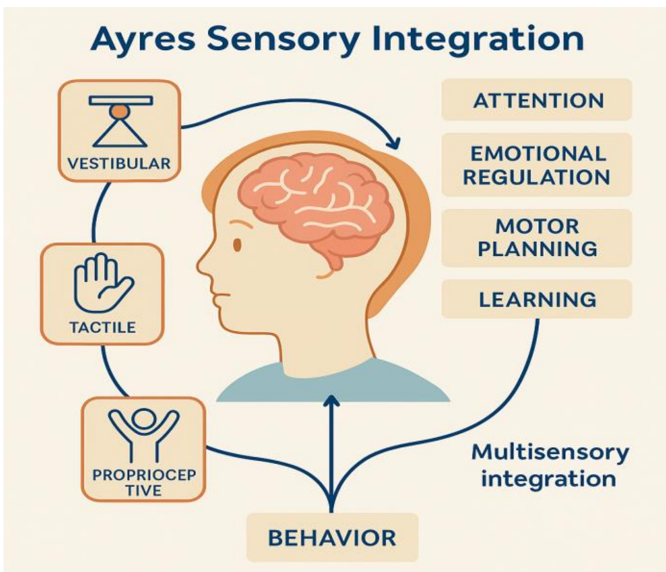

Figure 13. From Senses to Behavior (AI-generated image inspired by [55])

Modern neuroscience supports Ayres' ideas. Studies show that the vestibular system helps control posture, balance, and attention through connections in the brainstem, cerebellum, and cerebral cortex. The sense of touch and body awareness also plays a major role in understanding body position, coordinating movement, and learning how to plan and carry out actions. Another important part of ASI is sensory modulation, which means the brain's ability to manage sensory input and keep behavior and emotions at a steady level. When this ability is disrupted, a child may react too strongly or not strongly enough to things like lights, noise, or touch. This can make it hard to participate in daily life and social situations.

Ayres believed that therapy should give children the kind of sensory experiences their brain needs. These experiences should be playful, tailored to the individual, and appropriately challenging. This helps the brain form new pathways that improve how it processes sensory information, how the child moves and plans, and how they behave. Research has shown that this approach can help children with developmental challenges, especially autism, by improving focus, self-control, and motor coordination.

Based on this theory, the sensorized spinning disk toy brings ASI concepts into a modern device. It uses a custom electronic board (PCB) that includes rotary encoders, motion sensors such as the ADXL345 accelerometer, and an ESP32 microcontroller. This setup creates a rich sensory experience by giving real-time feedback, like changing lights or vibration, based on how the child interacts with the toy. The child might spin it fast or press it hard, and the toy responds right away. This supports sensory-motor integration through repeated, intentional movement and helps adjust the child's arousal level depending on whether they are over-sensitive or under-sensitive to sensory input.

The toy also supports key ideas in ASI such as praxis and ideation. As children use the spinning disk, they are encouraged to think about how their actions cause changes, to plan different ways of interacting with it, and to carry out those plans. This helps them improve in areas like body coordination, motor planning, and spatial awareness. These are skills that are often weaker in children with sensory or motor challenges. In addition, the toy records data about each session. Therapists can use this data to monitor progress and personalize therapy even more.

Most importantly, the spinning disk provides meaningful, hands-on sensory play that fits each child's needs. This kind of experience is exactly what ASI says the brain needs to improve and grow. By using this smart device in sensory rooms, therapy becomes more dynamic, informed by data, and personalized. The toy is not just a fun gadget. It is a carefully designed tool, based on years of research, that helps children build the foundations they need for daily function.

In this way, the spinning disk brings together engineering, therapy, and neuroscience. It brings Ayres' vision into the digital age and gives therapists a research-based, flexible tool that supports both sensory and motor development in children with complex needs.

Using DIR/Floortime Principles in Sensor-Based Therapy for Children with Autism

The DIR/Floortime model is a well-known approach used to support children with Autism Spectrum Disorder (ASD). DIR stands for Developmental, Individual-difference, Relationship-based. This model was created by Dr. Stanley Greenspan and Dr. Serena Wieder [56] to help children develop emotional, social, and thinking skills through playful and meaningful relationships.

