Inclusive improvisation through sound and movement mapping: from DMI to ADMI

Alon Ilsar
SensiLab, Monash University
Melbourne, Australia
alon.ilsar@monash.edu

Gail Kenning
UNSW Ageing Futures Institute, Felt Experience & Empathy Lab, University of New South Wales
Sydney, Australia
gail.kenning@unsw.edu.au

ABSTRACT

The field of Accessible Digital Musical Instruments (ADMIs) is growing rapidly, with instrument designers recognising that adaptations to existing Digital Musical Instruments (DMIs) can foster inclusive music making. ADMIs offer opportunities to engage with a wider range of sounds than acoustic instruments. Furthermore, gestural ADMIs free the music maker from relying on screen, keyboard and mouse-based interfaces for engaging with these sounds. This brings greater opportunities for exploration, improvisation, empowerment and flow through music making for people living with disabilities. This paper presents a case study of the a gestural DMI invented by the first author and shows that system-based considerations that enabled an expert percussionist to achieve virtuoso performances with the instrument, required minimal hardware and software changes to facilitate greater inclusivity. Understanding the needs of the users and customising the system-based movement to sound mappings was of far greater importance in making the instrument accessible.

CCS CONCEPTS

• **Human-centered computing** → **Gestural input**; **Accessibility technologies**; • **Applied computing** → **Sound and music computing**.

KEYWORDS

Accessible Digital Musical Instruments, gesture, improvisation, creative engagement

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1 INTRODUCTION

The creative and expressive physical and mental processes of making music through movement can strengthen our sense of empowerment and foster social relationships [11, 27, 30]. Improvising music can promote a state of flow and contribute to wellbeing [5, 6, 18]. In pursuit of exploratory musical experiences, many improvising musicians have turned to the field of computer music to open up new possibilities for sound generation [3, 21, 24, 25]. To access these sounds and maintain the physical and embodied experience of music making on acoustic instruments, gestural controllers are being used that allow a reimagining of how movement can be mapped to sound, replacing screen, keyboard and mouse-based interfaces [2, 7, 29, 58, 66]. This has led to the creation of gestural Digital Musical Instruments (DMIs) that can not only support virtuoso experiences for expert musicians, but also offer similar experiences of music improvisation to non-musicians and people living with cognitive or physical disabilities [40, 47, 58]. With personalised re-mappings, DMIs can become Accessible Digital Musical Instruments (ADMIs) and open up a new world of improvisation and creative exploration [23, 30, 34, 35, 49, 51].

In this paper we present the *AirSticks*, a gestural DMI originally designed by a professional percussionist for personal creative exploration to facilitate the improvisation of transparent and expressive real-time live electronic music [40]. The instrument has been primarily used by the designer in ensembles, but more recently other musicians and non-musicians have been invited to improvise with the instrument — including Alessio and 'Violet' who are discussed in this paper. For people living with disabilities, music engagement is often focused on music as therapy [38, 54, 72], and while valuable, it has different aims. This study explored engaging in music making for the activity itself, creative engagement, experience of flow promoted by improvisation, feeling of empowerment and the sheer enjoyment it brings [15, 20, 26, 27, 52, 57]. The aim was to see how the *AirSticks* could promote inclusion, help unlock creativity and empower people with diverse abilities to make and explore sound and music in a meaningful way through movements that are comfortable and bring pleasure. The hardware and software was developed as part of the **** project (ref). This paper focuses on the delivery of a musical 'experience,' using the hardware and software previously developed and adapting previous mappings to suit music makers with particular access needs.

We begin with a brief background of gestural DMIs and the field of adaptive musical instruments, more commonly referred to in recent years as Accessible Digital Musical Instruments (ADMIs), and their relationship with flow and empowerment. We provide details of the hardware, software and mapping approach before reporting on the experiences of two people living with disabilities.

