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Stim4Sound: A musical interactive system promoting communication between autistic people and society

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Acknowledgement

The project did last for a long time. Although various problems arose during the process, the study was successfully completed in the end. First of all, I would like to thank my supervisors, Jelle van Dijk and Rúben De Freitas Gouveia. They gave me a lot of professional advice during the research process, and they were always respectful of my ideas and supportive of my design. Also, they were concerned about my status, They helped me to complete this thesis successfully and I learnt a lot about research methods from them in the process.

Then I would like to thank my partner Christopher Benjamin Leonard, who has helped with implementing the electronics basement which is an important part of the project. I am very grateful to him for working with me in the early stages of this project to organise the workshops and contact participants, which was a great collaborative experience. He also provided me with a lot of help with my thesis. I learned a lot from him about electronics, programming and other technical aspects.

Moreover, I really appreciate the study advisor Monique Duyvestijn. She kept an eye on me and even visited me personally to see what kind of problems was having. It was really kind of her to gave me advice and helped me with many questions in life.

Finally, I would like to thank my family and my friends. Even though I am not in the same country with them, my parents have always encouraged me, taken an interest in my situation and created a situation where I could be more at ease with my studies. And when I had emotional problems, I am grateful to my friends for bringing me out of it and helping me to soothe my feelings. I would like to thank them for always supporting me at behind.

Abstract

Stimming is a self-simulating behaviour that refers to making repetitive movements or repeating sounds. It usually includes flapping the arms, snapping the fingers, banging the head, clapping, shaking, jumping, spinning or more complex body movements. Many people exhibit stimming behaviours and perform these actions unconsciously. However, in people with autism, these behaviours are more pronounced. They may display stimming actions that last longer and may perform in situations that can be inappropriate for a non-autistic dominant society. One of the most obvious features of autistic groups is he deficit in the ability to communicate with society, so they are not able to be aware of their own behaviours. This is why some other people have an aversion to their stimming actions. For people with autism, however, these behaviours can often arise as a result of their efforts to reduce sensory load, to reduce the unfamiliarity of their surroundings, or to show their frustration when they are unable to communicate effectively. Stimming is generally not harmful, but some that can be socially disruptive or destructive can be dangerous and therefore need to be managed through some behavioural therapies.

In order to help the autistic community socialise with those close to them, such as family and friends, the research named Stim4Sound has been started. The initial aim of this research was to develop a framework based on the DivComp concept of sensemaking, which connects people from different backgrounds, including autistic and neurotypical people, as well as other people around them so that they can understand each other better. On the basis of this concept, a system has started to be built, with the main target group being people with autism and their surrounding family members and friends. The system aims to create an environment where autistic people can perform stimming behaviours without being judged, but rather interact with others through these actions, thus helping them to better connect with the society around them. For the non-autistic group, the system is designed to allow them to experience the stimming behaviours on their own. It is hoped that the process can strengthen the connection and understanding between the two groups

The main event of the system is to allow the users to create different sounds with daily objects as well as to make variations of the created music by using common stimulating behaviours. During this time users are provided specific music and rhythms that will act as back-ups and guides to help them find inspiration. Auxiliary instruments can be used as examples or played out to give users more possibilities to create music. The main wearable device helps to record, and detect the actions and changes in the different properties of the music through changes in the movements. It is expected that the participants can enjoy communicating with each other non-verbally using postures, movements, devices etc. and promote social interaction in the whole process.

This article describes the initial building process of the Stim4Sound system based on the Divcomp concept, the completion of the various basic functions and the design and prototyping of the various devices included, and finally the testing with the target users. It concludes with a summary of the completion of the research and the areas where the system can still be improved, as well as a discussion of subsequent research and future development of the system.

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1. Introduction

Autism is a developmental disorder with symptoms that often begin to manifest in early childhood, but a formal diagnosis often takes more time. It is estimated that approximately one in every 100 children worldwide has autism (Zeidan et al., 2022). This number represents an average estimate and the reported prevalence varies according to studies. However, it also demonstrates the prevalence of autism in terms of epidemiology. The official diagnostic name for autism is Autism Spectrum Disorder (ASD). The term "spectrum" indicates that autism varies in its manifestations and severity, which means each person with ASD has their own unique strengths and challenges. But there are still some common manifestations of autism that can even be used as a basis for the diagnosis, which is some "unusual" behaviours. These include tapping, rocking back and forth, turning or banging objects around, repeating certain words or phrases, or other more complex actions. The behaviours are usually repetitive, even habitual. They are also known as self-simulating behaviours, or stimming.

As research and diagnostic techniques for autism have been improving in recent years, autism is also becoming more familiar around the world. However, along with the increased attention, the specificities of the autistic population seem to be being more emphasized. The stimulating behaviours of autism can appear to be inappropriate in many situations due to general social rules which people with autism are unable to notice due to their social deficit, such as emotional or aggressive actions that others see as inappropriate for the current situation, or talking to themselves without being able to communicate properly with others. Even though such behaviours usually happen as an attempt to relieve their discomfort, there are still many people who may misunderstand the behaviours of autism and even the group as a whole.

Therefore a study will be initiated with the main goal of helping people with autism to communicate better with the people and society around them, and also to help the non-autistic people around them to understand more about their behaviours. The research will focus on the aspect of user experience, hoping to create a scenario that provides enjoyable activities and helps users to interact naturally within it, even if they don't need to use as much language as usual. So the main research question for this study will be

How to create a new system with a different interaction scenario to help improve communication between autistic individuals and non-autistic people around them?

From this question, the following subquestions can be generated:

- How can the interaction be designed to suit the characteristics of the people with autism?
- What will the interaction approaches that are possible be like? How will they differ from common user interactions?
- What products or tools will be involved in the scenario to help complete the interaction?
- Can the system formed by such an interaction scenario be popularised to help more people with autism to communicate with the society around them?

The following research will mainly aim to address the research questions.

2. literature review

2.1 Defining autism

Autism spectrum disorder (ASD), often referred to as autism, is a developmental disorder characterised by persistent problems with social communication and interaction, as well as restricted and repetitive patterns of behaviours, interests or activities (American Psychiatric Association. 2013). It is not a rare disorder. According to Zeidan et al (2022), it was estimated that one in every hundred children worldwide has autism. As a heterogeneous disorder, the presenting characteristics and needs of autistic people vary and may change with developmental circumstances (Lord et al., 2020). Some will make great progress as they grow up and are able to live independently, but there are still some individuals with long-term problems that even last for a lifetime. The main and most common characteristic of people with autism is, as mentioned in the previous definition, some difficulty in social interaction and communication. They may also have abnormal sensory responses, excessive attention to detail or an overreaction to changes. Furthermore, many of them will also suffer from depression, anxiety, attention deficit hyperactivity disorder (ADHD) or other disorders (Peacock, Amendah, Ouyang & Grosse, 2012). All of these factors may have an impact on their ability to live in a non-autistic-dominated society, especially in terms of access to education and employment.

Autism was first realised and recognised as a coherent disorder in 1943 by Dr Leo Kanner, who produced a groundbreaking clinical description of 11 children with emotional contact disorder and recorded their behavioural characteristics in detail (Kanner, 1943). As the symptoms of autism tend to occur in childhood, early autism was thought to be a disorder similar to childhood schizophrenia (Fombonne, 2003). The common perception of the time believed that autism was largely related to poor parenting. And other studies suggested that rare biological or genetic disorders may also cause autism, such as phenylketonuria (Ivanov, Stoyanova, Popov & Vachev, 2015). It was not until the early 1980s that autism was categorised and widely accepted as a developmental disorder with features of biological origin (Geschwind, 2009). However, the influence of parenting and the acquired environment on autism had not been erased. Meanwhile, a number of adult experiments started to show that autism was a lifelong handicap (Fombonne, 2003).

The initial diagnosis of autism often requires clinicians to observe the target people's daily behaviour and interact with them in multiple long sessions to determine behavioural cues of autism. These typical behavioural cues used as judgements can be referred to as self-stimulatory behaviours. Self-stimulatory behaviours, also known as "stimming", are stereotypical, repetitive movements of body parts or objects. (Rajagopalan, Dhall & Goecke, 2013) Stimming behaviours have a large number of different types and vary from person to person. The most common stimming behaviours can be broadly classified according to sensory feedback. Some behaviours produce mainly visual stimuli, such as staring at a spinning fan or light for a long time or assembling the same puzzle repeatedly. Some behaviours are primarily vestibular stimuli, such as swaying physically while standing, nodding the head or rotating the arms. Some behaviours give tactile stimuli such as stroking, touching the body or rubbing the surface of a sweater or towel. Also, there are some behaviours producing auditory stimuli, such as tapping on the table at a particular frequency or repeating a phrase. Depending on the use of the patient's own body in these behaviours, or the extent to which the patient uses objects in the surroundings, these stimming behaviours can also reflect different levels of interaction between the patient and the environment. Although these behaviours vary in complexity, they appear to be similar in terms of stereotypy, a degree of detachment from social media and the creation of certain behavioural patterns (Lovaas, Newsom & Hickman, 1987).

Although there is still some argument about why stimming behaviour arises, most experts believe it is a tool for emotional self-regulation (Mazefsky et al., 2013). From a sensory perspective, for people with autism, stimming can be seen as a way of downplaying or blocking excessive sensory input, which is because autistic people tend to have sensory processing impairment. For example, they may over- or under-react to stimuli such as sound, touch and smell (Kapp et al., 2019). So stimming behaviours can help hypo-sensitive people make up for necessary stimuli and help highly sensitive people block out excessive stimuli, thus helping to digest emotions,

both positive and negative, that are too strong for them to fully process. It can also help to distract them from physical discomfort or pain.

While stimming can be very helpful for people with ASD, it is important to note that some self-stimulation behaviours can also cause harm to the person themselves or frighten those around them, such as excessive nail chewing, banging on their head or flapping their ears (Summers et al., 2017). These examples can cause physical harm while also often deepening the stigma of autistic people. As they become more rejected and isolated, potentially harmful stimulation behaviours may continue and become more severe.

In order to reduce the negative impact of autism on the life and development of people with ASD, timely treatment and intervention are essential. Currently, there is no standard treatment for autism, but many methods have been found to help reduce symptoms and maximise abilities. Autistic individuals who start the appropriate treatments and interventions early will be more likely to have a significant positive influence on their lives and on their future development, with greater opportunities to use all their abilities and skills. The most effective therapies and interventions are often different for each individual. However, for most people with autism, highly structured and specialised treatment programmes work best (National Institute of Mental Health, 2011).

2.1 Applied Behavioural Analysis

One of the most commonly used intervention therapies for the self-stimulatory behaviours exhibited by the autistic population described above is called Applied Behavioural Analysis (ABA). ABA refers to understanding people's behaviours in their real living environment rather than in a controlled laboratory setting. The aim of the approach is at improving their particular behaviours and helping them develop skills. It is based on traditional behavioural strategies such as rewarding appropriate behaviours and ignoring or discouraging inappropriate behaviours. ABA can be one of the most widely studied and frequently used therapies for people with ASD (Leaf et al., 2020).

ABA was influenced by German psychology in the early stages of its development. John B. Watson (1878-1958) was credited with being the first to propose an applied behavioural science. Psychology from the Standpoint of a Behaviorist (Watson, 1919) was one of the first scientific works to use the term behaviourism in its title. He used terms such as 'psychology, a behavioural science' in his work, which are still commonly used today by professionals who support ABA (Matson & Neal, 2009). From then on basic psychology principles and data-based applied experiments had been linked together. Subsequently, thank to the efforts of researchers such as Lightner Witmer (1867–1956) and B.F. Skinner (1904-1990), the study of behavioural science gradually spread to the rest of the world. In the process, they helped transfer the study of behavioural analysis from the closed laboratory to a more practical external application setting, and also their works helped to popularise behavioural science to the general public, leading to greater interest in this professional area and helping to give more people a clearer direction in solving related problems. In addition, the creation and publication of scientific journals such as the Journal of the Experimental Analysis of Behavior (JEAB) and the Behaviour Research and Therapy (BRAT) have given legitimacy to this fledgling field, and provided a good platform for the dissemination of information on experimental behavioural analysis and encouraged young researchers interested in the subject to express their views.

The research development of ABA and of ASD has always been keeping company and accomplished with each other. Before ASD was actually discovered, ABA started to be used as an intervention for some special children. Lightner Witmer was the first American psychologist to emphasise modern mental health treatment services for children. He had a psychotherapy clinic at the University of Pennsylvania, which took children whose parents or teachers considered them to be "morally deficient", "behaviourally peculiar" or "academically underachieving", providing them with mental examination and support, as well as recording experimental data. His connection of applied clinical work with basic research laid the foundations for ABA and provided important background information for the subsequent discovery and definition of ASD. Witmer stressed that clinical psychology was based on experimental psychology. Similarly, the study of ABA needed to be based on the experimental analysis of various behaviours. In the subsequent development of ABA, there were countless research studies that were integrated with ASD, including behavioural analysis, modification and treatment of specific groups of autistic people, which even formed a trend at that time. It can be argued that the expanding interest in ASD worldwide is probably one of the main factors contributing to the popularity of ABA among the general public.

An important reason for the close relationship between ABA and ASD research is

that ABA as a behavioural intervention is very effective in reducing the common behavioural symptoms of ASD. Where ABA differs from other behavioural analyses in that it applies behavioural principles to real-life situations, ABA therapists are mainly interested in the behaviours of the target population and the relationship between the people and the environment, focusing on their observable manifestations and using behavioural techniques to achieve changes in their performances (Behavior Analyst Certification Board, n.d.). The common techniques used by behavioural analysts include the following three types.

- Chaining: This technique involves breaking down a task into smaller components and ranking them in order of difficulty for the target patient. The easiest task is taught first and it is not until this task has been completely finished that the next task is prepared to be taught. This process continues until the whole sequence has been successfully linked together.

- Prompting: The therapist will use some type of cue to trigger the desired response in the target patient. This may involve verbal prompts, such as telling the person what to do, or visual prompts, such as showing a picture that suggests a specific response. These different prompts may be used for different tasks or combined for the same task.

- Shaping: This one is more of a generic strategy. The therapist will gradually change the target patient's behaviours over a long period of time and reward them as they perform and get close to the desired response. If some people engage in actions that are destructive to themselves or others with the intention of gaining more attention, the therapist will also help to reduce this negative impact behaviour by reducing the reward (Leaf et al., 2015).

As for ASD, ABA is designed not to cure autism, but to implicitly teach autistic individuals useful behaviours, reduce or eliminate harmful behaviours, and help them to learn skills and abilities that are necessary for living in current society. For example, in the treatment of ASD, ABA can help autistic children to control their temper, manage their aggression and teach them to express their needs more verbally. It can also teach life skills such as how to brush teeth properly, help improve concentration in studying and teach social skills such as how to share toys or food with friends. A study in 2012 suggested that long-term comprehensive ABA therapy can help children with ASD improve and develop their living and playing skills, language progression, socializing abilities as well as intellectual functions (Maglione et al., 2012).

2.3 Auditory sensory

As mentioned above, ABA can be effective in ASD because it targets and improves the most typical features of ASD, namely the lack of social skills and some repetitive self-simulating behaviours that they exhibit. The internal reason for these characteristics or symptoms is considered to be due to the unusual perception and attentional aspects of autistic individuals (Taylor et al., 2012). Studies have shown that people with ASD show superior discrimination and perception skills, as well as an increased likelihood of distractibility (Ames & Fletcher-Watson, 2010). Theories of attention and cognitive control offer a possible explanation for these phenomena. The greater perceptual capacity of autistic people means that they have to process more information than others at the same moment (Lavie, 2005). If a task is more perceptually loaded for them, in other words, they need to use more energy to complete it, they will devote more attention to that task and will show higher levels of concentration. Conversely, if a task is less of a perceptual load for them, they will appear to be more easily distracted by other things in the environment. This could go some way toward explaining the behaviours demonstrated by people with ASD.

The unusual perceptual profile of people with autism can encompass almost all sensory experiences, and sensory sensitivity can vary from individual to individual. A number of studies on the behavioural analysis of autism indicate that autism has a strong perceptual capacity in the visual domain (Remington et al., 2009), and they have been gradually extending to the auditory domain. Much research now shows that there are changes in auditory processing in autistic people, who can be more sensitive to sound. For example, people with ASD seem to show a greater ability to perceive pitch (Bonnel et al., 2003) and better recognition and memory of different notes (Heaton et al., 1998), as well as a stronger capacity for local processing of sounds (Bouvet et al., 2014). While these abilities can be their talents and can help them to develop better in related professional fields, they also seem to be accompanied by some disturbances. Excessive sound sensitivity may cause them to show great impairment in certain noisy environments and may appear to be either oversensitive or hypersensitive, and many are both. Hypersensitivity may cause them to deliberately avoid certain sounds that can be easily handled by other people, by running away, covering their ears and screaming, etc. Conversely, Hyposensitivity may lead them to be attracted to noises that are not normally tolerated, thus providing greater stimulation ("Sensory Issues | Autism Speaks", 2022).

2.4 Music therapy

Higher sensitivity to sound, although it may cause some problems, can be a tool to help intervene and treat ASD if used appropriately. Sound-based interventions include specialised therapies that use any form of sound for intervention. Music therapy is a sub-category of sound therapy. Sound is a generic term that covers all types of sound. Music, on the other hand, is a sound that has melodic, rhythmic and harmonic characteristics and is produced by some means. Sound therapy, including music therapy, intervenes by adjusting and modulating pitch, frequency, tone and intensity (Sinha et al., 2011). Sound therapy has been documented as early as the 1940s for the rehabilitation of soldiers who developed psychological problems after the Second World War. Since then it has been developed and adapted to suit different functions and application contexts. Some of the famous therapeutic approaches are Auditory Integration Training (AIT), the Tomatis Method and the Samonas Method. These methods are similar in that they all involve having the person receiving treatment listen to edited music through headphones and all require a lengthy process (Shahrudin et al., 2022). Of course, these methods are not fixed but need to be customised and adapted in time to suit the target groups. Sound therapy can be used in the treatment and rehabilitation of many psychological disorders, such as attention deficit hyperactivity disorder (ADHD) and autistic spectrum disorder (ASD), and has been reported to help enhance the development of emotion, imagination, perception and stimulate conversation (Shahrudin et al., 2022). For ASD, music therapy has been given feedback that the effects are significant. In an early postal survey study on the use and recommendation of music therapy for children with autism in Germany, researchers found that 56% of child psychiatrists and 14.5% of paediatricians recommended the use of music therapy to help with autism. In addition, 25.1% of paediatricians thought music therapy was useful for people with autism (Evers S, 1992).

