Unmasking the Power of Play Through TUI Designs

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Research on the potential benefits of technology for autistic children is an emergent field in Human-Computer Interaction (HCI), especially within the Child-Computer Interaction Community. At the same time, there are concerns about what these interventions and technologies are for and who benefits. We present a research and design approach for Tangible User Interfaces (TUIs) for minimally verbal to nonverbal autistic children following a neurodiversity narrative through three field studies developed and evaluated with three groups of children within a semi-structured scholastic environment between 2018 and 2021 in the UK. We discuss our insights for research and TUI designs in the context of social play for nonverbal autistic children and critically reflect on the methods and approaches we used. We do this to disrupt the normalisation agenda that subtly permeates the field of HCI and to direct designers' attention toward supporting autistic ways of being in the world.

CCS CONCEPTS • **Human-centered computing~Interaction design~Interaction design process and methods • Human-centered computing~Human computer interaction (HCI)~Interaction devices~Sound-based input / output • Social and professional topics~User characteristics~People with disabilities**

Additional Keywords and Phrases: children, play, neurodiversity, ecology, non-autistic adults, researchers' attitudes

1 INTRODUCTION

The benefits of play on child development have been studied extensively [59, 44, 2, 14, 35], with some researchers showing that play deprivation in childhood may lead to more aggressive young adults [34]. Play is fundamental for sensory-motor, socio-emotional and cognitive development and general well-being [44, 59, 71, 75, 99]. In 2013, the United Nations Convention on the Rights of the Child (UNCRC) fully implemented Article 31 by adopting General Comment 17, which formally values the child's right to relax, play and participate in leisure and recreational activities, as well as cultural life and the arts. Article 13 also states the right of every child to self-express, while Article 12 values the right of every child to have their views, feelings and wishes respected.

Studies on autism and play have shown that autistic children's play dynamics and interests sometimes differ from those of non-autistic children, such as by moving repetitively and playing more solitarily [121, 70] and their participation in leisure activities seem correlated to anxiety levels, social interactions, and sensory processing [52]. Rodgers et al. [2016] report that between 22% and 80% of autistic children experience anxiety, particularly when in social contexts. Farahar [2022] further explains that autistic people experience greater levels of anxiety and depression than neurotypical people (NT) due to having to navigate a world based on non-autistic needs. In other words, anxiety increases in social contexts due to the environment (i.e., for the lights, noise, temperature, space, etc..) [138] and the presence of other (especially NT) people (i.e., for bullying, judging, and causing a feeling of loneliness) [26].

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People across neurotypes perform repetitive behaviours to increase or lower self-regulation [21], what the autistic community refer to as stimming [116, 17, 63]. As anxiety is found to be higher when exposed to social contexts [102], and stimming is used as a strategy to lower anxiety [17, 117], it is only logical that to support a socially engaged play experience, we account for factors that affect children's anxiety levels and ability to self-regulate through adjustments of environments and attitudes of non-autistic adults and researchers toward neurodivergence. Given this and the fact that technology permeates our lives, we suggest expanding the design space of technologies for socially engaged play to be more inclusive.

Recent research within HCI highlights concerns about what the interventions and technologies developed are for and who benefits from them. Spiel and Gerling [2020] reveal that half of the corpus of the research they reviewed focused on educational goals, followed a medicalised approach, and developed technologies which were "driven by factors extrinsic to neurodivergent interests" [Ibid]. There is a tendency among HCI researchers to see differences (i.e. the autistic way of being/self-expressing) as problematic and in 'need of assessment'[1], 'correction' 'intervention' or 'improvement' [Ibid]. Autistic children, therefore, especially non-conventionally speaking ones, might be disadvantaged in fully experiencing their rights to relax, play, self-express and be respected for who they are because of the different ways they play, communicate, and participate.

More recent studies on play and autism are mainly focused on touchless or screen-based devices, robots, and virtual environments (VE) [9, 74, 83, 100]. Fewer researchers have investigated the potential of TUIs to foster socially engaged and spontaneous play of and between autistic children [27, 30, 33, 108, 29]. Although these approaches 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, they rely on verbal skills and design activities rather than play experiences. Yet, this reliance on verbal skills might further exclude many autistic children since around 40% of them are reported to be 'nonverbal' [119, 149]. Therefore, it is essential to expand the research space to also cater to the needs of those children who are minimally or nonverbal. We use the term minimally verbal to nonverbal to identify those children who do not use spoken language as conventionally understood but might nonetheless express themselves by using their voices (i.e., through echolalia and/or other sounds).

As technology permeates deeper and deeper into our everyday lives, it becomes increasingly vital that we develop an understanding of how we can create digital ecologies [113] to support social inclusion and play for non-conventionally verbal autistic children who are at higher risk of, i.e., developing mental health problems due to lack of acceptance [96], feeling disempowered [130], bullying [28, 16, 20] and isolation [73, 79] – that could be further amplified by the lack of 'functional language' as the dominant discourse understands it. While the drive to explore new technological opportunities might be high within the field of HCI, the necessity to develop

[1] Throughout the body of text, we used single inverted commas to display our disagreement with normative terms used throughout the paper to reflect on the normalised use of ableist language critically
[2] Skoog, http://skoogmusic.com/, Accessed 2020/04/20

approaches and designs that understand, accommodate, value, and embrace a diverse variety of people is higher and requires careful consideration.

We propose a shift in the interaction paradigm and challenge the notion that autistic people should aspire to simulate neurotypical behaviours to adhere to societal norms. We seek to extend the work started by Scheepmaker et al. [2018], Spiel et al. [2019], and Frauenberger et al. [2020] on designing social play objects for spontaneous social play with and by verbally fluent autistic children by offering an approach to design and evaluate tangible technologies for spontaneous social play with and for nonverbal autistic children. In line with the work carried out by Wilson et al. [2019] on designing TUIs with and for nonverbal autistic children, we extend the concept of co-designing beyond words to social play activities mediated by shareable e-textile TUI designs led by the children's interests, likes, needs and preferences [85, 88, 90], not by researcher's motivations, that take in considerations and embrace children's social, emotional and sensory needs. We do this to enable them to be their authentic selves, unmasked, and to provide interaction opportunities that they find meaningful [94, 95, 82]. We explore how this holistic or "ecological approach" can offer increased opportunities for social play and self-regulation to small groups of nonverbal autistic children during recreational activities. Holistic means "dealing with or treating the whole of something or someone and not just a part" [54], and we use this term to highlight the importance of considering the child as a whole, including the many factors that influence their experiences during a socially engaged play activity such as their sensory, social and emotional needs. Still, also the environmental demand and qualities, the adults that support the children, the researcher's attitudes, the offered play experience, and the designed technology influence children's experiences and are essential factors to address when using a holistic approach. Smith et al. [2013] suggest that technologies should be extended "to the whole ecology that emerges as a result of users' appropriation of artefacts into new meaningful practices" (i.e., looking at the technology, the space in which the technology is deployed, the enabled social practices, and at the people that use the technology).

Therefore, this research aim is to close the gap in the existing literature on the socially engaged play of autistic children and research-led agendas [115, 114] by expanding the work developed around a particular form of interactive technology – tangible interaction [58, 110]. We present a research and design approach for TUIs through three field studies, called Mazi, Olly and Olly Mazi, and two sonic e-textile TUI designs (also called Mazi and Olly) developed and evaluated during the first author's PhD research conducted in the UK between 2018 and 2021 within a semi-structured scholastic environment called the Garden school (also referred to as 'the Garden' for brevity). We propose several design and research principles to scaffold socially engaged play experiences between 'nonverbal' autistic children mediated by novel TUI designs following a neurodiversity narrative [152]. We do this to disrupt the normalisation agenda that subtly permeates the field of HCI [78] and to direct designers' attention toward supporting *autistic ways of being in the world*. Our engagement in this project was motivated by our main research questions:

mRQ1. How can we design TUI to support social play between autistic children?

mRQ1. How do children respond to the proposed play sessions? - How do they play?

mRQ2. Which design features are supportive of spontaneous social play and sensory regulation?

mRQ3. Can a TUI design apply to groups of children that do not lead design decisions?

