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Soundscape and Haptic Cues in an Interactive Painting: a Study with Autistic Children

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***Abstract* - This paper reports the results of a pilot study with autistic children based on our recent work examining the potential of combining haptic and sonic exploration with a real painting as a tool for neurorehabilitation. The study consisted of seven children with autism exploring a painting enhanced with haptic and sound feedback. Audio-visual and kinematic data were collected to evaluate the participants' behaviour and experience. The participants engaged with the interactive experience and interacted with each other in a positive. The results from this study suggest that the interactive painting is a feasible tool for autistic children to use on their own and when they interact with other children.**

Index Terms – Social interaction, motivation, engagement, autistic children, collaborative rehabilitation.

I. Introduction

Autism is a neurodevelopmental syndrome with a very strong genetic component and an early onset: it usually begins within the first 3 years of life [1, 2]. This syndrome is defined by deficits or unusual behaviours within three domains: social reciprocity, communication and restricted/repetitive interests [3]. Autism is heterogeneous i.e. children or adults with autism tend to have different profiles [4]. Although autistic children show a variation in symptoms, it is most likely that social impairments (e.g. lack of social-emotional interaction, withholding enjoyment with the others when they are happy, point to objects of interest, difficulty to use nonverbal communication) and impaired joint attention skills (a set of relevant skills involving attention sharing and maintaining sustained joint engagement with others) are the most common characteristics of all autistic children [4-8].

Several recent studies have focused on developing joint attention skills for children with autism [9-11]. Nevertheless these studies mostly relied on teaching children skills (usually limited to one skill at a time) rather than considering the naturalistic play settings. In these studies often target skills are taught to the children participating in the study, which presents with limitations in terms of the generalization of those skills applied to other people or context. There are several reasons that could be used to explain why target skills are not generalized. For instance, the skill might be taught in a structured and thus predictable context, consequently the child may find it is difficult to perform it in a more natural setting or with another person; or the skill might be unsuitable for the child or more specific, the child may not be ready yet to learn the skill [7]. Thus there is a need to develop an intervention which could be applied in a normal circumstance and deliver a playful way to teach autistic children joint attention skills.

Haptic interfaces are a particular group of robots that can provide safe interactions for humans and allow for the interaction to be customised to the individual. They can also enhance user's experience through kinaesthetic feedback via the sense of touch (tactile) or force feedback (proprioceptive) and enhance the kinaesthetic channels while interacting with virtual objects. Kinaesthetic learning is therefore a very appealing technique to explore with autistic children, as the learning takes place by the child while carrying out a physical activity, rather than listening to the teacher or watching a demonstration. It has been shown that virtual reality (VR) - haptic based systems can motivate and encourage participants to interact for longer periods of time [12, 13]. Although the majority of these interventions have been applied to people recovering from brain injuries, a similar approach of generating interest and promoting focused attention and engagement still stands in an intervention for autistic children.

With the emergence of low-cost haptic devices coupled with new gaming technologies such as the Nintendo Wii and the Microsoft Kinect, new affordable solutions arise for home-therapy paradigms due to the reduction of cost, the ease to setup and provision of unsupported exercise. Such exercise or task could be centred on social interactions and collaborative play in order to increase motivation and help reducing the sense of isolation and improving task engagement. Recent approaches combining tele-rehabilitation concepts with collaborative game play [14], and simple robotic sonic interaction [15] have showed the potential for increasing engagement and participation of individuals in remote and localized group therapy.

The work presented in this paper is motivated by the results of our recent study combining exploration of a painting aided by haptic and sound cues, which concluded that group interaction resulted in increased engagement with the interactive installation and increased execution of movements [16]. This work explores further the concept of using interactive paintings for neurorehabilitation by examining its potential as a playful tool to enhance sensory/emotional experiences and expressions, cognitive and social interaction development with a special subject group: children with autism.

II. METHOD

A. *Study Design*

Seven autistic pupils (all male, aged 7 y/o ± 14 months) diagnosed with severe general learning disabilities have been recruited from Watergate and Riverside schools. The children participating in the study showed similar severe impairment in their functioning relating to basic awareness and understanding of themselves, including the people and world around them. Participants were accompanied by their teachers/minders, which sat on the background away from the children while the children interacted with a painting through a haptic device. The teachers where not allowed to communicate with the children while the experiment took place. Prior to start of the experiment, the experimenter demonstrated how to use the device and allowed the participants to familiarize themselves with the device. The study consisted of seven single case studies and comprised two phases:

Phase 1: Participants where allowed to explore the painting unaided and on their own. Only one teacher/minder was allowed to remain in the background in the same room as the participant. Verbal communication between the teacher/minder and the participant was minimized upon painting exploration to avoid any interference leading to any specific guided interaction during the experiment.