Music therapy can be diverse in specific techniques and varies from person to person. But the essence of all these approaches is that the therapist and the patient use both of their musical experiences to connect and interact with each other. Commonly used music therapy techniques for ASD include free and structured improvisation, singing and vocalisation, and listening to pre-recorded and live music (Geretsegger et al., 2014). These techniques involve different forms of interaction and intervention, particularly musical improvisation, which can be understood and described as a form of non-verbal and pre-verbal communication (Alvin & Warwick, 1991). This kind of communication allows those with sufficient language skills, such as the therapists and other family members who assist in therapy, to have access to the other party's pre-verbal experiences, while autistic individuals who may lack language skills can socialise non-verbally. It enables all participants to engage in interaction on a more emotional and relational level, rather than through language. And listening to music, especially music that is meaningful to people with ASD, allows them to make associations and reflect on questions related to that music in the process, and then encourages them to express their opinions through language, which is often one of the key processes in music therapy (Møller et al., 2002). In the beginning, music therapy was usually a one-to-one interaction between patient and therapist. Later, however, the role of family and peer interventions for people with autism was gradually discovered and affirmed, and family or group-centred group music therapy became an increasingly important part of the music therapy process for people with autism, especially children (Thompson, 2012). The group therapy process can also help them gradually build more connections with the social environment around them. In summary, the main role that music therapy plays in ASD treatment is to reduce stress and help relax through non-verbal communication, as well as to develop sharing and social interaction skills.

In music therapy, apart from the interaction, the music used can be the most important part of the therapy for its effectiveness. Several types of music are commonly played in the therapy process. Firstly, there is some meaningful music for the participants based on their personal musical experience., which can be based on the conclusion that the two parties have previously learned about each other. This kind of music is often more familiar to patients so it can reduce their sense of panic and stress in the therapeutic environment.

The second is the music that results from live improvisation. Therapists and patients improvise using musical instruments or objects according to the scene. The music itself is not as important in this process as the interactive process of creating and playing the music. Pianos and guitars are popular musical instruments that are commonly used. They can be found almost everywhere and can provide various tunes and soft sounds (Chowdhury, 2019), making them ideal instruments for improvisation. Besides them, other instruments have been frequently used for live performances throughout the history of sound healing. One example is the singing bowls (Fig 1), an instrument commonly used in Buddhism. These bowls vibrate when struck and produce different long sounds that help to calm the listener, reduce stress and promote better sleep. Wind chimes (Fig 2) are another common healing instrument, they are easier to use and have a soothing effect with their soft sounds. Another instrument that is typically used is the Kalimba (Fig 3), which is more like a

smaller version of a piano, easy to play and has a similar sound to a music box (Harrison, 2019). The use of the musical instrument is also individualised and the therapist needs to choose the proper ones according to the environment and the patient's situation.

Fig 1

Fig 2

Fig 3

Fig 1-3. Three common tools used in music therapy

Moreover, another way to generate music is for the therapist to play music of their choice and have the patient be the listener. The music may be more random. The focus of the music in this case is to stimulate the emotions of the patient. As mentioned earlier, people with ASD have significant difficulties with emotional communication and social interaction. However, due to their sensitivity to sound, they have a natural affinity for music and can recognise simple emotions in music. So music that expresses different emotions can be used to help mobilise their social emotions (Molnar-Szakacs et al., 2020). The types of basic emotions that music offers to people have now been found to be thirteen. Although emotions are subjective, it has been shown that most people feel similarly about the general emotional characteristics that music exhibits, such as anger, joy, fear, sadness, and so on. However, the degree to which the same piece of music stimulates them varies, leading to differences in their responses, which can be related to personal experience as well as cultural background (Cowen et al., 2020). So that when the therapist chooses music, it needs to be tailored and adapted to the individual patient's background, emotions, behaviours and external environment.

Numerous studies have now been conducted to demonstrate the effects of music therapy on the social and emotional development of people with ASD. At the same time, more research has shown that music therapy can also assist behavioural and motor interventions for ASD. The assistance relates to rhythm, which is one of the most fundamental properties of music. The cerebellum in people with autism has been found to produce developmental abnormalities (Carper, 2000), which may lead to impairments in motor function (Allen & Courchesne, 2003). They show a general deficiency in motor planning and praxis, yet this is a fundamental skill in human movement function (Dziuk et al., 2007). Each of their separate actions is difficult to string together into an overall flow. The rhythm as an external cue plays a timing role in music therapy applications aimed at motor rehabilitation, providing precise reference intervals for each phase of the movement process. Similarly, rhythm can also be used in music therapy for ASD in the same way as the function mentioned above, to reduce the demands placed on the autistic individuals themselves, which may help improve the fluency and accuracy of their movements, as well as the organisation of the entire movement sequence (Hardy & LaGasse, 2013). In order to be more effective, this type of rhythmic cueing needs to involve getting the participants not simply to listen to the rhythm, but to feel the effect of the rhythm on their activity patterns and stability through their movements when cueing. It is also necessary to add melodies, lyrics, etc. to make up a complete repertoire, which may produce better results (Hardy & LaGasse, 2013).

2.5 Augmentative and Alternative Communication

As mentioned earlier, autism is a developmental disorder. Although people with autism, especially children, show a range of behavioural deficits, the core cause of these problems is their delayed development in language and communication as well as social interaction. They develop deficits in joint attention and have difficulties coordinating attention between people and objects. They also use many symbols when communicating and do not have as many gestures that are commonly used in social rules (Lal, R., 2010). So one of the focuses of autism intervention is to help them develop skills in language and communication. One common method is Augmentative and Alternative Communication (AAC).

AAC refers to any method of communication that can enhance or replace the usual methods of speaking and writing (Murray & Goldbart, 2009). AAC can be used by people of all ages who have problems with speech or language skills. Some people may need to use it all their lives. Others may only use it for short periods, for example when they have had surgery and cannot speak or write.

There are various types of AAC. Each user needs specific AAC methods, which

require communication with Occupational Therapists (OTs) and Physiotherapists (PTs) to customise the AAC system for all individuals. Non or low-technical categories include gestures and facial expressions, writing and drawing, expression by pointing to letters, pictures, objects and so on. One of the popular tools is The Picture Exchange Communication System (PECS). PECS (Fig 4) was developed by Lori Fros and Andrew Bondy in 1994 and was first used in the Delaware Autism Project (Sulzer-Azaroff et al., 2009). It is a picture-based package designed to teach children who lack oral skills to express their needs and their thoughts, and also help them to interact with others around them in a different way than usual. The pictures are divided into different categories to ensure that all aspects of their lives are taken care of. And the PECS is so practical as it costs very little and can even be made by the users themselves in-house.

With the development of modern technology, high technical AAC is now also common in the communication of autistic groups, which includes communication using tablets, computers or voice-generating devices and so on. A popular example is the Dynavox Maestro (Fig 4), which can be described as a tablet including a variety of speech, movement and gaze training software to help users communicate with others with different approaches and to develop their deficit skills. The company has been working on voice-assisted and eye-tracking technology. Due to the combination of various functions and advanced technology, the price of the device may not be affordable for everyone. So that there is also much popular software that can be downloaded directly onto existing tablets, mobile phones and smartwatches (Fig 4). Although not as powerful as the Dynavox device, the internal logic can be similar, as they all assist the users in communicating through pictures, movements and other approaches in addition to language.

Fig 4. Low-tech and high-tech AAC products/software

It can be found that visual, or picture and video-based interaction methods are more common among AAC that helps people with autism to solve their communication problems. It is probably because visual stimulation will be more intuitive and easier for the users to imagine and remember. Sounds and movements are used as auxiliaries in these tools. Therefore, it is possible to discover different ways of interaction in AAC systems from a non-visual-centric perspective.

2.6 Autism and embodied technology

In addition to the common commercially available products to help autistic people communicate with society, many related studies are also being conducted. According to Dr De Jaegher, the autistic experience is inherently embodied and the sensory awareness of autistic people follows different perceptual and rhythmic patterns (2013). To intervene or improve social interactions between people with and without autism, both patterns of experience need to be taken into account equally, in a way that also can be described as participatory sense-making (Spiel et al., 2016). With the recent rise in the popularity of autism, many efforts have been made to create techniques for the autistic group, using embodied interaction to help them socialise better with the non-autistic people and the society around them.

Two studies that help people with autism to communicate more with the society will be presented next. The first one is called Adaja (Fig 5), which is for users who are interested in exploring the sounds they create and the sounds around them. It is an environmental device consisting of an Arduino Mini Pro, a microphone and an OLED screen. Depending on the intensity of the noise it records through the microphone, the sound wave pattern on the screen changes constantly. It can help the users to visualise the surrounding sound level and thus helps them to observe and participate in the environment around them. It can also act as a noise detector, alerting the users that the noise exceeds a threshold and preventing them from possible discomfort due to excessive sounds. On the social side, people with autism can use it to explore with others. They can create sounds together to find various changes on the screen. People with autism can also share their experiences to help the non-autistic people around them better understand how they feel. Throughout the process, the use of the device is completely in the hands of the users, which can give them more freedom and security (Spiel et al., 2016).

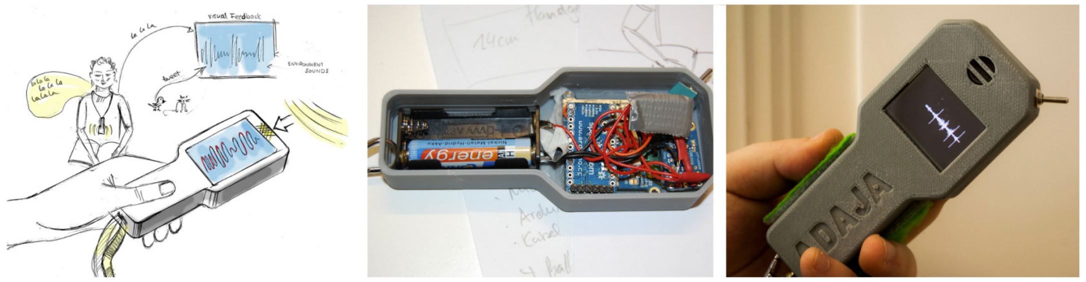


Fig 5. Adaja - An environmental companion for exploring sounds around

Another example is called ThinkM (Fig 6), which uses a wearable device as its main technological product. ThinkM is a device that helps users to look back and reflect on their actions after social situations, consisting mainly of a base station and a headband. There are two stages in the usage: recording and reflecting. During the social event, the users can put on the headband and it will take photos and record the users' heart rate at the time. After the social event, they can reflect on the situation by looking at the photos and if they had a large mood swing and acted in a way that was not appropriate for the occasion and did not realise it at the time, a replay can be used to help them reflect on their actions. Their family or friends can be on hand to guide them and help them become more aware of what behaviours are inappropriate for certain social conditions, thus continually reducing the frequency of the problem later. And the wearable device involved is designed to resemble headphones. It can be light and stylish enough to be worn as accessories, making the whole system educational and still casual (Spiel et al., 2016).

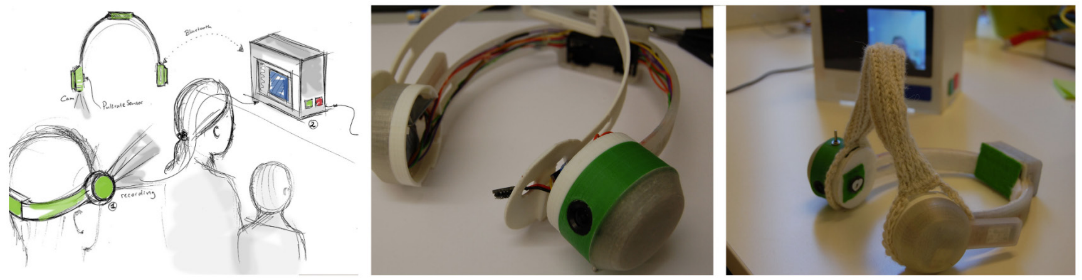


Fig 6. ThinkM - Reflect on failures of emotional control and inappropriate behaviour in social situations

Both studies use embodied technology to provide a sensory perspective on the connection between autistic groups and the world around them and, even though not commercially available, can still provide some indication of trends in the development of autism-related technology.

2.7 Introduction of Diversity computing

Diversity computing (Divcomp) was a theoretical roadmap that was previously proposed by Fletcher et al. (2018). It hopes to take existing and developing technologies as the medium to help facilitate sharing and communication between people, and it can be seen as a vision of group interaction. Divcomp aims to provide a scenario that invites different human beings to interact and engage together in a process of creating co-meaning in mutual communication and understanding. It emphasises the diversity of individuals rather than specific group divisions. So it is inevitable that different opinions will emerge from the discussions. Divcomp hopes that in the process of interaction, everyone can accept and respect the differences that arise and can express their views. In addition to human interaction, the scenario must also necessitate Divcomp devices as the supporting medium. The devices can involve different hardware, software, smart technologies, etc., which together form platforms that can assist individuals to participate and interact in person from an outside perspective.

The implementation and application of DivComp need to include philosophical and cognitive theories, participatory methodologies and digital innovations. Philosophical and cognitive theories help to better understand the users and the meaning of the interaction scenario, participatory methodologies can create more appropriate interaction scenarios and give the user a good interaction experience, and digital innovations help to build the technical medium used. Therefore, if a specific application based on the Divcomp concept is to be designed, appropriate supporting theory, methods and suitable technology are required.

2.8 Previous research

The study is based on a conceptual framework and prototype based on the DivComp roadmap created by Nguyen to help address the issue of dual empathy, called Stim4Sound, which aims to create a comfortable and interactive environment in which NT and autistic people can share through sound and music creation, facilitating their social communication and even mutual understanding (Nguyen,2021). The creation of this scene first needed to be based on guidelines for NT and autistic people to understand behaviour and feelings, as well as principles of how people can create shared meaning together. These definitions and theories provide the context in which the concept is founded and realised. In terms of interaction, Stim4Sound wanted to take a collaborative approach to enhance the comfort of the target users from the perspective of sound creation and thus engage them on an ongoing basis. Finally, the realisation of the above concept requires suitable interactive technology support, such as sensemaking technology. The concept is currently being realised in a scenario in which two participants are joined by two other people who can create sounds from objects in the environment and share their feelings with each other. The prototype is used to record the created sounds and the participants can control the soundtrack through simple gestures.

The system mentioned in this study is based on the above concept for further development and innovation. The next step is to develop this concept into a complete system that can be used in a better way. This system needs to include a more complete process design, improvements to the initial prototype, and refinements in the user experience. The technical improvements to the prototype needed to be informed by Leonard's research. The research focused on hardware and functional improvements to the prototype. Firstly, the hardware was improved. Secondly, the functionality of the prototype was increased so that it could not only record and stop the music but also add the ability to store background music and represent the user's feelings. Finally, the use of sensors has been added; the Xsens sensors help to recognise the various movements of the user, and this movement data can be transferred to the computer, enabling the user to control multiple attributes of the sound, such as pitch, volume and tempo, using more complex gestures (Benjamin Leonard, 2022).

According to the research issues mentioned above, the thesis will focus on the following areas of improvement. The first is to improve the flow of the system, including further defining the objectives of the system and designing the functions and activities involved in the system in a more specific way to ensure that the system has a complete and smooth logical relationship. The second is to improve the look and feel of the prototype to make it more like a complete product, even to the point of being marketable. The most important aspect is the improvement of the user experience. This study aims to explore how sound, an important element of the system, can provide a more interesting and comfortable experience for the user and increase their acceptance of the system, thus helping them to better fulfil the system's intended purpose.

3. Methodology: Research through Design

3.1 Introduction

The methodology used in the research is called Research through design (RtD). It generally refers to the process of research using a design approach and perspective (Dalsgaard, 2010). The core purpose of this methodology remains to begin with a research question and end with a solution to the problem. Specifically, however, designers need to use their expertise to lead the process of starting the research, experimenting and drawing conclusions. The main design activities include understanding the backgrounds and user needs, bridging the gap between the users and the design solutions, and the iterative process of continually reworking the design solutions and iteratively improving the prototypes (Jan Stappers & Giaccardi, 2014).

3.2 Application

The specific application of the RtD methodology in this study is shown in the diagram below (Fig 7).

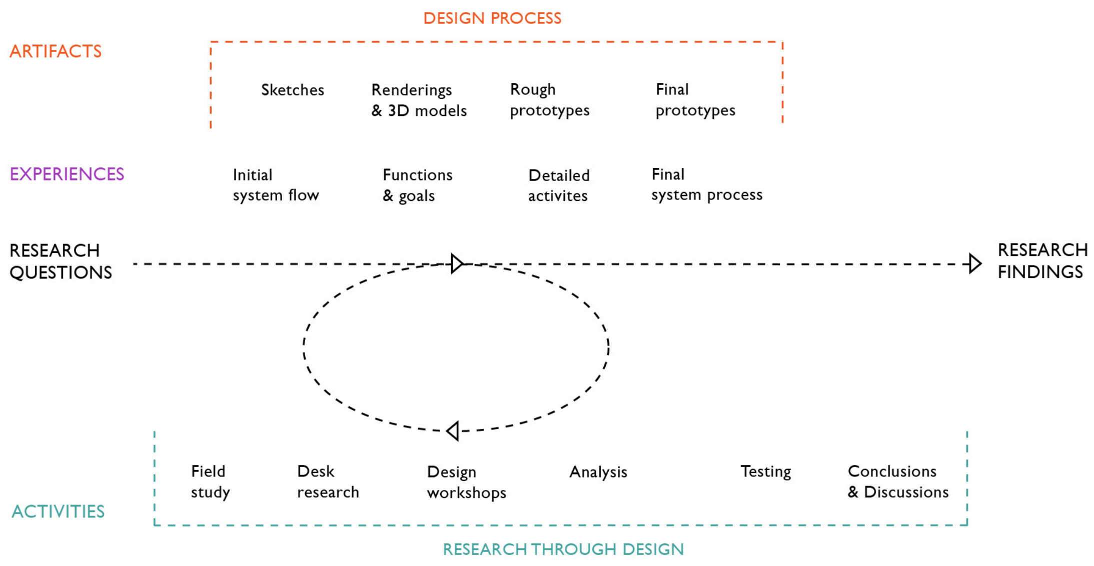


Fig 7. A schematic diagram of the application of RtD in this project study

The whole process involves the study of both information acquisition and design in parallel. The design of the system is not only about the design of the product, but more importantly about the design of the user experience throughout the system process. The experience design part includes the overall goal and function setting, the specific steps and activities, the supporting tools, the usage scenarios and so on that can affect the user's experience and feel when participating in the system. The important iterative part is also based on the user's thoughts and feelings. Since the user is provided with a more complete systematic process, experiential workshops are arranged instead of experiments. The study will consist of two iterations, which involve three workshops. Each workshop will begin with a set of objectives and system-related questions and will be conducted through interaction with participants to accomplish the goals and solve the questions.