2 BACKGROUND

2.1 Gestural Digital Musical Instruments

Gestural Digital Musical Instruments (DMIs) use motion capture technologies to trigger and manipulate sounds by moving hands, batons, gloves, or gaming controllers through the air, directing music like a conductor, conjuring up music from 'thin air'[65]. Digital Musical Instruments (DMIs) in general, and particularly gestural DMIs, open up possibilities for, and remove limitations on, sound exploration and improvisation for experienced and non-experienced musicians in ways that acoustic instruments cannot [14, 67, 70, 71]. With acoustic instruments, the relationship between a gestural input and a sound output is predetermined and fixed, but with DMIs, a designer can reimagine the mapping of movement (gesture) to sound (digital audio) in a myriad of ways [28, 58, 60]. This gives a designer, and the music maker, limitless access to sounds and ways of connecting sounds to gesture [53, 56]. The challenge of creating meaningful mappings of movement to sound, and overcoming the potential excess of possibilities becoming a 'mapping problem' [53] is well-researched in HCI and the NIME (New Instruments for Musical Expression) community, with DMI designers recommending several different approaches to this problem [1, 8, 12, 28, 29, 37, 53, 55].

2.2 Accessible Digital Musical Instruments

In her 2019 comprehensive systematic review of the growing field Accessible Digital Musical Instruments (ADMIs), Frid [30] identifies that of the 83 ADMIs she reviewed, motion capture techniques were surprisingly rare. She suggests that the choice of technologies seems to be often guided by the fact that most designers advocate for simple and affordable technical solutions. However, Frid calls for more DMIs to be adapted for inclusive music making [30]. The development of DMIs and ADMIs from 'scratch' is time consuming, labour intensive and requires a sustained iterative approach in the development of hardware and software. Developing ADMIs from existing DMIs — and DMI prototypes — can speed up the process and allow for the, much needed, more immediate access for those with diverse needs. Frid's conclusions, that the key concepts for the success of an ADMI is based on 'adaptability and customisation, interdisciplinary development teams, user participation, and iterative prototyping' [30], have been integral in the transition of the *AirSticks* from DMI to ADMI.

2.3 ADMI as empowerment

In a music making context, empowerment is about being able to access the experience of music, and regain the rights to hear, play and express music, attaining autonomy and agency through creativity [64]. For people with access needs their relationship with music is often positioned in terms of treatment or therapy. In contrast ADMIs explore how engaging with music can be empowering [68] and is at the core of inclusive music practice.[1] Engaging from an empowered perspective of exploration promotes personal knowledge, the development of individual skills, and importantly supports people in achieving personal goals, as opposed to those of the therapist in fulfilling the aims of the treatment [62]. It is in this empowerment approach to music that people with access needs are given opportunities to create, improvise, and experience flow. Csikszentmihalyi, suggests that 'the best moments in our lives are not the passive, receptive, relaxing times. The best moments usually occur if a person's body or mind is stretched to its limits in a voluntary effort to accomplish something… worthwhile' [19]. This experience of flow may occur in highly sophisticated engagements with improvisation and creativity. However, less profound experiences of everyday acts of creativity also impact individual flourishing [13, 63]. 'A player immersed in a DMI can express him/herself in a self-determinative way that strengthens his/her experiences of resilience, while producing qualitative benefits from a therapeutic perspective' [62].

3 THE *AIRSTICKS*

The *AirSticks* are a gestural DMI designed and created by a professional percussionist and a computer programmer [40]. The instrument utilises bespoke virtual reality gaming controllers and custom software to convert movement into sound, allowing the designer/percussionist to take advantage of their expertise as a percussionist in the timing and execution of rhythmic gestures that control complex sound textures. The *AirSticks* use the *Razer Hydra* virtual reality gaming controllers,[2] custom-designed spatial mapping software, referred to as the *Custom AirSticks MIDI Software (CAMS)* and customised mapping templates created in the Digital Audio Workstation (DAW), *Ableton Live*[3] (see figure 1). The gestural controllers send orientation and position data to CAMS which in turn controls changes to musical parameters in *Ableton Live.*

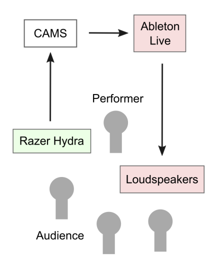

Figure 1: The *AirSticks* System Pipeline

The *AirSticks* have been used in hundreds of live performances and collaborations with musicians, dancers and visual artists. These are documented in several practiced-based research publications [40–45]. The creative and explorative nature of the development of the *AirSticks* has led to many diverse research projects including working with people living with cognitive and physical disabilities [48].