Another strength of the spinning disk is its ability to collect data. It can log how long each session lasts, how often the disk is spun, and how strongly the child interacts with it. Even though DIR/Floortime does not focus on strict measurement, this data can still help therapists understand patterns, track progress over time, and personalize therapy to meet each child's needs.

Most importantly, the device allows the child to be in control. The toy responds gently and adaptively, so it can be adjusted for children who are either very sensitive or not very responsive to sensory input. This matches the DIR belief that therapy must be adapted to the unique sensory profile of each child.

Figure 14. DIR/Floortime Integration with Sensory Room (AI-generated image inspired by [56])

Idea 2: Location Tracking and Movement Monitoring

Children with Autism Spectrum Disorder (ASD) often experience significant challenges related to communication, behavioral regulation, and safety. Among the most urgent concerns for caregivers and therapists is the risk of wandering or elopement, in which a child leaves a safe environment without supervision. Such incidents can lead to critical safety risks and cause heightened anxiety for families, educators, and healthcare professionals. In recent years, wearable technologies have emerged as powerful tools to mitigate these risks, offering both safety assurance and behavioral insights for children with ASD.

Additionally, the use of real-time alerts (when a child exits a designated zone) and visual tools like heatmaps enhances caregiver engagement and peace of mind. These tools contribute to resilience by reinforcing safety, predictability, and involvement. They also build a sense of partnership between therapists and caregivers.

Wearable devices embedded with sensors such as GPS, Bluetooth, or accelerometers enable real-time tracking, physiological monitoring, and structured communication support. These systems not only help caregivers maintain awareness of a child's location, but also provide therapists with valuable behavioral data information that can guide the design of individualized therapy plans. Recent advancements in mobile health (mHealth) platforms have combined these capabilities into unified systems that support independent living, therapeutic monitoring, and data-driven intervention.

A notable implementation of such technology is presented in a study by Koumpouros [57], which details the development and evaluation of an "all-in-one" wearable solution designed specifically for high-functioning children with autism. The platform combines a mobile application and smartwatch interface to deliver four core functionalities:

- ❖ Location Monitoring: GPS-based positioning and path tracking,
- ❖ Communication: Quick call, emergency call, and auto-answer options,
- ❖ Activity Scheduling: Alarms with text and image-based multimedia reminders
- ❖ Physiological Monitoring: Heart rate tracking to detect signs of stress.

The system was tested in a two-month field study involving twenty children with ASD and twenty-five caregivers. The design emphasized user-centered development, engaging both families and a multidisciplinary team of experts in special education, psychology, and speech therapy. The application architecture enabled updates every 5 seconds, securely transmitting data to a centralized server. Caregivers could view the child's live location through Google Maps and receive alerts triggered by movement patterns or biometric thresholds.

The PYTHEIA questionnaire was used to evaluate user satisfaction. The feedback was overwhelmingly positive, with location tracking rated highest 100% of caregivers reported extreme satisfaction regarding reliability and ease of use. The system significantly enhanced caregivers' sense of security, especially in open and uncontrolled environments. Additionally, the communication and scheduling features received high praise for their simplicity, particularly the use of visual and auditory cues, which support children with limited verbal abilities.

This study highlights the effectiveness, adaptability, and therapeutic potential of wearable solutions in real-world settings, offering children with ASD increased independence and caregivers a greater sense of control and peace of mind.

Building upon the foundations laid by the Koumpouros model, this report proposes an expanded application of wearable monitoring technologies within structured therapeutic environments such as sensory rooms. These rooms are designed to deliver controlled stimuli through visual, tactile, and auditory inputs to support sensory integration, emotional regulation, and behavioral development in children with autism and related neurodevelopmental disorders. In this proposed framework, wearable GPS or Bluetooth-enabled trackers (a smartwatch or smartphone placed in the child's pocket) are used not only for safety monitoring but also for behavioral mapping within the sensory space. The room is digitally divided into zones, each assigned a distinct therapeutic purpose:

- ❖ Calm Zones: Featuring dim lighting, soft cushions, and quiet sounds for relaxation.
- ❖ Tactile Zones: Equipped with textured walls, sensory bins, or touch-based stimuli.
- ❖ Movement Zones: Including trampolines, swings, and space for gross motor activities.