The first workshop takes place at the beginning of the iteration when the system features and processes are still being explored. The workshop focuses on exploration and brainstorming. During the process, participants are provided with ideas and options for the various functions of the system. We will observe their behaviours an choices and actively communicate with them. In this way, we can understand more about their thoughts on the concepts and their advice for further improvements, either verbally or in writing. Based on these ideas and suggestions, the basic system process will be defined and the initial design of the products involved in the system will begin. The first iteration will be completed after the initial prototypes of the device available for users to try have been designed and built.

The next iteration will be mainly aimed at refining the music-related user experiences in the system. The second workshop will have two main purposes, one is to allow participants to simply test out the already accomplished functions of the wearable device, and the other is to explore how sound and music can help improve the user experience. Compared to the first workshop, more participants will be invited to interact with each other and we will have less communication with them. The main focus will be on observing how they behave and interact with their partners and how they use the device and the items in order to find out their feelings about the activities, functions and products. At the end of the workshop, participants will be asked to share their views on the whole project and suggestions for the functionality. According to these performances, we will summarise and identify the final system process and the functions involved, get inspiration for the product design to help create the musical experience, and also gain ideas for further improvements to the electronic prototype. The second iteration will be completed after all the tools design and prototyping have been finished.

The third workshop can be described as a testing process of the entire system process and the device functionalities after the two iterations have been done. The main objective is to find out what can be improved in the current completed system and to get more inspiration and advice for the future development of the system. The testing will be conducted with target users of different conditions. They will be able to experience all the designed activities and functions. We will not interfere too much with the whole process, except to give instructions at the beginning and answer participants' questions. Similar to the previous workshop, we will observ4 the participants' behaviours and interactions during the activities, get more understanding of their thoughts about products' functionalities and appearances, as well as the system activities, so as to identify the aspects that still can be improved. We will record the overall process of the workshop as completely as possible for closer analysis and comparison of different groups' behaviours to draw final conclusions. But it can be assured that the video recording will not involve the privacy of the participants.

By going through the iterative process, we hope that the finalised system will be able to provide the most appropriate and comfortable experience for the target population and better achieve the goals set at the beginning, thus allowing the initial research questions to be addressed and providing more constructive inputs for subsequent research and development of the project.

4. Iteration

4.1 Preparation

First of all, an initial system process was set up based on the previous Stim4Sound framework (Fig 8). The process mainly showed the basic steps, functions and triggers that the system needed to contain as mentioned in the concept. The final system was developed on the basis of this flow. For the parts that needed improvement and refinement, a brainstorming session was held and possible methods and tools were listed. The four main parts of the development in order were introduction, creation of sounds, physical movements to change the music, and communication. Afterwards, the iteration took place and these initial ideas were presented to the users in the form of workshops. We observed and participated in their practice, discussed ideas and feelings with them, and eventually summarised the results into design-related feedback, which was used to gradually define the final concept.

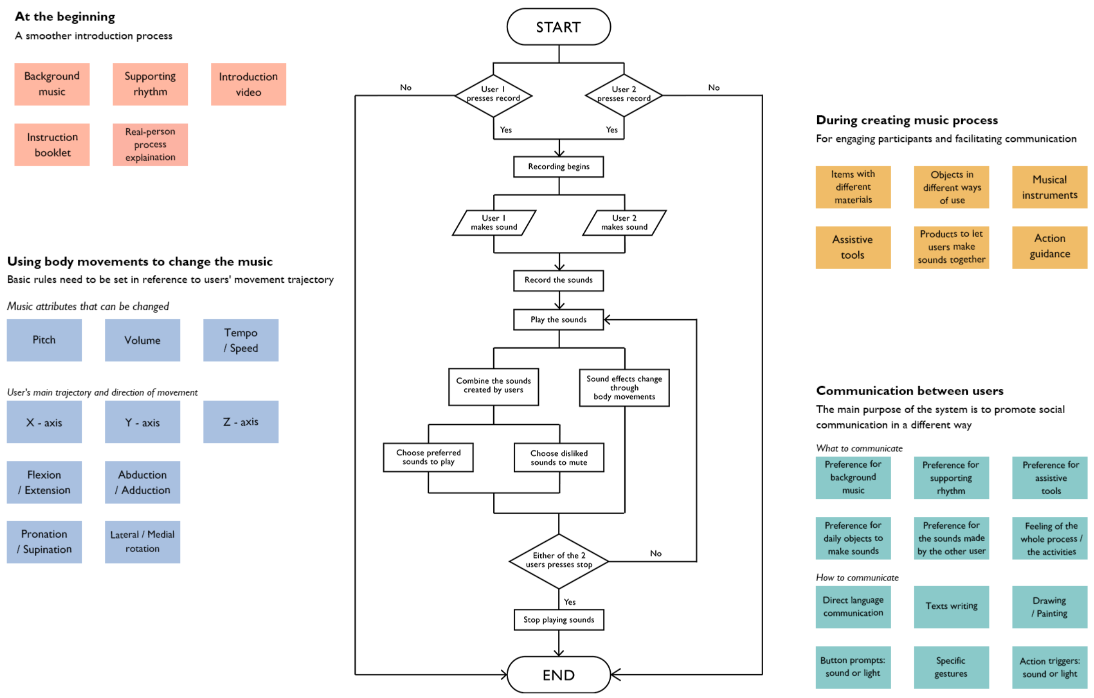


Fig 8. Initial system framework and functional brainstorming

4.1.1 Introduction

As an interactive scenario, Stim4Sound needed to have a complete storyline, which meant a smooth and logical flow of the system. The first thing that needed to be added to the original flow was an introduction process. At the beginning of the system, users needed a period of time to get used to the environment, to become aware that the system had started working and to understand and prepare for the activities they would need to do in the following steps. Common methods of getting participants to learn the information might be used such as watching short videos, reading instructions and having presentations by the organisers themselves. Since the next steps required them to create their own sounds with various objects, using some appropriate background music or rhythms to start the performance, as well as playing songs they were familiar with might help them get into the atmosphere of music more easily.

4.1.2 Creation of music using daily objects

In the process of creating music with daily objects, users were expected to get more fun and comfortable experiences. Two hypotheses could be put forward. In the first case, users could be comfortable with the environment, interested in the process of

creating music, and impressed or familiar with another participant. So that the whole process might not require too much intervention from the organisers and it would be easier for the users themselves to express their ideas through the actions. The opposite was the case, where for some reason the users felt uncomfortable with the tasks and needed the organisers to guide them through the process. Then some auxiliary pacing, props and behavioural interventions might be needed. The specific methods of assisting the users would need to be explored with the participants in the subsequent workshops.

4.1.3 Using body movements to change the music

The previous concept proposed that the users could change the music through a few simple gestures. In order to make it more functional, the restrictions needed to be minimised, hopefully allowing the users to change musical attributes through a greater variety of actions. Xsens dot, the sensor mentioned in Benjamin's research for detecting the user's movements in the wearable device, could detect changes in the position of the sensor in real-time and convert it into corresponding data (Benjamin Leonard, 2022). It meant that regardless of the users' body movements, as long as the position of the part wearing the sensor was changing, the real-time data would keep changing. In this way, the functional goal of this step could be developed so that people could move as they wish to change the music they created. However, a basic rule still needed to be set to help with the programming. Commonly there were three properties of a piece of music that could be varied, pitch, volume and tempo. Also, human movements could be seen as taking place on the x-axis, y-axis, and z-axis, as well as the planes and spaces they created. So the question of what kind of movement corresponded to which musical property might have to be set as basic rules, and then different user actions could be seen as combinations of these rules.

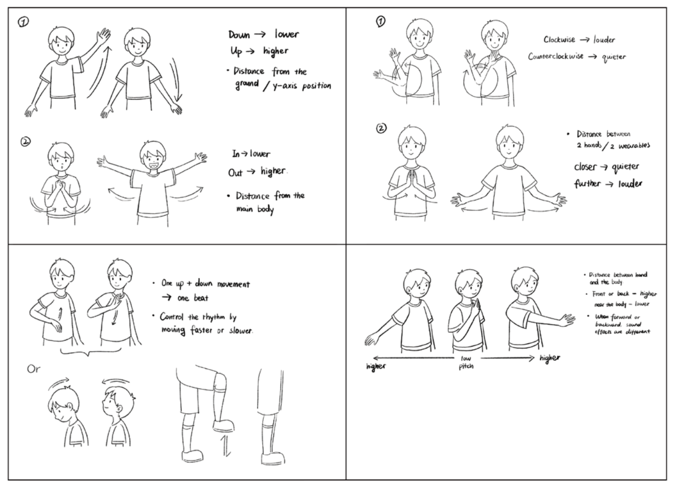


Fig.9 Brainstorming of the user's possible movements

How specifically these rules could be set would need further investigation and observation of different user behaviours. In the subsequent communication with the users, at this step, they might be asked to try out different possibilities of changing the music with the actions.

4.1.4 Communication between users

The ultimate goal of Stim4Sound was to help facilitate communication between autistic individuals and the people around them throughout the system process by creating a special multi-participant interactive scenario. So how the participants communicate with each other could be seen as one of the most important parts of the user experience in the system. Due to the specific nature of verbal communication for people with autism, music had been chosen as the main element of the system to help them communicate more non-verbally. In addition to the music, there were two aspects to consider. The first was what the participants need to communicate with each other throughout the process. Depending on the set process, it could initially be considered to include their preferences for the sounds and rhythms provided and created, their feelings about the various tasks in the process and their demands on the other participant. The second was the way in which the participants communicate. Apart from the most basic verbal communication, some visual cues such as flashing lights, colour changes and texts, as well as aural cues such as specific tunes and rhythms could also be included. Different communication methods would also be tried with the participants in the subsequent workshops.

4.2 Workshop 1

The first workshop was set up with the goal of getting to know the users better, refining the system flow and basic functions, as well as gathering inspiration for the design of wearable devices. In order to accomplish the goal, some questions had been prepared and we hoped to get answers to from the participants' feedback.

- What would the participants think about the project concepts? What would they like about it and what might make them feel uncomfortable?

- What would be the participants' preferences in terms of guiding music and rhythm? What would be the reasons for these preferences? Would there be any obvious differences between each participant?

- How would the participants perceive the experience of creating sounds by themselves? What types of objects would they use and what kind of movements would they use when making sounds? Would there be any problems in the process that the organisers could help to solve?

- How would the participants feel about using physical movements to change the music? Would there be some patterns to the movements that they produce during the simulated experience?

Feedback would be obtained not only through direct dialogue, but also by asking participants to express their thoughts through simple words or drawings, as well as observing their subconscious expressions and behaviours throughout the process.

4.2.1 Requirements for the offline workshop

- A room with lots of different props and enough variety of items for the participants to use to create music.

- A simple booklet with an introduction to the project and a step-by-step description was available for them to find out more information before the activity started and for them to make some notes and describe their ideas.

- Nine types of music were categorised according to the most common feelings that music could express (Cowen et al., 2020), as well as four different rhythms most common were provided for participants to listen to at the beginning and to choose as background music or as supporting rhythm later on in the process (Fig 10).

MUSIC CATEGORY		
■ Amusing	■ Joyful	■ Erotic
■ Beautiful	■ Calm	■ Dreamy
■ Sad	■ Heroic	■ Energizing

RHYTHM CATEGORY
■ Regular metronome
■ Irregular hand clapping
■ Slow waltz drumbeat
■ Intense rock drumbeat

Fig 10. Music and rhythms categorisation

- A laptop was used to play the music and for us to manually adjust the parameters of the music created to help the participants complete the experience of using body movements to change the music.

4.2.2 Participants

- Three university students. Due to time allocation issues, the participants came in a single person.

- The participants were either interested in our introduction to the study or knew someone with autism. They were chosen firstly because as young people they might be more receptive to new things. More importantly, as the goal of the Stim4Sound system was to facilitate communication between autistic and non-autistic people, it was also hoped that non-autistic people could learn more about autistic people through the interactive process, so the views of non-autistic participants were equally important, which could be the main reason why many non-autistic people would also be involved in the workshop process afterwards.

4.2.3 Steps offline

- In the beginning:
  A manual was provided for participants to understand the project's background, information about the system and the flow of the workshop. The organiser would be on hand to give them additional information on the more difficult or abstract questions.

- Step 1:
  Participants listened to different music and rhythms, and selected the opening music and supporting rhythms that might be appropriate for the introduction according to their preferences. Participants could choose more than one. They also needed to shortly explain their preference.

- Step 2:
  The participants selected items that were visible in the room to explore and create their favourite sounds. The interaction was between the participants and the organisers.

- Step 3:
  The sounds created were recorded and synthesised. The organiser manually changed the pitch and tempo of the sounds on the laptop, expecting the participants to show body movements that they thought fit the changes.

- Conclusion:
  The organisers discussed with the participants how they felt about the project concept and the system process.

Because of the COVID environment at that time and because we also wanted to involve a more diverse range of people, the workshop also had an online version.

4.2.4 Requirements for the online workshop

- The same version of the project background and system flow introduction booklet for the offline workshop.

- The same music and rhythms provided in offline workshops would be sent to participants, and they would decide whether they need the rhythm as background music or as support. If so, they needed to talk about the reasons for what they chose.

- There were no specific requirements for the participants. They could also invite their family members and friends to join the activities.

4.2.5 Steps online

The online process was much simpler than the offline one. Participants were provided with the same variety of music and rhythms as in the offline workshop and were expected to listen to them and choose the type of opening music and rhythm they would like. Different from the offline workshop, they were asked to choose everyday objects from their lives and create music with their family and friends, during which they could select some of the music and rhythms provided as background music or assistive beats. If they did not need the provided music or rhythm, they could create sounds only with the objects. They could also select their favourite music or rhythms from their music database if they were not interested in the provided content. All the files were emailed to the participants, and they needed to complete the process of creating the music and send us a faceless video of the whole process of creating music before the given deadline. From the videos, we found what objects they had chosen to create the music and what type of music and rhythms were used in the process as the background. When participants were playing with their friends or family, we observed their interactions during the process, including how they communicated about their choices of music and rhythms. After receiving the video, we spoke to the participants again, mainly to ask them how they felt about the project and what other features they would like to see added to the system.

Fig 11. Screenshots of some videos recorded by the online participants

4.2.6 Results

OFFLINE

Participant 1

- Male
- University student

Preferred music

- Joy
- Exhilarating

They can put me in a good mood

Preferred rhythm

- Metronome
- Regular hand-clapping

Simple and regular, give more room for creation

Objects used for making music

- Plastic toy
- Balloon
- Paper cup

Feelings about the experience

- It's a very comfortable way to express feelings.
- Body movements are easy to learn and interact with.
- It can take a long time to choose what objects to use to create music, and it is hoped that basic instruments can be provided at the beginning to keep participants more interested and engaged in the music.
- It seems that the interactive scenario can also be appropriate for long-distance communication.

Participant 2

- Female
- University student

Preferred music

- Relax

Preferred rhythm

- Regular hand-clapping

Objects used for making music

- Metal key
- Balloon

Feelings about the experience

- I love the way of communication. We both don't know what we will create in the end. Even though the sound itself is not that harmonious, the process is fun.
- When I started creating sounds myself, perhaps I would be more inclined to create something similar to the music or rhythm I chose at the beginning.
- As a lead-in to the opening music, I prefer something with a more interesting melody or rhythm.

Participant 3

- Male
- University student

Preferred music

- Joy
- Dreaminess
- Relax

Preferred rhythm

- Metronome
- Slow & calm
- Regular hand clapping

Objects used for making music

- Metal key
- Glass

Feelings about the experience

- The experience is cool in an abstract way.
- I wish there were more options with lyrics to choose in the first step while listening music.

Fig 12. Collation of the offline workshop results

ONLINE

Group 1

- Couple
- Teachers of medical-related subjects

Preferred music

- Beauty

We prefer more soothing music to start with.

Preferred rhythm

- Metronome

We prefer simple and clear beats.

Objects used for making music

- Glasses
- Wooden chopsticks
- Ceramic mugs

Feelings about the experience

- When giving choices to guide the music and rhythms, we would like to have a clearer classification of music and rhythms and need more options for people to choose from.
- We have chosen to tap the glass when making the music, but the sound is different if you rub your fingers against the mouth of the glass, so you can think about the different movements that make the sound when designing the instruments provided
- We think that autistic people and non-autistic people may feel differently about this, so we hope that you can still talk to autistic people afterwards.

Group 2

- Couple
- Working students

Preferred music

- Joy

I prefer upbeat music that can make people positive.

Preferred rhythm

Objects used for making music

- Tapes
- Ceramic mugs
- Forks
- Keyboards

Feelings about the experience

- I personally find fork & keyboard is very suitable to find the beat, it's easier to meet the rhythm. cups are also good, but it need to remember.
- For how I feel about this experience, it's a bit random and hilarious in the beginning, but as long as the beat can be detected and followed, it's easier to just have some fun. So strong and regular beat really suits well

Group 3

- Friends
- University students

Preferred music

- Dreaminess

Preferred rhythm

- Metronome

Objects used for making music

- Tapping a wooden table with the hands
- Glasses

Feelings about the experience

- After our game, we thought that crisper sounds, such as the crashing of glass against each other, sounded good and could be combined well with other sounds. But sounds like the electric fans that appear in the background sound a bit like noise.

Participant 4

- Female
- Newbie Programmer

Preferred music

- Relax

I prefer upbeat music that can make people positive.

Preferred rhythm

- Metronome

I prefer the simple rhythm as a backdrop.

Objects used for making music

- Switching the door
- Dogs barking
- Knocking wooden boards

Feelings about the experience

- Personally, I think using porcelain makes a nice sound, whether it's tapping, rubbing, or breaking it up. But it can be a bit dangerous to break them :D.
- I feel that there are many sounds in life that can be used in this interactive way. But is this music-related design too personal? Everyone has their own senses for different sounds.

Fig 13. Collation of the online workshop results

4.2.7 Analysis

The feedback we received from the participants could be summarised as follows.

- The music and rhythms provided to the participants at the beginning needed to be more varied, but if the participants spent too long listening to the music, participants might forget what they heard first.

- Most of the participants chose to use the simple rhythm provided as a basement in the process of creating their music, while one group chose a tune that was familiar to them as the basis.

- When asked to create music with objects, almost all of the participants' actions included the action of 'tapping' or 'knocking'.

- For some objects, different actions would make them make different sounds.

- Most participants were initially constrained to do the obvious action, especially in the presence of strangers. But the two groups of participants who were already in couples felt they had a better understanding of how to create music together, took less time to bond and were more able to have fun combining their interests.

- In the offline workshop, when asked to freely use their body posture to change the sound they were creating, movements of the arms were most common in the participants' behaviours.

From the above analysis, some inspiration was drawn for the system design and the improvement of the next workshop.

4.2.8 Suggestions for workshop improvements

- The time to try out the music and rhythms at the beginning should be shortened, while the content offered should be more varied. Reservations were expressed about the inclusion of music with lyrics, as the content of the lyrics could be a distraction.