Phase 2: Participants where randomly assigned to a pair or group of three and were allowed to freely explore with the haptic painting a second time, while interacting (speaking, cooperating, taking turns, etc.) with another participant(s).

Participants were allowed to interact with the painting for up to 10 minutes during each phase. Due to the number of participants it was not possible to have three pairs, hence the decision was made to include two pairs and a group of three participants in phase 2 and treat the analysis as single case studies to see if a larger group would result in different interactions. The design of this study has been simplified to avoid any likelihood of discomfort due to the vulnerability of this particular subject group.

B. *System Description*

The experimental setup (Fig. 1 and 2) for this study has been upgraded to enhance user's experience by producing 3D binaural sound instead of stereo sound as implemented with the previous version [16]. The system used in this study includes twelve speakers and two additional subwoofers to improve sound effects. A 6DOF Phantom Omni incorporating a stylus handle was used to replicate the shape (and movement) of a paintbrush. Two computers were used in this experiment: a PC running Windows 7, which ran our haptic application to generate and control haptic effects and a Macintosh computer (Mac OSX) running the 3D-Audioscape sound software (using Max/MSP environment) designed particularly for this setup to manipulate and produce 3D sounds. The two computers communicated to each other via a local network while the two software modules exchanged data via OSC (Open Sound Controller) messages.

The painting represented a seaside-landscape commissioned to a professional artist for the project. The environment was a dark room with light projected onto the painting and the device (Fig. 1). The computer and researchers were hidden from user's view. The robot was placed on the top of a plinth for the user to grab its end-effector (paintbrush shape) and move freely (limited by the mechanical workspace of the robot - approximately 13.44 x 10^{-4} m^3).

Fig. 1 User interacting with the painting.

The 3D sounds were modeled to be dependent on the position and velocity of the haptic device. This included:

1) an 'under the water' soundscape, where the participants could hear the sound of bubbles as they moved below the water surface (all other sounds were off). The feeling of moving through more bubbles increased and the velocity of the movements increased.
2) an 'just above the surface' soundscape, where participants could hear the sound of sea waves and wind. The feeling of moving through the wind was intensified by the type and speed of the movements, i.e. the faster the movements, the stronger wind.
3) an 'to the top' soundscape, where as participants reached to upper workspace of the device, the

waves and wind sounds would reduce and a thunder sound intensified.

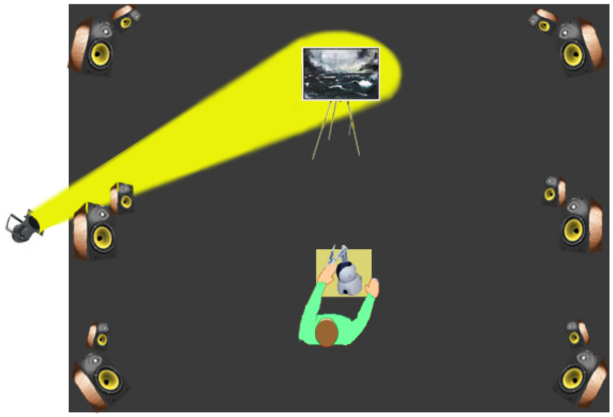

Fig. 2 Interactive painting experimental system. Participants interact with the painting by grabbing and moving the Phantom Omni's paintbrush-shape handle.

In order to match the changing movement-dependent sound, the haptic feedback algorithm has also been modified to optimize the user's experience. The decision came due to the users' feedback from our previous study suggested it would be beneficial to feel more different kinds of force feedback (e.g. participants want to feel the waves when touching them). This was implemented using the CHAI 3D library and modeling the water using a spring-damper combination [16]. However in our second implementation, instead of simulating the water's viscosity, the algorithm was modified to create a water bouncing effect, i.e. user's hand would be pushed in the opposite orientation of the force applied on the water. To be more specific, a force membrane has been created by a two-dimension array of nodes linked together by simulated virtual springs and dampers. The pseudo code in Table 1 summarises the algorithm used in this experimental setup.

