CymaSense: A Novel Audio-Visual Therapeutic Tool for People on the Autism Spectrum

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ABSTRACT
Music Therapy has been shown to be an effective intervention for clients with Autism Spectrum Condition (ASC), a lifelong neurodevelopmental condition that can affect people in a number of ways. This paper presents a study evaluating the use of a multimodal 3D interactive tool, CymaSense, within a series of music therapy sessions. Eight adults with ASC participated in an 8-week period using a single case experimental design approach. The study used qualitative and quantitative methodological tools for analysis within and beyond the therapy sessions. The results indicate an increase in communicative behaviours for both verbal and non-verbal participants.

ACM Classification Keywords
H.5.2. Information interfaces and presentation: Graphical User Interfaces (GUI); Prototyping; Screen Design; User-Centered Design; Visualization Theory, Concepts and Paradigms.

Keywords
Autism Spectrum Condition (ASC); Assistive Technologies; Music Therapy; Interactive Audio-Visual; Multi-Sensory Environments; Cymatics.

1. INTRODUCTION
People with autism typically have difficulties with communication, social interaction and self-esteem. From a historical perspective, recognised interventions for autism are largely behavioural based. Applied behavioural analysis (ABA) being considered the most effective and widely used [16]. Some critics, however, have pointed out that ABA relies heavily on responding to vocal-based instructions with vocalised responses, which can be difficult for many people with ASC. It can also be restrictive to the individual's freedom of expression [3]. Music therapy was established in the 1950s and can provide a non-verbal means of communication with autistic clients. A level of predictability within musical structure offers people with ASC a channel of communication through which to express themselves, which can result in a number of benefits. Lim states that the inherent structure of music stimuli and intact capacity of pattern perception and production in children with ASC has a positive effect on speech production [26]. Not all of the successes of music therapy are easy to quantify, however, as they can integrate medical, educational, sociological, psychological and musicological discourses within their practices [34]. This is largely due to the lack of randomised controlled trials that can be run with groups of people with autism. The nature of the spectrum condition being that no two groups or individuals have the same abilities or requirements. Consequently, this can lead to many funding bodies asking for longer term objective studies to back up existing case histories [33]. Simpson and Keen recognise that there is limited evidence to back up the efficacy of music interventions, but more research needs to be conducted, particularly within more naturalistic settings [44]. Nonetheless, case studies continue to back the validity and success of music therapy techniques, in particular, the improvisational techniques used by Nordoff and Robbins [52].

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Music and arts therapists often use technology within their practice to stimulate the senses of autistic clients. Simple and inexpensive iPad apps through to sophisticated music production tools are available, and in use within practices [19]. Computers have been shown to provide a certain amount of predictability and stability for people on the autism spectrum, providing an attractive environment due to the lack of human contact and stress involved in reading emotional cues from faces [15]. However, not all therapists are well informed about or proficient in the use of modern technology, and effective use of assistive technologies can be limited. Previous studies have shown beneficial use of interactive multimodal systems for children with ASC. The Reactable tangible user interface visualises synthesised sound as animated 2D graphical connections between modular blocks [51]. Gestural systems like SensoryPaint use sound to highlight animated movement [38]. Interactive Surfaces, like BendableSound, use tactile, visual and audio feedback to engage children with autism [5]. It is arguable that music therapy could be made more engaging if the musical channel of communication it aims to open between therapist and client were augmented by a visual modality.

This paper presents a study in which CymaSense, an interactive multimodal interface that generates real-time 3D visual stimuli based on Cymatics, was used to augment music therapy sessions involving adults with ASC [27]. The development of CymaSense was based on interviews conducted with music therapists. The study which involved eight adults with ASC intends to assess the hypothesis that use of an audiovisual tool within music therapy, such as CymaSense, could improve communication and self-esteem for people with autism. The following section lays out related work, in terms of autism, interventions, and the potential for constructive use of technology within current music therapy practices.

2. RELATED WORK
2.1 Autism
Autism Spectrum Condition (ASC), also known as Autism Spectrum Disorder, is a lifelong neurodevelopmental condition where people share the following features in their diagnosis [2]:

difficulties in social communication and interaction; problems in the use of language and verbal communication; limited and stereotypical behavioral patterns [35]; problems in perceptual processing; and inhibited use of their imagination [31]. A 2014 study by the Centres for Disease Control found that the condition affects one child in every 68, and has encouraged health professionals to consider ASC as a critical and urgent public health concern [36]. Research has shown that autism is a strongly genetic condition, however, not all of its genetic or biological signature has yet been identified [50].

People on the autism spectrum are said to be unconscious of the amount of control they can exert over their environment and obtain a coherent response, even when it is they themselves who are responsible for changes in their environment [31]. They can have little sense of the cause-and-effect a neurotypical person takes for granted, thus increasing a sense of lack-of-control and frustration. The isolating nature of this condition has shown higher rates of anxiety and depression, regardless of intellectual and linguistic abilities [32], prompting researchers to find solutions to a condition where relatively little is known concerning its causes [28]. Much of early and current research has focused on behavioural approaches to intervention, which provide success in terms of treating symptoms, but do not address the core emotional deficits of people with ASC [35]. Issues of low self-esteem, anxiety and attitudes towards relationships with peers can create additional negative physical and psychological illnesses [18]. Support for people on the autism spectrum seems to be lacking for both the adolescent and adult communities, partly due to the rising numbers of people being diagnosed with ASC at the beginning of the 21st century [18]. It has even been noted that there exists more support for parents of autistic children than for adults on the autism spectrum [35].