- When providing objects to create sound, it was important not to be too random, but to try to cover different materials and different ways to make sounds. So that the participants' choices would not be too limited.

- An initial prototype with sensors needed to be completed for participants to try out before the next workshop. Only relying on getting people to imagine how the whole process would work was difficult for them.

4.2.9 Design inspiration

- The supporting music and rhythms would be necessary for the beginning part as a source of inspiration for people to create their musical work in the next step.

- In the part of creating music, it might be better to have some instruments that could provide support in addition to daily objects. These instruments needed to provide a reference for the users, as well as more tune changes compared with the simple sounds made by other items.

- When the participants were using body movements to change the music, which is when the wearables started to work, we found that arm movements were more common in the stimming behaviours and actions of the participants, so the wearables could be tried on the arms, wrists or hands.

4.2.10 Design outputs

- System functions

Based on the results of the first workshop and the completed hardware section developed by Benjamin, it was possible to determine all the necessary functionality provided by the system throughout the whole process (Fig 14).

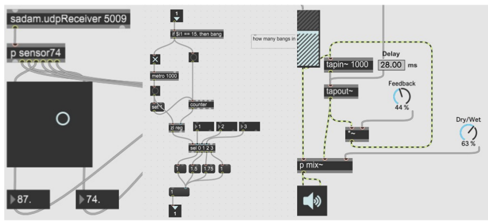
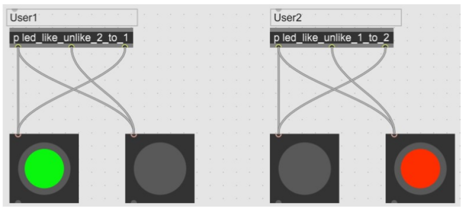
GUIDING	CREATING MUSIC WITH ITEMS
■ Provide different types of music or rhythms stored as examples and inspiration for the following step.	■ Auxiliary instruments capable of producing different tunes, as examples for creating music, or in combination with other items.
MOVING TO CHANGE MUSIC	**COMMUNICATING WITH EACH OTHER**
■ Wearable device - For recording music to different tracks - short press: recording start / stop - long press: delete the recording of the track. - With the device on, use body movements to change the tune, volume and tempo of the music created. 	■ A button on the wearable device to express the preference for the other's recording sounds. - short press [likeable]: LED turns green - long press [unlikeable]: LED turns red - very long press [neutral]: LED turns off 

Fig 14.The four main functions of the system and the programmatic diagram of the electronic section

- Sketches of the wearable devices

The initial design focused on exploring where the wearable device might be placed and its various shapes. In the previous workshop, it was observed that participants performed upper-body movements more. Also, there were many hand movements in common stimming behaviours such as shaking the wrist, clapping the hands and rubbing the body or objects with the hands. Therefore, the placement of the wearable device was mainly based on the arms and hands. While the size of the electronic components had not yet been finalised, the size of the device should not be too large for movement and aesthetics. And the shape of the device needed to fit snugly around the body to prevent it from falling off during movement, in order to enable the users to perform a variety of movements with greater flexibility. Moreover, the buttons and logos needed to be glanceable. For users who might be less able to understand and perceive the device, it was important to make it as easy as possible for them to understand how to use it in the first place.

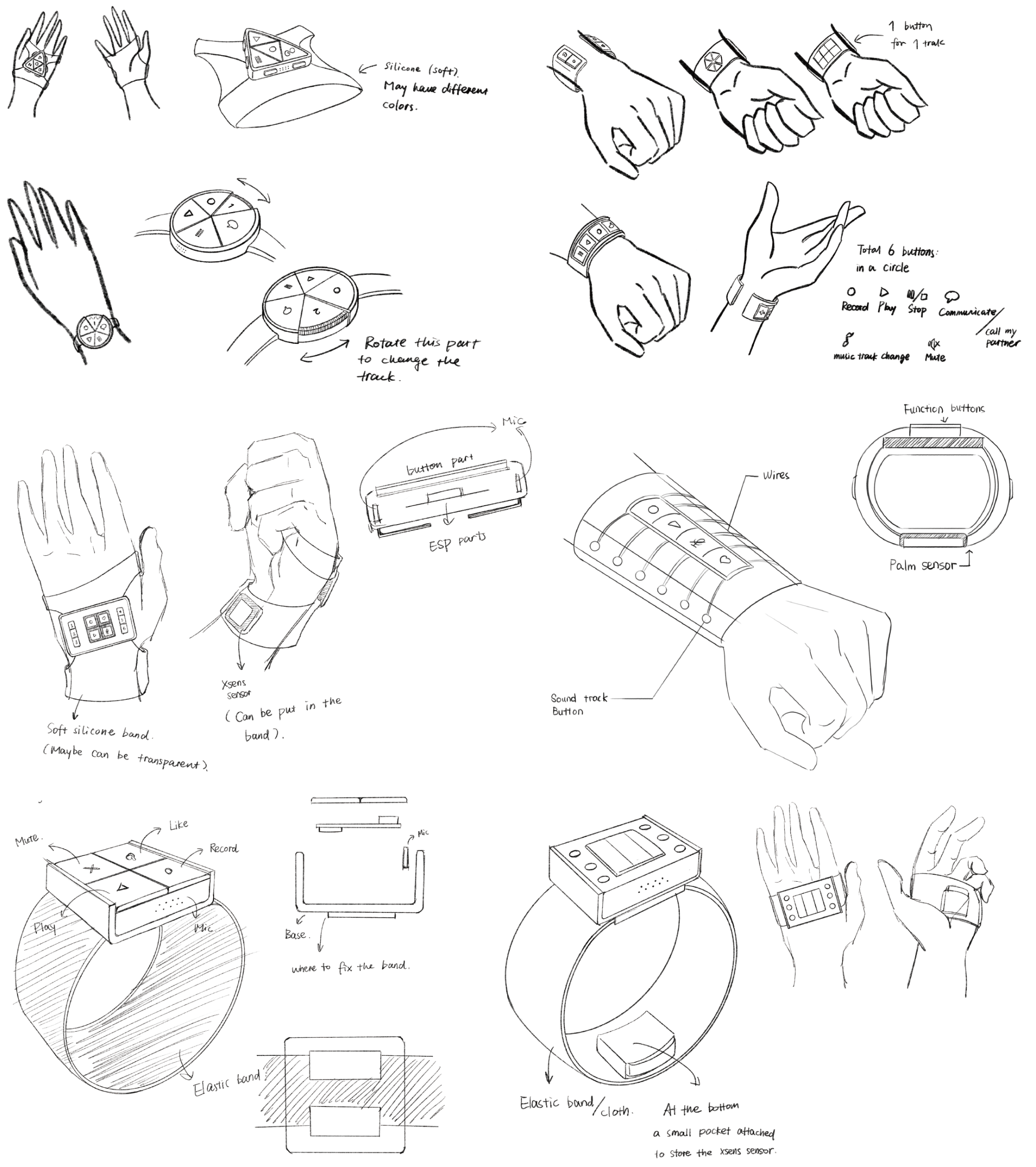


Fig 15. Sketches of the wearable device placements and shapes - part 1

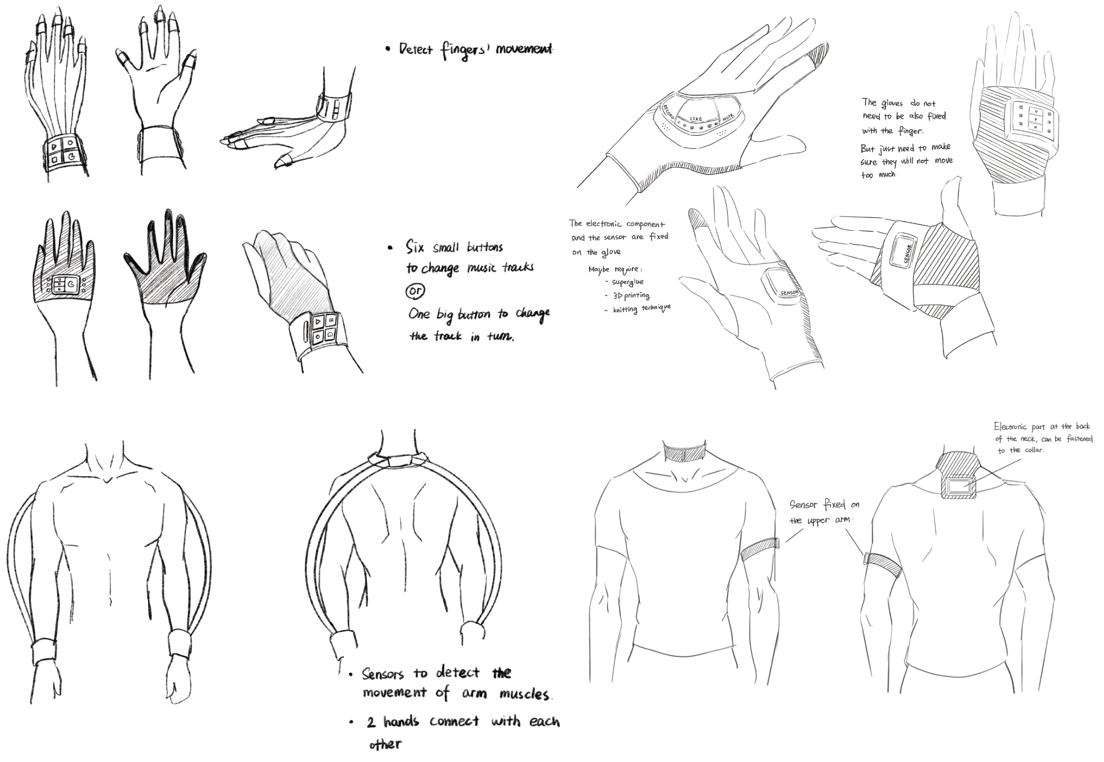


Fig 16. Sketches of the wearable device placements and shapes - part 2

The choice of material for the wearable device should be matched to its shape, and what material to build the selected shape with would be a question to be considered. So we would not determine which materials would be used after this workshop. However, for user comfort, a softer, more flexible material may be a better choice as a basement, and it would be easier to change the shape and adapt it to users' bodies.

The whole system intended to focus more on the interaction between autistic and non-autistic people during the process. Therefore, the wearable as an assistive device would be as minimalistic as possible, without too many colours and decorations, but mainly to highlight its functionality. The device would more likely use the classic and inclusive colours of black, white and grey, as well as the natural colours of the material itself, such as the grain of wood, leather or textiles. The final colours used should be matched to the auxiliary instruments and the overall setting.

- The initial prototype of the wearable device

For the participants of the next workshop to experience and test the full functionality, an initial prototype of the wearable device needed to be created. Based on the completed hardware, a 3D model was first used to build a case capable of holding and securing the entire electronic part as well as the connection wiring and battery. The case was assembled using separate parts to facilitate further modifications to the hardware. A complete electronic box served as the basis for the device.

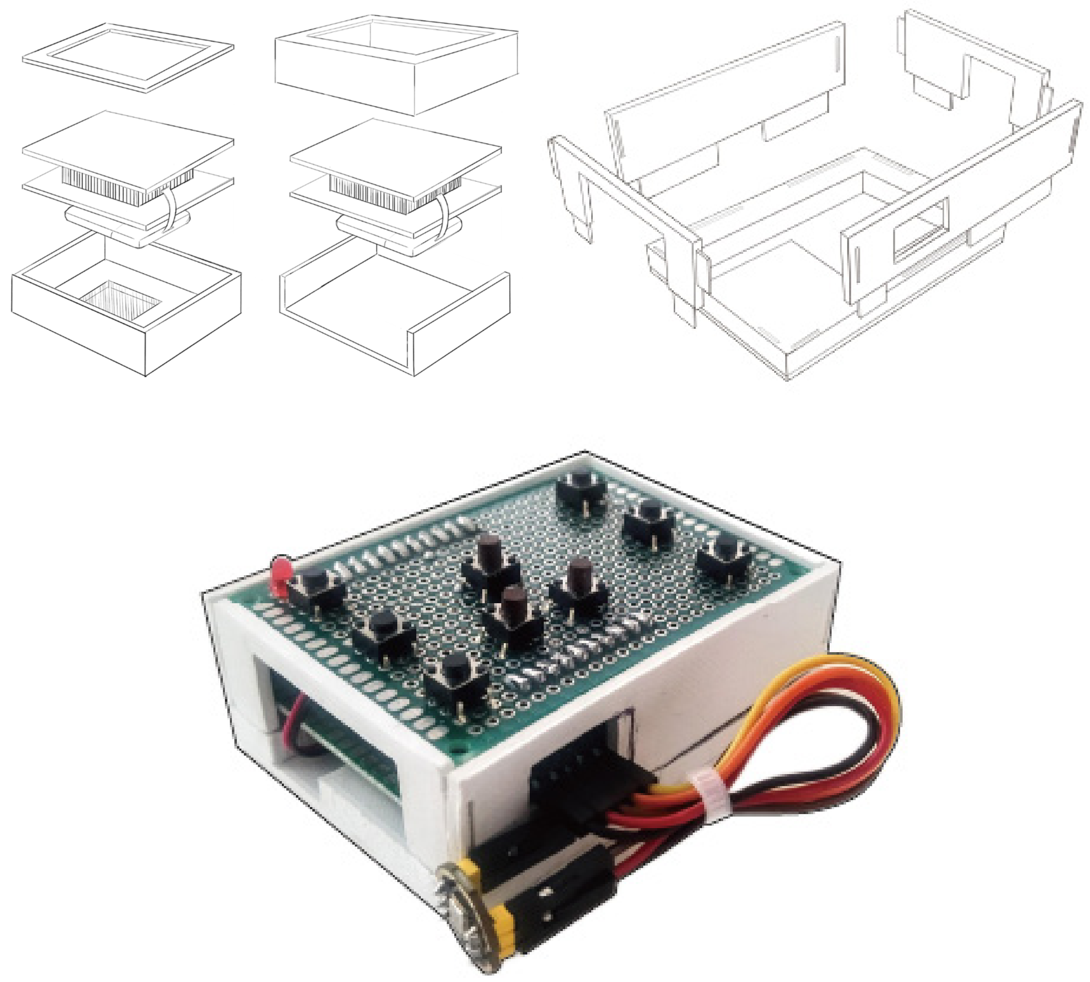


Fig 17. Structure of the electronic subject

Due to the large size of the box, which was not easy to wear, and the uncertainty of where to place the device, the sensors and basis were separated. Different sizes of elastic straps were prepared and the sensors were attached to the straps to allow people to wear the sensors on different body parts. It was to observe the wearing habits of the participants in the next workshop and to determine the final position of the sensor for the final design.

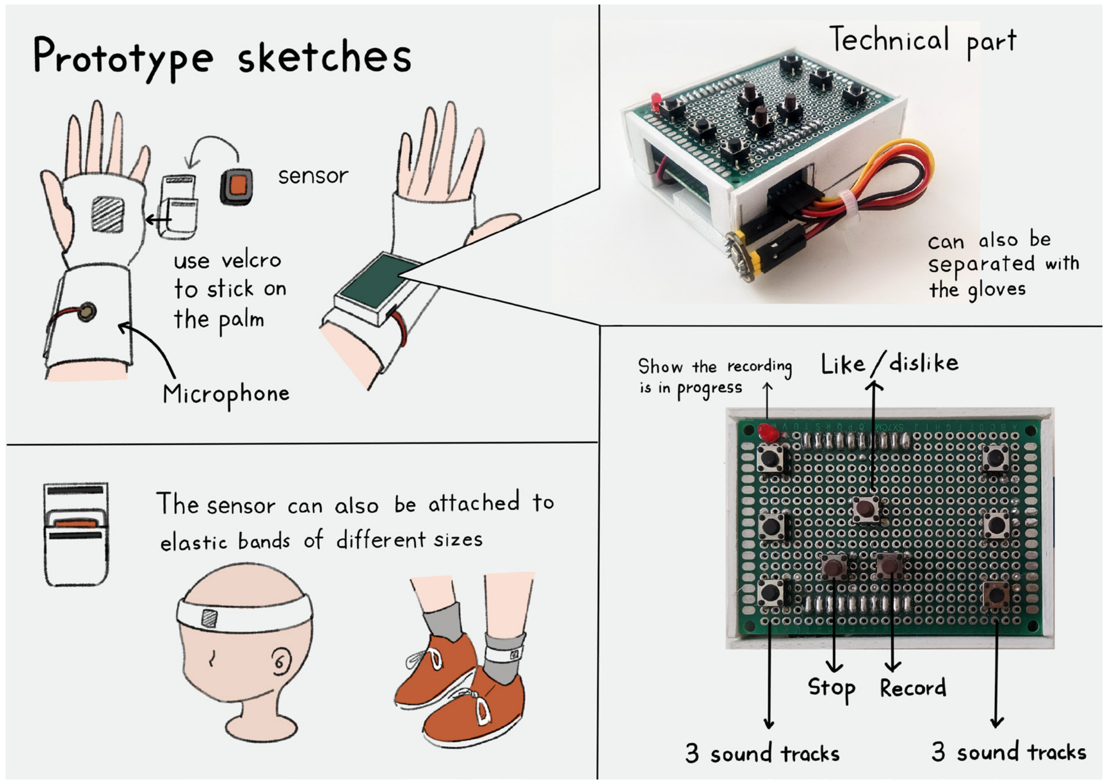


Fig 18. Illustration of the preliminary prototype for the coming workshop

4.3 Workshop 2

4.3.1 Preparation

In order to test the completed sensor functions of the wearable device and to search for more inspiration for the next stage's design, the second workshop could be prepared—this time the workshop had made several improvements compared to the previous one.

- The more detailed project background and workshop activities introduction had been updated.

- Guiding music and rhythms:
  The classification of music had been narrowed down by removing the pieces that were not selected in the previous workshop, which could shorten the time and increase the playing time of each piece. Also, the classification of rhythms had been changed. A more accessible classification for the general public was used (Fig 19).

MUSIC CATEGORY	RHYTHM CATEGORY
Joyful	Regular: The spacing between each drum beat is consistent.
Energizing	Irregular: The spacing between each drum beat is inconsistent.
Heroic	Accelerating: The tempo keeps getting faster throughout the section.
Beautiful	Decelerating: The tempo keeps getting slower throughout the section.
Sad	Overall fast
Calm	Overall slow

Fig 19. New categorisation for the guiding music and rhythms

- Several specific daily objects of different materials and different ways of sounding were provided (Fig 20), instead of picking items completely randomly in the room last time.