TABLE I
ALGORITHM: WATER'S BOUNCING EFFECT

```
//Set values for nodes
stiffness = 40; nodeRadius = 1.3; dampingPosition = 0.4; dampingRotation
= 0.1; nodeMass = 0.006  //(kg)
create nodes[10][10]
//Get end-effector's position, radius
devicePos = getDevicePos()
deviceRadius = getDeviceRadius()
//Compute reaction forces
for  y=0 to 10
      for x=0 to 10
            //Get position of nodes[x][y]
             nodePos = nodes[x][y]->getPos()
            //Calculate force
           force = calculate(devicePos, deviceRadius, nodePos, nodeRadius,
                                              stiffness)
          //Get opposite force applied on the water by negating the result
            oppositeForce = negate(force)
            nodes[x][y]->setExternalForce(oppositeForce)
      end for
end for
```

C. *Procedure*

The study was subject to Middlesex University's ethical regulations and an information package was provided to each participant's parents. Participants were admitted to the study following informed signed consent. Participants' teachers/minders were briefed at the beginning of the experiment. Before interacting with the system, each participant was informed that they would be exploring an interactive painting using a haptic device for as long as they wanted to. Once they finished, they were instructed to go to another room and waited until the next phase of the experiment, when they interacted with the painting again in a pair (or group of three) with another participant(s).

D. *Outcome Measures and Data Collection*

Audio-visual data (from user's interaction with the painting) was collected using three camcorders, while kinematic data (positions, velocities) recorded using the robot (Phantom Omni).

III. RESULTS

Fig. 3 illustrates how participants interacted with the painting by displaying the xyz coordinates of the haptic device's end-effector in 3D space. The results show that participants' movements are varied and some participants seem to be more explorative than the others (participant 1, 6&7). Observation analysis from the audio-visual data revealed that while participant 1 seemed active, he took his time and moved carefully. In contrast participant 2, looked more interested in the device than the painting making more ballistic movements associated in particular with the water splashing sound (device hitting the water) and the wind sound above the water, this is also apparent from the kinematic results presented in Fig. 3. Participants 3, 4, 5 and 6 showed a positive reaction towards the device and the painting, but were quieter and explorative, whereas participant 7 was more interested in all the aspects of the experience, exploring the painting gently but inquisitive as to where the sound of the water and touch sensation came from.

Fig. 3 also shows that when participants play together in a pair or in a group, they have a tendency to move differently from doing it alone. For example the z coordinates of participant 2's movements were most of the time greater than 0 pointing out that he preferred to move over the water surface however when exploring it again with participant 1, the pair became more explorative making more diverse movements. Nonetheless it took a while for participant 2 to fully engage and interact with participant 1. Pair 2 (participants 3&4) talked more to each other, and took turns more often to move the device. In contrast the group (participants 5, 6 & 7) took longer to engage as a group, most of the time resulting in individual exploration followed by wondering around before participants started interacting with each other.