In each study, we developed a set of sub-questions that helped us further explore aspects of the main research questions. Table 1 shows how these maps to the main research questions.

Table 1. Table showing the sub-questions developed in each study and how they map to the four main research questions

MAIN RESEARCH QUESTIONS	Study 1 Sub-questions	Study 2 Sub-questions	Study 3 Sub-questions
1. How can we design TUI to support social play between autistic children?	How does a group of 5 non conventionally verbal autistic children respond to a shareable sonic e-textile TUI inspired by their likes and needs that requires a simple interaction style?	How does a group of 5 minimal to nonverbal autistic children respond to a shareable sonic e-textile TUI inspired by their likes and needs that requires an overt style of interaction?	How does a group of 7 minimal to nonverbal autistic children respond to two shareable sonic e-textile TUIs that requires different (inter)actions?
2. How do children respond to the proposed play sessions?	How, do they play? Are they regulated?	How, do they play? Are they regulated?	How, do they play? Are they regulated?
3. Which design features are supportive of spontaneous social play and sensory regulation?	How do they use the TUI?	How do they use the TUI?	How do they use the TUI? What differences there are (if any) in children's behaviours when the power of the TUIs is turned off or on? Is there any difference on how they interact with Mazi or Olly?
4. Can a TUI design be applicable to more groups of children?			Can the designs of Olly and Mazi be used by different groups of children than those they were inspired by?

In the following section, we review relevant literature on social play, autism and tangible technological developments to support social play between autistic children. We then describe the research project in more detail, briefly presenting each of the three field studies, showing how we approached the research and the design of the TUIs developed, and briefly qualitatively presenting our findings. We then summarise our insights for research design and TUI designs in the context of social play for nonverbal autistic children and critically reflect on the methods and approaches we used.

2 BACKGROUND LITERATURE

2.1 Social Play

The psychologist Piaget [1967] considered play to be connected to the child's three developmental stages, what he called "practice games", "symbolic games", and "games with rules", the latter being the one category where social interactions are required because others impose rules.

Conversely, Vygotsky considered play a guided endeavour occurring and developing at a social level [126]. Whereas for Piaget, social influences were not part of the play experience before games with rules, though paradoxically, interaction with the environment was crucial for development to happen, for Vygotsky, the socio-cultural environment created by interacting with others was a critical element of development from infanthood. According to Piaget, in the first seven years of life, a child plays solitarily and for individual purposes, progressively developing collective symbolism and social play skills.

Similarly, the sociologist Mildrean Parten Newhall [1932] theorised and associated the development of social play with child growth by dividing it into six stages represented by the children's levels of social participation such as **Unoccupied**: No playing or interaction with players; **Onlooker**: Observing others playing without attempting to join; **Solitary** play: Playing close to each other but focused on own activity; **Parallel** play: Playing next to each other but not with each other; **Associative** play: Interacting during play with each other and using similar materials; **Cooperative** play: Playing together with a shared goal, coordinating behaviours. Interestingly, Parten assigned negative values to the first stages of play: "Unoccupied, solitary, and onlooker activity might be considered negative indices of social activity" [93]. Conversely, Vygotsky [1967] saw children in a social context, which he considered to be always part of their development, as they cannot be separated by their socio-cultural influences. For Vygotsky, optimal development is given by adult-guided play, while for Piaget and Parten, play is a free endeavour that is child-led [126]. Within an educational context, Wing [1995] emphasises the distinction between play and work by qualitatively analysing how a group of children perceived classroom activities as work or play activities. For example, children identified aspects of activities that made them more work-like or more play-like, such as obligatory activities (adults initiated) or spontaneous activities (child-led) [Ibid].

The dominant discourse around designing for neurodiversity seems to imply that autistic children lack intrinsic motivations to play [12] and social skills [127, 46, 57, 50]. Others propose that they might be socially motivated but lacking social skills [72]. We believe that there is a great misconception about autism and play, especially when realising that neurotypicality is always seen as the right way to play and socialise, and it is henceforth imposed on autistic children, causing harm and trauma [36]. The Autistic Self Advocacy Network [6] explains that autistic people "might not understand or follow social rules that non-autistic people made up". It stresses that "Some autistic people are extra sensitive to other people's feelings" [6]. Ochs and Solomon [2010] help us think about sociality as a "range of possibilities". Milton [2014a] argues that "autistic people are [..] indeed social beings, albeit perhaps a more idiosyncratic or outsider social experience and expression of social agency [compared to the average dominant way of being social]". In fact, in spaces where positive autistic people's identity is celebrated (i.e., communities of autistic people), social activities do take place [151]. As Farahar [2022] explains, sociality in these spaces might take different forms, such as the manifestation of noises and gestures, stimming, hiding, and/or inhabiting a space in silence.

2.2 Play & autism

Moving from the broader context of social play, when reviewing findings on autistic children's play, evidence shows that they manifest less symbolic and complex play [122], less 'functional' and social play [121] and increased self-regulatory behaviours [70, 121]. These differences in play and communicative styles seen in autism [130] are what neuro-typical researchers often consider 'disorders' or 'deficits', unloading the burden of the interactional efforts just on the autistic side of the interaction [79].

For example, according to Rosqvist [2015], autistic people's perception of friendship (which diverges from what non-autistic people might interpret as friendship but bears similarities) includes social and private aspects. Silence and balancing private and social time/space are essential to relationships. Therefore, we must consider that socially engaged play might take different forms for some people. These must be understood, accepted, embraced and valued as valid and worthy of respect [26].

2.3 Autism, the neurodiversity paradigm and being

Transitioning from the discussion on the play, we explore how understanding autism and the neurodiversity paradigm [152] might shape children's perceptions of playful experiences. A medical model would define autism in terms of its deficit [96]. Following a neurodiversity paradigm [152], autism is explained by differences (from the dominant discourses), which do not imply lessness. The Autistic Self Advocacy Network [6] explains that "Autism affects how we think, how we communicate, and how we interact with the world". The definition specifies that it affects "thinking, processing senses, moving, communicating, socialising, needing support with daily activities." The neurodiversity paradigm attempts to understand and value the world from a less ableist perspective. Farahar [2022] notes that "Autistic culture works from a shared understanding of the neurodiversity paradigm, where Autistic experience is a natural variation within the human species, enacted upon by social power relations and ideological notions of "normal" [original emphasis] [..] where Autistic experience needs acceptance and societal accommodation and support, not intervention or "cure" [original emphasis]." Both the neurodiversity paradigm and the movement are empowering for neurodivergent individuals because they are encouraged to embrace their own authentic identity [152, 101] and having a positive identity increases self-esteem and reduces feelings of anxiety and depression [26, 101].

However, we all mask our identities to conform to societal norms. This is to manage how we are perceived by society and avoid stigma [82]. Masking negatively affects people's well-being and causes feelings of disconnection across neurotypes [94]. However, Pearson and Rees found that there are characteristics of masking that are more specific to autistic people, such as the withholding of self-regulatory movements [Ibid], as this is a reason why they are often misjudged. Pearson and Rose [2020] and Pearson and Rees [2020] report that autistic people experience exacerbated mental health problems and physical pains, which causes them to burn out negatively, affecting their well-being and, in some cases, leading to suicide. Rosqvist et al. [2022] remind us that "The importance of fitting in socially is associated in the group with definitions of social competence in social circles dominated by non-autistic people, which can be thought of as non-autistic epistemic authority when it comes to meanings of communication and sociality" [Ibid].