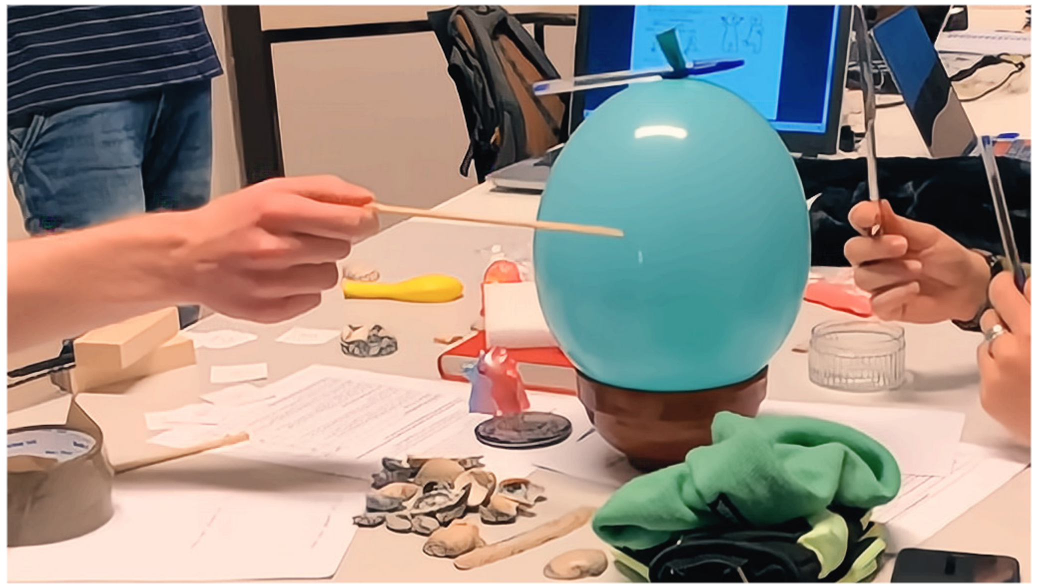


Fig 20. Participants play in an ensemble using the daily objects provided

- Based on the frequent ways of making sounds in the previous workshop and the common stimming behaviours of autistic people, four types of action groups were summarised and illustrated as examples for the participants (Fig 21), with the aim of allowing them to try out various ways of using daily objects to make sounds. It was also hoped that by allowing non-autistic participants to experience stimming behaviours, they could gain a better understanding of people with autism.

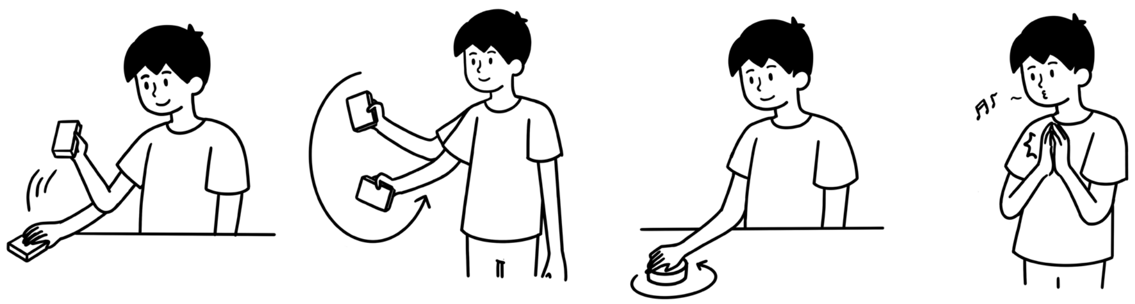


Fig 21. Diagrammatic representation of making sounds as examples

- The wearable device with basic functions finished could provide a more complete experience for the participants.
  - The audio tracks, recording function and sensor sections were almost complete. It was now possible to use the sensors to detect participants' movements in real-time and to convert them into data on the computer that could be used to change the recorded music.
  - Participants could wear the sensor part of the wearable device on their bodies to explore how different movements change the different properties of the sound.
- In this workshop, two people would be chosen to participate together as a group and there would be six groups of participants. Two of them were familiar friends participating together and the remaining groups were strangers meeting for the first time. This workshop will focus more on how would the participants interact with each other throughout the process.

4.3.2 Questions for the workshop

According to the upgrades to the workshop, the questions to be solved in the second workshop had also been improved.

- Guiding music and rhythms
  - The music and rhythms needed to make the participants feel comfortable and at the same time, they should all be recorded into the 6 tracks set up by the wearable device. There were still too many choices on offer, so would it be possible to narrow them down further and also reduce the time for the user to choose? What kind of emotional types of music would be more appealing to users?
  - With the change in the categorisation of rhythm types, was the choice clearer for the participants? What types of rhythms would the participants prefer and find suitable to play in the background?

- Creating music with daily objects and assistive instruments
  - Would providing participants with specific items make it easier for them to find the items they want to use to create music?
  - How would the participants feel about the experience of trying the recommended actions that resemble common stimming behaviours for autism? Could they get a further sense of autistic behaviours through these actions?
  - In the process of exploring various methods of vocalizations, which sound-creating actions would the participants prefer?
  - Would there be any new issues arising in this process that need to be further addressed?
- Using body movements to change the music
  - How would the participants move while wearing the sensors?
  - How would the participants' movements differ with changing the properties of the music?
  - When fully functional, participants would be able to change the recorded sound through their own movements. How would the participants think about this change?
  - Would it be appropriate to fix the sensor on the arm or the wrist? Would any other suitable positions could be tried out?
- Communication between the participants
  - What would the two participants discuss? Although it was recommended to try to communicate more non-verbally between the two people, would there be any topics that they need to talk about?
  - How would they express themselves to each other in a non-verbal way?
  - What would be the differences between communication between strangers and communication between familiar friends?

- Overall perceptions
  - Would the participants be able to understand the objectives of the project? How would the participants perceive the project?
  - What would the participants think of the whole workshop experience? For example, the questions might include whether the duration of the process was appropriate and whether the activities were interesting.
  - Would the participants have a better understanding of stimming behaviours after the whole experience?

4.3.3 Workshop process

With these questions, the second workshop was started, which followed the same steps as the previoue one, also divided into three main sections and followed in sequence. The biggest change was in the third step, where the participants' body movements changed the recorded sound. As the sensor part was almost complete, this step could also be used as a test for the wearable prototype. The participants in this workshop were able to directly experience how their actions changed the sound. The organisers used a laptop to play the recorded sounds from the previous steps and the participants moved their bodies freely while wearing the sensors to explore the changes in pitch, volume and tempo of the sounds due to the changes in the position of the sensors. The rules for the changes, in terms of which properties of the music would be changed, were not told in advance and the participants were expected to explore them themselves during the process, which could make the experience more interesting. However, if the participants were restrained or unsure of what to do, the organisers would be there to guide them through the process to help them experience all the upgrades and functions of the wearable device.

As the participants were working in pairs, the role of the organisers would be more of observers and facilitators than in the previous workshop. This time the organisers would not communicate too much with the participants, but rather observe the communication between each group.

4.3.4 Results

Group A		Group B		Group C	
A1		B1		C1	
Preferred music ■ Beautiful ■ Sad	Preferred rhythm ■ Regular ■ Accelerating	Preferred music ■ Beautiful ■ Calm	Preferred rhythm ■ Regular ■ Accelerating	Preferred music ■ Heroic ■ Sad	Preferred rhythm ■ Regular
A2		B2		C2	
Preferred music ■ Joyful ■ Energizing	Preferred rhythm ■ Accelerating	Preferred music ■ Joyful ■ Heroic	Preferred rhythm ■ Accelerating	Preferred music ■ Joyful	Preferred rhythm ■ Regular
Group D		Group E		Group F	
D1		E1		F1	
Preferred music ■ Joyful ■ Heroic	Preferred rhythm ■ Regular	Preferred music ■ Beautiful ■ Joyful	Preferred rhythm ■ Regular	Preferred music ■ Joyful ■ ENergizing	Preferred rhythm ■ Regular ■ Accelerating
D2		E2		F2	
Preferred music ■ Joyful ■ calm	Preferred rhythm ■ Regular ■ Overall fast	Preferred music ■ Joyful	Preferred rhythm ■ Regular	Preferred music ■ Beautiful	Preferred rhythm ■ Regular

Fig 22. Results of the first step: selecting preferred guiding music and rhythms

Creating music with daily objects and assistive instruments	Strangers group vs. Friends group	Other groups vs. Orchestra Group
■ Almost all of the participants were a little overwhelmed at the beginning when they had to create their own sounds. However, as the pictures of the movements were shown to them and with the organisers' guidance, it was more natural for them to follow the diagrams and choose objects to make sounds. ■ Most of the groups chose items to try in the order of the vocal movements shown and finally chose their favourite sounds to record. ■ When choosing items, as specific everyday items were provided, their hesitation period was not too long and did not overwhelm the participants as it did the previous time when the whole room was a range of choices. ■ Participants preferred items that could be combined to produce a higher pitch for the final recording. Two combinations were more popular, such as plastic and shells, as well as wood and ceramics. ■ Even without communication, two people could influence each other in their choice of items and actions.	■ The two participants who are friends would communicate more during the process and share their ideas naturally at each step, so it would be easier for them to start creating sounds while talking with each other. ■ The unconscious observation and imitation of each other's movements during the process of creating music was more obvious. And they would directly recommend objects to each other that they thought would sound good. ■ Their ensembles started earlier and worked better when they cooperate naturally with each other.	■ They took much longer than the other groups at this stage, not because they were hesitant, but because they enjoyed exploring too much. ■ The orchestra group did not rely too much on the movement diagrams provided, but explored different vocal styles on their own, and were able to start playing together very naturally with little verbal communication. ■ They did not ask to use background music or rhythms as assistance, as they had been exploring on their own how to make the daily objects sound in tune, as well as exploring rhythm, harmony, and so on.
Using body movements to change the music		
■ Most of the participants were still cautious at first and needed some guidance or a simple demonstration before they could slowly try to change their posture. ■ Two people in a group could influence each other in their behaviours. In a group of two strangers the situation was not particularly obvious, but it was still possible to find two people who watch each other's movements and then unconsciously imitate them. ■ When participants were using the communication function on the wearable device to express their preference, their attention was completely diverted to the laptop screen and thus neglected to interact with their partner as the colour change of the analogue LED lights was displayed on the screen. ■ Due to the difference in amplitude of movement, we found the movement data was more easily captured when the sensor was placed on the hand part, especially the palm, and the change in music would be more noticeable. These observations could further define the final position of the device.	■ As in the previous step, it could be more clearly observed that two participants who were friends with each other were unconsciously imitating or consciously matching each other's movements.	■ They were the two most active of all the participants at this step. There might be also personality reasons. They were able to complete a series of movements from the moment they learned the instructions, following the tempos they created and started using dance movements.

Fig 23. Results from observations and interactions in the remaining steps

4.3.5 Analysis

- Music that conveys a positive mood was more popular, especially the two types of music, happy and soft. Happy music they felt could be better suited as a prelude and to create an opening atmosphere. Soft music was seen as more suitable as background music, fitting in with a wider range of sounds.

- The new classification of rhythms was easier for the participants to choose from, in that there were fewer questions and less time spent thinking about the session. They preferred more regular types of rhythms as the support.

- Apart from the group formed by the orchestra members, the other participants gave feedback that they wished some tools could have been used to adjust the pitch during this step so that it would have been more interesting and the recording would have sounded better.

- Most of the participants preferred to use some existing background music or rhythms as assistance in the process of creating the music to help them through the audition. However, the orchestra group did not mention the above. More participants preferred items that could be combined to produce a higher pitch for the final recording. Two combinations were more popular, such as plastic and shells, as well as wood and ceramics.

- As a group of participants working together, it could be observed that even without communication, two people could influence each other in their choice of items and actions. This was even more evident in groups where two people were friends. This phenomenon occurred both in the creation of sounds and in the use of movements to change the music.

- For the participants, the wearable device's functions were complete. Participants in the workshop were able to wear the sensors and experience how their body movements changed the music they created. The only feature that needed to be improved was about the communication, which referred to how the users could indicate their preferences for their partner's recorded music on the wearable. The current design would show the result by pressing a button on the wearable, which would then change the colours of the simulated LED lights shown on the laptop. However, in this way the participants' attention was completely diverted to the laptop screen, thus neglecting to communicate with their partner. How the process could be transferred to the wearable device without using other devices could be a question that needed to be considered for future design.

- In this initial prototype of the wearable device, the sensor and an elastic band were fixed and then separated from the electronic part to allow the participants to move around more easily. In the previous workshop, the majority of people would choose to move their hands. To be more sure of where to place the device, this time the sensors could still be attached to any part of the body, including the arms, wrists, legs and ankles. However, still, almost all participants defaulted to placing the band around their hands or wrists for the exercise. The position was only changed when asked if they wanted to try placing the sensor on another part of the body. And it was also found that due to the difference in amplitude of movement, the movement data was more easily captured when the sensor was placed on the hand part, especially the palm, and the change in music would be more noticeable. These observations could further define the final position of the device.

- Generally, the participants were supportive of the system and most of them thought that it would be a fun game for many people if the system could be promoted. At the end of the workshop, they mentioned that they had learned more about the stimming behaviours of people with autism because of our project introduction and the whole workshop experience. The questions prepared for the workshop were solved.

4.3.6 Design inspiration

- Assistive instruments

  There were some principles to follow according to the results of the two previous workshops.

  - The use of instruments could be designed according to common types of stimming behaviours and the preferred ways of creating sounds observed in the workshops by the participants.

  - Their appearance should not be too bright or fanciful, as they were just auxiliary tools. The users needed to be more focused on the process of creating music.

  - The materials could be chosen or combined from those that were observed in the workshops as being more preferred by the participants.

  - It would be necessary to take into account the comfort of the users when playing with the product, including the size, weight and shape of the prototypes.

- Wearable device

  As with the auxiliary instruments, based on previous studies some principles regarding the appearance and structural design of the wearable device had been summarised as follows.

  - Sensors being fixed around the hand near the palm would be a relatively better option.

  - The size of the electronic components would require consideration of how to secure the device to the body.

  - Due to the wires involved, the internal structure of the wearable would need to be able to hold the components in place to avoid malfunctioning due to poor connections.

  - The electronic components were not light in weight, so the exterior design and choice of materials needed to be considered in order to allow the users to wear the device and still move around with ease.

4.3.7 Design output

The results and analysis of the workshop could provide a good preparation for the next stage of design. The inspiration gathered concerning the design focused on the assistive instruments and the advanced prototype of the wearable devices.

■ System process

Based on the workshops that had been finished, a complete system map including functions, user scenarios and the activity flows could be summarised (Fig 24).

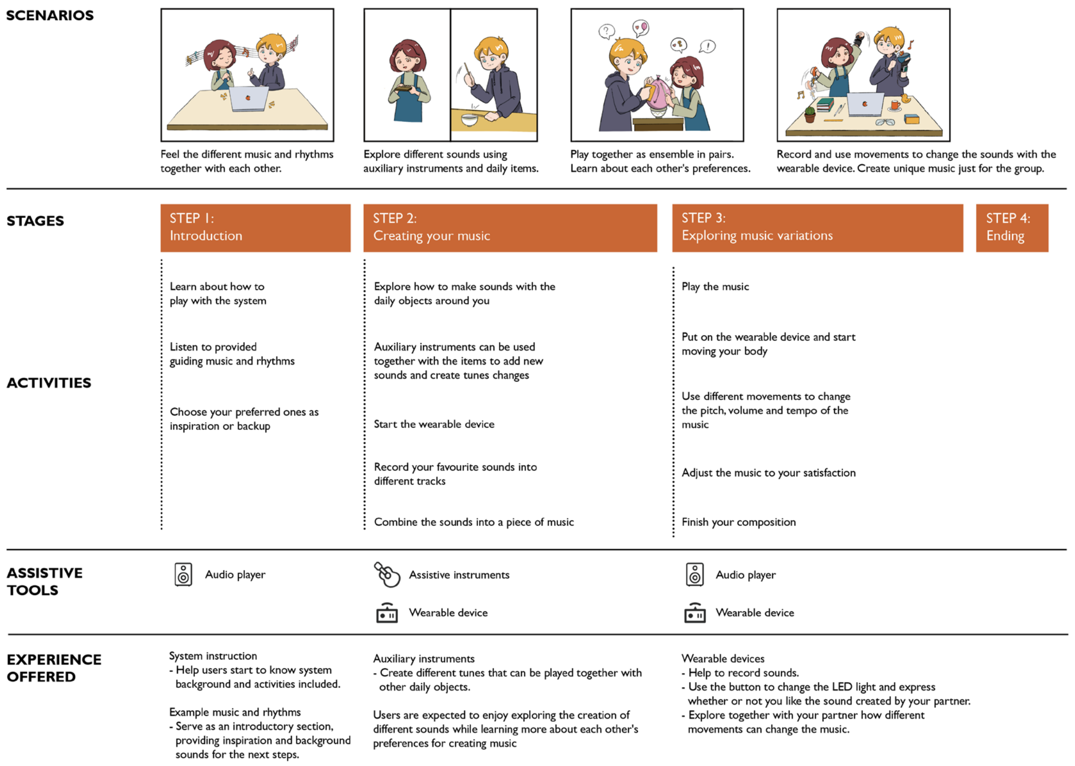


Fig 24. System map of Stim4 Sound with the scenarios and the functions

■ Assistive instruments

Firstly, a mood board was summarised based on the materials of the more popular items in the workshops and the instruments commonly used in autism music therapy from previous research (Fig 25).

Fig 25. Mood board for the assistive instruments

Then the design for the assistive instruments had been started according to all the resources of inspiration.