3.1 Hardware

The *Razer Hydra* gaming controllers (see figure 2) were chosen as the most appropriate off-the-shelf solution because they utilise high

[1] Personal Communication, Robbie Avenaim, January 2020

[2] https://support.razer.com/console/razer-hydra/

[3] https://ableton.com/

precision magnetic motion sensing technology. The unit comprises two joysticks tethered to a base station connected to a computer using a USB. The base station emits a magnetic field while the joysticks, which contain three circular coils orientated on three axes, act as the trackers. The joysticks can be moved freely in space (so far as the tethering cables permit) and their position and orientation are determined by their relationship to the base station. The device has a sampling rate of 250Hz, with measurement precision to the one millimetre and one degree for position and orientation, respectively. The controllers are relatively inexpensive and have a Software Development Kit (SDK) and a set of APIs for C++, which allows the developer to access and read the state of the motion controllers. The state comprises position and orientation in six Degrees of Freedom (6-DOF), and details of the button states. Other advantages of the controllers are they are lightweight, transportable, easy to set up, and have low-to-no interference [40].

Figure 2: The Razer Hydra gaming controllers

3.2 Software

The *Custom AirSticks MIDI Software (CAMS)*, was developed as an OSX application, with a *Razer Hydra* SDK translating the user's movements to a graphical representation (see figure 3). *CAMS* provides a user interface for tracking the controllers on-screen with outputs to OSC (Open Sound Controls) and MIDI (Musical Instrument Digital Interface) protocols, that allow for continuous data updates on position and orientation. The software also implements a triggering system allowing users access to note on and off values, which both include velocity data. A predictive filtering scheme based on Kalman state estimation is used to effectively up-sample the gestural analysis system to 1kHz, to move significantly beyond the perceptual limit for the sensation of causal association between gesture and aural result [36].

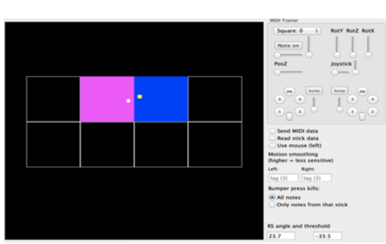

Figure 3: Custom AirSticks MIDI Software Graphic User Interface

The position and orientation of the controllers is translated into twelve virtual sliders that can be assigned to different parameters using the *CAMS* MIDI Trainer function. For example, moving the right controller up and down may be assigned to pitch, while moving the left controller right and left can change the tempo. Mapping different parameters to each of these twelve virtual sliders, and hence to the orientation and position of both hands, can lead to rich and expressive, yet transparent one-to-one mappings. The values can be calibrated to take into account small or large gestures. In addition, trigger buttons and a joysticks on each hand controlled by the forefinger and the thumb, respectively, are used to control more parameters of the designer's choosing. Six other buttons on each controller can be used to trigger sounds on and off, or to switch between modes. Here is an example of an expressive mapping of the *AirSticks*, utilising only the triggering system and no button presses.

3.3 Mapping

Hundreds of mappings of movement to sound have been produced for a range of performances. Below is a video of a performance utilising a mapping that clearly showcases some of the capabilities of this hardware/software system. Four virtual zones are laid out in front of the performer that allow the performer to trigger different notes. Once triggered, these notes can then be manipulated using various movements: reverb is added through the raising of the arm, and distortion is added by moving outwards. This video also showcases the original *AirSticks* triggering system designed for percussionists, one that is neither easy to master nor accessible to many non-percussionists.

'Sining':
https://youtu.be/3ts6azNzUPg

The mapping used in the video above is based on a metaphor of playing tuned percussion instruments. This strategy of imagining and basing the gestures on motions from an acoustic instrument is a common approach taken by DMI designers [28, 33]. An action is decided upon and then a sound is imagined and engineered to correspond with the movement. The sound choice may resemble the real-world sound one would expect from the gesture, but the *AirSticks* can extend the metaphor, allowing the performer to sustain sounds for as long as they want or manipulate the sounds with intuitive gestures. Pointing the controllers in a particular direction can change the panning of the sound (which speaker the sound is heard from) and turning the controller on its axis can filter the sound. The use of metaphor, like the one of a tuned percussion instrument, enables the audience to more easily understand the mechanics of the performance. It can also help the performer to call upon the expertise they may possess with a traditional instrument [59].