By defining digital boundaries for each of these physical zones, the wearable system can log detailed data, including entry and exit times, duration spent in each area, and movement transitions across zones. When combined with heart rate or accelerometer data, this enables the creation of behavioral heatmaps and session summaries that therapists can use to understand individual engagement and responses.

While GPS and standard Bluetooth technologies are commonly referenced for location tracking, both present significant limitations when applied in indoor settings such as sensory rooms or clinical therapy environments. GPS signals are prone to degradation or complete loss inside buildings due to structural interference, making them unreliable for indoor localization. Similarly, traditional Bluetooth tracking methods often lack the spatial resolution necessary for capturing fine-grained movement or zone-level behavior.

To address these limitations, Bluetooth Low Energy (BLE) beacon-based indoor positioning systems have emerged as a viable alternative. As demonstrated by Zuo et al. [58], these systems involve strategically placing multiple BLE beacons throughout a physical environment, enabling a wearable device to estimate its position based on Received Signal Strength Indicator (RSSI) values from surrounding beacons. Using techniques such as trilateration and graph-based optimization, the system can effectively reduce noise and improve accuracy, even in complex indoor spaces where signal reflections and attenuation are prevalent. This beacon-based triangulation approach allows for zone-specific localization, which is particularly valuable in sensory rooms where spatial behavior is a key therapeutic metric. When integrated with physiological and behavioral sensors, the location data provides therapists with a multi-dimensional understanding of the child's interaction within the space. This enables the delivery of real-time, adaptive interventions that are responsive not only to how a child is feeling but also to where they are and how they are moving. By leveraging such indoor positioning technologies, therapeutic environments can become more responsive, data-informed, and tailored to individual sensory needs.

Therapists and caregivers can utilize this zone-based monitoring system in a variety of meaningful ways:

- ❖ Safety Assurance: Real-time alerts are generated if the child exits the therapy room or enters a restricted area, ensuring continuous supervision and response.
- ❖ Activity Mapping: Automatically generated session reports highlight which zones the child visited, how long they stayed, and their navigation pattern, providing clear visual insights into engagement.

❖ Behavioral Insights: Movement behaviors such as repetitive pacing, avoidance of specific zones, or preference for particular stimuli can be observed and analyzed in context. These patterns offer valuable information for identifying stressors or sensory sensitivities.Session Planning and Personalization: Data collected from multiple

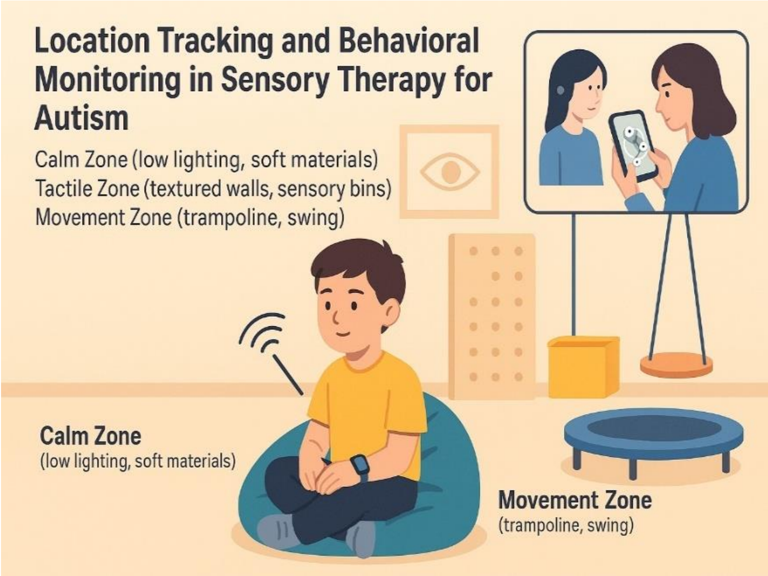

Figure 15. Zone-based sensory room with tracker (AI-generated image inspired by [58])

sessions can help therapists refine therapy plans. For instance, if a child consistently avoids the tactile zone and exhibits elevated heart rate near it, this may indicate sensory aversion, prompting therapists to introduce those stimuli more gradually or adjust their presentation.