Milton [2014b] explains, "Autistic people could be said to exhibit a dynamic quality of perception, one less stratified by learnt schemas, one less socialised into obeying normative ideologies, but an embodied sociality nonetheless". We emphasise that most of the misunderstanding of the autistic culture by the dominant discourses in HCI may happen because of a lack of understanding [105], which causes a double empathy problem where i.e., neurotypical people lack empathy with the autistic culture and vice-versa [79]. Morris et al. [2023] have very recently explored the double empathy problem in the context of inclusive social play between autistic and neurotypical children. We explore this problem in the context of non-autistic researchers and autistic children. Note that when we refer to the autistic culture in this article, we speak of a community of autistic people (medically diagnosed or not) whom people feel a sense of belonging and strongly identify with because they feel accepted, valued, and respected within this community [111, 26]. Milton calls this lack of understanding of "outsider" communities "interactional expertise", what Schutz refers to as the problem of "intersubjectivity" (or lack of) [120]. Following Milton's discourse on the intrinsic difficulties of finding common grounds between people of different communities, based on the lack of a shared understanding of lived experiences between neurotypical and neurodivergent people, finding this grounding space can be challenging.

However, Garfinkel [1964] suggests that the problem of intersubjectivity needs to be solved within the members part of the ongoing interaction. The concept of reciprocity perhaps can help us better position our point of view [43]. The Britannica dictionary defines reciprocity as "a situation or relationship in which two people or groups agree to do something similar for each other, to allow each other to have the same rights, etc.: a reciprocal arrangement or relationship". Gernsbacher [2006] talks of non-autistic people having to achieve true reciprocity, i.e., symmetrical and mutual, which they say should be developed more purposefully and applied more generously toward autistic individuals and suggests a few ways that non-autistic people can increase their reciprocity behaviours. These are joining the child's perseverative play, reading the child's behaviour as an indicator of interest, following the child's lead, responding to the child's behavioural state, matching the child's interactive pace, and expecting the child to react according to their temperament or behavioural style. Rosqvist et al. [2022], in an interview with autistic participants, found that "when autistic people communicate, often we communicate with our whole body. And other autistic people understand that the best because you are very … yeah. We think that is very, very, very important. … it's like … It's a great focus on … the topic. … We are very much 'here' [original emphasis]."

2.4 Self-regulatory movements and sensory-socio-emotional regulation

Farahar [2022] explains that self-regulatory movements, one of the differences in communication styles across autistic and non-autistic people, "is a language and communication in and of itself" not usually understood outside the autistic community. Regulatory strategies, which typically stimulate the sensory system, are necessary to rebalance regulation levels when there is a discrepancy between energy levels and environmental demand [68]. These stimuli are often achieved in what we see as forms of repetitive movements (note that every human does this). Children's self-regulating ability might be negatively impacted if the environment (intended as places, objects, and people) does not provide opportunities to do that [51]. The Transactional Model of Stress and Coping [69] proposes that people's capacity to adjust to and cope with challenges and problems is a consequence of interactions between a person and their environment. According to this model, when a person faces a potential stressor that is evaluated and perceived as a treat or a challenge, people can either do nothing or react in different ways (i.e., by developing means of coping with the stresses in terms of physical activities - typically for stressors that are out of the person's control or copying mechanisms). Stimming, or self-regulatory movements, may be exhibited in the child's fascination or fixation for something, which usually manifests in rocking, hand-flapping, twiddling strings, spinning, tapping body parts, finger flickering, spinning, leg jiggling, etc. [63]. Kapp et al. [2019] found that stimming also displays intense emotional reactions, indicating positive and negative experiences. Deep pressure is another self-regulatory stimulus which has a beneficial and calming effect on people. It is thought that autistic children seek this stimulus to self-regulate [17] in various forms, i.e., by using different types of pressured touch stimuli such as hug machines [132, 24, 66], garments to wear on sleeves [132] or on the chest [23, 123], and hand massage [25]. Because autistic people exhibit regulatory movements and activities in a more accentuated way than neurotypical individuals, support services and interventions tend to reduce or eliminate them [105].

2.5 Tangible User Interfaces for socially enabled interactions

Tangible User Interfaces (TUIs) can provide sensory feedback that could contribute to children's self-regulation during socially engaged play. According to Hornecker et al. [2007], TUI designed to be shared and used by multiple people should follow the principle of shareability concerned with entry and access points, where the former invites and entices "people into engagement", and the latter enables "users to join a group's activity" [Ibid]. Entry points allow people to plan their approach by providing an *overview* of the system and entice them with a point of attraction or *honey pot* effect to stimulate active interest and *minimise barriers* to access. Access points refer to characteristics that enable a group activity to happen, i.e., afforded by a combination of *perceptual access* (promoting social awareness), *manipulative access* (allowing active interaction), and *fluidity of sharing* (enabling easy flow of interaction).

Whether the size of a device positively affects socialisation and collaboration is still a debated argument [3, 131]. Rogers et al. [2009] and Marshall et al. [2007] demonstrate that tangible interactions might offer more equal opportunities than screen-based devices. Harris et al. [2009] note that multi-touch interfaces provide more opportunities for collaborative interactions between children than single-touch ones. Similarly, Rogers et al. [2009] highlight that a single-input technology constrains participation, while Marshall et al. [2009] emphasise how a limited number of access points could lead to competitive access and demonstrate how the "physical and interactive properties of an interface or object can interact with the structure and orientation of children's bodies when they are competing for access" [Ibid]. According to Hochhauser et al. [2015], interacting in successful conflict resolution is challenging for autistic children due to 'their lack' of self-confidence, communication, cooperation, and compromised skills. To our knowledge, the principle of shareability has rarely been applied to technology for nonverbal autistic children.

2.5.1 TUIs for Social Play and Autism

Some researchers, however, have explored the potential of TUI designs for social play and autism. For example, Farr et al. [2010] made a comparative study between neurotypical and autistic children on the social effects of using the construction TUI Topobo vs a physical construction toy such as the Lego® during a playful activity. Topobo is made of assembling parts for building different creatures, while the physical toys are Lego® pieces. The study demonstrates that within a structured task, Topobo encourages more parallel and collaborative play than solitary play when compared to the Lego® toys. The MEDIATE multisensory environment [92] allows a group of children to express themselves by interacting with three sensory interfaces through various stimuli: tactile, visual, and aural. For instance, some of the MEDIATE sensory textures can create music when touched [45]. Children interact with the system through their body movements and tangible elements attached to a vertical display. Lately, Frauenberger et al. [2020], Scheepmaker et al. [2018], and Frauenberger et al. [2019] have explored the process of designing "social play things" within a more inclusive setting. Scheepmaker et al. [2018] defined playthings as boundary objects "that are plastic enough to adapt to individual interpretations of playfulness and the constraints of the several co-players involved, yet robust enough to maintain a common or shared activity that is meaningful across players" [Ibid, p. 459]. By collaborating with a group of verbally autistic children aged 7 to 12 in a mainstream school context, they carried out a series of workshops which culminated with some insights for co-designing interactive objects with neurodiverse children [33], summarised as enabling children's control while balancing the complexity of interactions, providing the right balance between openness and structure through a process of modularity, manipulability, freedom with a frame, and layers, and allowing solitary detours within the group context.

2.5.2 TUIs, Music and Autism

Music is a powerful medium that can contribute to children's emotional regulation [153] and sonic (musicking) TUIs could enable this. However, sonic and musical TUIs deployed for 'Special Education Needs' (SEN) settings are often in support of specific skills development such as i.e. motor development [118, 19, Soundbeam Project] and music therapy [19, 125, 15].

Autistic people respond to music similarly to neurotypical people and deliberately use it for mood management [1]. Boso et al. [2009] and Salimpoor et al. [2015] demonstrate that people prefer harmonious to dissonant sounds, while Hardy and LaGasse [2013] suggest that elements of music, such as rhythm, can contribute to sensorimotor regulation. Consistent with these propositions, Kapp [2022] confirms that stimming "provides a soothing rhythm that helps them cope with distorted or overstimulating perception and resultant distress [Davidson 2010] and can help manage uncertainty and anxiety".