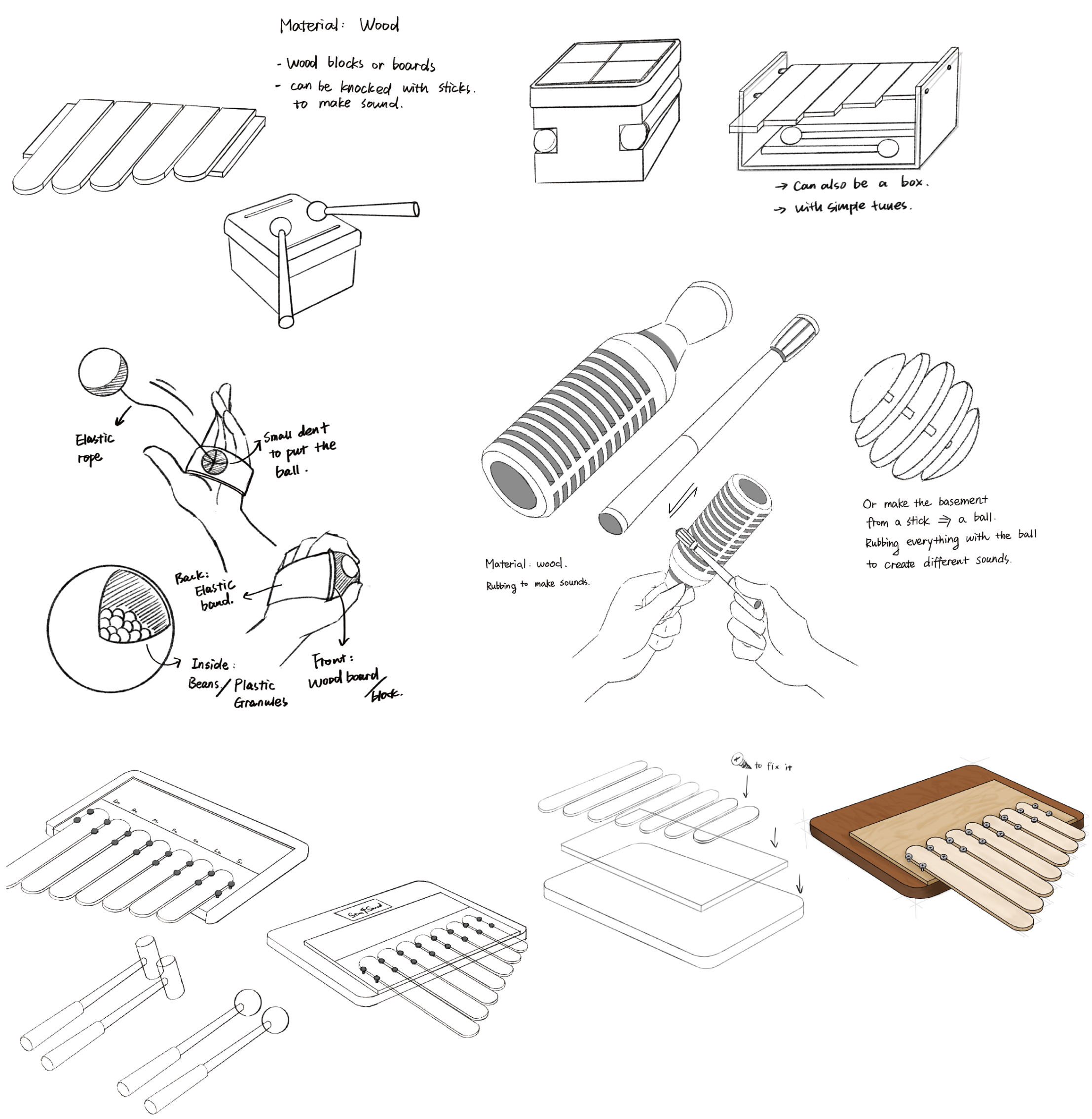


Fig 26. Sketches of the assistive instruments with wooden materials

First, to be considered were designs where the main material was wood (Fig 26). Wooden furniture or objects could be very common in daily life. According to the sounds made by wood and the behaviours of the participants in the previous workshops with wooden objects, the most common method to create sounds would be tapping or knocking. Although some references were made to the design that also uses rubbing or shaking to produce the sound, it was essentially because of the collision of wood. Therefore, the final design of the wooden auxiliary instrument would be based on knocking or tapping.

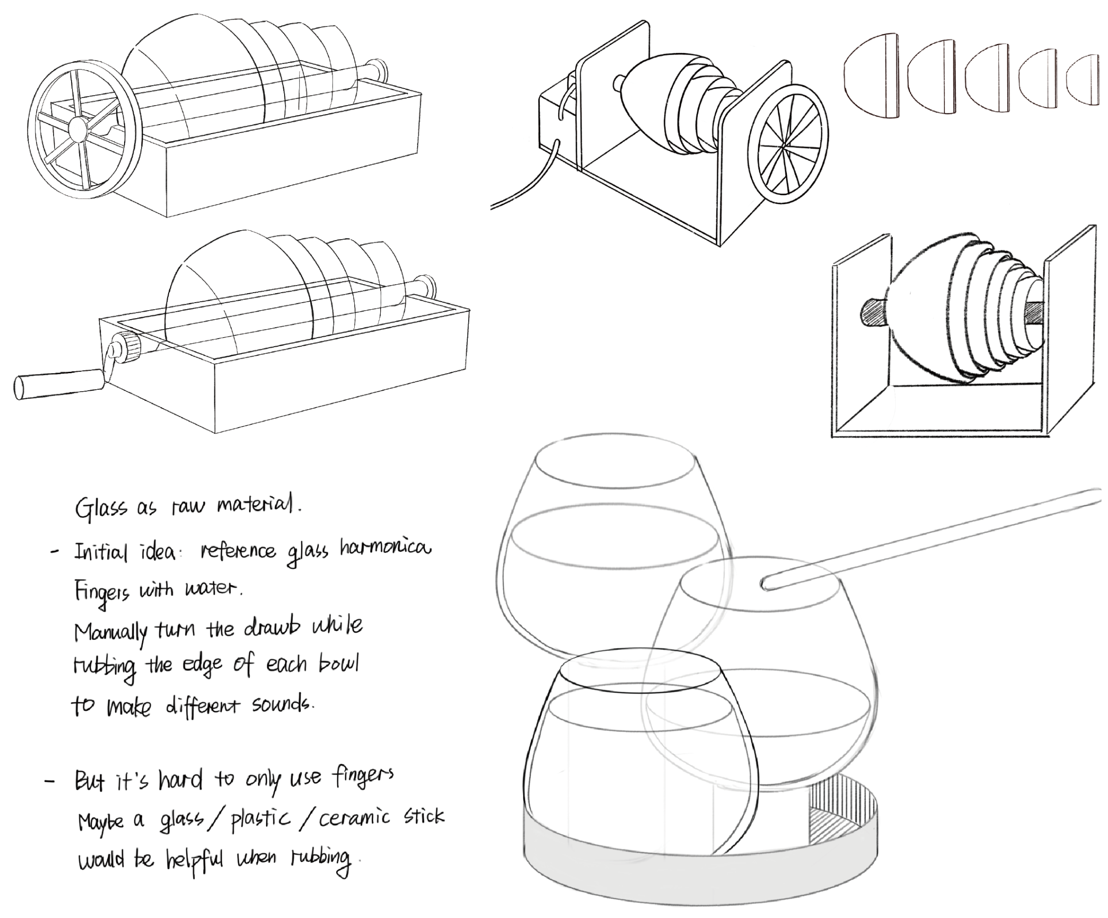


Fig 27. Sketches of the assistive instruments with glass

Another material that was often chosen in the workshops was glass (Fig 27), which could have a very crisp sound against other materials. However, glass might be dangerous if broken, so the body of the glass would need to be held in place. The original idea was to refer to a glass lyre, where the sound could be made by rubbing the rim of the glass bowls with a finger dipped in water. However, after some experimentation, there were two reasons why it was not possible to make a product at the moment. Firstly, the right size of glass bowl needed to be made to order, and secondly, it was difficult to make a sound by rubbing the edge of the glass without professional training. So the design was developed with the help of a glass rod. This would allow the users to rub the rim with the glass rod and also to make a sound by tapping it. The original glass bowls had been replaced with smaller and more manageable glasses, using the principle that changes in water level affect the pitch of the sound when rubbing or tapping the glasses.

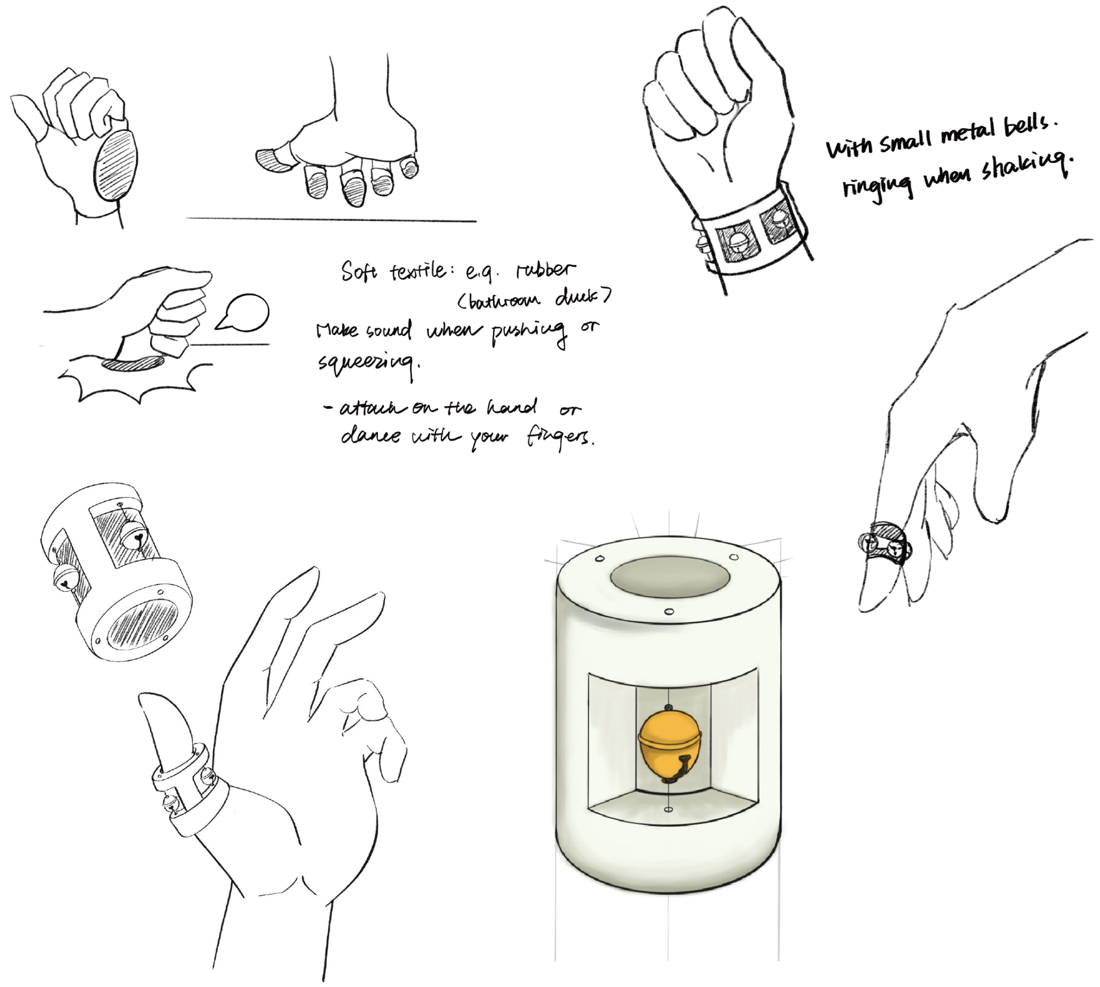


Fig 28. Sketches of the assistive instruments with metal and other material

The last material type was metal (Fig 28). As the sound of clashing metal might not be acceptable to everyone and may even be offensive to some people, the basic element for this auxiliary instrument would be the bells, which could be common in many music therapy objects or instruments. The sound of the bells was clear but not sharp, and their small size could make them very versatile. As the first two assistive instruments might restrict physical movements during use, the third instrument was designed to be small enough to be worn with the body and to allow free movement. Because it was close to the body, the softer material on the bottom would be more comfortable for the users.

Based on these various ideas and realistic experimentation with different materials and shapes, the final design of the three types of auxiliary instruments would be presented as follows.

Wooden kalimba

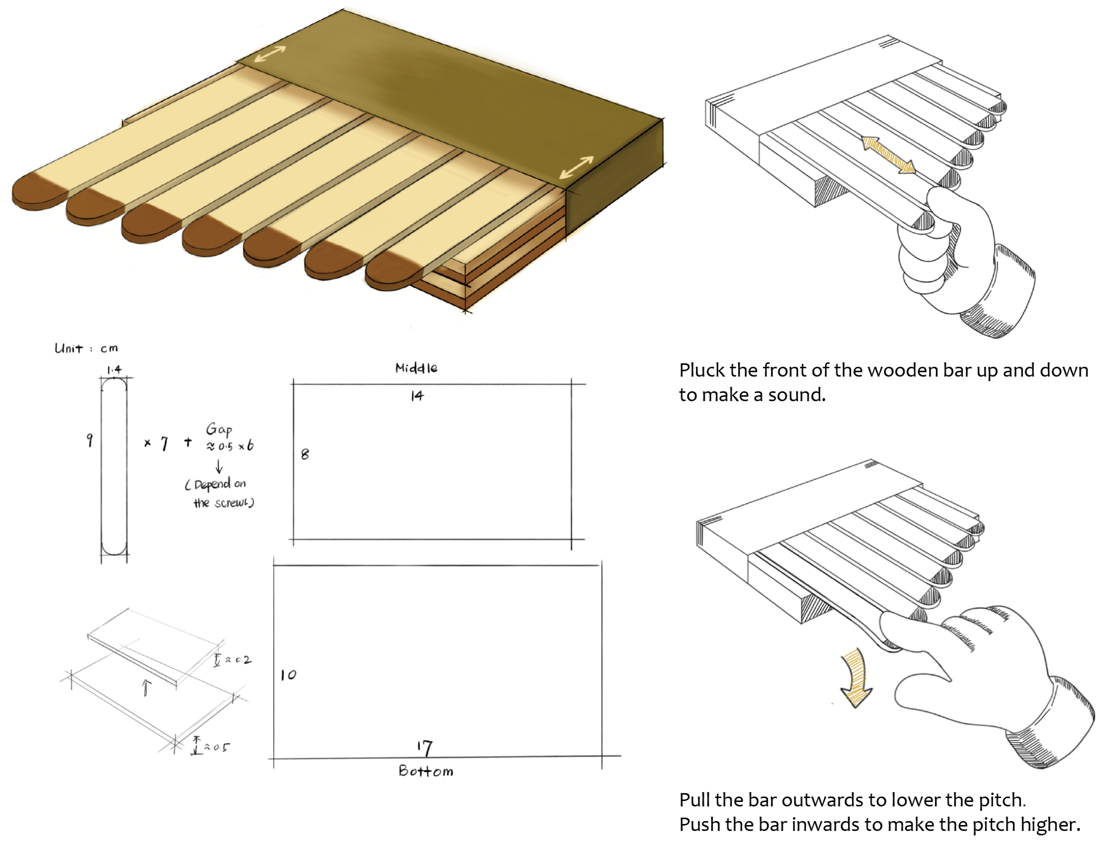


Fig 29. The illustrations and the usage of wooden kalimba

This one was inspired by the musical instrument kalimba. The main body and keys were made of wood and fixed together using screws. It was decorated using vellum in similar colours. The sound could be produced by flicking the front of the outstretched wooden piece with a finger. Each key had a different pitch as each wooden bar extended at a different length. However, the keys could still be slid back and forth to adjust the pitch manually. So there would be no definite pitch for the instrument, which could be adjusted by the users.

Bell ring

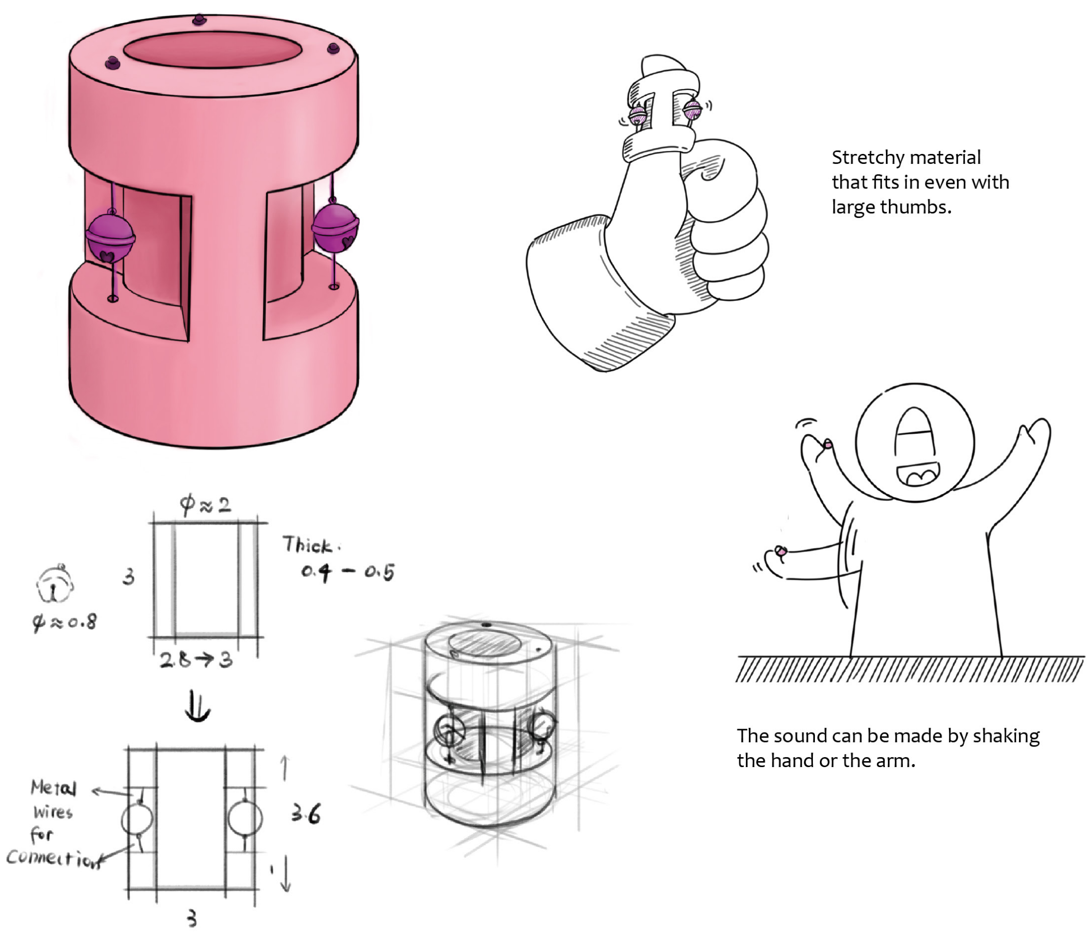


Fig 30.The illustrations and the usage of the bell ring

The body of the bell ring was made of soft silicone and kept the colour of the original material. It was inlaid with three bells. It could be attached to the thumb and would make a crisp sound when shaking the hand or arm. The ring was not capable of having different tunes, but the sound it made could be matched to various sounds and it would be easy to move around.