2.2 Interventions

Music therapy is considered an effective approach for addressing language and communication skills for children with ASC and can provide a non-verbal means of communication [27]. Improvisational approaches encourage freedom of expression within individuals, often improving confidence and independence [43]. In addition to traditional acoustic instruments and use of the human voice, music and arts therapists continue to embrace technology within their practice to achieve a greater sense of agency and stimulate the senses of autistic clients. This can include: electronic interfaces like the iPad or Launchpad [30]; existing assistive technologies and tangible user interfaces (TUI) like the Skoog [45] or Reactable [51], which have been shown to improve social interaction and play in people with ASC through a shared space [11]. Research has shown that sensory integration therapy has encouraged development of independence amongst autistic people [40].

2.3 Augmented music therapy

For people with autism, cause-and-effect can be problematic due to issues with sensory impairment. Therapeutic approaches involve teaching children how to combine sensory integration and body awareness therapies, known as Multi-Sensory Environments (MSE), which can aid in the attainment of therapeutic goals. MSEs have demonstrated the efficacy of this approach through previous research [38], but have not been widely adapted for use within music therapy sessions. Cibrian et al. successfully facilitated music therapy sessions using their BendableSound prototype which uses animation and sound in conjunction with a fabric-based interactive surface, designed to encourage attention and motor development, but is somewhat restricted to the playing of the interactive surface itself [5].

Current audio-visual applications that demonstrate simple cause-and-effect take many forms, from: web-based visualisers [4]; stand-alone applications that link to audio and media players [47]; iPad apps [17]; and VJing software for use in art installations and public performances. However, the majority of these use arbitrary visualisation of sound based on the amplitude of the audio and are not designed for people on the autism spectrum. Augmenting the auditory modality with real-time visual feedback may be an effective means of strengthening a sense of causality within a music therapy scenario. In order to achieve this goal, a suitable real-time music visualisation system is required.

2.4 Cymatics

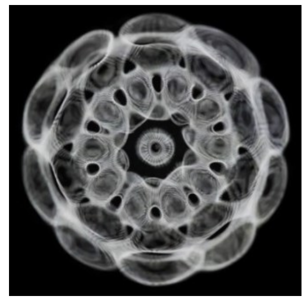

Figure 1: Cymatic image of sound vibrated through water

Cymatics are physical impressions of sound created in media such as water (see Figure 1) or by particulate material on a brass plate (Figure 2)[21]. They are the result of diffraction and refraction of sound waves created within the visualising medium [8].

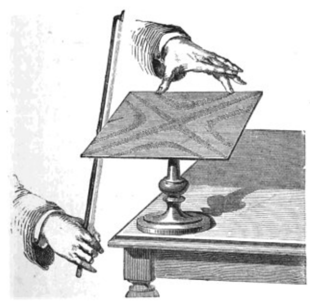

Figure 2: Chladni plate

Software simulations of these phenomena exist and are employed by artists including: the KIMA collective in performance and installations [14]; Graham Wakefield's 2D and 3D patches for a software Tonoscope, created in the Max visual programming language [48]. Chladni's 18th century principles, which are the basis for these visualisations, are merely a mechanism for visualising a cross section of a sonic bubble created by the resonant tone of a particular size of plate, not the shape of sound. Sound does not travel in longitudinal waves within rectangular blocks but rather propagates spherically in air due to diffraction. Water-based Cymatic visualisations provide greater detail due to their ability to visualise a wider spectrum of frequencies. Small changes in sound timbre can create complexities within the observable patterns, creating dramatic and aesthetically interesting results. These patterns are, however, deterministic and are used by some instrument makers to visualise the tonal qualities of their instruments. The combination of predictability and surprise that Cymatic patterns exhibit, as well as their physically accurate representations of sounds can make them a fascinating sound visualisation paradigm.

3. REQUIREMENTS

A preliminary series of semi-structured interviews were conducted to identify the needs of autistic clients within therapy sessions, and the potential for a visualisation tool. Two with clinical music therapy practitioners; one with a community music therapist; and one with the head music therapist of a charitable organisation. The goals of the interviews were: to outline current practice; highlight the ways in which technology is currently used; indicate where potential lies for augmented working practices using new tools; and to produce a requirements analysis for a prototype tool. The audio recorded interviews were transcribed and coded using NVivo data analysis software. The details of that study will be the topic of a separate paper. The information formed the basis for the development of CymaSense, a real-time music visualisation application based on Cymatics. The interviews identified a need for: clear cause-and-effect; customisability in terms of colour and Cymatic shapes; the use of tangible user interfaces for efficacy and to enable social interaction through sharing. It was decided that a proposed system for processing and mapping appropriate audio data to the visual domain would have to include: MIDI data (Musical Instrument Digital Interface); and the conversion of analogue sound into the digital domain. This would allow visualisation of a wide range of electronic and acoustic instruments.

Research into the use of shared interfaces has indicated improvements in turn-taking and eye contact amongst participants with ASC [51]. To facilitate visual musical interaction between a music therapist and client, implementation of a single and two-user version of the tool was recommended by the therapists. Information about the design and behavior of the tool is provided in the next section. For additional details, please refer to [27].