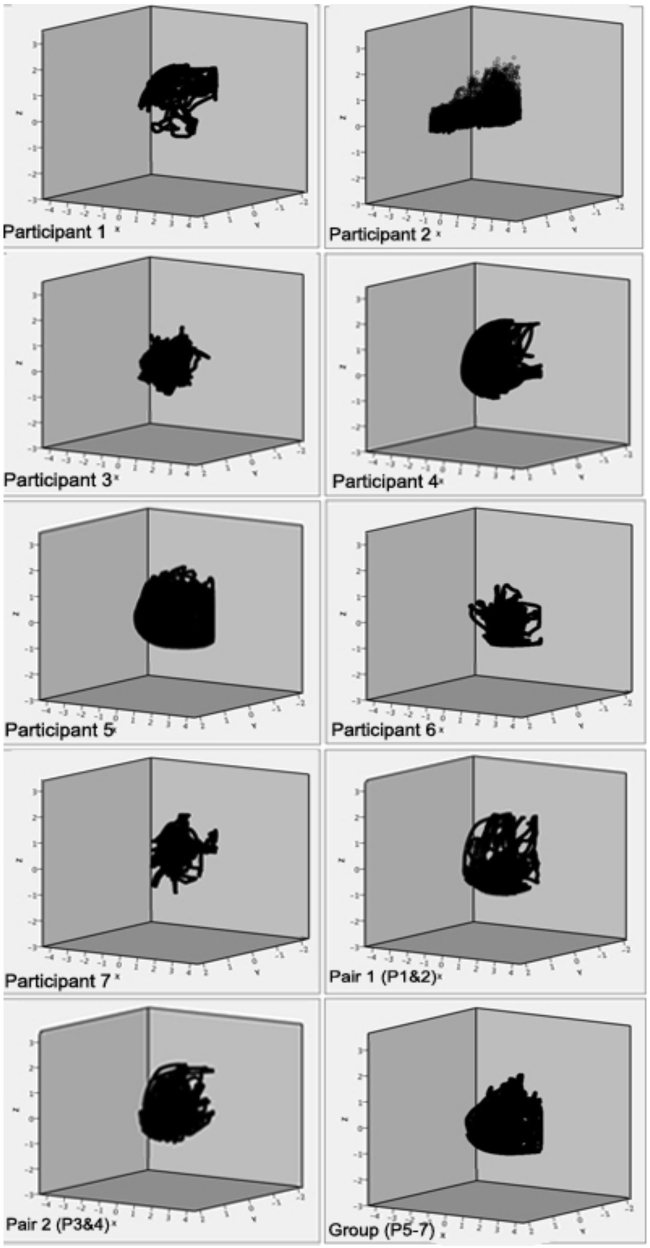

Fig. 3 End-effector movements in XYZ 3D-space. The zero at the Z axis illustrates the water surface level, below it participants experienced moving under the water.

To assess further the interaction effects as a whole on participants' movements, three different analyses were carried out. Fig. 4 compares the mean end-effector's velocities of different types of interaction (when participants explored the painting on their own or in pairs/group). The results seem to indicate that participants moved faster alone although there is no significant difference between interaction types (alone approximately 0.15 m/s, in a group approximately 0.14 m/s). In contrast, Fig. 5 and Fig. 6 show that the mean total time spent and total hits (the number of times participants touched the water) in groups are higher than individuals. As a whole, it appears that participants made more movements and spent longer times interacting with the painting while playing in groups. A closer inspection (Table II and III) looking at the individual contributions for the participants in the pairs and in the group suggests that participants spent less time exploring the painting (p = 0.06 and P = 0.19) and touched the surface of the water also less than they did while on their own (p = 0.46 and p = 0.27). This result is in line with the initial analysis performed on recorded robot end-effector movements presented in Fig. 3.

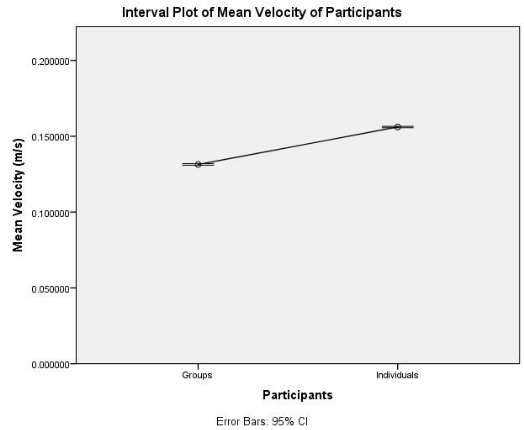

Fig. 4 Mean velocities between individuals (participants conducted the experiment on their own) and groups (worked in pairs or in a group of three).

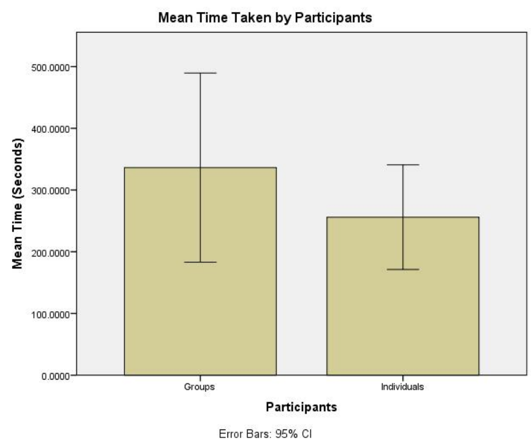

Fig. 5 Chart of the mean total time spent exploring the painting.

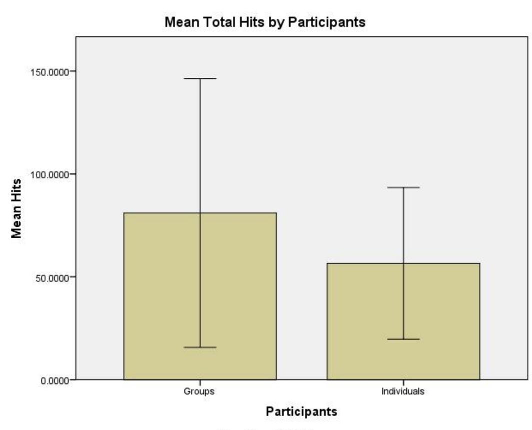

Fig. 6 Charts of the mean total hits: number of times participants touched the water.