Singing glass

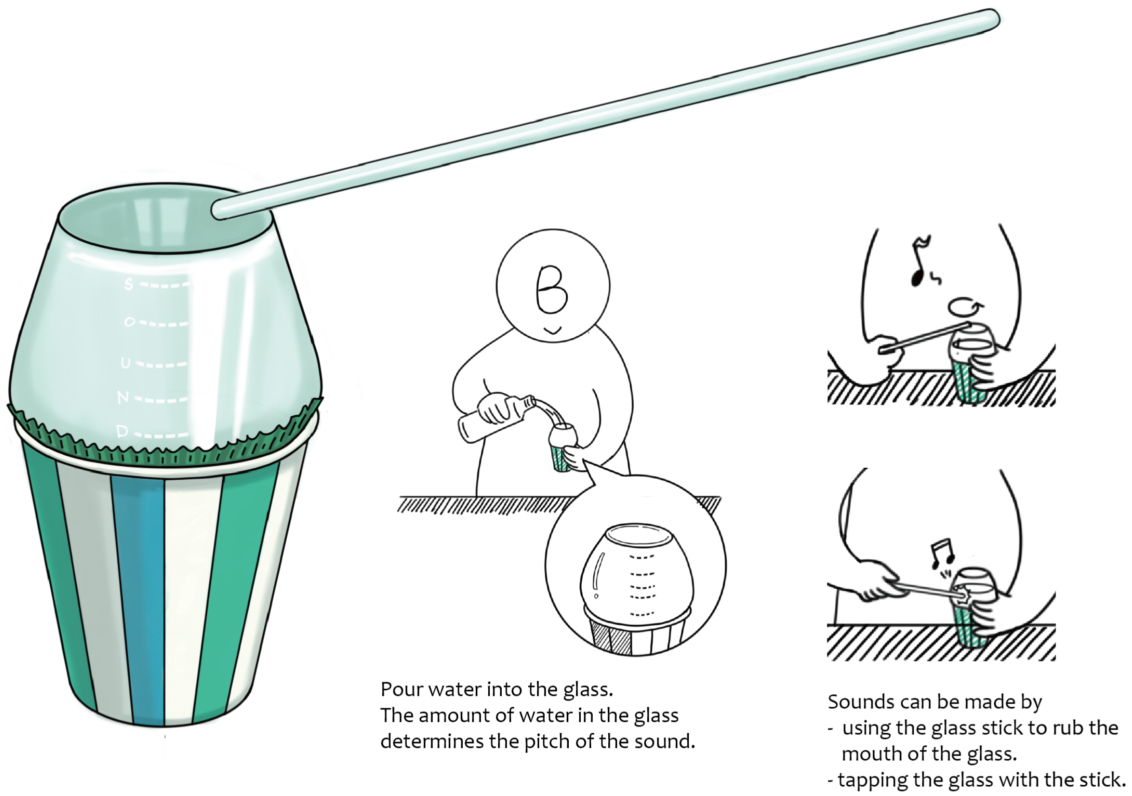


Fig 31.The illustrations and the usage of singing glass

The instrument was based on the principle that rubbing the mouth of a drinking glass with water could make a sound and that the pitch of the sound would change according to the amount of water in the glass. But to make the experience easier, the glass stick was provided as a secondary tool. The users could either rub the mouth of the glass with the stick or tap the glass wall to make a sound. The change in pitch could be experienced in both ways of making sounds. Similar to the wooden kalimba, the instrument's pitch was indeterminate, allowing the users to explore on their own. But the gauge marked on the glass would provide some recommended amounts of water as a reference, representing a more standard set of pitches.

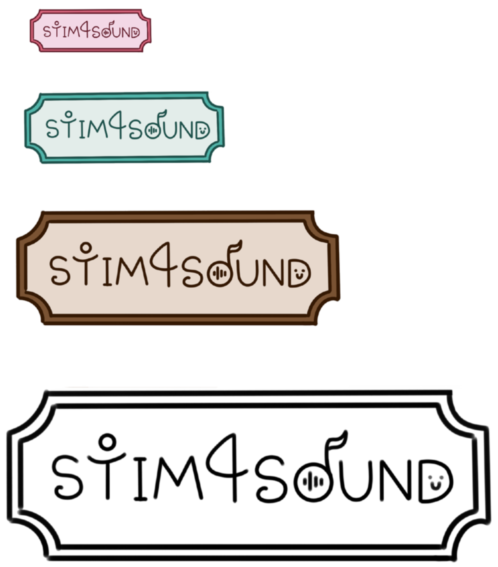


Fig 32. Logos of different sizes and colours

Furthermore, to enhance the unity of all the products in the system, a logo was designed and attached to the auxiliary instruments and would also be attached to the wearable device (Fig.32). The basement of the logo is the name of the system, with the addition of musical elements. The font was chosen to be more childlike, depending on the final colour schemes and shapes of the auxiliary instruments. Also, four different colours and sizes were chosen for the logo according to the appearance of the different tools.

Finally, there would be presentations of the finished realistic prototypes of the three auxiliary instruments. These prototypes would need to be tested by the users in the next workshop.

Wooden kalimba

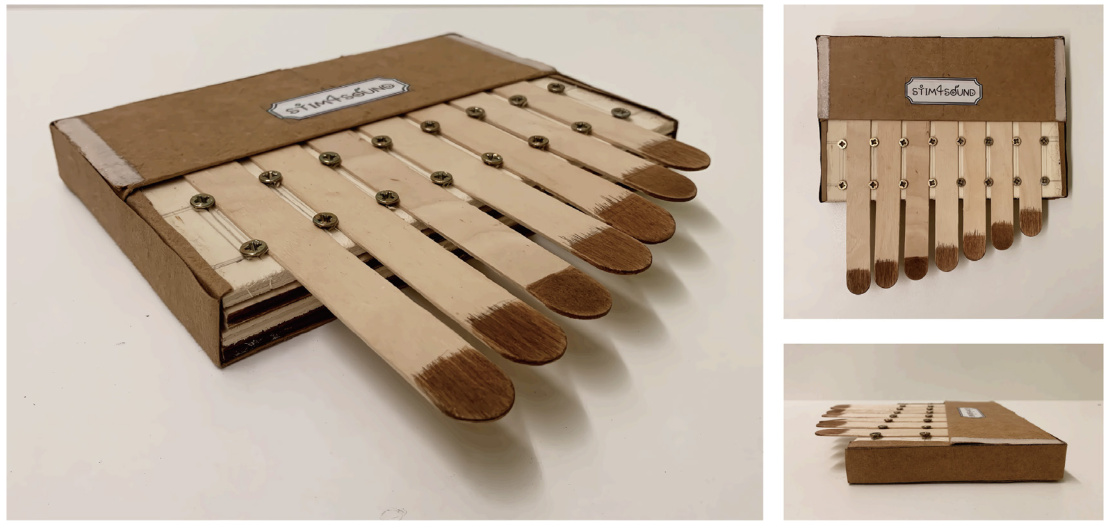


Fig 33. The solid model of wooden kalimba

Bell ring

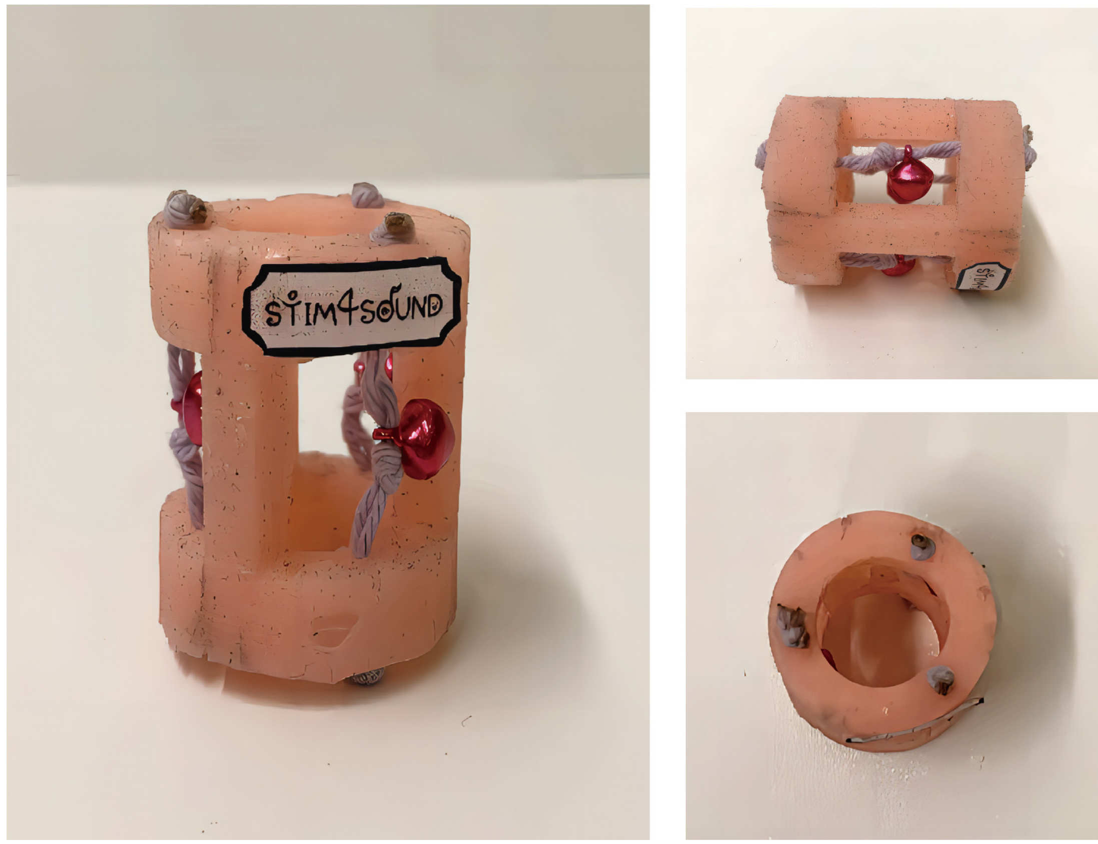


Fig 34. The solid model of the bell ring

Singing glass

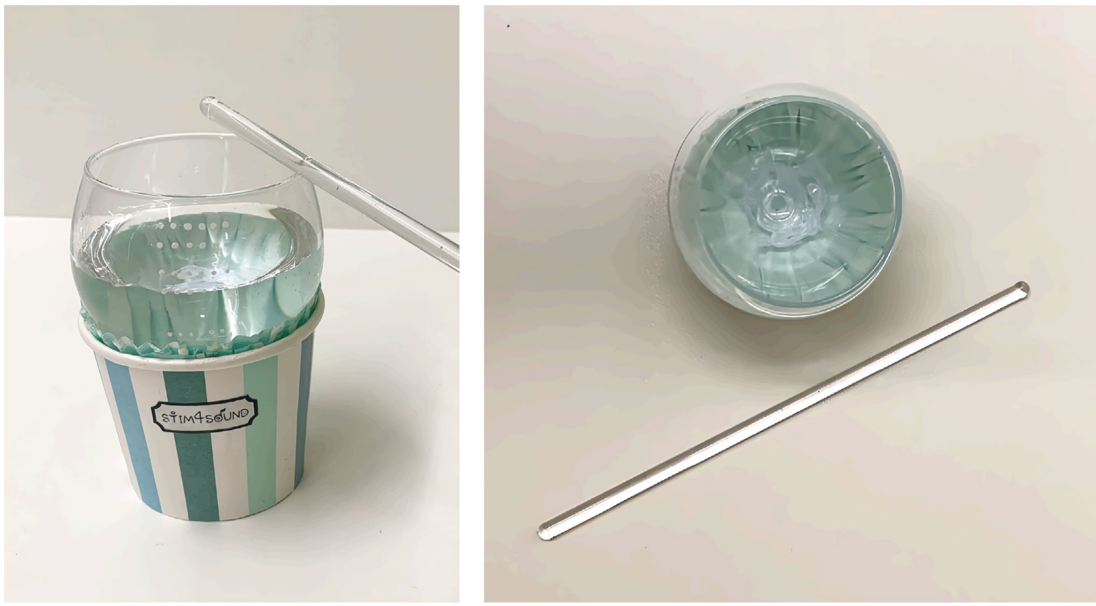


Fig 35. The solid model of the singing glass

■ Wearable device

The dimensions of the main parts of the electronic device were determined, as was the position of the wearable device to be mounted on the hand. The goal of the design was to upgrade the original prototype and implement a new one that would allow the users to experience the full functionality themselves. The basic design concept was that the glove acted as a base on which the electronics and sensors were fixed and that more thought was given to how to place and hide the electronics so that the device looked aesthetically pleasing and more like a complete product.

After various practical attempts, it was found that the electronic part had a certain weight that made it difficult to hold it in place while still allowing the users to move their wrists and arms freely. Therefore, in order to ensure the users' comfort and freedom of movement during the experience, the electronic part was made removable. This part could be removed when body movements began to be used to alter the recorded sounds, leaving only the glove base and the sensor for motion detection.

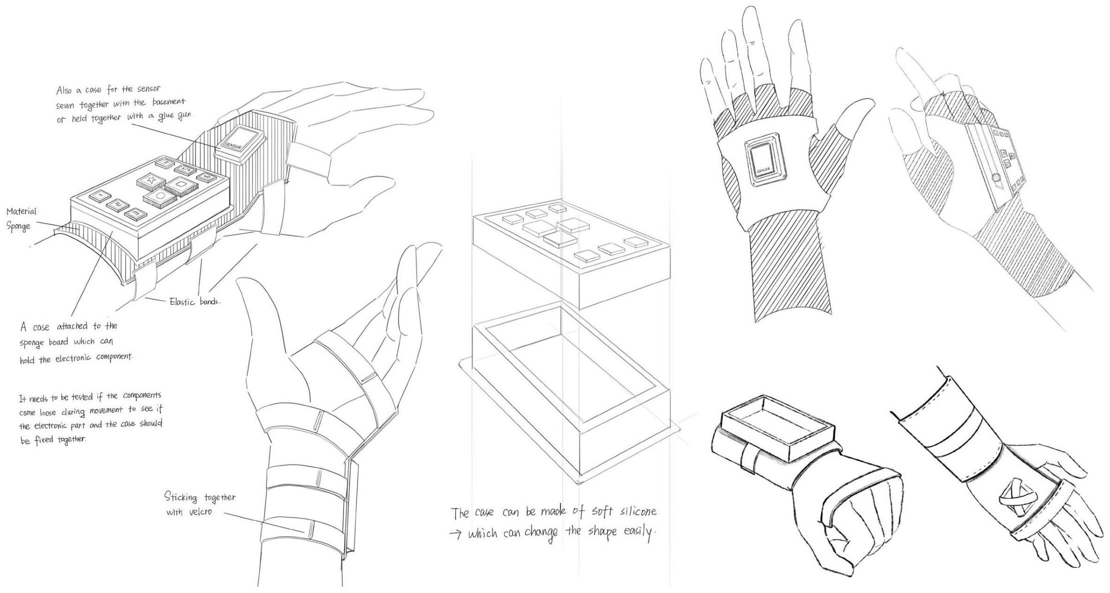


Fig 36. Sketches of the prototype appearance of the final wearable device - part 1

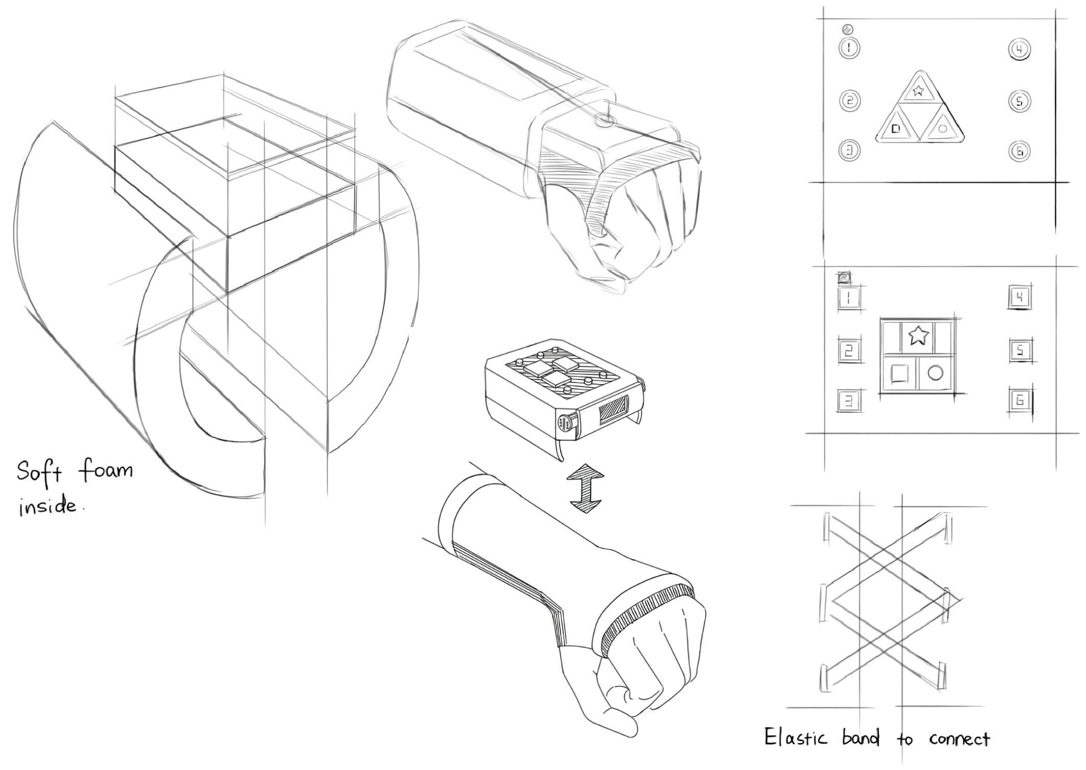


Fig 37. Sketches of the prototype appearance of the final wearable device - part 2

Some consideration was also given to the colours of the wearable device. As the combination of auxiliary instruments and various daily items was colourful enough, the wearable chose classic black, white and grey as the main colours, mostly to showcase its various functions.

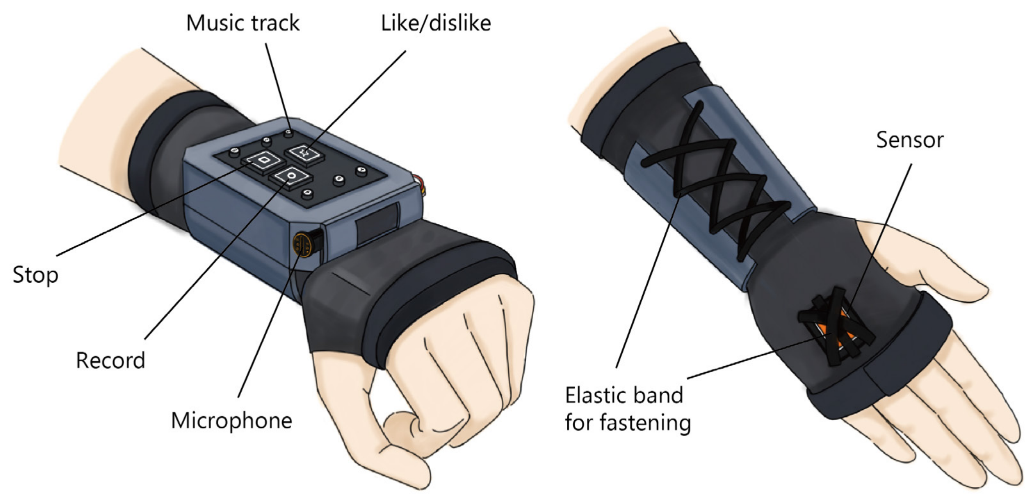


Fig 38. Illustrations of the prototype appearance and basic functions of the wearable device

Fig 39.The solid model of the wearable device

4.4 Workshop 3

Once the prototypes of the products involved in the system were completed, they needed to be tested by looking for target users in preparation for a final workshop. The workshop's primary purpose was to allow users to try out the complete system and its functionality, explore any remaining issues that needed improvement and get a sense of how users felt about the whole experience. The workshop process would be the same as the second one, but with the addition of secondary instruments and allowing participants to use the completed wearable prototype to make the experience more complete. In this workshop, we would invite both autistic and non-autistic participants to join us. We expected non-autistic participants to experience stimulating behaviours that could be common in the autistic community and to gain a greater understanding of the behaviours of their autistic friends or family members. For autistic participants, we hoped they would enjoy the process, not have to worry about being blamed by others and would like to use the system to communicate more with their partners.