4. CYMASENSE

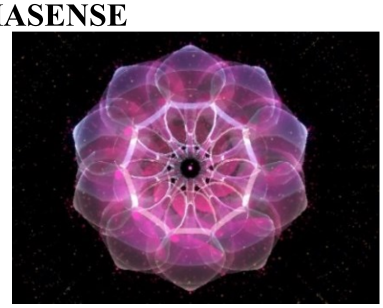

Figure 3: CymaSense sample output

CymaSense is an interactive application that visualises acoustic and electronic audio input. Processed audio is transformed into translucent 3D Cymatic shapes and projected onto a screen or interactive surface (Figure 3). Changes in volume affect the scale of the shapes being presented. Variations in timbre modify the surface qualities of the shapes being visualised. Changes in pitch determine which Cymatic shape (out of twelve) is chosen, as well as lightness of colour. A user interface allows background and Cymatic shape colour choices to be made. A single-user version displays a single set of Cymatic shapes in the centre of the screen, while a 2-user version displays shapes side-by-side on screen.

High definition Cymascope images of individual frequencies were used as templates for the creation of twelve 3D Cymatic shapes (Figure 4), relating to each of the semitones within a musical octave. The MIDI and audio inputs are analysed in real-time using Cycling'74 Max [7]. Relevant data (amplitude, pitch, harmonic content, velocity, pitch bend) is transmitted using the Open Sound Control (OSC) to the Unity games engine in which the visualisation is generated.

The CymaSense prototype comprises of (1) an interface to control audio input and visual output for single or multi-user interaction and (2) a separate output screen (Figure 3).

4.1 Mapping

The mapping between audio and visual attributes is based on audio visual associations validated by previous studies [13]. However, the novelty of the visualisation paradigm implemented in CymaSense also afforded experimentations with the less obvious aspects of the mapping. Amplitude to scale of Cymatic shape and particle size – mapping amplitude to scale is commonly referred to in literature [23].

Pitch to Cymatic shape – This is consistent with Cymatic shape behaviours observed. The 3D shapes created were inspired by Cymascope reference images [8] (see Figure 4).

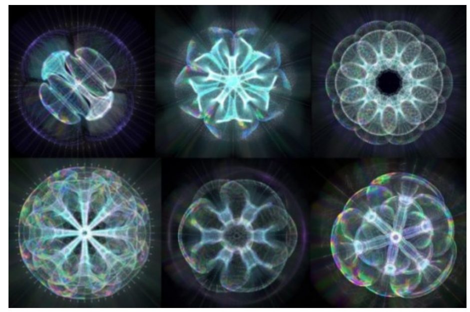

Figure 4: 3D Cymatics shapes modelled in Autodesk Maya

Pitch to colour lightness - lightness of colour is altered by MIDI note or microphone frequency, implementing a pitch to lightness relationship, referred to in synesthesia and cross-modality literature [53]. The higher the pitch, the lighter the visual component. This aids in differentiating the same Cymatic shape over several octaves.

Timbre to Cymatic shape surface quality – timbre is considered the most difficult characteristic of tone to describe [46]. It is also referred to as a potentially useful tool in audio-visualisation by therapeutic practitioners. Colour is commonly associated with timbre in audiovisual mappings, but colour was used for other purposes in the application. Therefore, it was decided to experiment with surface qualities as a means of representing the spectral qualities of a sound. The Cymatic shapes generated for a given frequency were modified using a 3D morphing technique as follows: the shapes of bright sounds were made to appear sharper, while dark sounds were transformed to appear more rounded.

4.2 Additional Interface Options

Cymatic shape colour and background colour choice - colour was identified in literature [6] and through interviews with therapists, as key to empowering clients in relation to facilitating their own choices. Each CymaSense shape is comprised of an external shell and two sets of animated particles. Colour assignment to both the shell and particles are possible to allow a variety of colour combinations. User selection of: Cymatic shape outer material colour; main particle colour; internal particle colour; and background colour have been made available directly from the interface.

Cymatic shape rotation – through observation of Cymatic shapes created in water, it has been noted that in addition to changes in shape dependent on frequency, subtle rotation occurs. A simple on/off button for no or random rotation values was deemed sufficient for the initial prototype where a change in frequency or MIDI note triggers a random quaternion rotation on all three axes between a value of -1 and 1, providing immediate but subtle audio-visual feedback. (Please refer to the video figures.)

5. EVALUATION

This section presents an evaluation carried out with TouchBase, a centre run by Sense Scotland charity [42] for people with a variety of disabilities, including autism.

5.1 Study Development

The intention of the study was to utilise CymaSense within a music therapy environment to test whether it would be of benefit to the communication and self-esteem of its autistic clients. Observation and analysis of the sessions were facilitated through a combination of video observation and a post-study survey. The creation of a Communicative Responses and Acts Score Sheet (CRASS) allowed detailed analysis of each session, where the time for an occurrence of musical and non-musical behaviours were totalled each week and used for comparative purposes. For example, participating in rhythmic give and take, matching a beat, creating a verbal response or establishing eye contact. The use of CRASS was based on the Edgerton method of determining the effectiveness of improvisational music therapy on communicative behaviours [10]. A post-study behavioural change survey with the participants' parents/guardians, care workers and tutor gathered information concerning observable musical and non-musical behaviours of the participants outside of the sessions.

5.2 Participants

Six adult males and two adult females, who have been clinically diagnosed as being on the autism spectrum, were recruited from Scottish Autism [41] and Sense Scotland [42] for the 8-week study. One of the males and one female worked together as a group (G1), while the other six participants took part in one-to-one sessions with the music tutor (P1-P6). Participants' diagnosis of autistic impairment ranged from severe to mildly impaired. Deficits in communication skills were common to all participants. Four participants were non-verbal, and two participants demonstrated limited functional language skills. None of the participants had visual or aural deficiencies. Parents or guardians provided informed consent for their children to be involved in the study. All participants were between the ages of 18 and 28 years.