A recent example of a sonic tangible interaction, Polipo [118], aims at developing fine motor skills in autistic children by promoting engagement, a sense of control, and cause-effect understanding. However, it is still based on a 1:1 therapeutic approach, where the child is taken out of context to practice playing with a plastic toy and an adult therapist to improve specific learning skills. Kossyvaki and Curran [2020] tested Cosmo (Cosmo) as a music-making intervention to 'enhance' engagement and social communication in autistic children with co-morbid conditions [65]. On the other hand, Cappelen and Andersson [2012] presented the design of novel interactive multi-modal technologies aimed at groups of disabled children in the form of different musicking objects made in e-textiles. Their work critiqued the limited affordance of traditional instruments and current music technologies that relied on non-accessible musical interfaces and switches that disempowered users. However, their approach is still heavily oriented towards improving the use of technology within the realm of music therapy. Accessible digital instruments have been deployed in SEN settings for several years. The Skoog is one well-known TUI developed to support music-making for everyone by minimising the entry barriers[2]. As in Cappelen and Andersson [2012], we would like to challenge the concept of the maestro or virtuoso performer used to describe some musicians by adopting the concept of musicking - coined by Small [2012] - and extending it within the HCI and CCI communities to marginalised groups of children, such as nonverbal autistic children, to enable participation in musical activities such as dancing, singing, and listening without prior musical experience. We discuss this point further in Nonnis [2021].

2.5.3 TUIs materiality and autism

Finally, we investigate the significance of materiality in Tangible User Interfaces, especially in the context of autism. MEDIATE is one of the first multi-sensory environments created for autistic children that uses soft materials such as polyurethane foam instead of PVC plastic. Karana et al. [2008] first coined the phrase "materials experience" to define people's experience with products' materiality, enabling sensory-rich feedback. Hornecker [2012] noted that physical artefacts "inherit a multitude of incidental properties (and affordance)" from the materials that are used to make them [55]. They say this is both an opportunity for TUI design and a challenge because the designers' capability to restrict affordances to the ones they desire is limited due to the "potentially endless" affordances of physical artefacts. However, we believe this is a great strength, rather than a limitation, that needs to be exploited and explored more, as it offers endless ways of TUI interpretation and appropriation. For example, e-textiles, also known as smart textiles or electronic textiles, are analogue fabrics with electronic and digital components embedded in them. Textile materials can be re-purposed and engineered without affecting their properties [49], which allows us to experiment with making fabric sensors that are versatile from scratch [97] and creating hand-crafted technologies [98] tailored to the needs of their users.

Studies claim that haptic sensations with soft objects or plush toys offer some coping mechanisms and reduce feelings of uncertainty [124, 18, 60]. Textile-based TUI are increasingly popular within HCI. For example, BendableSound [19] is an elastic multisensory surface targeted at developing motor skills in autistic children, and it was used in support of Neurological Music Therapy (NMT) sessions as a therapeutic intervention based on 1:1 use, where children played sounds when they touched the screen. However, the tangible elements are based on a technology

[2] Skoog, http://skoogmusic.com/, Accessed 2020/04/20

that resembles a flat, soft-screen interface. Several studies have explored the design of ball-shaped tangible toys to be used by single players, perhaps together with others by passing it around, but not by following the shareability principle [61, 128, 33]. For example, as part of the Music Ball project, Jensenius and Voldsund [2012] developed a ball stuffed with foam and covered it in fabric to support musical expression in children with ADHD. The ball-triggered lights and audio stimuli are activated by an accelerometer hidden inside the thick foam of the ball. Frauenberger et al. [2020] made crocheted balls with integrated LEDs which children could squeeze to metaphorically project the light onto a surface, controlling the intensity through the amount of pressure. However, both studies provide little explanation for why and how such materials (textiles) have been explored.

3 METHODS

3.1 Research Through Design Approach

Our research combines an “ethnographically informed design” [7] and Research through Design (RtD). It employs a pseudo-ethnographic approach because it takes a liberal approach similar to that used by Gaver et al. [2004], whereby artefacts are used as an object of inquiry and introduced in the observed context to analyse their effect on social play and self-regulation within a semi-structured scholastic environment. We used Research through Design (RtD) as an iterative process between design and research activities (Figure 1). RtD explores the space of interface designs (physical and digital) with a critical and reflexive lens, and it does so to stimulate public discourse and push the boundaries of common design spaces [148, 22]. Using RtD enabled us to develop new artefacts as an approach to learning about human experiences, and this encouraged us to move beyond the artefact itself to discover insights not just about the technology but also about the people and their interactions. As in Sue Fletcher-Watson et al. [2018], in this project, TUIs mediate human-human interactions; exploring technology and how people interact with it is a vehicle to support interaction between humans.

RtD allows us to uncover knowledge about the children's preferences, needs and likes through an iterative process of design explorations regarding materiality (materials, DIY e-textile sensors, forms, and interactions) and human activities. In RtD, prototypes are designed iteratively, then developed and evaluated, leading to rich qualitative insights. This process drives and informs reflections, knowledge generation, future design, and research directions [57]. Insights from the prototypes created in our three cycles (or three studies), such as sketches and low-fi to mid/hi-fi prototypes, informed new iterations of design and research questions. In this project, we used two main design iterations within three cycles. Every cycle is built upon the insights gained from the previous one, and the goal was to extend research and design knowledge about TUIs and social play for nonverbal autistic children. With this work, we aim to explore how creating novel TUI designs and research approaches sensitive to children’s strengths, preferences, likes, and socio-emotional and sensory needs could positively affect children’s social play experiences.

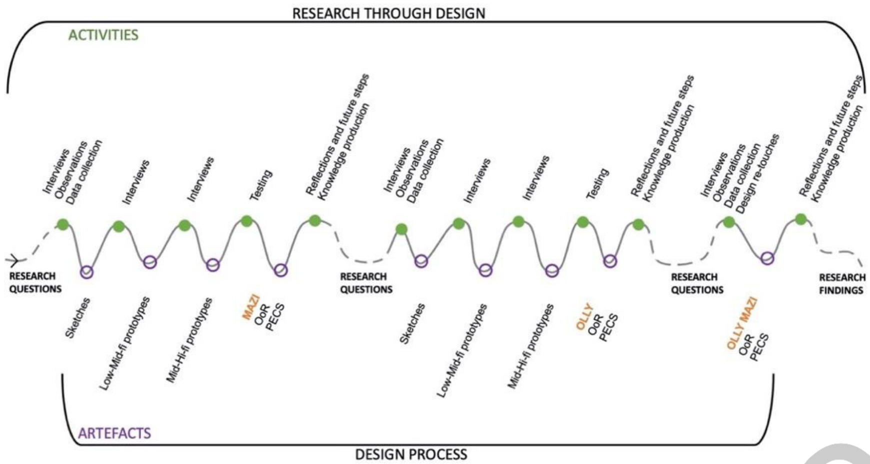

Fig. 1. Research through design as iterations between design artefacts and activities/knowledge generation. Inspired by[3]

As seen in Figure 1, we made a series of low-fidelity prototypes (hand-drawn sketches and material exploration) and two main hi-fi ones, Mazi and Olly, tested with three children's groups. The three studies were conducted in 2018, 2019, and 2020/2021. The testing phases of the first two studies (also called play sessions) happened over five weeks, once per week, on Thursday afternoons, in the Garden dance studio, whereas the final study's testing phase lasted for just three weeks due to COVID-19. Because it is an iterative process, it enabled us to switch between the children's and the design's needs. Exploring through design, i.e., by looking at children and noticing that they liked textile materials, hence exploring e-textile sensors and fabrics, offered us increased opportunities to engage children during the play sessions (also called test sessions) not just because they liked textiles but also due to the potentially endless affordances of the resulting physical artefacts [55]. It also allowed us to generate knowledge about materials and afforded actions about nonverbal autistic children's social play, better discussed in the last part of this paper.