Preparing the *AirSticks* for further development as an ADMI required changes to:

- how sounds are triggered,
- the types of sounds,
- how they are made available, and

- how to customise them to include a range of small and large gestures.

The *AirSticks* design needs to take into consideration:

- reduced dexterity and movement,
- people without musical expertise, and
- how people without experience of DMIs would relate to the sound and movement mappings.

3.3.1 Triggering. The *AirSticks'* triggering system was designed by and for a professional percussionist. A great deal of dedicated practice was needed to maintain the real-world metaphor with percussion instruments. The *Razer Hydras* provide no tactile or haptic feedback when a strike is made through the air, and so is not necessarily intuitive [4, 50]. But, assigning one button on each controller to trigger the sound, rather than through a physical strike, provided access to existing sound mappings. Sound could be sustained by holding the button for as long as desired. Different buttons could trigger different sounds, and were remapped to create a more comfortable sound experiences. The affordances offered by these game controllers in this way [10, 31, 32, 46] and the use of metaphor meant that no prior learning of appropriate gestures was needed as is required for some gestural DMIs [28].

3.3.2 Types of sounds and mapping. The mappings needed to be prepared before initial user engagement by people living with disabilities, limited experience of DMIs, or no musical experience, to create an experience which was welcoming and enjoyable from the outset. The sounds and mappings needed to generate familiarity in movement and the sounds produced. Therefore, metaphors and familiar sounds were used in all mappings. The sounds could be generated by large and small gestures, were not impacted by physical tremors or shakes, and the controllers could be operated with limited dexterity. Four main mappings were pre-designed, and then customised while in use, in this case study.

- `AirHarp`: The metaphor of a harp allowed for the playing of a five-note scale with one hand. The 'strings' are located in front of the player, with the lower notes to the left, and higher to the right. Pressing a button sounds a note. Holding the button accesses a six-note sequence going up. The sequence plays slowly to the left and faster in higher in pitch to the right. The attack of the sound is shorter pointing down, and longer or 'airier' when pointing up.
- `Warmth`: A variation on the *AirHarp* with timbre and intensity controlled instead of pitch. Both hands can be used. The right hand controls a drone (one long note) that sounds 'warmer,' or more wooden, the left, accesses 'colder' or more metallic sounds. To the right the intensity of the sound is increased by lifting the hand higher. The left hand controls a sequence of. The complex morphing of sounds create a fluid sound-world around the player which they can navigate by pointing and holding the button for sustained sound.
- `AirRadio`: This explores everyday sounds, sounds for reminiscence, sounds of nature and sampled music. Eight sound tracks are spatially located and include birds, famous speeches, wind, 50s pop, a ticking clock, Romantic piano pieces and waves. The player can cross-fade between different samples by pointing in different directions.
- `FluidDrum`: Pressing a button triggers a drum synth sound that can be morphed from an electronic kick to an electronic snare depending on where the controllers are pointed. Variations of this mapping include a drone version that resembled a lightsaber sound, and a pulse version, where the player can choose a tempo for the drum synth that automatically plays once the button is pressed.

4 CASE STUDIES

These mappings were designed to suit people with a range of abilities, from musicians to dancers. Here they will be discussed in relation to two people whose particular access needs were considered in the design. The first, Alessio, a teenage boy living with leukodystrophy, and another, 'Violet', an older woman living with advanced dementia. Both had profound experiences with the instrument with little to no explanation of how to 'play' the instrument, as can be seen from the video documentation. It is important to note that the study participants including those discussed here were selected through purposive sampling to focus on 'cases or individuals that differ on some characteristic or trait' [16] and 'provide information rich cases to the phenomena under investigation' [17]. We used in-depth qualitative analysis observing verbal and non-verbal communication, using audio and video recordings to engage in post-event analysis to identify the intensity and frequency of engagement.

For people living with dementia we used a best practice process consent approach [22], whereby consent is sought and gained verbally and revisited throughout the engagement. The participant can re-engage at any time if verbal or non-verbal communication suggests they would like to continue. Consent was also sought and gained from the legal guardian of people living with dementia whereby consent is sought and gained verbally and revisited throughout the engagement.