5.3 Procedure

A single subject design [1] was used consisting of two phases: (A) a baseline stage was determined over two weeks; (B) the intervention was introduced and tested over a subsequent six-week period. This is the same protocol use by Yang et al. [54] used to examine social behavior in 7-to-9 year old children with ASC, and by Hutchins [20] and Norris [29] researching the effects of Social Stories on autistic children. Each participant was scheduled for a 30-minute session per week for eight weeks, with the exception of the group who were scheduled for a 60-minute session each week. Due to illnesses and unforeseen circumstances not all the participants were able to attend all sessions. During the non-intervention baseline stage (A) the music tutor used a number of improvisational musical techniques. The techniques were aimed at establishing contact with and facilitating responses from the participants, and development of their musical and rhythmical abilities. The music tutor played guitar, percussion, electronic keyboard and/or sang, and provided each participant with the opportunity to do the same. Lazar et al. discuss ways to empower adults with cognitive impairments through art therapy via the Third Hand technique, where the therapist draws on and enables the skills of the client, builds on previous sessions and provides support [24]. Similarly, the tutor was sensitive to the desires, goals, and emotions of the clients, by providing support intent on minimising the imposition of meanings, ideas, or preferences onto their work.

In designing creative spaces for people with ASC, Makhaeva et al. discuss the advantages of participatory design with autistic users [12]. They highlight that the common contradictory misconception between autism and creativity can be overcome through subtle interplay and space that allows meaningful participation. By combining a well-known activity with familiar, but slightly modified elements, participants felt free to appropriate them in original ways. The authors employ a Play Partner and Active Observer which contribute to facilitating a creative process. Adopting this approach prior to the intervention stage (B), discussion between the music tutor (as Play Partner) and the researcher (as Active Observer) took place. Any new changes or tasks for people on the autism spectrum can be stressful, therefore, a phased approach should minimise the effects on each participant. Ringland and Cibrian discuss the importance of natural user interfaces to support body awareness and sensory stimulation within multi-sensory environments, regarding their respective SensoryPaint and BendableSound interventions for children with ASC [38][5]. Similarly, adoption of the participants' natural body interactions with the tutor from a musical perspective were taken into account. Designed to identify and agree upon each participant's communication and musical abilities, a short interview with the music tutor confirmed the most appropriate way to customise and introduce the intervention (see 6.2 for details). The intervention phase (B) was introduced gradually within a session, once the participant was identified as being comfortable. The intervention involved projecting the visualisation of the sound produced by the participants' respective instruments, either on a screen, or using an interactive table (see 5.4 for details) (Figure 5).

The music tutor could alter the lighting levels in the music room over the session allowing the participants to become more aware and engaged with the audio-visual interaction (Video Figure 2). During the intervention phase, the music tutor continued to respond to each participant's individual needs, based on the amount of gestural, verbal, vocal and musical responses and acts within each session.

Figure 5: CymaSense Interactive table

5.4 Materials/Settings

The music sessions took place in a large room with adjustable roof blinds and windows to allow control of available light and air entering the space, and had the following musical instruments available: acoustic and electric guitars; microphones; an assortment of acoustic and electronic percussion; a harp; electronic keyboard. All instruments could be height adjusted to suit each participant either sitting or standing. Chairs were available for both participants and tutor. A variety of beater and drum sticks were also available. In addition, two video cameras were installed to record the sessions: one mounted on top of a cymbal stand in the corner of the room; another placed on a small stand near the entrance to the room.

The CymaSense prototype was run on a laptop connected to an audio interface, placed at the side of the room. The prototype was used in three distinct ways. These were tailored to the needs of each autistic participant, which were monitored prior to, and during, the intervention sessions (see 6.2). Firstly, a microphone on a stand was used to capture all of the audio signals within the room. This allowed the tutor to use any instrument within the room and minimise changes to the established routine for the participants. A tripod-based projector on one side of the room projected the visual output from the laptop onto a screen (Figure 6, Video Figure 1). Secondly, two microphones captured audio inputs for the 2-user version of the prototype, allowing the tutor and participant to control their own set of shapes through the use of voice or chosen instrument. The 2-user version was also projected onto the screen with each set of Cymatic shapes positioned side by side (Video Figure 2). Thirdly, an interactive table was used as an alternative means of using the prototype, presented as a tangible user interface within the room. This facilitated the needs of those participants who were less capable of eye-hand coordinated activity – playing an instrument and looking at the screen – as well as those who were driven by rhythm-based activities (Video Figure 3). The table design comprised of: a Perspex transparent surface; a contact microphone to pick up audio vibrations; an interface adapter for iPad; an iPad app to generate synthesised sounds; a small amplifier; and a projector to visualise the CymaSense prototype on the underside of the table surface (see Figure 5, Video Figures 1 and 4). The music tutor was alone in the room with the participants with the exception of a few unanticipated interruptions and on occasion when the researcher's help was required with the prototype.

