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Olly: A tangible for togetherness

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ABSTRACT

This research explores how tangible interactive technology might offer opportunities for socialization and sensory regulation. We present a study carried out in an educational setting during leisure activities with a small group of children with autism who like music. We introduce Όλοι (pronounced Olly), a sonic textile Tangible User Interface (TUI) designed around the observations of five minimally verbal children with autism aged between 5-10 years. The TUI was tested for an average of 24 minutes once per week, over a period of five weeks in a specialized school based in North-East London, UK. We propose a methodological approach that embraces diversity and promotes designs that support repetitive movements and self-regulation to provide the children with a favorable environment and tools to socialize with peers. The findings show positive outcomes with regards to spontaneous social interactions between peers particularly when children interacted with or around Olly. These were observed in the form of eye-contact, turn-taking, sharing (of the space, the object and experience), and more complex social play dynamics like associative and cooperative play. We illustrate how the TUI was a positive stimulus of social behaviors and discuss design implications for novel technologies that aim to foster shared experiences between children with autism.

1. Introduction

It is commonly agreed that play is good for children's cognitive and social development (Ginsburg, 2007; Jarvis et al., 2016; Lillard, 2015; Mastrangelo, 2009; Piaget and Inhelder, 1969). In 2013 the United Nations Convention of the Right of the Child (UNCRC) fully implemented Article 31 by adopting the General Comment 17 which formally values the child's right to play and participate in leisure and recreational activities as well as cultural life and the arts. Despite the potential benefits of physical toys for supporting play, motor and cognitive development recent studies within the Human-Computer-Interaction community aimed at scaffolding social skills through playful activities focus on robotic toys (Andreae et al. 2014), virtual reality (VR) (Garzotto et al. 2017), touchless screen-based devices (Bhattacharya et al. 2015) and, virtual environments (VE) (Mora-Guiard et al. 2016; Ringland 2019). Furthermore, some of these studies use technologies or methodologies that implicitly rely upon affective and/or verbal skills and are high on cognitive demand (Frauenberger et al. 2017; Mora-Guiard et al. 2016; Andreae et al. 2014). This reliance on affective and verbal skills might exclude many children since around 40% of children with autism are nonverbal (Tager-Flusber and Kasari, 2013; CDC, 2020). Therefore, we believe that it is important to expand the research space to also cater for the needs of those children who are minimally verbal to nonverbal.

When designing technologies that aim to scaffold playful and social experiences for children with autism there is a need to expand the design space to be more inclusive and accessible. Tangible User Interfaces (textile TUIs) that are soft and malleable may address some of these challenges by introducing concrete interactions in real-world contexts that match children's sensory experiences, are accessible to direct observation, and afford physical manipulation and social behaviors. Studies demonstrate that autistic people enjoy touching soft materials more than plastic (Cascio et al. 2008) and engage more in physical contact with plush than virtual toys (Jeong et al., 2017). This affinity towards soft materials might be reinforced by the functional aspects of soft haptic feedback as this seems to also reduce feelings of uncertainty in neurotypical individuals (Van Horen and Mussweiler, 2014). Our work expands on the above findings of tactile perception and children's preference towards materials that have soft proprieties by introducing Όλοι, from the Greek "All/Everybody", a sonic e-textile TUI designed to address these points (Nonnis and Bryan-Kinns, 2020). The technology is made by combining different soft materials like wool, elastic ribbons, e-textile stretch sensors and a therapy inflatable ball with a hard microcontroller such as the Bare Touch Board used in Midi mode to trigger

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the sonic outputs. The study of Olly informs a wider body of research on the impact of musical textile TUIs on social interactions and sensory regulation for minimally verbal children with autism who like music (Nonnis and Bryan-Kinns, 2019a, 2019b). We choose to target social play and sensory regulation as children's sensory processing abilities seem correlated to their participation in leisure activities (Hochhauser and Engel-Yeger, 2010). Furthermore, as technological advancements enable us to be alone together (Turkle, 2011) by sharing networked virtual and digital spaces,we wanted to reinforce the value of the children's experience of being together, together (Christensen et al., 2019). We propose a shift in the interaction paradigm that sees design as a problem-solving activity and we challenge the notion that autistic people should aspire to simulate neurotypical behaviors to adhere to societal norms by proposing a methodological approach that embraces diversity and promotes designs that support repetitive movements and self-regulation by being multimodal and multifunctional. The aim is that of providing children with the most favorable environment and tools to socialize with peers. This allows us to take a holistic approach to TUI's development for autistic children, focusing on the broader context in which the technology is deployed, the ecology, not just the technology (Hourcade, 2015; Smith et al., 2013).

This paper offers several contributions. It contributes to the field of Human Computer Interaction (HCI) particularly Child-Computer Interaction (CCI) by presenting an exploration carried out over five weeks where an e-textile sonic TUI was assessed in terms of its support for social activities and self-regulation in a group of minimally verbal autistic children within a semi-structured ludic setting in a specialized provision for autistic children. This is achieved by reporting and discussing the empirical qualitative and quantitative findings that show positive outcomes in regard to spontaneous social interactions between peers particularly when children interacted with or around Olly. The TUI encouraged a shared-experience by virtue of its size, which is large enough to allow children to gather around it together and engage with it in either solo, parallel, associative or cooperative play etc. The research also presents a freshly grounded methodology in which methods intended particularly for Special Education Needs contexts have been applied to the research methodology behind the technology. We incorporate educational constructs, such as those from Social Communication, Emotional Regulation, Transactional Support (SCERTS), with an HCI lens on future design implications for TUIs and propose a holistic approach to the design and evaluation of TUIs for social activities between peers coupled with a positive attitude towards the sensory needs and strengths of this population (Brulé et al., 2019). Lastly, within the bigger body of this research we produced an evaluation framework inspired by a curriculum-based assessment and evidence-based practices and used it to evaluate Olly. This contributes to expanding the discourse on the open issue related to the lack of methodological guidelines to perform user-studies for autistic children (Bartoli et al., 2013).

2. Background

The benefits of play on child development have been studied extensively (Almon, 2003; Burdette and Whitaker, 2005; Frost, 1998) with some researchers showing that play deprivation in childhood may lead to more aggressive young adults (Frost, 2006). Defining play is a controversial matter, because it has both qualities of action and of activity. In psychology, researchers have come to conclude that play is a fundamental part of our physical, cognitive and emotional development (Elkind 2008; Lillard et al. 2013; Saunders et al. 1998; Mastrangelo 2009). Although atypical, the development of children with autism can still be studied within traditional perspectives (Burack and Volkmar, 1992). When reviewing findings on autistic children at play, evidence shows that they might manifest less symbolic and complex play, less functional and social play (Toth et al. 2006) and increased repetitive behaviors (Libby et al. 1998; Toth et al. 2006). It is thought that playing with peers, especially during unstructured dynamics like playtime, is often a challenge that many children with autism avoid by simply playing in solitary mode (Symes and Humphrey 2011). The American sociologist Mildrean Parten Newhall (1932) considered playing a free endeavour occurring and developing at a social level. Parten theorized play by dividing its development into six stages represented by the children's levels of participation and well summarised in (Scheepmaker et al., 2018). Similarly, to Piaget, Parten considered the first stages to be directed towards individual or private play while the latter stages evolved into social play. For Piaget the presence of others imposes rules on the playful endeavours, and games with rules are almost the only ones that persist in adulthood (Piaget, 1962). For this research play is considered an intrinsically engaging activity that has no other aim than that of being fun and pleasant and where children can lead the play and self-express. Since social interactions are experienced atypically by most children with autism it is our responsibility as researchers to develop design strategies and methodologies which consider and embrace a varied play environment. By contributing to the development of supportive environments and positive social playful experiences during childhood we could enable more children to become successful adults.

2.1. Autism

Children with autism often present common dyadic characteristics (American Psychiatric Association 2013) which affects areas related to:

- Social Communication and interaction
- Ritualized patterns of behaviors and unusual sensory responses

Today it is understood that autism has a genetic and biological component to its origins (Schopler and Mesibov, 1987) but there is no single biological marker. Diagnostic criteria are determined by atypicality in the above-mentioned domains. The different cognitive models that support the understanding of autism often explains it in terms of deficits, such as the Theory of Mind (ToM) (Baron-cohen, 1989) and the Executive Function (Baron-cohen, 1989; Joseph and Tager-Flusberg, 2004). Other theories see it in terms of assets such as the Weak Central Coherence Theory (Happé, 1997), the Hyper-Systemizing Theory (Baron-Cohen et al., 2009) and the Enhanced Perceptual Function (Mottron et al., 2009).

2.1.1. Sensory processing and modulation

Baranek et al. (2014) reported a prevalence of sensory features in preschool and school-aged children with autism ranging from 40% to 90%. Sensory processing challenges most frequently fall into two main categories, hypersensitivity and hyposensitivity (Grace and Baranek, 2002; Greenspan and Wieder, 1999) but other two sensory features have been found to be common in autism: 1) repetitive and seeking behaviors; 2) enhanced perceptions (Baranek et al., 2014). Repetitive and seeking behaviors may exhibit in the child's fascination or fixation for something, which might manifest in a repetitive behavior like rocking, hand-flapping, twiddling strings, light-gazing, tapping body parts, fingers flickering (Baranek et al., 2014; Murdoch, 1997). It is thought that autistic children perform these behaviors to increase or lower their arousal level and to self-regulate (Case-Smith et al., 2015) and these are a way of managing anxiety and sensory inputs (Suarez, 2012). However, repetitive and *stereotyped* movements are often considered inappropriate and they're perceived negatively from society. In fact some interventions within the HCI community tend to reduce, monitor or eliminate them (Albinali et al., 2009; Chen et al., 2016; Goodwin et al., 2008). With this research, we aim to move towards an inclusive ideology (Murdoch, 1997; Nind and Kellett, 2002) by defying the traditional views that stereotyped behaviors have no adaptive function or need changing, and we argue for opening up the design space to design for inclusion.

2.1.2. Tactile and auditory stimuli to overcome anxiety

Researchers have found that high arousal levels in children with autism are linked to hypersensitivity and both are thought to increase anxiety levels (Liss et al. 2006; Rodgers et al. 2016). Arousal levels might also be linked to tactile defensiveness (Baranek et al., 1997). Thus, hyperreactivity, especially tactile defensiveness, high arousal levels, repetitive movements and anxiety are all interconnected and difficult to study in isolation. Deep pressure has been found to decrease anxiety levels (Krauss, 1987) and contribute to self-regulation by affecting the nervous system, increasing dopamine level and decreasing stress hormone cortisol (Field et al., 2005). Several studies experimented with and demonstrated the beneficial and calming effects of deep-pressure by using different types of touch as a sensory integration strategy i.e. hug machines (Grandin 1992; Edelson et al. 1999; Krauss 1987); garments to wear on sleeves (Zissermann, 1992) or on the chest (Duvall et al., 2016; Vandenberg, 2001); and hand massage (Escalona et al., 2001). Within the HCI community a set of wearable devices has been deployed as a self-regulatory opportunity to manage anxiety (Simm et al. 2016) and hug vests remotely activated to provide deep pressure onto the upper body of the wearer (Duvall et al. 20016). Children's anxiety levels seem to also benefit from auditory stimuli in the form of music. The therapeutic potentials of music for children with autism have been widely recognized, especially for supporting social interaction for non-verbal communicative skills i.e. low level joint attention skills and initiation of behaviors i.e. eye-contact (Geretsegger et al., 2014) but also to stimulate emotions and lower anxiety levels (Allen and Heaton 2010). Findings show that some autistic people respond to music similarly to typically developing people (Gebauer et al., 2014) and they deliberately use it for mood management (Allen and Heaton 2010). Researches have also demonstrated that some autistic people prefer harmonious to dissonant sounds (Boso et al. 2009; Salimpoor et al. 2015).