4.1 Alessio

Alessio is a teenage boy living with leukodystrophy - a rare, progressive, metabolic, genetic disease that affects the brain, spinal cord and often the peripheral nerves. He was introduced to the *AirSticks* through a collaboration *Safe in Sound*[4] run by world-renowned improviser/percussionist, Robbie Avenaim. *Safe in Sound* aim to develop new methods of providing stimulation, entertainment and communication to bring joy. Creative expression and improvisation with sound are at the heart of the small intimate concerts that engage an improviser and the audience member or co-improviser.

Alessio was invited to engage with the instrument in his home with no prior training. The engagement was observed and the *Airsticks* adapted to suit his needs. The mappings described above, were adapted so that all buttons triggered the same note. This allowed him to calibrate his movements with the sound and find a comfortable way to hold the controllers. He began to explore the space above, in front and to the side of him. Alessio immediately reacted to the sounds and began to explore how different movements could affect the sound as he went on short improvisations with each mapping, accompanied by his brother, who has Cerebral Palsy, on keys and motorised percussion. The extent to

[4] http://www.safeinsound.com.au/

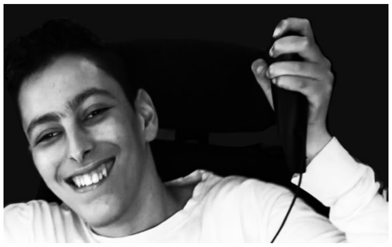

Figure 4: Alessio gives a public improvised performance using the *AirSticks*

which he was immediately able to engage was 'pretty amazing' Robbie Avenaim observed.[5] Alessio had a musical background and played guitar with support from his school. However, the guitar required a level of practice to reach an ability that sustained his interest. He was immediately able to engage with the experimental, digital and 'glitch aesthetic' offered by the *AirSticks*, gravitating towards the *FluidDrum* mapping. Avenaim suggested that 'for those who get electronic experimental music no explanation is needed... some need more time to get their head around it.'[6] By improvising alongside and observing how Alessio used the instrument, the *Airsticks'* mappings could be personalised 'on the fly' and provide greater opportunities to support Alessio's ongoing improvisation. These mappings could then be used by Alessio without the need for further assistance by any third party, promoting autonomy and agency.

Alessio performed solo on the *AirSticks* at *Copy That, Copy Cat, JOLT Sonic Festival* in 2019, in Footscray, Victoria, Australia (see figure 4 and link to video below). In this video, which edits together three short clips from his ten-minute performance, Alessio can be seen picking up the controllers and calmly finding a way to most comfortably hold them. He then engages in pressing a button which triggers a loud electronic beat. His brother is heard encouraging him from the audience. Alessio explores the sound world around him by holding in the button and lifting both hands up, out and back. In the rest of the video, Alessio re-engages with the button that triggers sound, but in shorter bursts, as he explores different areas of space around him. The tempo of the pulse speeds up throughout the performance, controlled by the designer side stage.

'Alessio live jolt 2019':
https://youtu.be/wWDa1--gbu0

Alessio continues to improvise with the *AirSticks* supported by *Safe in Sound* and his family. He is able to provide input into sound mappings development by illustrating through sound manipulation the way of improvising that works for him. In the last session, Alessio improvised for forty minutes on a new mapping that combines the *FluidDrum* with the *AirHarp* and continues to enjoy exploring the space around him, to the point where a member of his family commented on how sweaty he gets from extending his arms out to reach for new sounds.

[5]Personal Communication, Robbie Avenaim, January 2020
[6]Personal Communication, Robbie Avenaim, January 2020

4.2 'Violet'

'Violet' is a 93-year-old woman with advanced dementia living in a residential aged care facility in Australia. She has mobility and can make sounds. She often appears to be talking, but her words cannot be understood. She is alert and enthusiastic. It is not known whether she has any musical background or played any instruments. The *AirSticks* with the above adapted mappings were introduced to 'Violet' and five other residents at the care facility where she lives. The aim of the workshop was to engage with a range of people with dementia to explore to what extent the *AirSticks* could be used by people with advanced dementia for creative engagement, and to see if the instrument would promote improvisation. The engagement was observed and analysed by three researchers.