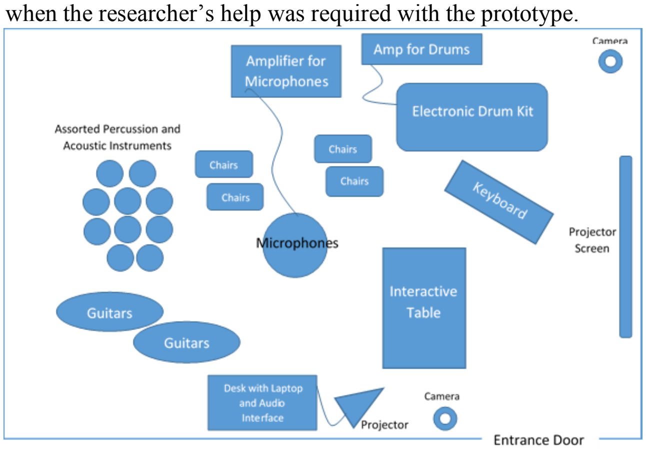

Figure 6: Music room overview

5.5 Sessions

The sessions were customised for each participant, however, a general set of structured activities were as follows: (1) Directed activity – the tutor began sessions with an introductory welcome and interaction with a chime bar. He would continue with personalised interaction with the participants' chosen instruments and/or voice. At the end of the sessions conclusory activities included simple breathing and stretching exercises to finalise the session. (2) Free activity – the music tutor would identify favoured instruments for each participant and encourage them to initiate interaction during the sessions. Independent play was also encouraged with the tutor being on-hand whenever the participant required assistance or encouragement.

5.6 Hypotheses

This research was designed to test the following hypotheses: (1) there is a significant difference between the number of musical and non-musical communicative responses demonstrated by the autistic participants in the first and last sessions of the eight week study (see 6.1); (2) there is a significant difference between the number of musical and non-musical communicative responses demonstrated by the autistic participants in their last non-intervention and first intervention sessions; (3) there will be observable changes in the communicative, social/emotional or musical behaviours of the autistic participants by parents, care workers or tutor at the conclusion of the 8-week period.

5.7 Measurement

Villafuerte et al. [51] used a composite variable based on social interaction when evaluating the Reactable tangible user interface for children with ASC. Their approach was to measure self-initiated contact and responses to social interaction. In this study, the contingent measurement was communicative behaviours. The CRASS scoresheet, described by Edgerton to evaluate improvisational music therapy approaches, was used as a basis for data gathering [10]. Divided into two sections: musical CRASS data deals with communicative responses influenced by the tutor and actions initiated by the participant that demonstrate an element of independence; non-musical CRASS data similarly details responses and actions including eye-contact, verbal, vocal and gestural communication. Non-musical CRASS data could be considered the more significant communicative factor beyond the music sessions and is referred to in more detail in Table 3. The frequency of musical and non-musical CRASS data was totalled for each session and was used to validate hypotheses (1) and (2). A post-study questionnaire provided qualitative data concerning observable changes in the participants' behaviours outside of the sessions. The survey questions were grouped into three categories: communicative behaviours; social/emotional behaviours; and musical behaviours. This data was used to validate hypothesis (3).

5.7.1 Quantitative Data

A total of 57 hours of video were analysed (two cameras recorded six weekly 30-minute sessions plus one 60-minute group session over eight weeks – minus absences). The number of occurrences of musical and non-musical communicative behaviours were observed and totalled for each participant for comparative analysis (see 6.1).

5.7.2 Qualitative Data

In addition to the video material, this research used interview and questionnaire methods for qualitative analysis. The objective was to gather data concerning the participants' behaviours outside of the sessions that could contribute to understanding results concerning communicative behaviours (see 6.2).

6. RESULTS

The recorded video material was analysed in order to elaborate all of the research results. Each participant was due to participate in eight sessions in total: two sessions of baseline non-intervention improvisational music therapy, and six intervention sessions with the CymaSense prototype. Entries in Table 3 indicate which sessions were attended by each participant.

6.1 Quantitative Analysis

Figure 7 shows the means for musical, non-musical and combined communicative acts and responses (CRASS) for all participants over the eight sessions. An overall increase was noted, however, reduction in scores in sessions 2 and 4 are notable and could be explained by absences skewing the data. This will be discussed in Section 7. To evaluate the six individuals and one group of two (G1), we decided to analyse the data in two ways: (i) by including the group in the analysis and (ii) by excluding it (see Table 1). All participants' last session scores were greater than their first session scores indicating a positive level of change over the eight sessions. The combined musical and non-musical scores ranged from 55 to 213 points, with a mean of 75.7 with G1, and a mean of 69.8

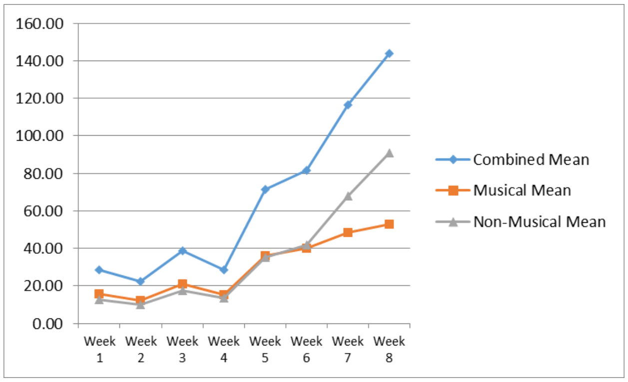

Figure 7: One-to-one and group mean scores over 8 sessions

without G1 included. Musical scores ranged from 23 to 77 including G1 data, 23 to 62 without, with mean scores of 35 including G1 and 32.6 without. Non-musical scores ranged from 38 to 174 points, with a mean of 40.6 with G1 data included and 37.2 without.