3. Technology based approaches in Special Education Needs settings

At the end of the 20th century researchers started to explore the use of digital technology as a pedagogical tool for playful-learning. Within the Child-Computer Interaction (CCI) community (Read et al., 2008) some researchers explored the potentials benefits of technologies in various settings and contexts such as schools (Bhattacharya et al., 2015; Gelsomini et al., 2019; Tam et al., 2017), homes (Read et al., 2018) and hospitals (Jeong et al., 2017) and for different purposes including for therapeutic interventions (Vaucelle et al. 2009; Cibrian et al. 2017), wellbeing and play (Marshall et al., 2015), health and self-monitoring (Simm et al., 2016), education (Bhattacharya et al. 2015; Gelsomini et al. 2019) motor skills (Salivia et al., 2013; Tam et al., 2017) and to improve social interactions and communication (Sampath et al., 2013). For example, Bhattacharya et al. (2015) developed a set of motion-based activities for a group of children with autism in two classroom settings via a Kinect system aimed at promoting social interactions and motor development in two groups of children aged between 8 to 19. Individuals were portrayed on the screen with an avatar or their live images, depending on the mode they choose to play. The live images were found to be preferred by some as it helped them in making a correlation between their real-life mirrored images and their actions. Sensory mismatch could be a further challenge when designing for autistic children because many experiences sensory information differently (APA, 2013). Several studies have investigated the benefits of including school children in the design and evaluation process (Frauenberger et al. 2017; Horton et al. 2012; Read 2015). For instance, Malinverni et al. (2014) used this method to enhance the creative contributions and decision-making skills of children with autism by a process of empowerment in a Kinect-based game workshop. Frauenberger et al. (2017) describe some of the Participatory Design (PD) approaches that researchers could use with children with autism i.e. brainstorming sessions, interviews, collage, low-tech prototyping, fictional inquiry, contextual mapping and co-operative inquiry. However, these approaches, although are critical to designing technologies that promote social integration (instead of social exclusion) and contribute to creating mutual understanding and social inclusion in some children, pose high cognitive demand and require communication and social skills that some of the children we work with might find challenging. Less demanding approaches that address a child beyond their verbal abilities and level of support needs, and in line with our approach, can be positively implemented by using immersive observational approaches (Wilson et al., 2019).

3.1. Sonic Tangibles in SEN

In Special Education Needs settings (SEN), Tangible User Interfaces that use auditory stimuli in the form of music are either in support of motor development (Tam et al. 2017; Cibrian et al. 2017; (Soundbeam Project. Soundbeam 1989), music therapy (Cibrian et al, 2017) or deployed through screen-based interactions (Villafuerte et al. 2012). A recent example of a sonic tangible interaction for autistic children is Polipo (Tam et al. 2017), a toy aimed at developing fine motor skills by promoting engagement, sense of control and cause-effect understanding. The children are rewarded with a preferred rhyme once they finish to carry out an action on the toy. The design development and specific targets follow therapeutic guidelines so that the resulting tangible enables the therapists to check for progress against the set goals. However, Polipo is still based on a 1:1 therapeutic approach where the child is taken out of context to practice playing with a plastic toy for improving specific learning skills. Similarly, BendableSound (Cibrian et al., 2017) is an elastic multisensory surface targeted at developing motor skills in children with autism in support of Neurological Music Therapy (NMT) sessions. Nonetheless, the study is based on a technology designed to resemble a flat soft screen interface and it's a therapeutic intervention based on 1:1 use where children play sounds when touching the screen. We take a critical stand toward using flat screen based tangible interactions as it is believed that the screens take away from behaving socially e.g. decreases eye-contact (Brudy et al. 2018; Zagermann et al. 2016). On the contrary, Cappelen and Andersson (Cappelen and Andersson, 2012) adopt a similar approach to that adopted in this paper and propose the design of novel interactive textile technologies aimed at groups of children with special needs in the form of different musicking objects. The work critiques the limited affordance of traditional instruments and of current music technologies that rely on non-accessible interfaces and switches that disempower the users.

4. TUI Design

Considering that some autistic people enjoy touching soft materials more than plastic, it was interesting for us to combine the soft proprieties of e-textile with the benefits of music into coherent multi-users non-flat designs focused at scaffolding open-ended social playful activities. The design process lasted around 4 months and included: 1) a Formative study design (preliminary research), 2) an Iterative design phase (preliminary design ideas and testing), and 3) an Observational study (tested the prototype 'in the wild'). We focused our design on one semi-spherical shareable multi-users sonic textile tangible interface aimed at offering opportunities to practice social interactions by gathering around one artefact in a circular fashion and also by providing opportunities to self-regulate (Fig. 1). The resulting design was inspired by the children's observations during the data gathering period where we collected a broad range of information about the children which helped create a rich profile of each child (Table 1).

4.1. Participants' recruitment and children's profiles

The Formative study design and Observational study took place in a school based in North-East London, UK, specialized in autism, where the

Fig. 1. Children playing with Olly on day 3

first author previously worked as Teaching Assistant. Parents of the children participating in the research reported in this paper were contacted and informed of the proposed study via the school's administrator at the beginning of January 2019 when information sheets and consent forms were also distributed through the school. All the parents returned the signed documents by the end of January in their child's bag used between the family and the researcher to exchange documents and pictures throughout the study. The Garden school is a specialized provision for 4-16 years-old autistic children that offers a safe and inclusive environment for children to flourish. The Head Teacher and the Dance Teacher recruited and selected the five participating children in December 2018. Three pupils that were part of our previous exploratory study (Nonnis and Bryan-Kinns, 2019a) were re-selected by the Head Teacher while two new boys were added to the group. As summarized in Table 1 to maintain children anonymity we refer to the children as C1 for Child 1, C2 for Child 2 and so on.

The first three children, C1, C2, C3 participated in our previous study. Among the group there were 4 boys and 1 girl (C1). The children's Performance scales – P scales, which define the attainment targets for pupils with special education needs, ranged between P2 to P8 levels while their communication stages, combined by Social partner (SP), Language partner (LP) or Conversational partner (CP) were ascertained from the Social Communication Emotional Regulation Transactional Support (SCERTS) (Prizant et al., 2006), an evidence-based approach used at the Garden school which also inspired our evaluation framework (see section 5). C1 and the researcher had previously worked together on a 1:1 basis and in the same classroom during the researcher's employment at The Garden School in 2015. C2 and C3 were familiar both to the research format and the researcher because they participated in the previous study as well as C1. Although it was reported by the teachers that C4 and C5 shared the same playground space, they never approached one another during playtime, and had never met the other children before this study. There was some concern with C5's behaviors at first due to a developed habit of hitting other children either to get their attentions or to look at their reactions. However, there were plenty of opportunities to monitor the children closely and avoid any discrepancy that could rise from challenging reactions. All children followed regular music lessons in school. C1 participated in their first music therapy lesson the previous term and C5 participated in a drumming session conducted in the same period. Lastly, C4 usually attended the dance lessons of several other classrooms. Children attended school activities with 1:1 support and for this reason, the same level of adult support was requested for the study. C3 was unaccompanied on the 4th session, while every other child came with their TA. C1 also came unaccompanied for the last session as we requested so.

4.2. Formative research: requirements gathering

The first three months of fieldwork were carried out to inform the design of the TUI. Children were observed during Dance and Physical Education mainly due to the fact that the former was the same environment where the study would take place, and the latter was the only place where the children used a choice of physical equipment and tools. This allowed us to make informed design decisions led by the children's preferences and likes. During this period, most of the children showed

Table 1
Summary of the children's profiles.

Child	Likes	Dislikes/Triggers	Support strategies	Age	Gender	P Levels	SCERTS
C1	Tidy, quiet, calm spaces; listening to songs; dance; singing; drawing; mirror; bubbles, dressing up	Crowded spaces; noisy environments; unexpected sounds; fast movements;	Encourage to use symbols or say no if doesn't want something; give space/time	9 9	F	3; 4	LP
C2	Deep-pressure; hugs; soft blanket; familiar routine; being independent; quiet and calm environments; gym ball; scooter; trampoline; spinning; swimming; splashing; shapes; magnet letters; looking and reading books; listening to favourite songs; interactive board; tickles; squeezes	Waiting; changes of routine; cold weather; stop something I'm enjoying; too many changes; not being prepared for new activity; not knowing whereabout of familiar people	Use individual timetable; wait symbol; give big hug; magnet letter and/or reading books for play; use keywords; visual prompts with verbal communication; model communication; walking; give time/space	10	M	6; 8	LP
C3	Manipulates fabric/ribbon; physical contact and deep massage; time in corner to self-regulate; fine motor skills activities; sand and dry messy play; holding adult's arms in transitions, dancing, playing with water and soap; regular play time; independent transitions	Waiting long; noisy environments; communicating without objects; wet clothes and shoes; new people around my routine; working at the table; others to touch my food	Encourage breathing; clap hands together; give a pillow; allow to rock; provide deep pressure; give a ribbon/string; give time; tap fingers, allow independence; follow actions and be playful	10	M	4	SP
C4	Ribbons; running; sensory activities; outdoors activities; playdough; light-up toys; puzzle, interact with adults; foam; music; singing; swimming; being independent; routines; chasing games with adults; messy play; spinners; bubbles; blanket or comfort object; wind-up toys	Being rushed; waiting and taking turns; playing with peers; people touching my feet	Offer symbols to communicate; give choices; ask what C4 wants; give some deep pressure	5	M	2	SP
C5	Bouncing on gym ball; running, chasing, dance lesson, dry food; make choices, bubbles, snacks, facial emotions/ reactions, splash pool, swimming, scooter board, receive attention of peers	PP by adults; not being given space/ time; small spaces; lights on in empty rooms; too much stimuli; lights	Structure a turn-taking activity; model; praise; offer support; offer chasing games/ bouncing on gym ball; give time; redirect him; allow to lay down and rock	5	M	4; 5	LP

sensorimotor seeking and self-stimulatory behaviors. The most observed seeking behavior was deep-pressure touch. The stimulus that the children sought and repeated the most included but were not limited to: deep-pressure (by rolling, sitting, bouncing on therapy ball and/or using different body parts to balance on it, requesting hand-patting or body massage to an adult, self-patting chest and legs, pushing whole body onto floor surface, stomping feet, jumping in place, pillow squeezing), running, tasting (playing with saliva, picking and eating tiny pieces from any surface including floor and walls) smelling, visuals stimulation (hand flickering, head shaking), vocal stimulation (vocal repetition), vestibular (rocking). C1 wore ear-defenders from several months. Whereas these are usually provided to people with hypersensitivity to sound as they work by masking auditory inputs, studies have found that this strategy might actually exacerbate hyperacusis (Stiegler and Davis, 2010). During the class meeting held in the data gathering period the TAs and class teacher confirmed that C1 was "*not annoyed by loud music, on the contrary she enjoys it*".