There were three groups of participants in this workshop. Each group of participants had a different background, so the ideas and suggestions provided for the project encompassed different aspects.

4.3.1 The first group

The first participant in the group was a professor whose research interests are related to the use of movement to control music. He was participating in this workshop alone. As a professional researcher in his field, he was more of an observer of the activities during the experience. For guided music, he preferred joyful as well as natural music. The former he found to put him in a good mood, while the latter was relaxing. He also chose the simplest of regular rhythms as assistance in the part of the rhythm, giving the reason that it could be adapted to a wider range of sounds. In the section on creating music, he tried all the ways of making sounds according to the illustrations provided during the introduction. But he was more interested in auxiliary instruments than in using daily objects. He preferred the bell ring because it was easy to carry, had a lovely appearance and the sound of the bell was clearer. Throughout his experience, he focused more on the third step, the part where he used his body movements to change the music. Firstly he said that the wearable looked a bit bulky and although the sensors could be worn separately for use, it would be more convenient if they could be used without having to be removed. Then he liked the interaction of the two people using movements together to explore the various variations of the music. He also brought up a discussion about the principle and programming of the feature and how it could be improved. He mentioned that the current rules are still quite monotonous, as the movement of the sensor in a particular direction still changed one specific property of the music. It would be more interesting to have all the properties of the music change randomly with movement, but that would probably involve more complex programming and a re-selection of sensor types. If the system could be made generally available in the future, the randomness could make the events more interesting. Moreover, he wondered whether the workshop or the system activities outside in good weather would have a different effect on the mood of the users. So for the next participants, we would offer the choice of environment.

4.3.2 The second group

The second group of participants were two university students, and both were friends. One of the participants had autism as a child and will be referred to as Student A in the following. He had not shown any obvious signs of autism for a long time. He was also positive and talkative throughout the whole process. He was particularly active and able to express his thoughts clearly when referring to his professional knowledge. He and his non-autistic partner (Student B) showed a lot of verbal communication during the activity.

They had similar preferences for guiding music, preferring joyful and exuberant music, both of which they felt could convey positive energy. For the auxiliary rhythms they chose overall fast or gradually accelerating rhythms, giving the reason that they were more in tune with the feeling of the music they wanted to create in their minds. But at this beginning step, they did not show a great deal of interest in the music or the rhythms offered. Both mentioned that because they themselves had songs they liked very much, the pure music and rhythms being offered were relatively unfamiliar to them. They would probably have been more engaged if it had been a tune they were familiar with. So they suggested that in addition to providing some basic music and rhythms in this session for users who were completely uninspired or had a hard time

thinking of how to create music, some empty tracks could also be provided for users to add their own favourite content.

When starting the step of creating music using everyday items, the two of them felt that the workshop offered an excessive number and variety of items that seemed a bitcluttered and random, and might cause some distress to people in terms of choosing everyday items. The previous workshops offered as different items as possible to find inspiration for the design of auxiliary instruments. Still, in normal circumstances, users might not come up with a wide range of items to put together for a tour at once. So the items offered to the next group might be streamlined and altered in some way.

The two then naturally began to collaborate and exchange different ways of creating music because they knew each other so well. Student A showed a greater interest in the wooden kalimba, which is one of the auxiliary instruments. He spent most of his time playing the instrument compared to other daily objects. He showed a lot of concentration in this process. On the other hand, Student B was more evenly experimenting with different objects and auxiliary instruments to create sounds. The two hardly stopped interacting during this process, but it was possible to observe that student B was more cooperative with Student A. She would sometimes observe his movements and take the initiative to pick out objects to play with the sounds he was creating using the wooden kalimba.

Fig 40. The second group of participants created music

Two people took a long time to create the music, which led to the fact that when the sound was recorded and the next step was introduced later, Student A started to find the workshop long and was losing patience. So they didn't make too many comments during the activity of using the body movements to change the music but just explained that the process of gradual exploration was very innovative. However, they also wondered whether using movement to change music would become boring once the users become familiar with the rules of music change. They gave the suggestion that the two steps of creating sounds and using body movements to change the sounds could be combined, which meant that once the users had a sound they liked they could start recording and changing it, rather than trying out all the items before starting to record.

During the second group's process, Student A, the participant with autism, did not show many differences from Student B. The two interacted with each other although B took more care of A, A initiated the communication positively. However, perhaps the two were chatting all the time because they were so familiar with each other, and the non-verbal communication involved was a little different from the previously envisaged process. Coupled with the fact that the simulated LED lights displayed on the laptop screen were now being used, the buttons and lights on the wearable used to express preferences for the partner's sounds did not help much.

4.3.3 The third group

The third group of participants were two colleagues. The autistic participant (Colleague A) was an older man who said that he was able to live and work normally, but his autistic symptoms never stopped and he would start rubbing his arms when he felt very uncomfortable, but not very often. The other participant (Colleague B) was a young man who worked together with A and would help with translation and care throughout the process as Colleague A was not very fluent in English.

In the first step, they both chose the same music, both exuberant and sad, but for different reasons. Colleague A thought that the exuberant music sounded mysterious, while for the other one, he said he had always liked music with a sad undertone. Colleague B, on the other hand, found both types of music relaxing. In terms of the rhythms, Colleague A preferred a slower rhythm, while Colleague B chose the simplest rhythm. Both of them were very attentive during the listening process.

When it came to the stage of creating music, both participants had separate favourite auxiliary instruments. Colleague A played the wooden kalimba more often, while Colleague B found the singing glass interesting. Both spent a long time exploring the use of these two instruments to produce different tunes. This group was less communicative and quieter in this process than the previous group. Colleague A would hum a song while using the objects to create sounds. However, similar to the previous group, Colleague B would also be more considerate of Colleague A's actions and match Colleague A's sounds much of the time. Although both were told that they could start recording as soon as they found a sound they liked, together they tried almost all the objects and auxiliary instruments provided, as well as the various ways of making sounds, and were interested in the activity.

Fig 41. The third group of participants tried the assistive instruments

Both of them still showed a lot of commitment while recording their sounds and Colleague A even sang his favourite song while Colleague B accompanied him. However, when they started to change the music using body movements after the recording, Colleague A first showed hesitation and was not able to start moving easily. When he heard the sound he was creating changing, he showed obvious resistance and discomfort, even explaining to me that he wanted to rub his arms a bit, so the process was stopped. When I talked to him after he had calmed down, he indicated that he was not very receptive to the change and that it was too intense for him. Also, he was a little uncomfortable with the change of steps or tasks in the whole process. The change from listening to music to creating music was acceptable to him, but after that it was too much for him to receive a new task and start a new activity, not to mention the new task was making him more uncomfortable. So for the whole flow of the activity, he would also have preferred not so many steps or tasks, but more time for full exploration on his own. This was also a different view from the ones gathered from the previous participants.

4.3.4 Summary and analysis

First of all, it was related to guiding music and supporting rhythms. Mood-enhancing, as well as soothing music and basic rhythm types, were more than welcome. They were necessary to help users who were not inspired to create sounds. But there should also be room for users to import the music and rhythms that they like, offering the opportunity for customisation. For users with specific musical preferences, providing music that may not be of interest to them may detract from the process of creating music and interacting with their partners.

Auxiliary instruments were very popular in the process of creating music, the relatively most favoured being the wooden kalimba, probably because of the ease of changing tunes. With the provision of auxiliary instruments, apart from the participant in the second group, there were no instances of focusing on auxiliary instruments rather than daily objects, with most participants still combining the two groups to create sounds and then playing together.

Followed by the discussion about the wearable device. The appearance of the wearable device still needed to be streamlined. Although none of the three groups showed a more negative view of the appearance, it was still mentioned that it would be easier to use if it was smaller and did not need to disassemble the sensor and the main electronic part. All three groups of participants were more concerned with functionality. The wearable device could affect the three attributes of the music by moving the sensor in specific directions and changing the frequency of movement, which would be innovative for new users. But once the rules were explored, this feature might not be as appealing. For users who would like to experience the process of changing music with their partners and communicate about their preferences

once the rules were fully understood, the process would become more purposeful and less fresh and experiential. For those who would like to create their music with their partners through movement changes, the process of interaction with their partners would only become more neglected once they understood how the movement would affect which properties of the music. So suggestions about the improvements to this main function could include increasing the randomness and playfulness of the music changes. Finally, in the case of the analogue LED lights that could show users' preferences for created sounds, as the current analogue lights were on a laptop screen, the two people interacting with each other could not pay much attention to that. So it should be taken into consideration how to transfer it to the wearable device and make it more visible.

Last but not the least, the overall flow of the system needed to be put into more consideration. While following the steps and tasks in the workshops facilitated the participants to gradually understand all the functions covered by the system and also made it easy for the researchers to observe and record their behaviours, the division of the steps might need to be less obvious in the final system. Too many steps might cause users to lose patience and might make users who are not accustomed to variation, especially some sensitive autistic users, feel more uncomfortable and thus not able to easily entertain and interact in the scenario. Therefore the whole system may need to be set up with only one main task and all other activities and functions as supports for the users to choose whether or not to complete.

5. Discussion

By the end of the test, the whole RtD process had almost come to an end. Looking back over the course of the project, we were continuously trying to solve the research questions that were initially posed.

In the first iteration, we built on the initial system flow and explore additional system functions by conducting workshops and brainstorming with the participants. During the communication, we learned about their preferences for sounds and thus specified an initial range of introductory music and assistive rhythms to help them find inspiration. Due to the confusion they created when creating music, we identified auxiliary instruments as another system equipment in addition to the wearable device. Also, through discussion and observation, we tried to understand their common movements or dance habits in order to establish the basic procedure for using movements to change musical properties. The focus throughout the first iteration was more on defining the activities and the functions of the system, as well as designing and implementing the feasible prototype of the wearable device.

The second iteration followed the previous one, defining the flow of the system and upgrading the wearable device prototype to make it a more complete product available to the users. More importantly, we were able to gain inspiration for the design of the auxiliary instruments, mainly by observing and analysing the behaviours of the participants, while further narrowing down the scope of the music and rhythms that guide the users, with the intention of creating a comprehensive musical experience for the users as a context for their interaction. The second iteration focused on enhancing the user experiences in the system from a musical perspective and exploring and defining how participants interacted with each other in the system flow.

The final testing of the whole system helped to test the rationality and fluidity of the flow and to check the usability of the devices involved. The results of the test helped us to reflect on the remaining problems with the system, the subsequent improvements and the future development of the project.

During the entire project, not only did I gain information through interaction with the users, but I also learned a lot outside of my profession in order to realise the functionality of the product, such as researching the classification of various types of music and how different moods can be experienced and felt by different groups, as well as studying the methods to produce sound from various objects and instruments and how to adjust the musical properties when creating realistic prototypes. Meanwhile, many thanks to the electronics engineer Benjamin for his technical contribution to the project. He did a great job helping implement the basic functionality of the wearable device. I also learnt a lot about programming and how to use software and sensors to control sounds when working together with him. However, there were still some regrets about this project. Although the basic functionality had been completed, the size of the electronic basement that Benjamin created did make it more difficult to design the appearance of the wearable device, so that it was still inconvenient to wear. Also, due to the previous corona environment and the timing of the scheduled workshops, not enough autistic users were sought to participate in the workshops, so the results of the overall study could still be limited. Fortunately, these are the issues that can be addressed in future research.

After the whole process of acquiring knowledge, we can return to the original research questions. The main idea of the Stim4Sound system is to provide a scenario in which users can create music, modify music and interact with each other. The system uses sound as a thread throughout the whole process. In contrast to normal social interaction, verbal communication is not as important in the scenario. Users can communicate with their partners more through gestures, body movements, creating sounds or using the light changes of a wearable device. And both methods of creating sounds and changing the properties of the music are relevant to the stimming behaviours of people with autism. In the system, stimming actions will not be judged but encouraged. So autistic groups are hoped to be less stressed about the common social rules. For non-autistic people, the system does not require them to act as only helpers or teachers for the socialisation of autistic people. There is also a lot of fun to explore with the activities and features offered by the system and they can still enjoy the whole process in a playful and relaxed mood. The functions involved such as the guiding music and rhythms, the auxiliary instruments and most importantly the basic concepts of the wearable device have all been realised. However, if the system is to be further developed and popularised as a commercially available range of products, there is still much more that can be done to improve everything from its appearance to its inner functionality, making many of the features more accessible and other interesting features that can be discovered.

6. Future development

Although the Stim4Sound system is now essentially complete in terms of basic functionality and the auxiliary devices included, there is still plenty of room for development from the results of the final testing. The following three aspects will be discussed as to how the system can be improved and popularised in the future.

6.1 Wearable device

The first and most obvious content that can be upgraded is wearable devices. The electronic part is the basis and main body of the device. Some of the shortcomings now include the overall size being too large and the wiring connections being too obvious. The development boards available on the market today, such as the Raspberry Pi and Arduino, are similar in size despite being fully functional, and some of the more advanced mini-development components are either expensive or only available to specific companies. But it does not mean that this problem will not be solved in subsequent development. The developer of the electronics section, Benjamin Leonard, mentioned in his article that the circuits can be printed on flexible PCBs to reduce the size of the controller (Fig 42). As technology advances, the trend for development boards in the future will continue to be smaller sizes and a wider range of data connectivity options, as well as longer lifetimes. If the system can be popularised in the field of interaction for people with and without autism, and developers have access to more advanced basic components for development, the problem of bulky size can be naturally solved.

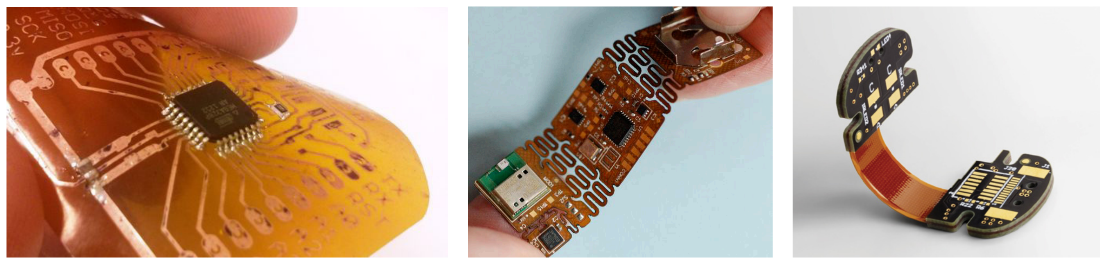


Fig 42. Flexible PCBs with different shapes

Another important functional component is the sensor. The current sensor, the Xsens DOT, is sensitive enough to detect movements but has certain shortcomings in terms of stability and compatibility with laptops. In terms of how it can be upgraded, Christopher also mentioned in the article that it can be used with other wireless sensors with appropriate interfaces to help get a more stable output. There are also LEDs for expressing preferences for the music recorded by both parties, which can be mounted on the device via an external connection. More LEDs can be placed to provide a wider range of colours or to add brightness variations and flicker, which can reflect the magnitude of the likes or dislikes. Finally, a database that plays guided music and rhythms can also be placed on the wearable through some MP3 music modules and leave room for the users to import other music by themselves. If the functions described above are implemented, the whole system would be largely computer-free, allowing the users to focus more on the interaction with their partners rather than focusing on a laptop as the controlling centre. It would also be more acceptable to the user as a series of commercial products.

In addition to functionality, the design of the wearable device could be made simpler in appearance. Buttons can be arranged in a flatter way or hidden under the device's casing to appear less obtrusive from the outside. The type of buttons can also be chosen to suit the style of the device.

A more rigid material could be tried for the case of the device. The current housing is made of softer materials such as foam, which does not make it easy to build the internal structure. The solid construction adds weight and is slightly prone to deformation even after completion. If a more rigid material is used for the internal structure, it will provide both protection for the electronics and stronger support for the interior. The outermost surface needs to match the style of the whole system and can be painted or coated to change the texture of the outer surface.

6.2 Assistive instruments

Although the auxiliary instruments don't seem to have any significant problems at the moment if the system is to be popularised as a commercial product, the improvement needed for the auxiliary instruments is that they need to be unified in style so that they look more like a range of products rather than just a logo on each instrument. And at the same time, they would still need to retain the original character by using different ways of producing sound and different materials. So for the future of the auxiliary instruments, the sounding styles and the main part to create sounds remain the same, but there will be some components on each instrument where the materials and colours are the same. The overall style can be adapted to the user groups. For example, suppose the overall system style is more minimalist. In that case, the kalimba can be made entirely wooden, the ends of the bell ring can be decorated with additional wooden circles, and the underneath support of the glass can be made with a wooden base (Fig 43). The logo can be carved into the wooden part. The grain and colour of the wooden components on the three instruments need to be similar. It can also be accompanied by peripherals such as paper tapes, stickers, ribbons, craft materials etc. to allow the users to decorate their equipment on their own to create their styles. This process could also be extended to create another non-verbal communication scenario.

Fig 43. Visions for the design of auxiliary instruments

6.3 System flow

As mentioned in the previous analysis, only one main task can be given in the whole system flow, which is to create and edit music. The task needs to be accomplished with a change of body movement. The rest of the guiding music, the assistive rhythms, the auxiliary instruments and the wearable devices are introduced as necessary functions to assist with the task. And since the main target group of the system is still people with autism together with their friends or family members. Therefore, the workshops and tests required in the subsequent development also need to be careful to control the number and type of tasks, to prevent any further discomfort to some sensitive users.

7. Conclusion

In conclusion, the research has developed a complete Stim4Sound system that provides a sound-mediated environment in which people with and without autism can interact in a variety of non-verbal ways by creating and changing music using common stimming movements. The project hopes to help them become more relaxed about interacting without worrying about the rules of social situations and to promote mutual understanding between the two groups. The completed system has basically achieved the project's goals in terms of functionality and experience, but there are still limitations. The system can be improved and developed in the future through more advanced technology and more complete user research, and also hopefully as a technological foundation to help facilitate communication between autistic people and society on a wider scale.

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