The Wilcoxon Matched-Pairs Signed Ranks Test was used to determine whether the differences observed between weekly sessions were significant. The average scores were compared between the following weeks: (a) the first and last sessions of the trial; (b) the first and last sessions of the intervention stage; (c) the third and last sessions of the intervention stage – this was to test the effect of resistance to change autistic people display [9].

Table 1: Wilcoxon Matched-Pairs Signed Ranks Tests Overview (one-tailed)

Test	Combined Musical and Non-Musical p-value	Musical Only p-value	Non-Musical Only p-value
a(i)	.009	.014	.009
a(ii)	.014	.023	.014
b(i)	.022	.034	.022
b(ii)	.034	.055	.034
c(i)	.014	.022	.009
c(ii)	.022	.038	.014
d(i)	.034	.034	.034
d(ii)	.055	.055	.055
e(i)	.014	.014	.014
e(ii)	.023	.023	.023

It is assumed that by the third intervention week, resistance to change is minimal; (d) sessions two and three, designed to be the last non-intervention and first intervention session – however, absences led to missing data; (e) the last non-intervention and first intervention session for all participants – this would vary on a session number basis as five of the participants' initial intervention stage was affected by absence. For all of the above, tests were conducted for the combined musical and non-musical data, musical data only, and non-musical data only (see Table 1).

A significant difference was observed between first and last session scores for all conditions a(i) and a(ii). The difference between the first and last sessions with intervention were significant for all conditions except b(ii) for musical scores only, Z=-1.6; p=0.055 (one-tailed), which showed no significant change. To validate the introduction of the intervention session for all participants, barring absences, sessions test c(i) and c(ii), indicate a more accurate level of significant change for all musical, non-musical and combined conditions. Sessions two and three d(i) showed significant differences for one-to-one sessions only at the .034 level (one-tailed, Z=-1.8). However, the follow-up test, e(i) and e(ii) comparing all last non-intervention sessions with first interventions sessions, indicate significant levels for all conditions.

The post-study Behaviour Change Survey was completed by four parents, four care workers and one music tutor. Twenty surveys were distributed and sixteen were returned (80% return rate). The survey consisted of a series of 7 point Likert-type scale questions, where a value of: 1 represented the negative end of the scale; 4 represented the central position; 7 represented the positive end of the scale. Table 2 shows an overview of the means for each. The means from all three behavioural categories fell between 5 and 6, indicating a change from slightly more to somewhat more. The musical category had a mean of 5.7 whilst both the communications and social/emotional categories had a mean of 5.6.

Table 2: Mean Scores for Behaviour Change Survey

Communicative Behaviours	5.6
Social/Emotional Behaviours	5.6
Musical Behaviours	5.7
Overall	5.6

6.2 Qualitative Analysis - Participant Results

6.2.1 Participant 1

P1 has ASC and was 18 years old. He was a non-verbal communicator, but used facial expressions, body language, gesturing and pictorial methods to communicate. P1 vocalised, although he did make verbal sounds and could say some words such as "Night, night", "Where", "Da Da". He could be loud in his vocalisations. He appeared to respond more positively to short, simple sentences. He usually required time to process information as well as transitions to and from different activities. Initial observations of the non-intervention sessions noted that he had a preference for percussion.

"If we brought in that extra element then he realises that his percussion instruments can be triggering visuals." [Tutor]

Table 3: Non-Musical CRASS Data

	P1	P2	P3	P4	P5	P6	G1
Week 1	19	14	13	10	4	14	16
Week 2	13	-	16	8	6	11	17
Week 3	37	9	-	22	-	20	34
Week 4	-	19	-	23	17	-	35
Week 5	41	39	24	41	20	45	36
Week 6	52	-	-	95	12	46	87
Week 7	66	44	51	117	26	71	101
Week 8	51	85	34	182	68	84	133

For the first intervention sessions, a microphone was used to visualise room sounds and project them onto the screen. The interaction with CymaSense indicated an improvement in his sense of agency through encouragement to vocalise and see the results.

However, the interactive table was chosen by the tutor as a more suitable intervention, for sessions 4 to 8, due to his preponderance toward leaning slightly forward and using his energy in a percussive manner (Video Figure 3). During subsequent interventions, P1 became more communicative through eye contact and gestural interactions (Table 3).

"[P1] developed greater understanding of the Cymatics environment and sharing these activities... He did so with curiosity, energy and enthusiasm…could be extremely valuable and meaningful to explore music and creative expression receiving such rich auditory and visual feedback to his verbal and non-verbal actions." [Tutor]

One of P1's parents expressed interest in the techniques used within the sessions - "We are interested…to learn how you carried out these sessions and if we could replicate them at home".

6.2.2 Participant 2

P2 has ASC, had been diagnosed with "profound learning disability" and was 27 years old. He was hypersensitive to loud noises or boisterous environments, and would seek out quieter areas. He communicated using non-verbal means by using different vocalisations to express happiness, distress or anger. He also used facial expressions, body language, gestural communication and objects of reference to communicate.

Initial observations of the non-intervention sessions revealed that he responded to the music tutor sitting close with turn-taking rhythmic activities on the keyboard or electric guitar. "He likes quite subtle sounds, tones. So that could be interesting finding something that's sensitive enough to have the visual responses to his sounds." [Tutor]

His first two intervention sessions had a microphone set up to visualise any sound on a screen. However, this approach did not seem effective as he has a tendency to look toward the instrument and was not capable of playing and watching the screen simultaneously. Subsequent intervention sessions used the interactive table, which indicated a more effective increase in cause-and-effect and subsequent sense of agency, as well as an increase in non-musical CRASS data (Video Figure 4) (Table 3).