4.3. Design principles and motivations

Inspired by the literature and children's observations, instead of scattering a series of pieces around the space or having multiple TUIs as in (Cappelen and Andersson, 2012) we designed one big (around 70 cm in diameter) semi-spherical musical TUI. This strategy was used to invite children to join in the play together by sharing space, objects and experiences. In place of offering many modalities of interactions we focused our design on haptic and auditory stimuli. Limiting the output modality and focusing on what we knew children liked enabled us to account for and perhaps minimize occurrences of over-stimulation. The design principles that the design of Olly aspired to address were:

- promote (basic) social interactions: eye contact, proximity, sharing and turn-taking
- stimulate independent and social play
- provide sensory regulation
- build on children's past experiences, likings and preferences

We choose to design a semi-spherical technology to enable social interactions to take place effortlessly because circular configurations facilitate natural communicative and collaborative mechanisms providing a mean for socialization (Luff et al., 2013). Furthermore, round shapes convey positive meanings whereas shapes formed by acute angles are perceived more as a threat (Larson et al., 2009). When designing a system aimed at groups of people, to facilitate socialization and enable same rights of participation around a technological device, a principle of shareability should be addressed (Hornecker et al., 2007). Two main concepts, entry and access points, should be considered when designing shareable interfaces. The former allows people to plan their approach by providing an overview of the system and entice them with a point of attraction or honey pot effect aimed at stimulating active interest and minimize barriers to access. The latter refers to characteristics that enable a group activity to happen i.e. afforded by a combination of perceptual access (enabling social awareness), manipulative access (enabling active interaction), and fluidity of sharing (enabling easy flow of interaction). To achieve these goals, we designed the TUI to recreate the illusion of an imaginary space around where interactions are often organized (Kendon, 1990), and around which children could meet together, tolerate each other's proximity, practice sharing skills, turn-taking, joint attention, eye-contact and other social activities as they liked. According to theories of embodied interactions (Kendon, 1990), body orientation and the configuration of the space contribute to social interactions in different ways. In Kendon's F-formation for instance, social interactions organize through a spatial-orientation system called the O-space, maintained to grant the same access to all parties involved in the interaction and jointly manage their attention. The O-space is specific to human-human communication. It may take a variety of shapes (facing each other; L-arrangement; side by side) and depends on different factors such as the numbers of participants, the arrangement and layout of physical space and the type of activity. The position of the participants also pinpoints their speaking rights and their agency within the group of participants. The O-Space seems to address the perceptual access aspect of the principle of shareability (enabling social awareness) as well as that of fluidity of sharing.

The design of Olly (Fig. 2) reflected these principles by offering a clear *overview* of the technology in its environment; using colors, textiles and the sonic output to create a *honeypot effect* that alongside its shape and circular design aim at fostering social awareness and enabling *perceptual access*. Furthermore, the size and the form including its *access points* i.e. the sensors and their materiality such as the elastic ribbons and felt, aimed at enabling *manipulative access* and *fluidity of sharing* while still *minimizing barriers* to access. To facilitate children's appropriation of the artefact, the design of the TUI borrowed the concept of *Opera Aperta* (Eco, 1997), which resonates with those of ambiguity and design for pleasure detailed in HCI by (Gaver, 2002; Gaver et al. 2003). For Eco "The *work of art is a fundamentally ambiguous message, a plurality of meanings that coexist in a single signifier*" and it's a "*dialogues between form and openness*". The *Open Work* offers therefore the idea of an open design rather than a finished one, that it's open to interpretations and appropriations and completed by the people that interact with it (Eco, 1997). These approaches were adopted to enable children to have a positive experience and to facilitate agency and freedom of expression beyond current PD practices (Frauenberger et al., 2017; Malinverni et al., 2014). Accordingly, the study explores the effect of embedding stretch sensors in a sonic textile TUI on a) children's sensory regulation, and b) on children's social activities.

4.4. Iterative prototyping

The decision to design a system that used stretch sensors was informed by some of the children' likes and preferences and driven by the manipulative properties of textiles. During dance lessons it was observed that one child particularly enjoyed participating in the session with the Stretchy Band™ used for encouraging group activities. This preference particularly influenced the design of Olly. Lastly, from the data collected it was noted that most of the children liked or needed access to a blanket, pillow or to any type of textile material either to cuddle up to, to receive comfort from, to dress up or fiddle with. Similarly, to our previous study (Nonnis and Bryan-Kinns 2019b, 2019a), we designed the sonic interactions around harmonic sounds. The music choice was influenced by the children's observations during P.E. when children were invited to relax for few minutes by listening to some music playing the Hang online. The Hang plays 8 notes, seven of which are harmonically tuned around a central tone. We noticed that all children were enchanted by it and were all very calm, present and positive. For this reason, we choose to design a tangible that would allow to trigger different chords (triads) made by different instruments each based on

Fig. 2. Three children gathered around Olly in the Dance studio of the Garden school.

the C major key. We worked with the on-board Midi functionality of the Bare Touch Board, so we choose similar sounding instruments to that of the Hang from the available General Midi Level 1 Instrument Sounds bank i.e. an acoustic piano, a vibraphone, guitar harmonics, and an electric bass. The purple ribbon played Dmin, the green played Gmaj, the blue played Fmaj and the orange played Cmaj. We decided to have an enhanced sonic experience emerging from the collaboration of more players and given by the harmonious choice of sounds and the more complex sound arrangements. Furthermore, Olly affords "heavy work" which in combination with the choice of music aimed at offering a calming and relaxing experience counteracting the potential anxiety levels that could arouse from participating in a shared experience. Due to size restrictions we were unable to place 5 ribbons on Olly, which would have matched the number of children but in our view deprived them of the possibility to maintain their personal space. Therefore, we decided to put four sensors to enable enough personal space even when playing together.

4.5. Physical design

Olly is made by using an inflated therapy ball placed on a 3 mm felt sheet which forms the base of about 150cm x 150cm (Fig. 3). The ball is wrapped in 3 mm felt sheets cut to shape to adhere to the semi-spherical body of the installation. This is topped with 4 elastic colored Lycra ribbons sewn onto the round cover itself placed on the top of the ball.

Embedded inside each ribbon there is one stretch sensor connected to 4 analog inputs of a Bare Touch Board via conductive threads. The ribbons play different instruments and as they get pulled each of them activate a progression of 8 notes which goes higher in pitch. This enable to play soothing melodies when playing in solo-mode while when more ribbons are pulled together pleasant harmonies emerge from the collaboration (Fig. 4).

We used industrial felt to create a smooth surface around the ball. The two layers of felt (top-bottom) are secured together by strips of Velcro (hard to the bottom; soft to the top) (Fig. 3). At the base, in between these two layers there are 5 $\times$ 5kg ankle weights placed around the perimeter to stabilize the ball. An additional inflatable stability ring is secured to the bottom of the ball to prevent it from rolling around when the ribbons are pulled. The circuit is placed on the base in between the weights that are spread around it. The box is located behind the Minirig speaker.

The circuitry is powered by a 3.7V lithium battery enclosed in a wooden box and it's connected with a 3.5 mm audio cable to a Minirig speaker enveloped in a felted pouch and placed on the base. The ribbons are sewn onto some white elastic bands themselves stitched to the inside of the round cover top (Fig. 5).

Fig. 3. Base with felt attachments (top); bouncing ball (bottom left); felt ball cover

Fig. 4. Olly in the maker space at QMUL

5. Observational Study

The semi-structured format of the study was based on educational approaches and aligned with practices used at the school. The study's sessions ran every Thursday afternoon for 5 weeks, from 2:15 pm to 2:45pm, in the Dance Studio of the Garden School. Parental consent was received prior to the study implementation as described earlier. Olly was tested with a group of five children aged between 5 to 10 whose attended different classrooms (Table 1).

Using, the Picture Exchange Communication System (PECS) (Bondy and Frost 1994) we prepared a social story to facilitate C4, to be introduced to the new activity with Olly during the holiday. Social stories are pictures-based stories that tell about events that happens or are about to happen in a child's life. These usually help some children with anxiety to process and accept new information and breaks in routines. Symbols and Object of Reference for the children's timetables, social stories and their transitions were made before the study commenced. As further explained below, we used a mix of educational interventions to enable children to have the optimal experience from when they transitioned in the space to when they transitioned out of the space.

PECS is a system of visual and verbal communication (cards or symbols) implemented to facilitate understanding and emotional regulation and promote independent communication. In our study PECS and Objects of Reference where created specifically to represent Olly. The activity with Olly was divided in 8 phases: *Shoes and socks off, Hello, Under the cloth, Touch and listen, Interaction, Celebration, Finish, Good bye.* There was a timetable attached to one of the walls in the room where children could see the schedule of the session and gain an overall sense of its duration. The symbols were moved from a red background over a green one as soon as one phase finished. The red/green division signaled that a particular activity was currently happening or finished.

Similarly, the SCERTS Model (Prizant et al. 2006), an acronym that stands for Social Communication, Emotional Regulation and Transactional Support is a) an educational framework used to develop targets especially in the areas of communication and self-regulation and encourage children to be competent communicators, and b) an assessment tool that helps to identify developmentally appropriate goals. The SCERTS defines three communicative stages for children with autism: Social partner (SC $<$ 3 words), Language Partner (LP $>$ 3 words) and Conversational partner (CP $>$ 100 words + 20 combined creatively). As seen in table 1 our children covered the SP and LP communicative stages. Lastly, another intervention developed by UK based Gina Davis, a specialist speech and language therapist, is Attention Autism (AA). AA aims to foster children's attention and communication skills by offering activities that inspire the child's engagement and consequently develop shared experiences that is worth communicating about (Davies, 2017). Consequently, we adopted this approach to attract children's joint attention during the introduction phase to Olly and to provoke curiosity.

Fig. 5. Sensors embedded inside the ribbons; Speaker; Olly's circuit box; Sensors combined together

5.1. Study set-up

Upon entering the Dance studio children were encouraged to sit on the bench placed against a wall of the room, and to take shoes and socks off (as per Dance lessons). A black drape was pulled in front of the bench to divide the room in two places, 1) to welcome the children, 2) to play with Olly. The tangible was on the opposite side of the curtain, in the middle of the room and it was covered by a cloth laid over it (Fig. 6).

It was revealed to the children over two times 1) by opening the black drapes after the children said hello and 2) by uncovering Olly from under the cloth at the end of a song inspired by the Attention Autism practices used in school. To model and stimulate the interaction after the song finished, the teacher played with Olly and waited for the children's responses. If the children showed spontaneous interest by approaching independently the TAs would not offer any support, whereas if the children needed some encouragement the adults would come and play with Olly and/or offer some prompts in the form of spoken language, gestural cues or physical contact. The study was recorded using two mini cameras, one attached to one of the walls and the other one on top of an existing cupboard used for storage. A third hand-held mobile was used by the researcher to record the children's impression from when they entered the studio and for the duration of the hello, as the view of the cameras were obstructed by the curtain being pulled.

5.2. Analysis

Evaluation was carried out using the framework (Table 3) developed in our previous study for a different TUI (Nonnis and Bryan-Kinns, 2019a) combined with an adapted version of Parten's play stages (Table 2) (Parten, 1932). Inspired by the SCERTS assessment measures, we adopted some of the key areas tracked within the Social Communication domain and the Emotional Regulation domain of the SCERTS (Fig. 7).

Fig. 6. Olly about to be uncovered after the Attention Autism inspired song

For example, the way that children gazed at people, initiated interactions, requested comfort, shared attention and emotions are all domains of interest in the SCERTS model. Our evaluation guidelines are mainly theory-driven and were based on the SCERTS as well as on the school teacher's assessment forms, especially some key areas within the fundamental skills and the cooperative skills domain of the P.E. and dance lessons' assessments.