Idea 3: Gamified Wearable Audio and Video Monitoring for Behavioral Analysis

Gamification involves adding game-like elements, points, badges, rewards, levels to non-game activities to increase motivation and engagement. Popular examples include Kahoot [59]! in classrooms or fitness apps that reward progress. Gamification can make tasks that feel boring or overwhelming more enjoyable and easier to manage.

Gamification works by tapping into both intrinsic and extrinsic motivation. Intrinsic motivation is doing something because it is fun or interesting. Extrinsic motivation is driven by external rewards, like prizes or praise. According to Self-Determination Theory [60], motivation is strongest when people feel autonomous, competent, and connected to others. people are more likely to stay motivated and succeed when three psychological needs are met: autonomy (feeling in control of one's actions), competence (feeling capable), and relatedness (feeling connected to others). These three needs also play a vital role in therapy for children with ASD, who often struggle with motivation, communication, and emotional regulation.

The framework presented by Rutledge et al. [61] explains how gamified systems can meet these needs when thoughtfully designed. For example, wearable feedback like lights or sounds when a child successfully completes a task provides a sense of competence by giving immediate positive reinforcement. Allowing children to explore tasks at their own pace or choose between sensory challenges supports autonomy. When therapists and parents engage with the child's progress, providing encouragement and shared feedback, relatedness is enhanced.

Children with ASD often experience challenges with motivation, especially when tasks feel difficult, abstract, or disconnected from immediate feedback. Gamification can help bridge this gap by providing timely, visible rewards that encourage desired behaviors. For example, wearable devices can vibrate, light up, or play a sound when a child makes eye contact, uses language, or calms themselves. These immediate reinforcements support the development of executive function skills. Using wearable sensors that collect real-time data is giving therapists a powerful new way to watch, understand, and help children during therapy. In a study by Cumbo and Leong [62], children wore small cameras on their chest that recorded video and sound as they played outside. This helped therapists see what the child was doing and feeling during natural play, like when they spoke to others, showed emotions, played with peers, or reacted to their environment. These behaviors are sometimes hard to notice in regular therapy sessions. The recordings gave therapists a chance to understand how a child uses language, how they move in space, and what situations might make them feel upset or uncomfortable.

Another study by McElwain and colleagues tested a device called LittleBeats [63]. This wearable device can record sound, movement, and heart rate all at once while the child is at home. Parents said the device was safe and easy to use, and most children didn't mind wearing it. For therapists, this kind of device gives them more accurate information about how the child is acting and feeling not just what they're doing, but also how their body and emotions are responding. For example, if a child's heart rate goes up or they move a lot when a light turns on, it might mean the light is too stimulating for them.

Now imagine if these wearables could also give rewards to the child in real time. This is what gamification means turning the activity into something fun and rewarding. A therapist could program the device to vibrate softly, light up, or make a fun sound whenever the child does something positive, like making eye contact, using words, or playing calmly. These rewards help the child feel motivated and focused without interrupting their play. This idea is based on behavior training, where giving small rewards helps build good habits.

The data from the device can also show how the child reacts during different parts of the session. For example

- A high heart rate and lots of movement might mean the child feels overwhelmed.
- More talking and calm heart activity might mean the child is doing well and feeling safe.

Therapists can look at this information over time to see what works best and how the child is improving. This helps them plan therapy that is just right for each child. It also makes it easier to adjust the sensory room environment (like changing the lights, sounds, or textures) based on what the child needs.

The audio recordings are also useful. Therapists can listen to how the child talks—whether they repeat words (echolalia), speak in a flat tone, or talk to themselves. These are important signs for understanding children with autism. If the system uses smart software like machine learning, it can help find these patterns automatically.

Another benefit is that therapists can share this progress with parents. They can show graphs or videos that explain how the child is improving and why certain therapies are working. This builds trust and teamwork between families and therapists and helps keep therapy consistent at home and in the clinic.