TABLE II
PAIRED T-TEST RESULTS ON THE HITS AND DURATIONS OF INDIVIDUALS AND PAIRS

Factor	Individuals	Pairs	Paired t-test (95% CI)
Hits	52.75 SD = 36.09	45.25 SD = 29.9	p = 0.46 CI : (-20.6, 35.6) t = 0.85
	Diff = 7.5		
Duration	245.9 SD = 97.82	167.09 SD = 110.7	p = 0.06 CI : (-9.83, 167.46) t = 2.83
	Diff = 78.81		

TABLE III
PAIRED T-TEST RESULTS ON THE HITS AND DURATIONS OF INDIVIDUALS AND GROUP

Factor	Individuals	Group	Paired t-test (95% CI)
Hits	61.67 SD = 52.32	20.67 SD = 6.11	p = 0.27 CI : (-74.6, 156.6) t = 1.53
	Diff = 41		
Durations	269.47 SD = 101.9	113.42 SD = 54.4	p = 0.19 CI : (-185.3, 497.4) t = 1.97
	Diff = 156.05		

Note. N = 4 in table 2 and N = 3 in table 3. SD: standard deviation, CI: mean confidence limits (lower, upper) Diff: Difference between means

IV. DISCUSSION

The results show the overall engagement of all participants regardless how and who they interact with. They seemed to be happy and to have enjoyed the experience. The analysis of the kinematic data with audio-visual data revealed an interesting fact: children interacted with the painting differently depending on their imagination and which sound they preferred. For instance, participant 2 spent almost all of his time moving over the water because he seemed to like the water splash and windy sound while participant 3 on the other hand, liked the underwater sound. It also appears that some children might develop their analytical skills through this kind of interaction. As mentioned before, some participants seemed to be more explorative than the others, they moved in various ways to explore different sound and haptic feedback. This finding might indicate that adding more sound and haptic feedback could result in longer exploration and engagement with the installation.

The 3D sound effect also had a strong impact on user's reaction. Participant 7 was looking and then running around the room to find out where the sound came from. It is interesting to see how the sound effect contributed to the way the children interacted with the artefact. In fact, humans in general, have the tendency to use their imagination while interacting with good sound effects. In contrast, one participant in our study used the device while making circular motions and one can assume this related to imagining stirring (mixing) the sea because he could actually hear the sound corresponding to his action.

The way participants communicated to each other while interacting in pairs or group is also worth mentioning. On conversation with their teachers following experiment completion, we have learnt that this cohort of autistic children always has difficulty to talk to each other. Nevertheless, in this particular experiment, when participants explored in a group (or pairs), they had to 'negotiate' with each other and take turns to use the device - this also possibly explains the results observed in Table II and III.

It rises the opportunity to apply this type of interaction for social skills development which is important in human cognitive development especially for children with autism. However, the fact that took a while before participants in the group of three to engage as a group only reinforces the notion of the difficulties autistic children face when the number of people they have to interact with increases. But it is also encouraging to observe, that perhaps because of the curiosity that the interactive painting generated, the individual bursts of wondering around slowly resulted in coming together and converged towards participants starting to do things together.

V. Conclusion

This paper examined further the concept of using an interactive painting for neurorehabilitation by conducting a pilot study with a vulnerable group. Our approach aims to promote the possibility take rehabilitation beyond hospital and home by creating a playful activity based on the social nature of art exploration with haptic and sonic cues.

The results obtained from this study are promising and encouraging. Although only a long term study can provide sufficient evidence in support of our approach, it is promising to find that such rhythmic sound might have an impact on synchrony for learning, improved motor control and emotional well-being. Our study does suggest however that the interactive painting paradigm might be beneficial for autistic children and certainly showed that it is a feasible tool for autistic children to use on their own and when they interact with other children.

The interactive haptic painting is far from being considered a neurorehabilitation tool, but in order to promote the development of spatial perception, imagination and enhancing social skills through the touch/sound sensory channels, it is necessary to investigate how interactions with such artefacts can be used with bigger groups. Such interventions should engage children in activities promoting social connectedness, cognitive development, increased motor activity and self-expression.

Acknowledgment

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Further information at: www.intotheframe.org

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