The teacher evaluated each child independently, whilst each TA tracked the child they worked with. A mix of data was gathered for an in depth analysis. These includes, pre and post-study interviews, children's profiles , extra notes and the annotations of the video analysis carried

Table 2

Themes	Definitions	Analysis
Theme 1 (T1)	**Look interested** in the presentation of Olly (teacher Attention Autism)	Time each child spent: showing signs of interest towards the introduction of Olly by looking at it
Theme 2 (T2)	**Approach** Olly	Time each child spent: approaching Olly independently (I), or receiving gestural/verbal (GP/VP) and/or physical prompts (PP)
Theme 3 (T3)	**Pull to activate sounds**	Time each child spent: playing sounds independently (I), receiving gestural/verbal (GP/VP) or physical prompts (PP)
Theme 4 (T4)	**Music making** together	Time each child spent: playing music together with peers, by themselves or with adults
Theme 5 (T5)	**Show use of Olly for else than playing notes** (i.e. deep-pressure, climbing, squeezing, patting etc.)	Rate of occurrences of different actions performed by the children when using Olly other than to trigger sounds
Theme 6 (T6)	**Share emotions**: express appropriate emotions, able to self-regulate	Time each child spent: displaying emotions i.e.: *positive, negative, giggles/over-excitement, vocalizations, running, jumping, playing around/hanging from curtain etc.*
Theme 7 (T7)	**Eye-contact**	Instances of eye contact between peers and child-adult.
Theme 8 (T8)	**Play Types**	Time each child spent: exhibiting different types of social play such as those in Table 2

Class: Ivy Name of child:	Area of learning	Cycle 5		Year: 2019		
Extra notes:	Social Interaction and collaborative Play	Week 1	Week 2	Week 3	Week 4	Week 5
	Looks interested in the presentation of Olly (Debbie Attention Autism)					
	Approaches Olly with confidence					
	Pull to activate sounds					
	Plays notes together with peers or partner					
	Shows use of Olly for else than playing notes (e.g. deep pressure; patting; squeezing; climbing etc)					
	Share emotions: express appropriate emotions (pleasure/calm) and he/she is able to self-regulate					
	Share attention: When not in Olly's proximity, shows attention towards others interacting with Olly and follows what's going on					

Tracking according to independence see guidance document below

from dependent **Prompting** *to* independent				
Learners complete tasks independently				
Full/Total 100% 1	Substantial/A lot 75% 2	Some 50% 3	Minimal 25% 4	Independent/None 0% 5
Not achieved		Partly achieved	Achieved	

Fig. 7. Tracking sheet and 5-point rating system

out using ELAN Software.

Throughout the study the dance teacher and the TAs weekly completed their tracking sheets in relation to seven themes (Fig. 7). For the video analysis, we decided to change T7 Shared attention to T7 Eye contact to better identify instances of eye-contact between children (Table 2). This was important for us to determine what level of social behaviors happened around Olly.

Annotations with logs of timings enabled the researcher to calculate the amount of time that certain behaviors and emotions were exhibited by each child and enabled an understanding of children's engagement . This time-based approach facilitated a quantitative approach to the analysis. We recorded time logs of each activity and converted all the times into seconds. We then calculated the percentages as proportions based on the individual attendance of each child and on the amount of time that they spent approaching, playing with Olly, looking at Olly and even sharing emotions. The themes (T) analyzed during the video recordings were checked against each child and are described in Table 2.

A combination of deductive and inductive thematic analysis was applied to the annotations of the video recordings following a qualitative inquiry approach inspired by Heath et al. (Heath et al., 2010) and based on the tenets of embodied interactions such as facial expressions, body posture, positions, gazes, shared objects and shared spaces.

The themes helped contextualizing the annotations' procedure of the video analysis. Sections of each videos have been selected on a visual timeline of the ELAN software, an annotation tool for audio and video recordings. Inside each selection we noted a brief description of what happened within that time. For each session we were able to identify for how long a child did something, what they did and in relation to what/who. Analysis was undertaken on the video recordings of the entire sessions for each of the five weeks of all the five children. Starting from a set of themes which were mostly theory driven the analysis included other recurring sub-themes i.e. levels of prompts, types of uses, types of initiated interactions and refusals to join in the play. Lastly, the researcher was always present throughout the sessions . This helped addressing practical issues such as limited camera angles during the hello part.

Table 3 describes the categories of play (T8) and the definitions we used. In addition to Partens categories from our analysis we observed and included other types of behaviours that children exhibited when not playing such as Child-initiated seeking of adults (CISA), Child-initiated affectionate interaction with adults (CIAA), Pro-social interaction and positive response (ProS +) and Pro-social interaction with no response (ProS -), Refuse to Join (RJ), Competitive play and Turn Taking.

6. Findings

We conducted five sessions with an average session length of 23 minutes and 58 seconds. Within this time an average of 54.6 seconds were spent introducing Olly to the children. Due to a technical fault on the fourth day Olly was tested for a period of 23.11 minutes without sound. The teacher started as usual using the same methods and excitements as per the previous sessions. Nevertheless, at the entrance of the Dance room we attached a message at the door to inform the TAs that the technology was broken, and some children might have read that message or possibly heard their TAs when reading it before entering. We reported this in percentages of time spent per type of play by child as we believe this time-based analysis offers a comprehensive view on the type of play that children displayed the most, which in turn gave us an indication on what types of play Olly supported the best. If we were, for instance, just to count the number of occurrences, in our view the results would not be fully representative in certain cases of how much a child spent doing something which we interpret to mean that they enjoyed doing that activity. In the following sections we'll present the analysis of our findings using a mix of quantitative and qualitative approaches. T1

Table 3

Categories of Play *(adapted from Parten 1932)*	Definitions
Unoccupied (U)	Child plays with own body/clothes, goes off/ on bench, stands around, sits in corner, fiddles with string/symbols
Onlooker (O)	Child looks at other children but does not participate. This can be performed from beside people or from far away.
Solitary (S)	Child plays alone by doing imaginative play by vocalising on their own and running around/ wiggling body, making funny body movements, spinning around the room, running around the space and or behind curtains. Child can also play alone with Olly.
Parallel (P)	Child is next to peers using Olly in different ways than that displayed by their peers i.e. touch felt and/or ribbons, speaker pouch, steps on speaker etc. Plays beside peers rather than with them.
Associative (A)	Child displays identical or similar activity (watching, copying). Children act as they wish, and the activity is not organised but there is a sense of togetherness and belonging
Cooperative (C)	Child actively engages in same activity. There are not spoken rules (child might sign to communicate to peer), but children influence or modify activity of others. There is a sense of belonging.
Child-initiated seeking of adults (CISA)	Child approaches adults to satisfy a sensory desire i.e. requesting legs massage, deep pressure on body parts, touching adult's ear lobes, armpits etc..
Child-initiated affectionate interaction with adults (CIAA)	Child approaches adults to request for comfort i.e. lays on adults laps, strokes adult face or body parts, leans with body on adults, hugs, caresses.
Pro-social interaction and positive response (ProS +)	Child initiates a social interaction and receives a positive response by peers or adults
Pro-social interaction and no response (ProS -)	Child initiates a social interaction and receives no response by peers or adults
Refuse to Join (RJ)	Child clearly avoids being prompted to Olly or offered a ribbon
Competitive (Cm)	Child clearly displays a competitive spirit i.e. by taking ribbons off adults' hands or pushing a peer away from Olly.
Turn-taking (TT)	Child clearly waits for his turn when other peers are on Olly.

to T6 give illustrative and quantitative examples of how children responded and reacted around Olly while T7 and T8 are more descriptive of the play types and interactions that occurred between children.

6.1. T1 Introduction to Olly

To understand the level of children's engagement at the beginning of the session, we observed the direction of children's gazes, body orientations and behaviors exhibited in each session.

These data are reported per child in the graph above (Fig. 8). To calculate the percentages all the times logged have been converted into seconds. We calculated the length of T1, from when the children did the hello to the end of the song inspired by Attention Autism when the teacher unveiled the TUI. The percentages have been calculated over the daily introductions that the children attended. Children were expected to sit down during this part of the activity and the teachers often prompted them to wait on the bench until Olly was uncovered. On day 1 C3 arrived later and missed the introduction. Children looked at this part of the session with interest. We knew from previous class interviews that some of the children found it difficult to follow Attention Autism activities in their regular classrooms, hence we considered this result positive. For example, C2 class teacher said that *"He does have concentration issues" and "you need to grab his attention"*. At the beginning of the study C4 was unable to sit and wait during the introduction and most of the times needed physical prompt to wait while as the sessions progressed he was able to sit for longer. Nonetheless, we interpreted their unwillingness to sit/wait as a positive sign because, a) they were the youngest in the group (so not used to the concept of waiting yet) and b) they wanted to play with Olly straight away which we took as a sign of their interest toward Olly. As we can read from C4's teaching assistant feedback on day 4 it seems that although the child had a difficult day, as soon as they arrived at the session they manage to engage more than during other activities of the same day *"After a slightly difficult day (changes in routine, little accident, less outside play) he was able to wait more on the bench for "Hello""*.

6.2. T2 Approach Olly

Here we checked how much time the children spent approaching Olly. Following theories of proxemics (Hall, 1966), we considered it an approach when a child was less than around 150 cm far from Olly. The approach' times have been calculated over the daily times of the sessions minus the introduction times (children were asked to sit down for that part) (Fig. 9).

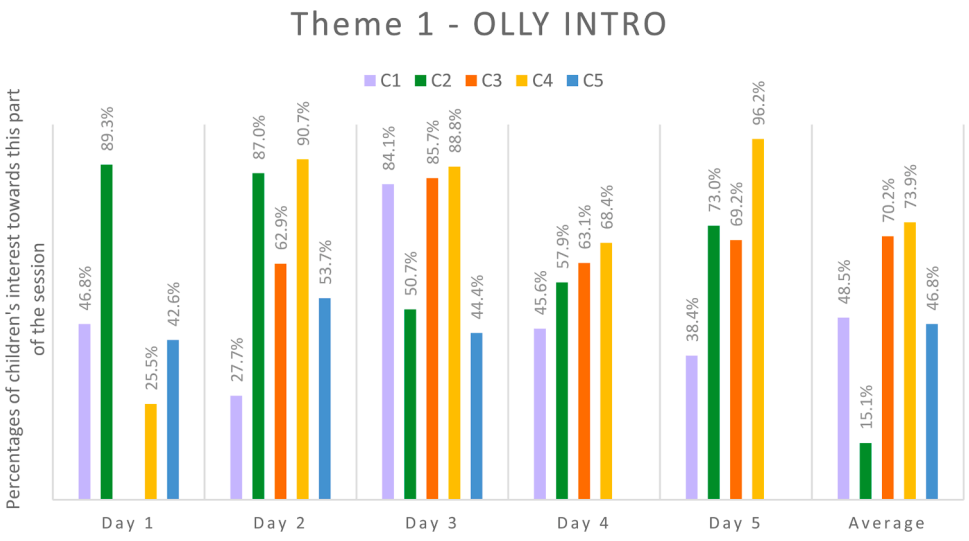

Fig. 8. Theme 1. Graph showing percentages of daily interest towards T1 per each child

In general, it seems that Olly was enticing to the children and offered good entry and access points. The Dance teacher wrote that *"The cloth was perfect for C1 to interact with pulling with 2 hands wrapping the cloth around her waist.* . It was confirmed by the class teacher and TAs that C1 "*needs physical prompts to participate and lots of encouragement*". The last day C1 was stopped while playing independently because the session ended and sought adult's attention for an average of 7.3% of their approach's time which indicates that the majority of the time that C1 was in Olly's proximity they were engaged with it.

Interestingly C2 approached less on the last day. However, it's important to notice that they were very excited of the holiday half-term starting the following day. C2 often sought adult's attention during their approach's times (average of 26.4%), particularly in session four and five.

C3 is the child that approached less among the children who always attended but they did so more independently. Perhaps C3 did not approach much because as the class teacher stated "*C2 was on top of Olly, C3 wasn't feeling comfortable and was waiting. When C2 moved from Olly, then he was approaching with confidence.*" C3 also sought adult's attention during their approach times for a total of 6.7%. This was mainly in the form of requesting hand massage on their legs. Feedbacks in the post study interview with C3's class teacher read *"He likes to stretch. He liked the feeling. He was also really interested in the vibration of the speaker because he was putting always his feet on top"*.

C4 TA's commented after day one "*C4 was eager to interact with Olly. [..]He amazed me with his brave initiation to go and explore Olly first of all kids in the middle of the room*". C4 also sought adult's attention during their approach (average of 10.4%), mainly in the form of cuddles when it seemed they needed reassurance (i.e. when C5 tried to hit him) or to touch the TA's ear-lobe, which we knew it was something C4 liked doing. However, C4's TA said after day three "[C4] *spent a balanced time with playing with peer and came back to Olly pulling string*" Importantly, C4 played with C5 for an average of 50.6% of their approach times (day two, day three) i.e. by running after each other around Olly. Day 4 is the session that C4 sought most adult's attention when around Olly which interestingly is the day that the sound was off.