Play is an essential aspect of doing RtD [42]. We learn about the children and the design through their play, but we also play as designers and researchers to achieve a new understanding of technology [38]. In our opinion, this creative engagement fuels the imagination of alternative forms of knowledge around technologies for nonverbal autistic children and opens opportunities for more inclusive design spaces.

3.2 Ethics and children

Queen Mary University of London's Ethics of Research Panel fully approved the research in December 2017. Information sheets were circulated to parents/carers and participating teachers alongside consent forms, usually returned within two weeks. Consent was given by the children's

[3] Dalsgaard, 2009, Designing Engaging Interactive Environments: A Pragmatist Perspective

parents. However, during the studies, children's assent was always prioritised, and they were free to withdraw at any point if they wished to do so and/or if it was visible during and after the sessions that the child was dysregulated or uncomfortable. No child withdrew from the studies or showed signs of distress during or due to the sessions. Parents have approved publishing their children's pictures without blurring their identities for academic purposes and scholarly publications. The information sheets contained information related to the aims and scopes of the research, introduced the methods and approaches used for data collection and evaluation, and some details about the dissemination of the work, including the use of clear pictures for academic publications. Table 2 summarises the children who participated in each study, their ages and personal interests.

Table 2. Children participating in the three studies, including ages and children's preferences

MAZI (* same children as study 2)				
Alice 8 *	**Pete 9 ***	**Joshua 8 ***	**Tom 6**	**Leroy 6**
Tidy, quiet, calm spaces; listening to songs; singing; edible messy play; drawing; mirror's reflection; blow bubbles, dancing; tickles; animals, dressing up	Deep pressure; puzzles; reading; familiar routine; being independent; quiet and calm environments; gym ball; TV characters; shapes; joking; numbers; letters; fiddling with fabric	Manipulates fabric/ribbon; physical contact and deep massage; time in corner to self-regulate; dry textures; time at the corner, mirror, rocking; cover with a blanket; fine motor skills activities (i.e., threading, screws, torches etc); blankets	Hula hoops; trampoline; therapy ball; deep pressure; nursery rhymes; vibrations; dry food; climbing	Shows, people; movements; things happening; chewy tube; soft toys; running; music; dancing; chasing; straws; eating tiny things

OLLY (* same children as study 1)				
Alice 9 *	**Pete 10 ***	**Joshua 9 ***	**Isaac 5**	**Ben 5**
Tidy, quiet, calm spaces; listening to songs; dance; singing; drawing; mirror; bubbles, dressing up	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 favorite songs; interactive board; tickles; squeezes	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	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	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

OLLY MAZI						
Anna 5	**Elodie 5**	**Selina 5**	**Tula 5**	**Steve 5**	**Theo 5**	**Ray 5**
Clear, consistent routine, holding a small toy, Snacks, Playing, Running, Being outdoors, Adult attention, Tickles, New things	Clear routine, Songs, music, Bubble, Sensory play, Feathers, Foam, Relaxing, Dance	Knowing routine, Bubbles, Music, Dance, Singing, being outdoors, Musical toys, Dance, drama, Repeating things, actions twice	Warm water bottle, Snacks, Clear routine, Songs, music, Dance, sitting on vibrating cushion, play time/climbing, Nap when tired	Clear consistent routine, holding small stretchy toy, Snacks, Playing, running, Being outdoor, Adult attention, Tickles, New things	Clear routine, Singing, Music, Outdoors activities, Climbing, Legos, Dance	Adult attention, Straws and strings, clear routine, Singing, Music, Outdoors activities, Climbing, Interaction with others

A more comprehensive profile of each child can be found in our previous publications of each study [85, 88, 90] and the first author's thesis [89]. All children attending the Garden must have a medical diagnosis of autism. Most of the children in school were assisted by Teaching Assistants on a 1:1 basis, meaning that 1 adult worked with 1 child, and the participating children were accompanied by their respective TAs during the play or testing sessions. On a few occasions, the class teachers accompanied one of the pupils. We always booked the dance studio for 30 minutes, but the length of each session changed slightly. We asked the dance teacher to lead the sessions of each study, and the first author was always present in the room as an extra support.

3.3 Contextual overview and research approach

The Garden School is a provision for children aged 4-16 specialising in autism and is based in North-East London, UK. It mainly uses evidence-based educational approaches to enable and encourage autistic pupils to reach their full potential. The research design was developed to align with the curriculum and practices of the school.

For example, in the three studies carried out throughout this project, PECS [147] and Objects of Reference (OoR) - used with children who did not use pictures, were created specifically to represent the two developed sonic e-textile open-ended TUIs, called Mazi and Olly, and were used on the children's classes and individual timetables and on their "now and then" cards, which they carried around and used as a transition tool from one activity to the other. At the Garden, the teachers also used a bigger format of PECS for a shared class timetable. Therefore, the play (or test) sessions were each divided into smaller sections represented by a visual symbol. The structure of these testing sessions was decided upon discussions with the dance teacher. We used PECS displayed in sequential order and usually moved by the dance teacher, the breakdown of which was:

- taking shoes and socks off
- saying hello
- looking at the teacher while the teacher sang the Under the Cloth song
- looking and listening (at the teacher touching the TUI)
- inviting children to interaction and or free play
- celebration (used just in studies I and II)
- sign language for the finish to indicate that the session was finished
- goodbye symbol

We used the SCERTS Model [154] to understand how children communicated (Social partner (SP) - when the child uses less than 3 words to communicate (e.g., using sign, language, or pictures); Language Partner (LP) - when the child uses more than 3 words), and as an inspiration for developing our evaluation framework, better explained in [89]. Aside from one child (Pete in study 2), the children who participated in this research were at the Social and Language Partner stages. This information was used as a starting point to inform some design strategies (i.e., when creating symbols and/or Objects of Reference and when deciding how much talking the children should have been exposed to during the testing sessions).

We introduced the TUIs to the children as the sessions started following an approach inspired by the first stage of Attention Autism (AA) [155] and developed by the first author. For instance, ‘Under the Cloth’ is an Attention Autism-inspired song invented by the first author following AA practices, sung to the children by the dance teacher at the start of each play session in each of the three studies, when the teacher used a cloth to cover the TUIs. At the song's end, the cloth is lifted, leaving the TUI(s) visible to the children, and the adults in the room (Teaching Assistants) make surprised exclamations. The children are then invited to play with the TUIs or left free to play around.

Finally, some of the Treatment and Education of Autistic Children and related Communication-Handicap or TEACCH [146] strategies were adopted throughout the three testing phases of the studies to create a semi-structured environment and to clearly show the children what to expect from the sessions through environmental modifications, visual and tactile schedules, semi-structure sessions to allow understanding of expectations and freedom.

3.4 Positionality

Aside from a few examples within the HCI community [115, 31, 128, 8, 84], most researchers working in the space of play, technology, and autism often adopt a deficit narrative and take an “outsider” approach to autism, which does not support children exercise their rights. We, the authors of this paper, are guilty of this as well, albeit very much unintentionally, because we have used inappropriate words and language at times, perhaps amplifying an ableist view of neurodiversity [85, 88, 86], and for this, we apologise.

With this article, we aim to readjust our position and acknowledge that our understanding of autistic culture is a work-in-progress endeavour that might need refinement. Being NT (as to our knowledge when this manuscript is submitted), we might never fully understand the embodied experience of being autistic (and we should never think that we do as it might silence the *voices* of autistic people). Still, we believe we can do better as researchers and human beings. We are committed to continually developing a better understanding of the autistic culture to better our empathic abilities, and in this research, we tried to avoid an ableist language [11, 13].