In short, wearable devices that collect sound, video, and body data especially if they are gamified, can help therapists do a better job. They can respond to children's needs more quickly, give feedback during the session, and track progress over time. This is especially helpful in sensory rooms, where therapists work with children who have autism or other challenges. These smart wearables make therapy more fun for the child and more informed and effective for the therapist.

Figure 16. Gamified Child Therapy (AI-generated image inspired by [63])

The implementation scenarios presented in this report highlight the promising role of wearable sensor technologies in advancing sensory room therapies for children with Autism Spectrum Disorder and related developmental challenges. From PCB-based interactive toys and real-time physiological monitoring to location-aware tracking and gamified behavioral feedback, each approach offers a pathway toward more personalized, engaging, and effective interventions.

These innovative tools demonstrate how technology can bridge the gap between observation and action, enabling therapists to respond in real time to a child's behavioral and emotional cues. Additionally, they provide caregivers with valuable insights that extend the benefits of therapy beyond clinical settings and into everyday life.

Building on these implementation strategies, the following discussion examines the broader impact of integrating wearable systems into therapeutic practice. It explores how these tools enhance clinical decision-making, support caregiver involvement, and contribute to more responsive, data-driven, and inclusive models of care.

Discussion

A comprehensive examination of recent practices and theoretical approaches highlights the growing potential of wearable sensor technologies to transform sensory room therapy for children with Autism Spectrum Disorder (ASD). These technologies, including GPS-enabled trackers, biometric sensors such as heart rate and galvanic skin response (GSR) monitors, and continuous behavioral logging systems, offer therapists a non-intrusive, data-driven method for observing and interpreting a child's sensory and emotional responses. Such real-time feedback allows for immediate adjustments to therapy, ensuring more accurate alignment with each child's unique sensory needs.

Tools like the LittleBeats [63] device and sensor-integrated therapy zones have demonstrated the ability to identify aversive stimuli, monitor progress over time, and guide more individualized session planning. These wearable systems create a dynamic loop where sensor data informs environmental adjustments such as changes in lighting, auditory stimuli, or tactile input in real time. As a result, therapy becomes more responsive and adaptive, minimizing overstimulation while maximizing engagement and emotional regulation. The integration of wearable sensors also plays a key role in supporting caregivers. Session summaries, behavioral heatmaps, and real-time alerts contribute to increased transparency and continuity of care beyond the therapy room. This transparency fosters a deeper sense of reassurance, reduces caregiver stress, and encourages stronger collaboration between parents and therapists. Families gain insight into their child's behavior, allowing them to reinforce therapeutic strategies at home with greater confidence and competence. Theoretical frameworks such as Bronfenbrenner's Ecological Systems Theory and Resilience Theory provide essential context for understanding the broader impact of these technologies. Bronfenbrenner's model highlights the multiple layers like family, school, community that influence a child's development. Integrating wearable systems into therapy facilitates better alignment across these environments by sharing relevant behavioral insights with all stakeholders. Similarly, Resilience Theory emphasizes the importance of structured support systems and predictability in reducing caregiver stress and promoting emotional well-being. When wearable technologies provide consistent, actionable feedback, they directly contribute to the protective factors identified in resilience-building frameworks.

By incorporating theoretical perspectives specifically, Resilience Theory [64] and Bronfenbrenner's Ecological Systems Theory [65] into the design of these technologies, we can develop more holistic, family-centered interventions.

Resilience Theory, as outlined in the study by Dijkstra-de Neijs et al. [66], emphasizes a caregiver's ability to recover from difficult situations and maintain well-being despite ongoing stress. The theory identifies two primary factors that support resilience: intrapersonal traits, such as planning skills and emotional regulation, and contextual factors, such as satisfaction with social relationships and environmental stability. The study highlights that satisfaction with social relationships is the strongest predictor of resilience, suggesting that structured support systems play a key role in managing parental stress.