Finally, C5 spent most of their independent approach times (when not playing with C4) seeking their TA's attention and this was exhibited through lovely interactions of affection towards her especially when C5 was perhaps getting overloaded by playing with C4. Within their approach times C5 spent an average of 66.7% running with C4 around Olly. C5's TA reported after day 2 that "*C5 played with Olly in short bursts […] mainly ran around with another child [..]*".

6.3. T3 Play to activate sounds

Within the total times that each child spent approaching Olly we checked how long each child played with Olly in order to trigger sounds by pulling the elastic ribbons. This point was the most difficult to assess and further research is required to understand to what extent children interacted with Olly to play music rather than to play with the elastic ribbons. We assumed that if a child would play by themselves or with others and with Olly by pulling the ribbons and creating music, and they did so repeatedly and perhaps smile after their actions the purpose was that of creating music. The graph below (Fig. 10) shows the daily percentages of sounds triggered by each child for each day calculated over the daily approaches of each child. If they triggered the sounds just sporadically we did not take that into account as a purposeful music playing endeavor but rather as an appreciation of the elastic properties of the materials used (T5).

Most of the children played music by wrapping the lycra either around their necks or around their waists and touching it while moving back and forth. After week 3 the teacher wrote "*C1 independently wrapped the Lycra around her waist touching back and forwards*". In week 4 she reported that "*C1 was very engaged and calm on arrival-ready to play with Olly"* but added that *"Once she realized there was no music […] she became unhappy*". C1 left the room after crying very loudly as it seemed that the absence of sound upset them. On the other hand, C2's TA reported that "*C2 was very curious about Olly and explored well. C2 enjoyed laying over the top and rocking*". In fact, we noticed that C2 rarely grabbed the ribbon to activate sounds but they were able to trigger sounds by rocking on Olly as the ribbons got caught between the base and the ball. C3's teacher however thought that they still didn't understand cause-effect and was not sure if the child pulled the ribbons to trigger the sounds *"I think he was stack [sic]in the point of, oh I can pull this, it wasn't like cause and consequence because his development. […] it was a sensory experience."* Conversely, the dance teacher reported at the end of the study that all the children understood the cause-effect interaction "*I*

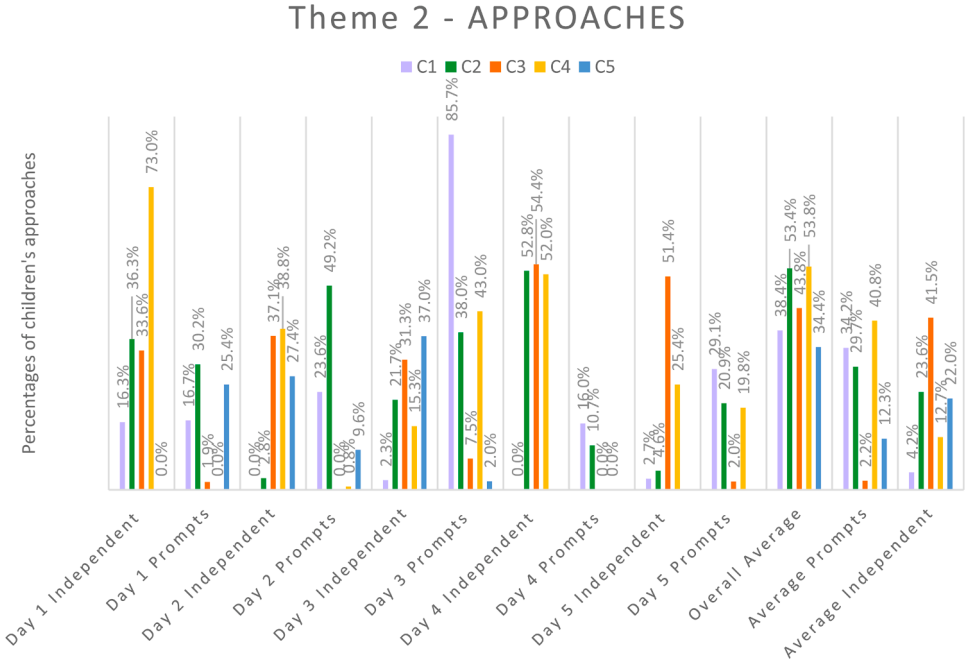

Fig. 9. Theme 2. Graph showing percentages of daily approaches demonstrated by each child

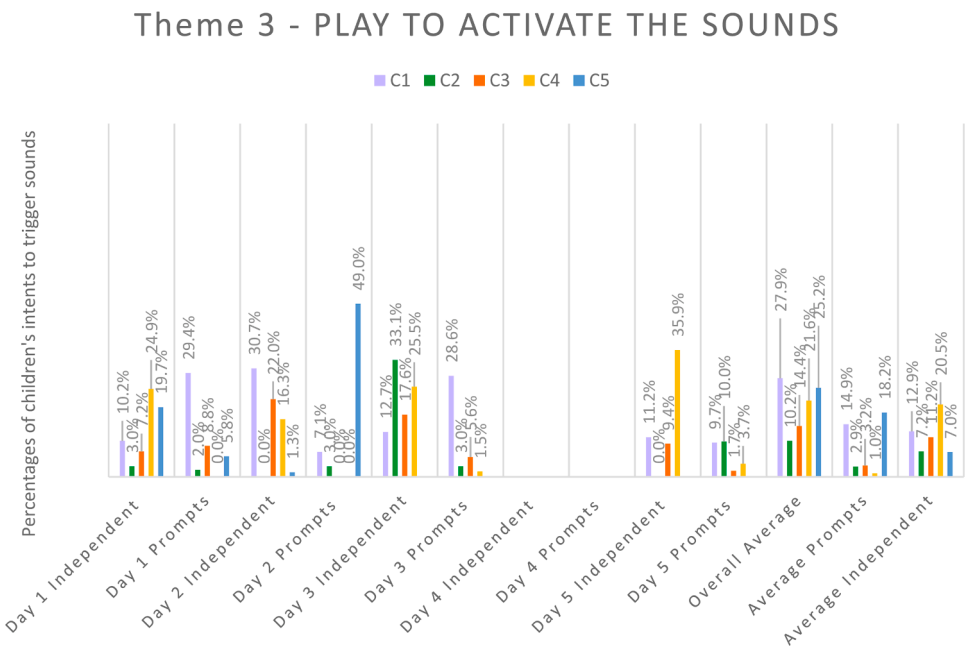

Fig. 10. Theme 3. Graph showing percentages of daily sounds activations counted per child

believed that they had worked out that the music came when you manipulated the cloth." C4 TA's feedback after the first day reads "*He pulled the cloth. Placed his body inside the cloth. C4 explored the cloth with C5 running around Olly*". After the third day she wrote "*C4 returned to Olly many times – touching Olly gently*". On day four, C4 created sounds by patting on Olly's body alongside a TA and communicated vocally when they wanted her to stop patting on it (see T8). We took this as an indication of C4 missing the music as they were the child that played the most independently. Finally, C5 explored all the ribbons and span around Olly holding the elastic and making music with two peers (C4 and C2) especially on day 1. The teacher stated after the second day that C5 "*was eager to touch Olly* […] *C5 and C4 laid at the speaker touching and listening*". In the three sessions they attended C5 never had the chance to play solo and this might have impacted their understanding of the cause-effect interaction.

6.4. T4 Music making together

Among children's play times we analyzed how much of it was spent playing together with peers, with adults and/or solo. The latter helped us identify which children had the chance to understand that the sounds were created by their own actions. Figure 11 (Fig. 11) shows the daily combined percentages of children playing together which include playing solo, with peers, with adults or with both peers and adults. These are calculated over the daily approaches of each child.

C1 played the most with both peers and adults on day 3 which is also the same day that they received most PP, while during the last session C1 played mostly independently the most indicating that with more time they could have mastered the use of Olly. During the pre-study class meeting it was reported that *"C1 would not share spontaneously"* and that they would not initiate interactions. As C1 shared Olly with several peers more than playing solo, this result was appreciated because we saw

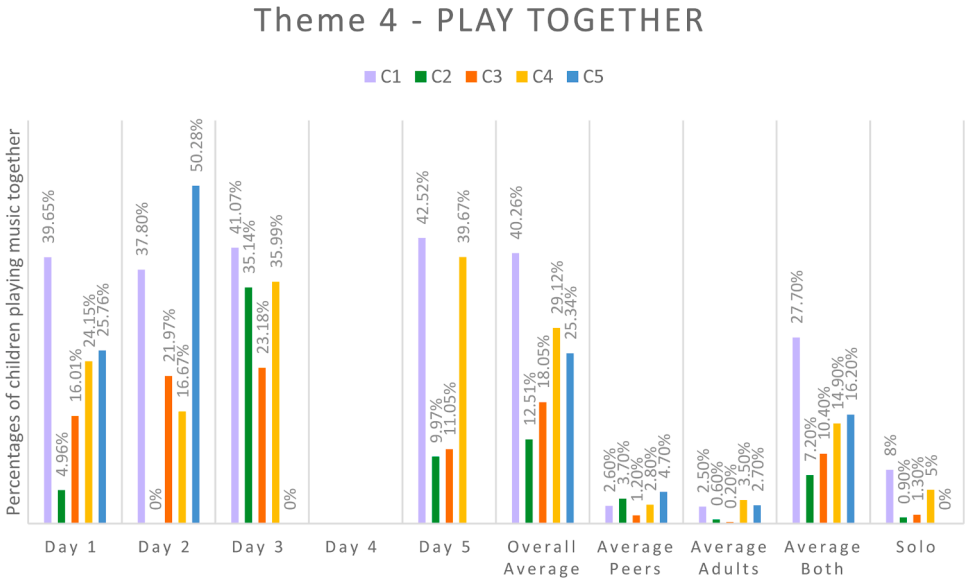

Fig. 11. Theme 4. Graph showing percentages of children playing together shown daily per child

sharing skills perhaps not exhibited in other school contexts. Similarly, in the post study interview the dance teacher confirmed that this was a good experience for C2 because "*To share space is very new ideas for C2*". The last week C2 "*wrapped the Lycra around his feet the same time as C3"* and for the dance teachers *"watching this brief interaction was wonderful."* The Dance teacher added "*I think that C2 was much better than he'd ever been […] You never really get him in that close proximity with others. He's always on the perimeter, but he did that a lot.*". C3's class teacher wrote after session 4 that "*C3 was more confident with less students in the room*". However, although she confirmed that C3 was not used to play with peers or to share a toy she added *"I think he really, really liked Olly, because he's always by his own, you know, he's not really sharing with anyone at least here in the school."* and after day 3 C3 "*enjoy[ed] the other children's games*" and joined in by pulling the ribbons and coordinatively releasing when C4 and C5 were passing by to chase each other around Olly. C4 and C5 developed a sort of friendship while playing chase around Olly. said C4's TA after day 3 and continued *"in early years playground he found it difficult to play with peers*." Contrarily to the other children C5 never played solo and was absent for the last two sessions missing the day that Olly was not working. This makes it harder for us to see if they would have reacted differently without the sound interaction.

6.5. T5 Novel uses of Olly

Theme 5 looked at the different ways that children interacted with the TUI without triggering sounds. The types of creative uses performed the most are listed in terms of number of instances exhibited (xNumber) by each child and displayed in (Fig. 12).

When designing Olly, we envisioned multi-uses for interacting with it i.e. that of providing belly pressure by laying on it and hand/arms pressure by pulling the ribbons. However, children displayed a variety of novel interactions and expressed their adaptation to and appropriation of the piece. The actions displayed by the children were combined and coded under the umbrella term "creative use". By creative use we mean any use that was not meant to activate sounds i.e. jumping on or holding the ribbon without (or randomly) playing.