Throughout the three studies, the first author was the observer, the designer, the facilitator, and the evaluator (together with teachers and Teaching assistants (TAs)). Furthermore, she worked at the Garden as a Teaching Assistant for about 2 years before her PhD and knew how the scholastic system worked, many of the children, teachers, and TAs. Therefore, she positions herself both as an insider and as an outsider to the scholastic community (or culture) that collaborated with this PhD and acknowledges the influence that this might have had on the research’s process and its outcome. Milton [2012] writes that a non-autistic person has no pertinent personal requirement to understand the mind of the autistic individual unless “closely related socially in some way”. Rosqvist et al. [2022] refer to the concept of “the wise” as the relative of someone who is disabled. In this paper, we use the term insider to refer to the first author as someone with an awareness of neurodivergence due to this relation of familiarity with it (which emerged after starting her PhD), but also and mainly to someone who has experienced first-hand many bonding experiences with many (minimally verbal to nonverbal) autistic children. Therefore, the first author's positions overlap in different ways, levels, and stages of the process. Note that when using the term neurodiversity, we refer to the different neurotypes that exist within the scholastic ecology of the children attending the Garden School, such as the teachers, teaching assistants, therapists, and, particularly, (non-autistic) researchers.

3.4.1 Manuscript framing

The research reported in this journal article is part of the first author's PhD thesis [89], and it is related to five prior publications discussing the individual findings of the three studies carried out throughout the PhD. More details about the first study (Mazi) are published in [85, 86]; about the second study (Olly) are published in [88, 87]; and about our third and final study (Olly Mazi) are published in Italian in [90], but an English version is also available in the first author's thesis [89].

This article discusses unpublished materials, including the research and design approaches used throughout the three studies, offering novel insights into how these have evolved over the years. This article also contributes a reflective discussion of the overall findings of the TUIs design and research insights in the context of play, autism, (non-autistic) researchers, and schools specialised in autism, in contrast to the previous five publications and the thesis, which offered an exploration into the outcome of each single study concerning the main RQs and their practical contributions (i.e., the TUIs and the framework) rather than the theoretical contributions.

4 DESIGN PROCESS

The design process of Mazi and Olly (Figure 1) was influenced by the children's observations and drew on lessons of human-human interaction in the social science [135] with an HCI lens on future design and research implications. The main design values that guided the initial development of the two systems were:

1. Build on children's past experiences, needs, and preferences, hence their strengths
2. Support self-regulation
3. Encourage spontaneous social activities

To achieve these values, we tried to build two TUIs that supported stimuli that the children liked, needed, and sought, and we went into the design phase with a lot of information collected from different channels (i.e., observations and documentation carried out by the first author, class meetings, interviews, previous and personal knowledge of the school and children etc.). The OT and our experience inspired the three main design values. Following the OT suggestion at the beginning of study 1, attention was given to building TUIs that would scaffold social play because they suggested that children lacked opportunities to do so. Due to our experience working with autistic children, we also aimed to potentially offer individuals the opportunity to self-regulate when playing (i.e., to regulate their arousal and energy levels). During this phase, the first author talked to the dance teacher to understand how to set up the space and defined a session plan.

Aside from the OT, class and dance teachers and teaching assistants (TAs) were interviewed at the beginning of each study to acquire more information about the children and, in the end, to evaluate the TUIs. For example, after the testing sessions of Study 2 and 3, the teacher and TAs were asked for further information, e.g., their level of prompts, the children's engagement, if they noticed anything, and so on. In Study 1, this did not happen because we did not think about it, and in Study 3, instead of meeting face-to-face due to the spread of COVID-19, we sent questionnaires via email and kept in contact via WhatsApp. These conversations helped us understand the children more comprehensively and accurately. All the interviews were audio-recorded to be used for later analysis.

In addition to the above, in all studies, before the testing sessions began, children were observed for about 2 to 3 weeks during dance and P.E. lessons. These generated notes and initial sketches helped form a better understanding of each child (see Figures 2 and 4). We observed children during physical education (P.E.) and dance lessons because the dance studio was the same environment where the studies took place, and the P.E. Hall was the only place where the children in the Garden were offered a choice of physical equipment. This was a chance to observe their preferences and use of tools and toys and to find out what sensory stimuli they sought out the most during current group free-flowing scholastic activities. During the observations, the first author occasionally interacted with children, sat next to other TAs, or moved around the room other times. Additionally, many times, she was approached by some children. She was brought around the space or prompted by a few to play with them, i.e., singing along, letting them caress her face, rolling balls at each other, touching hands, providing pressure, helping to balance, and so on, or sitting in front of each other while holding hands. We call these **immersive observations**.

We worked with 14 children in total, but the main design decisions were led by the 7 children who participated in Studies 1 and 2 (Table 2).

4.1 Mazi Concept

In Study 1, we noted that some of the children liked to be rolled over an inflatable ball while they laid on it on their back or their belly (Figure 2), others liked to bounce on the ball while sitting on it, some liked to balance on it, and few pressed their hands on the ball or squeezed smaller balls or malleable toys and fabrics.

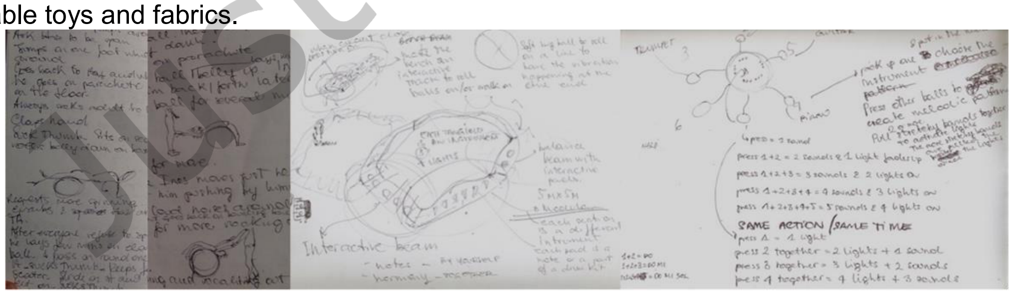

Fig. 2. Example of observations notes of children Study 1 (left) and Mazi's first conceptual design ideas

Alice loved dressing up, and Joshua liked twisting textile materials and fiddling with soft textures. Tom liked interactive musical toys and loved rolling on the inflatable ball, as well as Pete and Joshua. It was reported that Joshua did not like stuffed toys, playing with objects, or interacting with the environment, and Tom did not like wearing jeans. We also noted that the teachers invited children to come together by using a big multicoloured nylon parachute with a circular shape, and children would go either under it all together or hold it by standing on the outside. This inspired the idea of designing the first TUI in a circular shape. As seen in 4.4, the literature confirmed the benefit of using a circular design for enabling social activities.

The first TUI was developed by the first author and is called Mazi (μαζί), from the Greek "together". It's a stand-alone sonic e-textile foam dome covered in wool roving felted using wet and dry techniques (Figure 3). The interactive areas are made of five e-textile bubbles covered in conductive jersey and wool. The TUI allows people to play up to five sounds polyphonically, and its design offers multiple uses. People can, among other things, press, sit, climb, lay on the main body, and touch the tops of the five coloured bubbles to activate the sonic outputs. Figure 3 shows how children in Study 1 played with Mazi.

Fig. 3. Children in Study 1 playing Mazi

The idea behind it was that children would use the round shape of the body and its bubbles to gather around it together and to receive some deep pressure stimulus, which some of them liked, while perhaps enjoying its soft materiality and musical qualities. After exploring different design options and getting to know the children, the first author showed the ideas to the dance teacher and then picked the (two) final design(s). We experimented with different materials and opted to work with felt because it is easily reusable and can be repurposed [49]. A mix of bright primary and secondary colours, in keeping with colours used in the school, were chosen to help attract children's attention to the active sensors' areas and, as we will see later, to define entry points. In this cycle and the next one, we explored the main research questions 1, 2, and 3. The design process continued throughout the testing phases (also called play sessions), i.e., by fixing broken bits or adding felt, one speaker, etc... As explained below, some of the findings of Study 1 fed into the design of Olly.