'Violet' was given the *AirSticks* to engage with. She was first given the *AirHarp* mapping to explore. She very quickly understood that the change of sound related to how she moved the controller. She began moving from side to side, swaying and singing loudly. 'Violet' continued to sing although the words were not intelligible. She paid little attention to anything else, seemingly 'lost' in her playing and singing. A researcher reflected, 'she began to sing over the sequence, rapidly moving from left to right creating a 'harp' arpeggio type effect. The singing was so spontaneous and present and continued for a while with little variation but great intensity.'[7]

'Violet' was then introduced to the *AirRadio* mapping. She remembered how to change sounds by moving the controller in space. A researcher observed, 'the sound she was creating was quite disjointed, jumping from Chopin to 50s pop and the ticking of a clock in microseconds.'[8] 'Violet' seemed less interested in these sounds. Therefore the mapping was immediately changed to *Warmth* (see video link below). With a button she could control a drone and change its sound quality with various movements. A researcher observed, 'the participant again took to this mapping with vigour, sweeping left to right and singing confidently on top, in a strangely tuned scale that lacked technique but no shortage of emotional content. She would also raise intensity either in volume, pitch and/or timbre when raising her hand higher.'[9]

"Violet' playing with the *Warmth* mapping':
https://youtu.be/yI-2bHYq7zM

The designer of the *AirSticks* joined in scaffolding her engagement with the *AirSticks* [39, 69](see figure 5). They were observed by the researchers who audio and video recorded the engagement and analysed the experience post event. It should be noted as a qualitative study the reflexivity of the researcher is key to understanding the phenomena under investigation [17].

In his notes taken immediately afterwards the designer explains: 'So I grabbed the second controller and started to improvise with her, firstly mirroring movements, and then trying to get her to follow me, which she did in a truly collaborative way, picking moments to go with and against both the music and the movement... She would build to little climaxes as her movement and singing intensified.'[10] As the designer began to bring the improvisation to

[7]Researcher 2 notes
[8]Researcher 2 notes
[9]Researcher 2 notes
[10]Researcher 2 notes

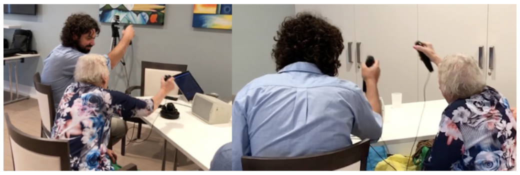

Figure 5: 'Violet' and a researcher improvising together

a close, 'Violet's' movement and singing lessened in intensity, and a feeling of melancholy came into her voice. She didn't appear to want the improvisation to end. The designer commented that as a professional musician with vast experience of collaborating and improvising 'it was a truly magical and spiritual moment of improvising with someone I had never met. As a seasoned improviser myself, and often finding myself in situations where I'm playing for the first time with a musician I'd never met in front of people, I find the level of non-verbal communication that can be expressed in improvisation to be one of the greatest and most unexplainable elements of music making, particularly social music making.'[11] As the designer began to wind down the improvisation by slowly bringing his controller down onto the table, 'Violet' began to also wind down her movement and singing. But as the designer began to take his hands off his controller, 'Violet' quickly relaunched into loud singing and large movements. The improvisation was not over for 'Violet', and the designer and her laughed as she rejoined the improvisation. Only then did 'Violet' lead the improvisation, and the designer, back down to a calm ending by slowly putting her controller back onto the table.

5 DISCUSSION

These case studies show the immediacy with which both Alessio and 'Violet' were able to engage with the motion capture technology used in the *Airsticks.* Importantly this paper argues that it is not in the re-development of hardware or software that shifts the *Airsticks* form a DMI to an ADMI, but in the recognition of the ways in which the hardware, mappings and sounds needed to be adapted, customised and personalised to the users. For Alessio this meant:

- Limiting sound possibilities to one note initially to understand how he moved his hands, and to map sound and movement accordingly;
- Selecting mappings that were innovative and novel to him, such as the 'glitch' of the *FluidDrum* mapping;
- Recognising the extent to which Alessio could inform how mappings could be adapted to his needs;
- Encouraging autonomy and agency through improvisation with others (his brother and Robbie);
- Supporting Alessio to publicly perform his improvisations.

For 'Violet' this meant:

- Scaffolding her engagement with the *Airsticks* to support her in her understanding of how sound could be generated, through showing rather than telling;
- Selecting sounds that would be familiar, for example, a harp, music samples of Romantic music etc;
- Adapting the mapping 'on the fly' from *AirRadio*, which created 'glitch sounds' not pleasant to her to *Warmth* where she could explore a range of movements and sounds and extend her range of movements accordingly.