For example, C1 used Olly for an average of 42.7% of their approach times. The actions C1 performed the most were: keep ribbon around waist (x18), manipulate the ribbons (x14), tuck feet in between the bottom of Olly's body and the base (x11), keep feet up on Olly (x10), touch the speaker cover (x6), sit/walk on the base (x5), wrap feet inside the ribbons, and touch the felt, and pressing Olly's body (x2), and lastly with just 1 instance each she looked at circuit box, and held ribbon under armpits, and stroked fabric on face.

C2 spent an average of 59.5% of their approach times interacting with Olly and he's the child who used it the most for novel purposes other than that of playing music with it. C2 exhibited the following behaviors in descending order of instances of occurrence: lay on Olly and balance on Olly's top using knees (x23), bounce on Olly (x19), sit on Olly, and rock/swing, on Olly (x15), sit/walk on the base (x10), touch the speaker (x8), manipulate the ribbons (x7), press/push Olly's body (x3), touch the felt, and keep feet up on Olly (x2), pat Olly's body (x1).

C3 displayed a novel use of Olly that average to 53.7% of time. C3 is the only child who attempted to (and did) move Olly to a different place of the room by pulling the ribbon strongly and sliding the whole installation across the floor. This unfortunately affected the responses of

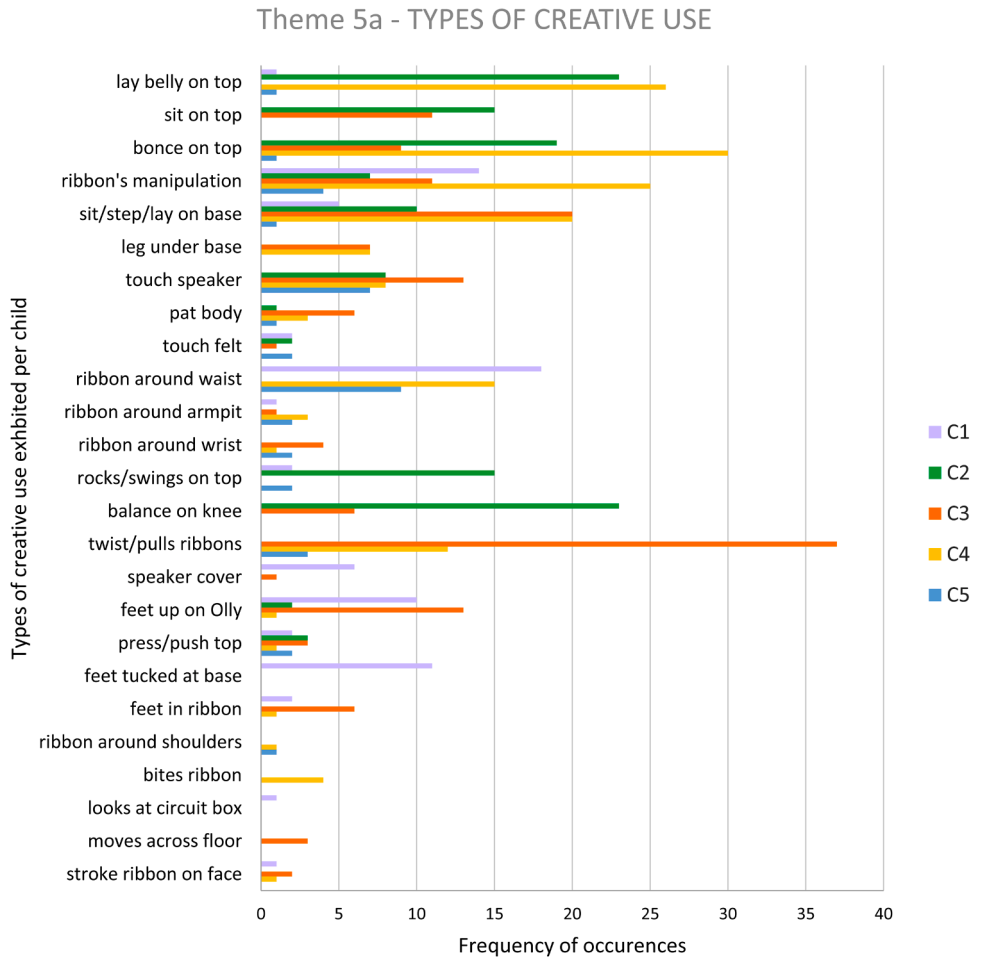

Fig. 12. Theme 5. Graph showing types and quantities of total creative use of Olly per child

some of the sensors pulled to move Olly around. C3 mostly displayed: twist and pull the ribbons (x37), sit/walk on the base (x20), touch the speaker, and keep feet up on Olly (x13), sit on Olly, and manipulate the ribbons (x11), bounce on Olly (x9), cover legs under the base (x7), pat Olly's body, and balance on Olly's top using knees, and wrap feet inside the ribbons (x6), press/push Olly's body, and move Olly across the room (x3), stroke fabric on face (x2), touch the speaker cover, and the felt (x1).

C4 used Olly in novel ways for an average of 40.1% of their approach times and mostly demonstrated the following uses: bounce on Olly (x30), lay on Olly (x26), manipulate ribbons (x25), sit/walk on the base (x20), keep ribbon around waist (x15), twist and pull the ribbons (x12), touch the speaker (x8), cover legs under the base (x7), bite on ribbons (x4), pat Olly's body, and hold ribbon under armpits (x3). C4 also kept their feet up on Olly, and pressed/pushed Olly's body, wrapped the ribbon around their shoulders, and wrapped their feet inside the ribbons once throughout. The dance teacher said "*C4 really liked that because he loves the ribbon in dance (*Stretchy Band*), and I also liked the way he stepped into it. Put it around his waist [..] That was a lovely thing to see him getting some kind of regulation around his abdomen"*.

Lastly, C5 displayed a novel use of Olly (average of 51% of their approach time) and exhibited the following actions: keep ribbon around waist (x9), touch the speaker (x7), twist and pull the ribbons (x3), touch the felt, and hold ribbon around wrist, and rock/swing on Olly, and press/push Olly's body (x2), and to conclude lay on Olly, and bounce on Olly, and sit/walk on the base and pat Olly's body (x1). C5's TA observed that *"pulling was good for him [..] because he likes the pull he likes the actual motions of doing things […]it was quite good because he could go back a bit."*

6.6. T6 Share emotions

As described below, all the children expressed a mixed range of emotions throughout the duration of the five sessions. The graph (Fig. 13) shows the overall combined amount of emotions that each child exhibited each day over the duration of each session and includes children's repetitive behaviours such as twiddling with strings, rocking, hand flapping, stomping, and spinning. These were calculated from when children took their shoes off for the introduction to when the TUI was covered again at the end of the session.

Most of C1 shared her emotions were vocalizations in the form of echolalia and solitary imaginative play. However, C1 was also singing, usually alongside the music triggered by people playing with Olly and or just after the music was played. When the sound was off on day 4, C1 sang the less and exhibited most negative emotions. For negative emotions we coded any sound that had a negative connotation to it i.e. moaning sounds (which were usually followed by smiles as C1 was perhaps PP to Olly) but also distressed/loud shouts. As later explained by the Dance teacher in day 2 C1 left and came back because "*she had needed a drink of water and toilet [..]*." Positive emotions were in the form of visible smiles and other behaviors such as touching adults' body parts often around and under their arms, playing with a thread found on the floor and chewing on it (day 5).

C2 expressed high arousal and over-excitement such as vehemently patting hands with the teacher, clinging on her back, pressing and/or manipulating body parts especially under arms. At times C2 asked an adult (usually the teacher) to press their head but more often C2 sucked their thumb and was visibly calm. Rarely they would keep their eyes closed perhaps to block out some of the visual stimuli. C2 never displayed a negative emotion. C2 started manipulating adults' body parts (arms and hands) from day 3 and particularly on the last day when indeed they also approached Olly for less time. "*C2 became quite over-stimulated"* reported the teacher. However, she said that *"the vibrations from the music calmed him down*." After day 1 she wrote "*C2 was engaged and able to follow instructions*" and on day 3 she reported "*he was singing, calm and relaxed*" while after the study she confirmed that "*he really did explore and self-regulated himself"*.

C3 shared positive experiences by visibly smiling and they vocalized in the form of sounds. C3 also manifested negative emotions on day 1 and day 3 but these where in response to being PP to Olly by an adult. As we could read from their documents during the formative stage of the study important to C3 was "*being independent*". This might have reflected in their reluctance to being physically prompted. Often C3 sucked their thumb, requested a leg massage or would hang from or be around the curtains. They would spin and twist a string and once in day 4 they pulled their trousers off. At times they stomp their feet. Comments from the dance teacher reads "*C3 moved in the space confidently (that was amazing as C3 is an anxious student who needs a great deal if support).*" Feedbacks in the post study interview with C3's class teacher who accompanied the child to the sessions read "*he was feeling happy and safe [..] he was feeling comfortable with the space and, with us."*

C4 expressed negative emotions through visible signs of distress i.e. laments because the TA prevented C4 to touch her ear lobes or visible distress as C4 could not wait sat for the intro to be finished. However, C4

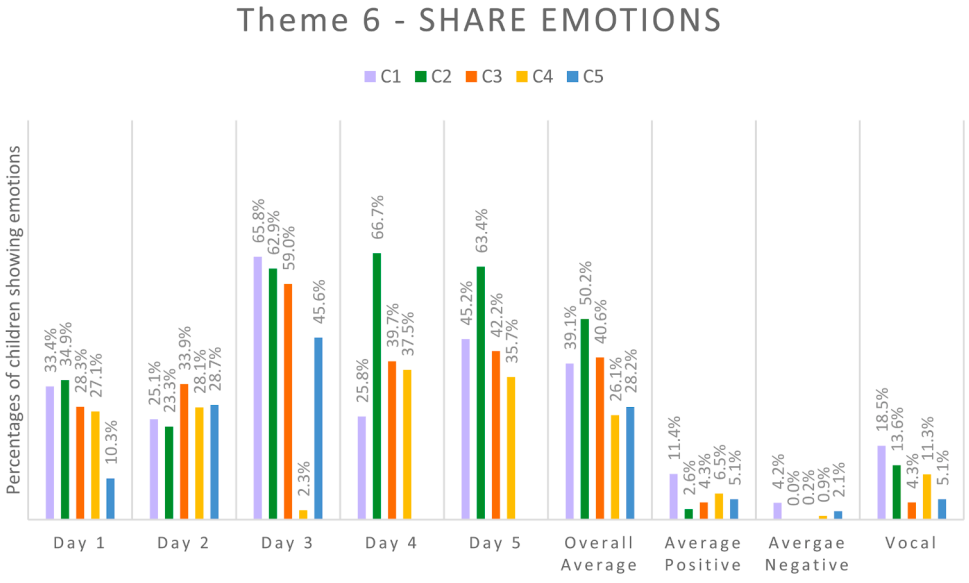

Fig. 13. Theme 6. Graph showing percentages of daily emotions exhibited by child

became much more regulated as the sessions progressed. C4 also joyfully ran around the space and hanged their body from the drapes of the curtains or ran through it, bit their nails and sought to touch or cling onto their TA's. When vocal, C4 was either communicating i.e. needs for toilet (in day 1), asking for help, telling adult where to sit around Olly by vocalising few words such as no and there, or they were playing either solitarily or with C5 and C3. C4 repeated out loud in different occasions "*O*" or "*Oi*" and "*pull*" while pulling the ribbons and playing with Olly. C4's TA wrote after day 3 *"Very inspiring how he regulated himself and he enjoyed the session"*. After day five the dance teacher commented "*he really likes the interactive nature of Olly pushing – pulling – laying on – sitting on. [..] He was less anxious than earlier in the day*".