Bronfenbrenner's Ecological Systems Theory adds another important dimension. This model proposes that child development is influenced by multiple, nested layers of environmental interaction: the microsystem (immediate settings like home or therapy rooms), mesosystem (interactions between different microsystems), exosystem (external systems that influence development indirectly), macrosystem (cultural and societal structures), and chronosystem (changes and transitions over time) [67]. When applied together, these two theories provide a comprehensive framework for understanding and enhancing the use of wearable tracking in sensory room therapies. First, from the perspective of the microsystem, wearable sensors that monitor real-time location and zone engagement (time spent in calm, tactile, or movement zones) give therapists direct insight into the child's sensory preferences and stress triggers. This structured feedback environment promotes behavioral understanding and helps therapists personalize intervention plans. It also establishes a sense of environmental predictability, which supports the contextual stability needed for parental resilience.

In the mesosystem, the connection between home and therapy settings can be strengthened by sharing this sensor data with parents. Consistent routines and coordinated strategies between therapists and families enhance both child outcomes and caregiver confidence. For parents, access to clear, reliable behavioral data reduces the unpredictability that often causes anxiety. According to Resilience Theory, this improved sense of control and planning supports maternal resilience, enabling caregivers to feel more competent and engaged.

At the exosystem level, data collected from location tracking can inform decisions made by organizations and institutions, such as therapy providers, schools, and healthcare agencies. These systems though not directly interacting with the child can use the behavioral insights to improve programming, resource allocation, and staff training. This indirectly supports the family by making therapies more accessible and tailored.

In the macrosystem, societal attitudes toward autism and the inclusion of assistive technologies influence the adoption of such interventions. Integrating wearable tracking into sensory therapy reflects a broader cultural move toward data-driven, inclusive, and individualized care. However, barriers such as cost, lack of insurance coverage, or geographic limitations must be addressed to ensure equitable access. As noted in resilience literature, systemic support is key to reducing family burden.

The chronosystem highlights the importance of tracking change over time. Longitudinal use of wearable tracking systems allows for observation of developmental trends, behavioral adaptations, and responses to therapy across weeks or months. This aligns with both theories helping therapists adjust strategies and helping parents visualize progress, all while maintaining emotional stability.

From a therapeutic standpoint, the value of wearable sensors lies in their capacity to make therapy both more precise and more comprehensive. Children benefit from interventions that are continuously tailored to their physiological and behavioral states, increasing their ability to remain calm, focused, and socially engaged. Therapists benefit from reduced guesswork and increased confidence in their interventions, while families are empowered with knowledge and inclusion in the therapy process.

Prospectively, integrating wearable systems into regular therapeutic practice holds promise for scalable, equitable, and family-centered care. Developers should prioritize designing devices and interfaces that are user-friendly for both therapists and caregivers. Real-time dashboards and accessible reports should deliver meaningful, actionable insights without requiring specialized technical knowledge. Additionally, schools, therapy centers, and government programs should consider investing in such technologies particularly in underserved areas where specialized therapy services may be limited. Strategic collaborations among educational institutions, healthcare providers, and technology developers can accelerate widespread adoption and innovation.

Facility Requirements for Integrating Wearable Systems in Therapeutic Environments

The successful integration of wearable sensor technologies into therapeutic practices requires a comprehensive and strategic upgrade of both general therapy spaces and specialized sensory rooms. These environments must be adapted to support continuous real-time data collection, secure processing, and responsive feedback mechanisms. While both types of rooms share core technological needs, their unique therapeutic functions call for specific configurations to preserve their intended atmosphere and maximize the effectiveness of wearable-enabled care.

In general therapy spaces, a robust technological foundation must be established to support the use of wearable devices during individual or group therapy sessions. The first essential component is the implementation of a secure, high-bandwidth wireless network infrastructure. Dedicated wireless access points or IoT hubs must be installed in each therapy room to ensure uninterrupted, encrypted connectivity for wearable sensors transmitting sensitive physiological data.

Supporting this network infrastructure, a centralized server and data storage system is required. A secure, climate-controlled server room or data closet within the facility should house high-capacity servers and network-attached storage units. These systems will collect, organize, and store biometric data from all therapy spaces. Redundant storage, cloud backup capabilities, and uninterruptible power supplies (UPS) are necessary to ensure data reliability and service continuity.

Wearable devices themselves form the core of this system. Facilities must be equipped with a sufficient inventory of multi-modal wearable devices such as wristbands or skin patches that monitor heart rate, galvanic skin response, movement, and other relevant biometrics. To support their use, each therapy room should include device charging stations and secure, labeled storage cabinets for hygienic and efficient device management between sessions.