4.2 Olly Concept

In Study 2, some of the children often used soft blankets or cloths, we were told, as a way of comforting and regulating themselves. For instance, in dance lessons, Alice dressed up and played with plush toys in the mirror while Pete put some fabrics and pillows inside a big cardboard box and hid inside it (Figure 4). Pete, Joshua, and Ben enjoyed receiving deep pressure either through patting their hands, foot massages, the inflatable ball, the floor or hugs. Joshua also usually fiddled with a string of fabric or a ribbon, and he liked to twist it and make sticks out of it. Isaac was found to enjoy participating in dance lessons in other classes. We observed one where the teacher proposed a group activity with a large stretchy band, which he seemed to like by standing inside it with the band positioned behind his waist, holding the stretchy ribbon with his hands, and then moving back and forth while forming a circular shape. This information fed directly into the designs and influenced the choice of using stretch e-textiles and a soft body that could reproduce the sensation given by the inflatable ball. At the end of the P.E. lessons, the teacher played melodic and/or rhythmic music (made using the hand-pan), and the children responded well to them; this affected our choice of sounds.

Όλοι (pronounced Olly - from the Greek "All/Everybody") is the second study and the name of the second sonic e-textile tangible user interface design made in natural wool fabric and stretch lycra (Figure 5). Its design was an iterative process, for initially, we wanted to propose an upside-down version of Mazi by attaching stretch fabric ribbons (with embedded e-textile sensors) to the ceiling of the dance studio (Figure 4). However, this was not feasible as the structure could not sustain its weight. Therefore, we decided to see what worked in Mazi and tried to replicate those features.

In iteration 1, we learned that children liked the interactions afforded by Mazi's shape, size, and materiality. However, we noticed that the simple touch-once-and-play-one-note paradigm was too simple for some. Hence, we aimed to offer an interaction style that evoked longer and more complex interactions. Consequently, after exploring different types of sensors (conductive jersey, conductive wool, graphite, stretch e-textile) and materials to pair them with, inspired by the children's observations, we decided to use stretch lycra and lycra-like stretch fabric sensors from EMF because they could be pulled. We decided to use pulling because Isaac showed interest in this kind of interaction. Furthermore, a sensor that can be pulled also enables many other types of interactions [55], such as rotation, twisting, pinching, etc., which are actions that Joshua liked doing. The ribbons could have also been used to cover body parts.

We replaced the soft-play dome used to make Mazi's main body with an inflated therapy ball of 65 cm diameter, as we found this to be a cheaper and easier option that allowed Olly to be moved around by deflating it. The bouncing ball was the same tool that Pete, Joshua, and Isaac were observed using the most before the design stage began, while Ben used to seek deep pressure by rocking his whole-body belly down on the floor (Figure 4).

For practical reasons related to the shape and size of Olly, we embedded four sensors instead of five, which would have corresponded to the children's number. Contrary to Hochhauser et al.'s

[2015] proposition, we considered that offering limited access points could have left space for positive conflicts to emerge [32, 76]. Learning from the previous cycle, instead of felting Olly's cover from scratch using wool fibres, we used industrial felt sheets this time because we thought this would speed up the design process and make the surface smoother. In Study 1, felting Mazi from scratch took a long time, and its fibres could still be picked and pulled. Therefore, we thought this option would improve the design.

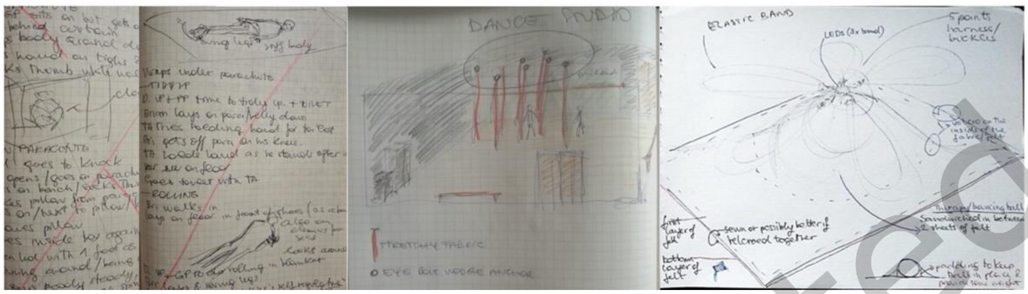

Fig. 4. Example of observation notes of children Study 2 (left) and Olly's first conceptual design ideas

The installation is topped with 4 stretchy coloured lycra ribbons with the stretch e-textile sensors embedded in them. These play different instruments as they are pulled, activating a progression of 8 notes and enabling people to play soothing melodies when playing solo. The more ribbons are pulled, the higher the notes pitch and the more harmonies emerge from the collaboration. The intent was to enhance the sonic experience emerging through the collaboration of more players, giving more complex sound combinations and harmonious sounds. Figure 5 shows how children in study 2 played with Olly.

Fig. 5. Children in Study 2 playing with Olly

The ribbons trigger different chords (triads) based on the C major scale, enabling the creation of melodies when playing solo and harmonies when playing together. With Olly, people are able and invited to form beautiful compositions. On day 4, Olly was not working but was left in the room for the children to explore even though the power was switched off and the TUI did not play any sounds. The dance teacher was worried that this would have upset some children and was seen as a challenge, but it was decided to carry on the activity as normal, just to avoid disrupting their routines.

4.3 Olly Mazi Concept

In Study 3 (Figure 6), learning from what we found in Study 2 (i.e., flimsy connections) and from the new group of younger children (very curious), we aimed to solidify connections and the stability of the sensors and overall designs. Hence, we remade the circuits and connections by replacing the previously used conductive threads with softcore wires soldered to male-to-female header pins connected onto a protoboard [90, 89].

The final iteration of this research project is called όλοι μαζί (pronounced Olly Mazi), from the Greek “All Together”, reinforcing the idea of togetherness, which resonates with one of the research’s aims of eliciting playful social interactions between children (Figure 6). In Study 2, the dance teacher compared Olly to Mazi and said that children could create more music with Olly and had more possibilities to use it together and for different purposes than Mazi. Reflecting on those comments, we became curious to see if one of the two technologies worked best for scaffolding social play dynamics. Therefore, we tested the TUIs simultaneously, in the same space, and with the same group of children. This study (Study 3) aimed to compare the children’s responses about the two tangibles to understand further key factors for effective TUIs for social play in autism. Particularly, we wanted to understand if other children could use the designs than those who inspired their features.

Fig. 6. Children in Study 3 playing with Olly (and) Mazi

From the previous iterations and studies, it was still unclear to what extent the music impacted children's experiences because the TUIs were tested just when the power was on (aside from day 4 of Study 2). Thus, this time, we tested Olly and Mazi in two states: with the music on and off. To do this, we alternated the order of the presentation of the two TUIs. For instance, the first session started with Mazi and Olly's power turned off for the first half of the session, then for the second half of the session, the power was turned on - order *a*. The second session started with the TUIs' power turned on for the first half of the session, then off for the second half - order *b*. This alternation was done to see whether the results were replicated in both conditions (for instance, the children could have had more energy during the first half of the sessions). This last cycle addresses the main research question 4 and provides further evidence for main research questions 1, 2, and 3 (particularly the musical aspects of question 3).

4.4 Literature's contribution to design

Studies on human-human interactions show that *circular configurations* facilitate natural communicative and collaborative mechanisms, providing a means for socialisation [145]. According to theories of embodied interactions [134], body orientation and space configuration contribute to social interactions differently. In Kendon's F-formation, for instance, social interactions are organised around an imaginary circular *O-space* maintained to grant the same access to all parties involved in the interaction [134]. The O-space is specific to Human-human communication and may take a variety of configurations (facing each other; L-arrangement; side by side) depending on different factors such as the number of participants, the arrangement and layout of physical space, and the type of activity. Mazi and Olly (Figures 3, 5 and 6) were designed to recreate the illusion of an imaginary *O-space* around which interactions are often organised [134] and where children could meet and tolerate each other's proximity by having multiple *access* and *entry points*. The position of the sensors was also considered, as this pinpoints the children's speaking rights and their agency within the piece [103, 76]. For example, face-to-face interactions usually give the same rights to speak to participants. They can also denote competitiveness, while a parallel alignment usually indicates collaboration [134]. Furthermore, round shapes convey positive meanings, whereas shapes formed by acute angles are perceived more as threatening [67].