C5 also showed their passion for running around and hid behind the drapes. Sometimes they clang on their TA's back. Negative emotions were in the form of moans i.e. in disagreement that they had to leave earlier (day 1), loud shouts as if they were not happy with C1 being upset in day 2 and C4 not sitting down when asked to do so, or when they hit a child. C5 hit few children in the three sessions they attended but the teachers always reacted promptly avoiding any issues to continue between children. During the last session C5's TA asked to C4 (by using voice and signs) to run together on behalf of C5 and waited for C5 to copy. Interestingly, C5 asked repeatedly throughout the sessions to the peer to run together using signs and sometimes voice. The requests were almost always reciprocated (see T8) as noticed by the dance teacher *"C5 was able to communicate and C4 was able to understand.[..] this prevented hitting to get attention from a pupil."* C5's TA wrote after day three "*He stayed for the whole session, his communication was really good."* This suggest that if C5 would have attended the last two sessions perhaps the two children might have been able to develop their friendship further. However, we are certain that the activity with Olly enabled that friendship to spark.

6.7. T7 Eye contact

T7 looks at instances of eye-contact demonstrated between the children or between a child and any adults. Children showed eye-contact just when around Olly. We took this as an indication of the positive impact Olly had on children' social interactions. Table 4 shows the overall combined amount of eye-contacts displayed throughout the sessions and between parts.

For instance, C1 showed one instance of eye-contact with C4 on day five when they were playing music using the ribbon wounded around their waist and C4 joined in bouncing on top of Olly, while on day 1 C2 and C5 made eye-contact when the former approached the latter while playing on Olly. C3 showed instances of eye contact with C5 on day one (x2), with C4 on the last three sessions (x1 each day) and with C5 on day 3. C4 made eye contact with C5 on day one x1 time as they first approached Olly, and on day three x4 times when they asked each other to play run, while on day five C1 and C3 gazed at each other once. The Dance teacher thought that *"because they're [C4 and C5] quite small, their eye contact was really good"*.

6.8. T8 Play Types

In order to understand how Olly might be applicable to different play stages we report on the overall percentages of times that children displayed different types of play adapted from Parten's play stages (Table 3). These are calculated over the daily times of the sessions minus the introduction times as illustrated in Fig. 14. Below we give illustrative examples of each of these categories of play.

Table 4
Number of times children displayed eye-contact and who with

T7 Eye contact	C1	C2	C3	C4	C5	Adult
C1				1		1
C2					1	
C3				3	3	
C4	1		3		5	6
C5		1	3	5		2

6.8.1. Unoccupied

Unoccupied (U) play was indicated by a variety of behaviours. Children exhibited an average of 9.51% of this type of play. For instance, C1 waggled their body while sat on a bench or touched their feet, pulled trousers up, took few steps next to the bench , while C2 crawled on the floor, walked across the space sucking thumb or flicked fingers and squeezed their eyes. Similarly, C3 sat around corners of the room manipulating Olly's cloth cover or fiddled with a string while sat or standing around the space, sucked their thumb, or just stood around. Finally, C4 fiddled with some symbols, or scratched their head, slid across the floor on his knees or stood around perhaps waiting for C5 to join the chase game, while C5 crawled on the floor and at times also span around and laid down on the floor. When children were prompted to Olly by an adult (PP) it was coded under the Unoccupied play because usually children were exhibiting Unoccupied play during or just before being prompted.

6.8.2. Onlooker

Onlooker play (O) was observed for an average of 18.30% of the time. Usually children showed onlooker behaviours within a distance of up to 5 meters. C1 and C4 exhibited the most Onlooker play corresponding to an overall average time of 25.55% and 24.83% respectively. For example, C1 usually distanced themselves from peers when they were getting too close and often gazed at them when they were not in Olly's or the peers' close proximity i.e. when sat on bench 1 or 2. C4 instead did O play also when standing beside or closer to people. However, sometimes C1 sang along when looking at peers playing with Olly from afar, suggesting that they made a connection with the ongoing activity. Some children such as C1 and C3 would prefer to spend some time looking before joining in indicating that perhaps they used this time to get comfortable enough to then approach.

6.8.3. Solitary

Solitary play (S) was exhibited in different forms and when averaged between the children is the most observed type of play (19.80%). For instance, C1 and C5 would often play alone on their own i.e. without using Olly. For example, C1 hopped about, wiggled their body and made funny voices, while C5 would mostly run around the room and hide behind the curtains. However, the last session, C1 showed Solitary (S) play using Olly suggesting that with more time they could have mastered its use. On the other hand, C2 demonstrated more S play while using Olly than on their won. Similarly, C3 and C4 played solo mostly using Olly but they also played independently i.e. with the light settings of the room (C3), running around the space (C3 and C4), pulling the drapes closed (C3) or staying behind them (C3 and C4).

6.8.4. Parallel

Parallel play (P) mostly happened between peers but also between child and adults and always by using Olly in different ways i.e. by being sat on it, leaning against it, or playing with its various textures and parts. Children displayed an average of 16.33% of this type of play. For instance, on day one, C2 was curling backwards towards their heels with their face over the speaker and at times pulled the orange ribbon. Consequently, C4 got hold of the ribbon and started playing himself by wounding his body in it and pulling back and forth, while C5 manipulated Olly and laid their belly on its top and C2 kept looking at and laying very close to the speaker while sucking their thumb. The Dance teacher was beside them and all other adults were sat at the bench. On a different day i.e. day three, C1 was playing and manipulating the purple ribbon while laying on their TA's laps around Olly, C3 laid on the floor around the TUI and next to his TA and kept the blue and orange ribbons

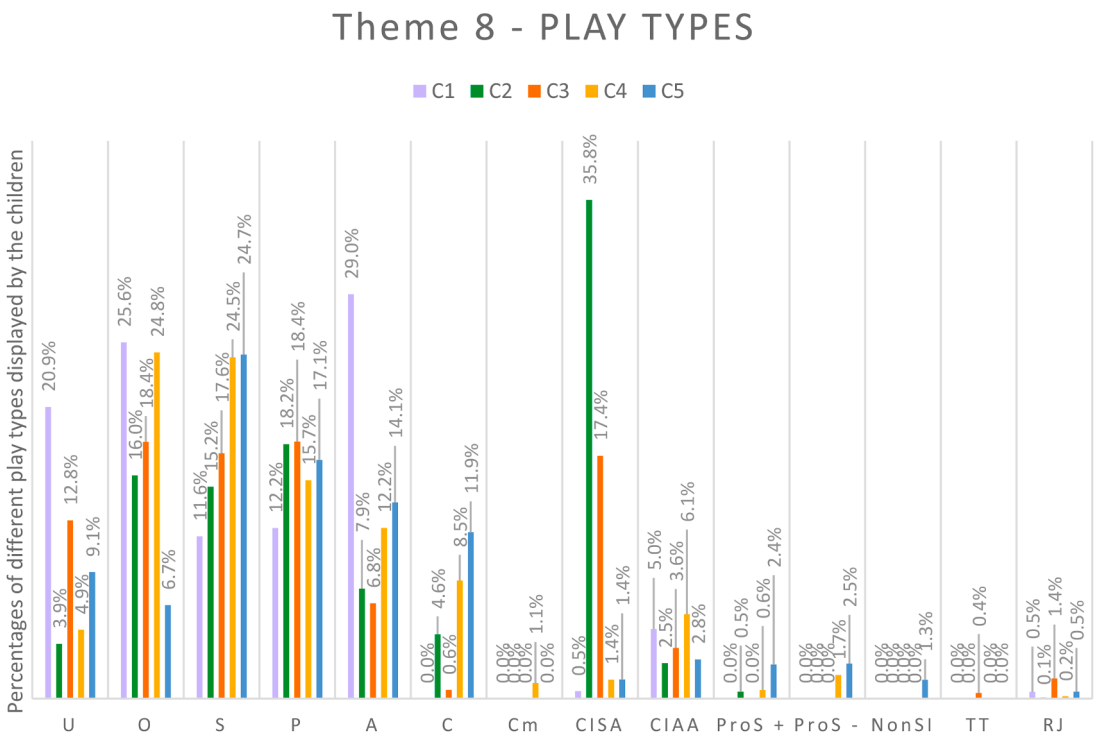

Fig. 14. Theme 8. Graph showing overall percentages of types of play over the five session

around their ankles (encouraged by the adult) and C4 was leaning on Olly. All children found their space around Olly and displayed different use of the TUI indicating that the *open* attributes of the design, and its multimodal aspects, allowed the children to form their own meaning of and connections with the technology and allowed them to share them with their peers.

6.8.5. Associative

Associative play (A) occurred for an average time of 14% and mainly when using Olly in groups of two to three peers. Usually adults also joined the play or were sat around Olly. For example, on day 3, C1 laid between their TA's laps and was playing the purple ribbon (wounded around their waist) while C2 laid on Olly's base keeping their legs on it and pulled the green ribbon, C3 pulled the orange ribbon and another TA pulled the blue. There was a sense of togetherness and belongings that was not felt in the previous types of play and this was indicated by the positive emotions displayed by the children and the contributions of each child in terms of their agency within the group activity (in this case making music). However, C4 exhibited associative attempts also by copying C5 and running after them few times with no response before developing a friendship and playing cooperatively around Olly.

6.8.6. Cooperative

Cooperative play (C) happened for an average time of 5.12% and it was exhibited mainly around Olly by C4 and C5 during a chasing game that they initiated. For example, C4 copied or attempted pro-social initiation of a chasing game few times before C5 embraced the game. As C5 realized what was happening they started asking C4 for more running and so they did. Both were waiting one another whenever they stopped i.e. if one needed a moment to rest and regulate perhaps by stopping by their TAs. This indicates that children established their own rules beyond those which are typically spoken, and these were visible by how the children: a) looked at or toward each other, b) decided when to start running by either signing more to the other or looking at each other's bodily cues, and finally c) waited for each other. They shared the same passion for running and they found some strategies to share their interest with one another. Children also displayed cooperative play while using Olly. For instance, C4 played music cooperatively with adults on day 1, and on day 4 when Olly was broken, one TA patted the ball while C4 laid with their upper body on Olly's top. At first C4 said "a" when the TA stopped as to indicate that they wanted it again, then started asking for "more". As the TA kept playing without C4 saying "more" they signaled their discontent by saying "No! No!" so the TA stopped and C4 held her hand before asking again for more. On the other hand, C2 also demonstrated some cooperative attempts once. C2 laid on Olly's top, touched speaker and started rocking solo. However, adults and children (C5, C1, C4) all joined in by pulling different ribbons (C4 was Onlooker) and created a rocking motion that C2 seemed to have took advantage of by untucking his feet from the floor and perhaps enjoying the music created by the others. This suggest that although their peers' actions were influencing what C2 was doing by themselves i.e. rocking they joined along and cooperated with the other in letting them direct Olly's wobbly inclination as its ribbons got pulled.

6.8.7. Other behaviours

As seen in Fig. 14 Competitive play (Cm) was only observed in C4 both toward adults and peers (1.11% of the time). For instance, as soon as adults joined in after being asked to approach Olly for the first time on day 1 by the dance teacher, C4 took off the ribbon from around their waist and grabbed those held by two TAs. Furthermore, C4 was also vocal as if they didn't want the TAs there. On day four when Olly was broken, C4 gently pushed C2 who was balancing on Olly's top, bounced on themselves and looked back at C2 while doing so. This was a positive result as it indicates the children were able to express themselves and find their own way out of disagreements.

Other types of behaviours have also been noted such as a) Child-Initiated Seeking of Adult (CISA), when a child sought adult's attention by i.e. grabbing their arms, b) Child Initiated Affectionate Interaction with Adult (CIAA), when a child showed behaviours such as caressing adult's faces as in the case of C1, and c) Pro Social Interaction with positive response (ProS +) and d) Pro Social Interaction with no response (ProS -). For example, C5 initiated Pro Social Interaction with C4 by running but received no response. It seemed that C4 got confused by looking at both people signing and this resulted in no immediate

response. Also, C4 initiated a chase game with C5 by looking at them but they were unable to notice at first so C4 waited beside. Although C4 and C5 didn't do cooperative play using Olly but running around it there was harmony between the two of them and we believe that the setting enabled the friendship to nourish as it was reported by the TAs that the children did share the playground but never interacted before. This indicates that Olly, but more in general activities such as this, provided the children the opportunities to develop a friendship that could have been unnoticed. Lastly, we also saw instances of e) Non Social Interactions (NonSI) such as when C5 hit another child or pulled a TA's hair, f) visible signs of Taking Turns (TT) just notice with C£ where he was visibly waiting before approaching, and finally g) of Refusal to join (RJ) i.e. when a child was offered a ribbon but deliberately refused it or if they complained when they were PP to Olly.