"He gradually came to understand and interact with the Cymatics environment as well as with me. Developing a verbal and non-verbal, dialogue between us…I can see gradual sustained focus, attention levels and a greater sense of sharing and communication with me in these creative, expressive activities. All towards greater independence and initiating activity, away from his typical repetitive behaviours…very significant developments…often a motivating, and joyous experience..." [Tutor]

6.2.3 Participant 3

P3 has ASC, was non-verbal and was 24 years old. Her care workers commented that she often displayed a sense of detachment, withdrawal and non-participation, and had an obsession with spending lengthy periods of time in the bathroom. This led to the absences within the study and issues concerning participation within the sessions in which she was present. The music tutor commented: "I feel that she wasn't ready to explore new unfamiliar activity, for example Cymatics, when fundamentally the trust between us had to be embedded first…In the latter sessions there were some small but significant moments, where she was 'opening up' and feeling more at ease with gradual confidence." Consequently, the intervention did not indicate any significant improvements within her communication levels.

6.2.4 Participant 4

P4 has ASC, was 28 years old and had been diagnosed as non-verbal. He did not have functional language skills but used vocal expressions, body language, gesturing and pictorial methods to communicate. He was known to have an interest in computers, but little was known concerning his interests as he was the only participant not to have worked with the tutor before.

During the sessions, P4 developed a relationship of trust and understanding with the music tutor. He identified a number of plucked and percussive instruments that appealed to him and, similarly to P2, the initial two intervention sessions used a microphone which would visualise any sound on a screen. These sessions indicated a small change in communication levels but also established a set of rules for further exploration. "This was all about creating an environment relating to [P4]'s requirements and levels of communication, social rules, personal space, where he could establish a sense of trust and agency in the sessions". [Tutor]

Subsequent sessions changed the intervention to the interactive table, where greater improvements in communication were notable (Table 3). This allowed him to experiment with a range of percussive instruments that could be placed on top of the table simultaneously visualising the sound. He also developed a greater sense of agency through increased use of the CymaSense interface by choosing his own colour schemes at will. The tutor noted: "There were so many positive developments here over the 8 weeks towards greater confidence choice making, independence and gradual co-improvisation. Would certainly like to explore Cymatics possibilities further with [P4]."

One of his parents also commented: "For 20 to 30 minutes after each session, [P4] is extremely animated and puts more words together than he does in any other circumstances (for example, five words in a row 'music room good go back'). He tries to tell friends and family about the sessions and uses the tutor's and researcher's names (in his own special pronunciation). These sessions have definitely produced a positive effect in his overall communication."

6.2.5 Participant 5

P5 has ASC, was non-verbal and was 25 years old. He did not have functional language skills but expressed himself though vocalisations, using a microphone within previous music therapy sessions. It was evident through his use of the microphone that it would be suitable to introduce the intervention as a projection on screen that could provide meaningful audio-visual feedback. The tutor commented: "The consistency of the setting supported a sense of anticipation and excitement to grow in him, as he looked for the visual responses to his actions independently and also within our vocal and musical interplay."

P5 developed a musical relationship with the tutor that showed significant improvements in non-musical CRASS data toward the end of the sessions with the introduction of the two-user version of CymaSense (Table 3). His care worker noted "I have noticed in [P5]'s diary entries, an increase in singing at home." The tutor commented: "The use of the two-way Cymatics microphone set up really promoted this…I could observe some significant exchanges between us with some very meaningful pauses, and emotional peaks, which [P5] expressed with laughter, and greater close direct eye-to-eye contact than previously before the study…also to motivate him to initiate expressive ideas and encourage choice making within our musical interaction." (Video Figure 2)

6.2.6 Participant 6

P6 has ASC and was 22 years old. His language skills were functional and his communication was spontaneous. Having previously worked with the tutor, he was known for creatively expressing himself through musical improvisation. His tutor commented: "[P6]'s quite set in that he creates improvised songs. So he likes to sing and he likes to play an instrument…and he's playing on his own. And then we can have parts we do where he'll ask me to play drums or accompany him." A combination of using the microphone to visualise sounds and use of the interactive table allowed P6 to fully express himself and enhance his creativity (Video Figure 1). At the end of the first intervention session P6 commented on CymaSense to the tutor: "I love it! It gives you more focus on the song itself…it affects you…better as a singer."

The tutor went on to highlight P6 "…seemed inspired working within the Cymatics creative environment, enjoying control of the visual responses. He enjoyed the dynamic movement and intense colour responses to his energetic musical improvisations. A very immersive and personalised environment…"

6.2.7 Group 1

Finally, the group of two (G1) comprised two 24 year olds with ASC. One non-verbal male (M1) and one female (F1) with functional language skills. They were childhood friends and had subsequently participated within a number of therapeutic sessions together. Due to the diversity of both of their needs (M1 preferred percussion and strumming guitar, F1 preferred singing and percussion), a combination of using the microphone to visualise sound on screen was used, in addition to the interactive table.