The hardware was accessible to both users with minimal intervention. The ADMI was achieved through developing an understanding of the players' needs and reimagining the mappings accordingly. This also meant understanding when immediate change was needed and adapting mappings to on the fly. While Alessio was familiar with game controllers and therefore had prior knowledge on how to build on the affordances of the technology, the hardware was not familiar to 'Violet.' Therefore, a more scaffolded approach was needed. People living with advanced dementia are often not able to follow detailed verbal instructions, and this was the case with 'Violet.' She was, however, able to watch, listen and feel her way through the use of the games controllers in the generation of sound, supported by someone who could use them with expertise. She quickly came to understand the relationship between her movement and the sounds heard.

How the software operated, reading the position of the controller using motion tracking and mapping the position to the sound, also did not need to be adapted for Alessio or 'Violet' to use. The key aspect for promoting improvisation and creativity in this context was the mapping of sounds. This allows for access to a range of sound which in Alessio's case can create a 'glitch aesthetic' and allow for the *AirSticks* to be used to create loud electronic drones and techno-inspired beats. Alternatively, the mappings can include pleasing scales and 'warm' and 'cool' sounds which allow for a melodically based improvisation that inspired the haunting melancholic wailing of 'Violet.'

The ability to change mappings quickly, build mappings according to personal preferences and to access sounds and instruments ensures that there is no repetition for the user and there is always the potential to explore anew. Importantly, the players' experience to engage and improvise with sounds is not reliant on mastering skills that require dexterity, rhythm, timing or musical knowledge. This also means there is no delay, due to the need to practice and hone skills, in being able to engage in playing with the *AirSticks.* Importantly, the motion capture technology can be calibrated, adapted and customised to suit different players. The player is not required to adapt to the technology. This means that each player can operate according to their strengths, giving them agency and autonomy over how they play. We highlight here that the development of the *AirSticks* as an ADMI to support people living with disabilities to improvise, be creative and engage in musical expression is located within a framework of empowerment. The *AirSticks* allowed two people with differing abilities to find their own sense of 'flow' and engage in the creative exploration of sound.

6 CONCLUSION AND FUTURE WORK

We argue that the key concepts suggested by Frid in the development of 'adaptability and customisation, interdisciplinary development teams, user participation, and iterative prototyping,' are integrated in the development of the 'Violet' [30]. This shows that existing DMI prototypes can be adapted quickly for use as ADMIs

[11] Researcher 2 notes

enabling people living with disabilities to be part of the development process. Importantly, this process of development can speed up the iterative processes to allow more people to gain from these experiences sooner.

Our contribution is to show that the use of motion capture technologies can help provide a desired immersive experience, and that utilising the knowledge gained from creating the *AirSticks* as a transparent and expressive gestural instrument for professional creative use is a great building block in the design of a successful ADMI. Furthermore, the technology allows for an unobtrusive translation of the movements of the body in physical space and the location in virtual space of sounds to be accessed and reformulated in a unique experience. The interaction does not require musical skills or practice, and does not rely on musical knowledge to engage in profound improvisational experiences.

Furthermore, the findings from engaging with people with diverse access needs, informs the development of DMIs more generally. Although the *AirSticks* is a fully-functioning instrument, they continue to be refined, redesigned and upgraded. The designer has made efforts to keep certain mappings unchanged in order to gain a more intimate relationship with the instrument [56], but like most DMIs used in artistic settings, the *AirSticks* are constantly evolving and adapting to knowledge learned through practice, research and reflection [9, 61]. Each time the *AirSticks* have been used in a workshop for people living with disabilities, upgrades to previous mappings are made and repurposed for future workshops. Also, notes for further developments to the hardware and software are kept for when the opportunity to design new hardware and software arises.

Continuing to reach out to musicians and non-musicians living with disabilities is the next part of our research, providing more *AirSticks* case studies without compromising the personalised experience of improvisation. We are currently prototyping custom wireless hardware, new user interfaces and applications for using the motion sensors built into smartphones, to allow greater accessibility. There are also possibilities to extend the hardware by developing controllers for use by feet, through eye tracking, or head movements. These possibilities need to be explored through working more closely with participants.

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