7. Reflexive discussion

In general, children purposefully and independently approached Olly to play with it or around it, suggesting their interest for the TUI by smiling, touching, and singing along and by either triggering music or through finding novel ways of appropriation. Theme 5 particularly indicated that the multi-functionality of the TUI, its *openness* and *ambiguity* (Eco, 1997; Gaver et al. 2003) allowed the children to be creative with their use of the technology (Scheepmaker et al. 2018) and enabled freedom of expression and agency beyond current PD practices (Frauenberger et al., 2017; Malinverni et al., 2014). Consistent with previous findings (Larson et al., 2009; Hornecker et al., 2007) our results confirm that the round shape design built to be shareable, conveyed positive meanings and affected social behaviours. As confirmed by one TA *"[Olly] was good because it was round. So, there were no edges, and there was access to everyone. And it was soft, so it's really welcoming. It made sound, like song. As a shape, as a something, there was no gender of this. There was no very harsh colors. It was just like a nest. It was accessible. It was really good"*. When given the chance children exhibited affect-driven behaviours, and genuine, spontaneous play with a marked sense of belonging (Turkle, 2011).

Some of the children struggled to pay attention to Attention Autism's practices (AA) during usual school hours. However, we found that the children demonstrated joint attention abilities and a general interest toward the beginnings of the sessions, indicating that framing the introduction around AA practices worked well to grab the children's attention.

We found that Olly encouraged different types of play. Children in our study displayed slightly higher average percentage of Solitary (S) and Onlooker (O) play than Parallel (P) and Associative (A) play. Among Parten's play types the least displayed behaviour was Cooperative (C) play perhaps unsurprisingly when considering the level of support that our children received on a daily basis which is also reflected in the amount of adult prompts some children received (T2, T3). Contrarily, to how Parten described them (Parten, 1932b), S, O, and Unoccupied play were not seen as negative social activities in our analysis, instead, they seemed to have enabled the children to gain access into the ongoing activity (Rubin et al. 2006). As in (Francis et al., 2018) we found that all children needed some private time either to regulate, relax or observe before they showed intentions to social bids of interactions. Also, the youngest of our participants displayed more complex play dynamics than their older peers indicating that the age of the children was not correlated to more socially engaged play as in (Parten, 1932). Nonetheless, Olly fostered complex social scenarios where children exhibited shared goals, shared attention, joint actions, play and intentions. Furthermore, instances of eye-contact between children were observed just when people played with or around Olly suggesting that Olly was effective in fostering a variety of social activities including eye-contact, important to establishing a connection with peers. Interestingly, uncoordinated social attempts have also been noticed i.e. when C5 initiated Pro Social Interaction with C4 by running but received no response, or when C4 initiated a chase game with C5 by looking at them but received no response. Although C4 and C5 didn't do cooperative play using Olly but running around it there was harmony between the two of them and we believe that the setting enabled the friendship to spark. C5's TA reported that *"giving them the space was really good"*. Moreover, the youngest of the group brought a real bounce to the sessions and we think that having mixed aged children might be beneficial when studying social play and regulation in autistic children. Surprisingly, C4's TA reported that *"[..] he really did– sometimes, I felt like he really did neurotypically. Just a neurotypical, very active someone."*

The combined use of textile such as felt and elastic lycra with music provided a rich multisensory feedback and a soothing experience appreciated by all the children. People were regulated indicating that they enjoyed the manipulative proprieties of the textile and the softness of the design. Most of the children exploited the versatility of the TUI and used it either to gently stroke it and manipulate it (C1), feel the vibrations of the speaker (C2, C3) or to self-apply some body-pressure using Olly's multifunctional proprieties (C2, C3, C4 and C5) such as its bouncy-soft body, the felt, and the elastic ribbons. Olly was also used as a weight bearing activity indicating its versatility in providing means for developing self-regulation and calming strategies. Music seems to have influenced moods particularly with C1, when on day 4 when the sounds was off, they started crying and being upset as noted by the Dance teacher *"Once she realized there was no music […] she became unhappy"*. All the children reacted noticeably differently on day 4 as they used Olly more roughly than usual. C3 started sliding it across the floor in that session but on that day, they also went to the cupboard where the music is usually played by the stereo during Dance as if to indicate that they wanted the music on, while C4 was making music by drumming on Olly's body with a TA and C2 displayed over-excited behaviours. However, at the beginning of that session C2, C3 and C4 exhibited 3-way interactions on Olly before C4 pushed C2 off Olly's top (something they never did before then). The choice of music seemed appropriate as it was reported by the Dance teacher that Olly was *"so peaceful"*. The children reacted positively to it by smiling or singing along. C1 particularly enjoyed singing and replicated similar melodies to those played by Olly and as confirmed by the dance teachers' other children liked singing along too *"he (C2) was singing, calm and relaxed"*. The beneficial potential of music for supporting non-verbal communicative skills i.e. low-level joint attention skills, and initiation of behaviors i.e. eye-contact (Geretsegger et al. 2014) have been confirmed by our findings. Music can be a powerful medium that contributes to children's emotional regulation (Zachariou and Whitebread, 2015) and mood management (Allen and Heaton, 2010). Therefore, when working with children who like music, the implementation of sonic features outputs, might be appreciated by most children and conrtibute to their engagement. However, mixed-feedbacks were received in regard to the sonic impact. For example, C3 TA said *"I think he was stack [sic]in the point of, oh I can pull this, it wasn't like cause and consequence because his development. [..] it was a sensory experience."* while the dance teacher reported that *"the music playing stimulated C3 – he was listening and smiling"*. Nonetheless, Olly makes an important contribution to the development of an approach for Musicking Tangibles for empowerment (Cappelen and Andersson, 2012) to be extended within the HCI and CCI communities through providing a rich observational analysis and a detailed methodological approach.

We observed that children were coming and going as they pleased and there was a fluid flow of interaction (though adults were found to be a barrier at times – see limitations). We think that the design, including its different *entries* and *access points* coupled with the semi-structured nature of the sessions facilitated Olly's *shareability* (Hornecker et al., 2007) and enabled children to join the play together when and if they felt like it. The multifunctional and multimodal interactions offered by the TUI and the open and ambiguous design (Eco, 1997; Gaver et al., 2003) allowed the children to be creative with their use of the technology (Scheepmaker et al., 2018) and enabled freedom of expression,

participation and agency. This was achieved by adopting the principle of Open Work during the design of the TUI (Eco, 1997) to enable children's interventions and self-expression and to allow the work to be completed by them. The concept of Open Work resonates with those of ambiguity and design for pleasure detailed by Gaver (Gaver, 2002; Gaver et al., 2003) and can be used successfully by other researchers interested in autism, spontaneous play and technology. Furthermore, we suggest Tangible User Interfaces are preferred over flat screen based tangible interactions as it is believed that the screens take away from behaving socially i.e. decreases eye-contact (Brudy et al., 2018; Zagermann et al., 2016). Indeed, some autistic children like textures and engage more in physical contact with plush toys than other plastic or virtual toys (Cascio et al., 2008; Jeong et al., 2017). Therefore, we advice using malleable surfaces and soft textures as an effective design feature for TUI development for autistic children. Moreover, Rodgers et al. (Rodgers et al., 2016) found that anxiety levels are usually higher in social contexts and a natural and malleable material might help in this regard as children could use it as a sensory strategy to self-regulate

The implementation of a multidisciplinary approach focused on social play and sensory regulation and grounded in evidence-based models to the design and evaluation of the TUI allowed us to adopt a more holistic and comprehensive understanding of the children (i.e. by focusing on them, their sensory needs, preferences and likes) and to evaluate more holistically the impact that Olly had on the children's experiences. This approach can enable researchers to expand our understanding of social interactions and could contribute to strengthen a consensus within the HCI community on how to evaluate technologies more holistically (Brulé et al., 2019). It also demonstrates how researchers can develop technologies to enable free play, children's self-expressions, spontaneity, and agency beyond current PD practices (Frauenberger et al., 2017; Malinverni et al., 2014). This is achieved when researchers tune in to the needs, likes and preferences of the children they work with and take those forms of expression into account in the final designs. Furthermore, the concept of sharing a toy during a free playful activity is not extensively explored in the field of HCI (Spiel and Gerling, 2021) nor within education (Wood, 2007) hence it was considered important to explore how to give the children this opportunity.

7.1. Limitations

Our findings highlight some broader limitations. Firstly, the institution we worked with offers highly specialized provisions for individuals with autism and all staff is regularly trained in child protection safeguarding and in evidence-based approaches in Special Education Needs. Other schools might not offer the same level of staff training and access to expertise as the Garden school does. This could have potentially affected the outcome of our study as we worked in an almost ideal environment. Secondly, some adults appeared to be a barrier to the children's participation. For example, C5 was prevented by their TA (the less experienced staff member) to stand from the bench and to move/play freely, perhaps to approach Olly and peers. At one time the same TA also prevented C3 to play on Olly as they pleased. This seems to be in line with what Smith et al. (2013) propose about how the whole ecology in which the system is deployed including the space, the set-up and the presence of adults affect outcomes and it's an important aspect that designer should account for when working with children with high support needs. Consequently, we suggest researchers gain some experience working with marginalized children in their preferred contexts prior to start any research in the wild, and to demand support from highly qualified staff members. Our technology was not left at the school for the children to continue to play with because a) it was a prototype and we realized that it needed some improvements in terms of its reliability with the sonic outputs and robustness of the connections, b) there was no storage space at the school were the technology could have bene kept safely and c) the teacher was not confident in using the microcontroller. Nonetheless, the teachers praised Olly and the activity and with some design tweaks and training sessions with teachers on the electronics (and assuming we could have found a suitable storage for Olly) we believe that the activity could be part of children's scholastic curriculum in Primary and Early Years. Lastly, we tested the technology with a small group of physically able children who like music. These children showed preferences for textile materials and the bouncing balls. The same design might not suit all, as not everybody like music and/or benefit from deep-pressure touch. However, our approach could be used to evaluate the impact of different TUIs on social interactions and sensory regulation in different contexts and with different groups of children independently from their abilities and age.

8. Conclusions

We investigated the types of play and regulatory opportunities afforded by a sonic textile multi-users tangible technology in a group of minimally verbal autistic children within a semi-structured ludic educational setting. We argued that when designing technologies that aim to scaffold playful and social experiences for minimally verbal children with autism there is a need to expand the design space to be more inclusive and accessible. This could be achieved by for example taking a more holistic approach toward understanding the children as a whole and to the analysis of the findings. Important to us was to focus on different aspects of play, particularly spontaneous and social play but also to provide opportunities for self-regulation because children's participation in leisure activities is influenced by their sensory processing abilities. Hence, we based the design on a multidisciplinary approach based on HCIprinciples such as that of: shareability, openness and ability to evoke agency and freedom of expression while satisfying children's likes (i.e. using music, pressure, textiles), multifunctionality and multimodality. We contributed a design study carried out over five weeks with a group of minimally verbal autistic children and presented a freshly grounded methodology in which approaches intended particularly for educational contexts have been applied to the research methodology behind the technology. Lastly, we incorporated therapeutic and educational constructs into the analysis of the finding using an HCI lens on future implications for the design of TUIs for minimally verbal autistic children.

CRediT authorship contribution statement

Antonella Nonnis: Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Data curtion, Writing – original draft, Visualization. **Nick Bryan-Kinns:** Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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