They were both quite fluent with the use of computers and became more comfortable and confident in choosing their own colour schemes via the CymaSense interface. As the sessions developed they became more enthused creatively and communicatively and as their care workers noted: "Since Cymatics, [F1] has been more into her music and happier that she has something else music related…" - "Her clarity in singing has improved greatly…instead of humming…She has disclosed that this is her favourite activity, both verbally and using symbols…I can also see [F1]'s skills at drama has improved, maybe due to more [involvement] at Cymatics."

M1 seemed to develop his level of immersion with the intervention over the course of the sessions but not out-with the sessions. His care worker noted: "It appears to increase his social/musical interests during sessions. But he hasn't shown any long-term changes that I have observed." Their combined level of non-musical CRASS data indicate significant improvements over the sessions (Table 3).

7. DISCUSSION

The results of the study indicate that the combination of improvisational music therapy and use of CymaSense can improve communication for people with ASC, thus validating the hypotheses. These results support other studies related to music therapy [25], TUIs [51][5], and with natural user interfaces (NUI)[38], with respect to enhancing communication for people with ASC. This study differs through employing a combination of music therapy techniques, NUIs and TUIs. It provides the participants with an additional sense of agency and independence through the ability to experience tactile, auditory and visual feedback, within an improvisational music setting. The study suggests they can create a greater sense of predictability and control through use of the interface to control visual elements.

A surprising dip in P1's score for the final session can be noticed. It was noted that he was suffering from a heavy cold that day and his subsequent energy levels could have affected his poorer than expected performance. Similarly, P5 had dental treatment prior to sessions 4 and 5, making him physically tired and less energetic than normal. Participants' absences have already been stated with regard to their emotional health, additionally the physical health of some participants is likely to have affected their scores and consequently the results of this study.

One recognised trait of people with ASC is the fear of novelty or change within a situation [49]. In this study, there was no negative novelty effect observed. The results show there was no decrease in CRASS scores when the tool was introduced, and that scores typically increased with use. Multimodal NUIs have also been identified as a means of alleviating potential stress for people with ASC [38]. In addition, the tutor had experience working with all but one participant, P4, prior to the start of the study, further reducing potential change-related stress for the majority of participants.

One limitation to interpretation of the data relates to the single subject AB design used in the study. The experimental design used may not be as strong as one where the intervention is withdrawn and then reintroduced [37]. A withdrawal phase was considered but was advised against by a music therapy expert as it would run the risk of distressing participants if a successful intervention was withdrawn. The practicalities of carrying out this type of study were an important factor that affected its design. It is challenging to secure the participation of a therapist and participants for a long duration, which limits the duration of the different stages of the study. The baseline (A) phase was thus decided to be a two-week period, a compromise that enabled us to run the intervention over a longer stretch of time, which we judged preferable. However, consideration for a repeat or continuation of the study is on-going for further validation. An additional BAB reversal design would provide comparative data to highlight the effect of the music therapy itself compared to the intervention.

It could be argued that CymaSense, when used as an interactive table, not only visualises interaction with the table surface itself, but also creates a novel percussive instrument. This creates new opportunities for social interaction through a shared space and turn-taking, while independent use could also encourage cause-and-effect and a subsequent sense of agency.

Interpretation of the data, from an audio-visual perspective, relied on a number of variables relating to the study environment and the nature of each participant's level of ASC. For example, the amount of light within the room may affect the comfort levels of the participants in differing ways. Hypersensitivity and hyposensitivity is well known within autism and may be a factor [39]. However, the lighting conditions were altered and continually assessed during each session by the tutor for the participants' comfort levels.

The size and location of the projected image may have affected the participant's ability to appreciate the cause-and-effect nature of the system. This was noted by the researcher and the tutor through constant review of sessions and video, and subsequent decisions were made as noted in the results section (6.2).

Colour may have affected how participants experienced the sessions. The tutor initially used the default colours (black background and spectrum colours for the Cymatic shapes) for a number of sessions to allow familiarity with the tool. Alternative colours were chosen at random by the tutor in future sessions while some participants chose their own colour schemes. None of the participants were diagnosed with visual or auditory impairments. However, further studies would be required to determine the effectiveness of the colours chosen and the effect of environmental factors like temperature or noise - for example, the hum of the projector. Similarly, little is known concerning how the animation of the shapes themselves affected each participant. Again, however, participants with functional language provided positive feedback concerning the dynamic movement and colour responses.

8. CONCLUSION AND FUTURE WORK

The majority of participants used CymaSense successfully. Although it is difficult, or even impossible, to gather a homogenous group of people with ASC, the design, implementation and results based on the sample population in our study support the initial hypothesis that the use of an interactive audio-visual tool can improve communication for people on the autism spectrum. Further research is planned to include interviews with parents in an attempt to identify the elements of CymaSense that make it successful. In addition, the effectiveness of the audio-visual mapping implemented in CymaSense is currently being evaluated in a study in which the response of neurotypical respondents is compared to that of autistic users.

This evaluation of CymaSense opens up new possibilities for other sensory impaired groups. The CymaSense system architecture can support visualisation of any sound through 3D graphics, making customisation for alternative groups simple. Future studies concerning its use by children and by alternative disability groups, including the hearing impaired, may promote social interaction and self-esteem by encouraging group play and turn-taking.

TUI interventions [51] or NUI interventions [38], used in other studies, promote communication and social interaction within autistic children. In this study, which involved eight autistic adults, four of which were non-verbal and two only exhibited limited language skills, we have demonstrated that significant improvements in communication can be observed by augmenting music therapy with real-time visual feedback. The single case qualitative analysis has provided specific insight into the usefulness of the intervention and of the system developed.

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