To translate data into therapeutic insights, therapy rooms must also include therapist interface devices such as tablets or dedicated computer workstations. These interfaces display real-time sensor dashboards, biometric alerts, and session summaries, enabling therapists to make informed, data-driven decisions during therapy. In group settings, wall-mounted displays may be added to allow multiple facilitators to simultaneously monitor clients' physiological and behavioral states.

All wearable and dashboard systems must be supported by integrated software and IT platforms. The facility should deploy real-time data acquisition and processing software on its servers and synchronize this with therapist-facing applications. Ideally, these platforms will also integrate with existing electronic health record (EHR) systems, ensuring that wearable data is automatically recorded in client files. Strict adherence to healthcare data protection standards such as encryption protocols, audit logging, and authenticated access is essential throughout the system.

To secure this infrastructure, the facility must implement enhanced cybersecurity measures. Firewalls, secure virtual private networks (VPNs), and role-based access controls are necessary to safeguard data integrity and confidentiality. All networking and IT hardware must be physically secured, and data-handling policies must be revised to reflect new protocols introduced by the wearable integration.

Facility-wide physical upgrades are also required to accommodate new equipment. These may include installing additional power outlets, managing cables discreetly, and renovating underutilized spaces to serve as dedicated server rooms. Cooling systems, restricted access, and noise insulation should be incorporated into these renovations to maintain equipment performance and security without disrupting therapeutic workspaces.

In contrast, sensory rooms which are tailored specifically for clients with sensory processing challenges require more nuanced and carefully balanced upgrades. These environments must remain immersive and calming while integrating responsive technological capabilities.

A key addition to sensory rooms is an adaptive environmental feedback system. This system connects wearable sensor data to smart room elements such as lighting, audio devices, and visual displays. For example, if a child’s sensor detects elevated heart rate or increased stress, the system can automatically lower lighting levels or play calming music, adjusting the sensory environment in real time to the child’s physiological state.

Given the time-sensitive nature of sensory regulation, sensory rooms may also benefit from a localized processing system. This could take the form of an edge computing device or high-performance workstation that enables instant processing of sensor data and triggers immediate responses from the environmental control system. While this device would sync with the central server for logging, it ensures that therapeutic adaptations occur without delays caused by network latency. In addition to conventional wearables, sensory rooms can incorporate specialized environmental sensors. These may include pressure-sensitive mats, motion detectors in soft play areas, or spatial sensors in interactive equipment. Advanced monitoring tools like EEG headbands [68] may also be utilized for clients who benefit from neurofeedback. All devices must remain wireless and discreet to uphold the room's calming and clutter-free aesthetic. Therapists operating in sensory rooms require a means of monitoring clients without disturbing their sessions. A monitoring station should be positioned just outside the room or embedded in a handheld device. This station enables therapists to view real-time biometric data, receive alerts, and manually adjust room settings if needed. It also allows for immediate intervention if signs of distress or overstimulation appear. Effective device management is also crucial in sensory environments. A storage cabinet or wall-mounted unit near the sensory room should house wearable devices, accessories, chargers, and cleaning materials. This station ensures that therapists can deploy, sanitize, and recharge equipment efficiently between sessions while maintaining hygiene and readiness.

Finally, all sensory room upgrades must meet strict safety and therapeutic standards. Any added wiring must be hidden or securely fastened, and electronic components like projectors or speakers must be mounted out of reach. Visible lights or sounds from devices should be adjustable or concealable. Additionally, both software and hardware-based emergency override mechanisms should be available to immediately shut down all sensory stimuli if a child becomes overwhelmed or equipment malfunctions. These precautions help ensure that the therapeutic purpose of the space is preserved and that technology complements rather than compromises the therapeutic experience.

Staffing and Personnel Requirements

The integration of wearable sensor systems into therapeutic settings necessitates not only infrastructural and technological enhancements but also the involvement of specialized personnel. A coordinated team is essential to ensure that these technologies are deployed effectively, managed securely, and aligned with the therapeutic needs of both children and their families.

One critical role in this framework is that of the Device Setup Technician, who is responsible for preparing, maintaining, and managing wearable hardware before and after therapy sessions.

This includes charging devices, updating firmware, performing basic troubleshooting, and assisting therapists in fitting the devices on clients to ensure comfort and accuracy. These technicians are also tasked with maintaining proper hygiene standards and ensuring adherence to data privacy protocols. To perform these duties effectively, they typically require a background in biomedical engineering or information technology, complemented by training on the specific wearable systems used within the facility.

Equally important is the role of the Wearable Data Analyst, who transforms raw physiological data collected by the sensors into clinically meaningful insights. By processing this data, the analyst generates visual dashboards and reports that help therapists make informed decisions and monitor the child's progress over time. This role requires strong proficiency in data science, including experience with time-series analysis and physiological interpretation. Ethical data handling practices and an understanding of healthcare privacy regulations are also critical components of this position.

To support the digital infrastructure, the IT Systems Administrator is responsible for maintaining the facility's network systems, servers, and data storage platforms. This includes ensuring system uptime, performing regular updates, managing user access to therapy dashboards, and safeguarding data security through best practices in cybersecurity. The administrator also troubleshoots technical issues promptly to minimize disruptions during therapy sessions. This role demands strong IT credentials, familiarity with healthcare technologies, and the ability to communicate technical information clearly to other staff members. Another vital position is the Family Communication Coordinator, who serves as the primary link between the therapy team and the families. This individual explains the purpose and function of the wearable technologies in accessible terms, manages the informed consent process, and delivers clear summaries of therapy outcomes based on sensor data. In cases where wearable devices are used at home, the coordinator also provides training and ongoing support to families, helping them integrate data-driven strategies into daily routines. This role typically requires a background in psychology, health education, or social work, along with excellent interpersonal and communication skills.

Together, these personnel constitute a multidisciplinary team that ensures the ethical, secure, and therapeutic application of wearable sensor systems. Their collaboration enables data-driven care to be delivered in a way that remains centered on the needs and well-being of the child, enhancing both the effectiveness and inclusivity of modern therapeutic environments.

Conclusion

In conclusion, using wearable sensors in sensory room therapy for children with Autism Spectrum Disorder (ASD) has two main benefits. First, it helps therapists give care that fits the child's needs more exactly. Second, it helps parents feel more confident, supported, and involved in their child's therapy. These smart tools like GPS trackers, heart monitors, and movement sensors, give real-time feedback and help adjust the sensory room based on how the child is feeling and acting. By connecting these tools to Resilience Theory and Bronfenbrenner's Ecological Systems Theory, we can make sure the technology supports both the child and the family. Resilience Theory shows us how strong planning, support, and relationships help parents deal with stress. Bronfenbrenner's theory reminds us that a child's development is shaped by many layers like family, school, and the wider community. When therapy includes these ideas, it becomes more complete and helpful. We recommend that future therapy programs start using these wearable tools as part of their regular work. Developers should design the tools to be easy to understand and use not just for therapists, but also for parents. The tools should give clear reports and helpful feedback that families can use at home. Schools and government programs should invest in this kind of technology, especially in areas where therapy is hard to find. Partnerships between schools, hospitals, and tech companies can help bring these tools to more families. Also, more long-term studies are needed to see how these tools affect children's progress over time. We should track things like how well the child focuses, stays calm, and interacts with others, as well as how the parents feel about the therapy. Overall, wearable sensor integration offers a meaningful step forward in therapy for children with ASD. It combines technology with care, data with emotion, and structure with flexibility making therapy not only smarter, but more human.

Future research can help make wearable sensor therapy even better. First, we need long-term studies to see how using wearable sensors affects children's growth and how it helps parents feel less stressed over time. Second, it's important to include therapists, families, and children in designing and using these tools. When the people who use the tools help build them, the tools work better for real-life needs. Third, researchers should try using these wearable tools in special education classrooms, so that therapy and learning can happen together in school. Also, future studies should look at how well these tools work for different budgets, how to predict children's needs using sensor data, and how to make sure all families even those in hard-to-reach places can get access to this helpful technology.

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