Alongside the *configuration of the inputs*, the physical properties of digital objects also need careful consideration. Their shareable characteristics can be designed to facilitate social interactions, such as we did in Mazi and Olly by:

a) offering a clear overview of the technologies in their environment through placement in the space, size, and sensors' placement
b) creating a honeypot effect by using colours, fabrics, materials, and sounds, which, together with the circular shapes and overall designs, aimed to promote social awareness and allow perceptual access
c) aiding manipulative access by having an appropriate amount of access points, being usable beyond its digital potential, and allowing a balance between personal/social space

d) enabling fluidity of sharing through their sizes and shapes, lack of elevation, and their access points, i.e., the sensors, and their materiality such as the elastic ribbons, the bubbles and the felt, and lack of elevation used to minimise access barriers.

Finally, the designs aim to facilitate *appropriation*, *agency*, and *participation* in social play by borrowing the concept of *openness* [144]. This allows the TUIs to become an unfinished toy that is open to interpretation and use and that is completed by the children. TUIs in this project are toys in the way that Baudelaire defines them as “the child’s earliest initiation into art, or rather it is the first concrete example of art” because of their aesthetical qualities that enable them to address the “childhood notions of beauty” [143]. Therefore, following this principle, Mazi and Olly enable a varied type of play and aim to be “meaningful even if the power is turned off” because “technology should add to a toy, without sacrificing the good qualities inherent to its class of toys” [142]. Lastly, Gaver [2002] and Gaver et al. [2003] recommend a) using *ambiguity* to support meaning-making - which resonates with the concept of *openness*, and b) designing for *pleasure* to entice people’s exploration.

Ambiguity and openness in our designs are reflected in the fluid, non-figurative shaped designs and their materiality, which allow them to be used and appropriated in many ways. The concept of designing for pleasure instead is offered in the types of interaction afforded by the two TUIs, which should resonate with the children, but also in striking a balance between challenge and simplicity.

5 STUDIES

Below, we briefly present how the three studies were conducted. Section 7 summarises the main insights of Studies 1, 2, and 3 to frame our new contributions in Section 8.

5.1 MAZI

Table 3 shows the children who participated in Study 1 (Mazi). The Headteacher organised a meeting with all the parents in the initial phase of the study, and four of the five children’s mothers attended. This lasted roughly 1.5 hours. One of the parents expressed their wish to have the study results given to her as soon as possible. Hence, we provided all the parents in each study with visual and written feedback after each session. This consisted of a set of pictures of their child and a brief written report where we informed them of their child's experience in the sessions. The first author exchanged these documents with the families through the children’s bags, usually the day after the play sessions happened. In this study (Study 1) and in Study 2, we left the TAs the freedom to intervene as they pleased. The prompts were verbal or gestural, and children were never forced to approach. To signal that the session was finished and to give enough time for each child to process what came next, the teacher usually started a count-down from 5 and then covered the technology with a cloth again. Alice and Leroy were supported on a 2:1 basis, i.e., they were both accompanied by one TA, while every other child was assisted on a 1:1 basis. When the first author worked as a TA at the Garden, she worked 1:1 with Alice and Tom. Furthermore, Alice and the researcher became very close when they worked together.

Table 3. Profiles of children who participated in Study 1

MAZI				
Alice 8	**Pete 9**	**Joshua 8**	**Tom 6**	**Leroy 6**
Tidy, quiet, calm spaces; listening to songs; singing; edible messy play; drawing; mirror's reflection; blow bubbles, dancing; tickles; animals, dressing up	Deep pressure; puzzles; reading; familiar routine; being independent; quiet and calm environments; gym ball; TV characters; shapes; joking; numbers; letters; fiddling with fabric	Manipulates fabric/ribbon; physical contact and deep massage; time in corner to self-regulate; dry textures; time at the corner, mirror, rocking; cover with a blanket; fine motor skills activities (i.e., threading, screws, torches etc); blankets	Hula hoops; trampoline; therapy ball; deep pressure; nursery rhymes; vibrations; dry food; climbing	Shows, people; movements; things happening; chewy tube; soft toys; running; music; dancing; chasing; straws; eating tiny things

5.2 OLLY

The cycle of this second explorative study (Olly) included the children shown in Table 4. Three of them (Alice, Pete, Joshua) were re-selected by the Headteacher and dance teacher from study 1, but two new boys were added to this group (Isaac, Ben). The first author had never met Isaac and Ben before this study, whereas Pete and Joshua were familiar with both the researcher and the research format. Ben came from a disadvantaged background, and social services followed him, hence the dance teacher and the Headteacher thought that he would have benefitted from such activity. There was a concern with his behaviours at first due to a developed habit of hitting other children either to get their attention or to look at their reactions. However, there were plenty of opportunities to monitor the children closely and avoid any discrepancy that could arise from challenging reactions, therefore he was welcome. Apart from Ben, who just attended the first three sessions, as was absent from school for the next two sessions, all children attended all five sessions. It was reported by the teachers that Isaac and Ben shared the same playground space, but they never approached one another during play time and had never met the other children before this study.

This time, it was decided with the dance teacher to avoid meeting with the children's parents/carers because three out of the five participating children's parents had already attended the meeting in the previous study and knew what the study was about as the scope was not changed. Also, Ben's mother had learning difficulties and could not read or participate, and the teacher told us that Isaac's mom was open to their child experiencing many activities in school. Hence, it would not have been necessary to have an in-person meeting. However, the consent of Ben's mother was ensured after we were told that the informed consent was explained to them by the person who supported them, who ensured that they understood the purpose of the study. Additionally, the first author focussed on capturing more pictures of Ben's experiences and reduced her verbal language when communicating with Ben's mother (but once again, we were told that our feedback was read to them by the person who supported them; we are not sure if daily). Through the informed consent forms and the teachers, all the parents/carers could raise any questions and request a meeting if they wished to do so. Children attended school activities with 1:1 support, so the same level of adult support was requested for the study.

Table 4. Profiles of children who participated in Study 2

OLLY *Same as study 1				
Alice 9 *	**Pete 10 ***	**Joshua 9 ***	**Isaac 5**	**Ben 5**
Tidy, quiet, calm spaces; listening to songs; dance; singing; drawing; mirror; bubbles, dressing up	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	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	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	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

5.3 OLLY MAZI

This last iteration (Study 3) was carried out in collaboration with 7 new children, all aged 5 (Table 5). Before this study commenced, a new interim Headteacher was appointed, and the dance teacher selected this group because she knew the pupils best. The selection criteria for recruiting participants were different from the previous studies. The dance teacher was asked to choose pupils that they thought would enjoy Mazi and Olly's features. The tested technologies, therefore, were not designed around the needs of this group of children. Conversely, the features of the designs guided their selection. This group was overall younger than the others who participated in the previous two studies. The researcher did not know any of them but knew the class teacher because they were both teaching assistants (TAs) when the first author worked at the Garden. However, they never worked in the same classroom. In contrast to the previous two studies, these children came from the same classroom but had less experience with the Garden and its system than the other children. Anna and Steve were supported on a 2:1 basis, i.e., worked together with one TA, and Selina and Theo were accompanied by one other TA; Elodie, Tula, and Ray were supported on a 1:1 basis, i.e., individually, by the other three TAs.

Contrary to the previous studies (Study 1, Mazi, and Study 2, Olly), where the TAs were given the freedom to intervene as they pleased, this time, they were explicitly asked not to intervene unless a child needed them. They were told to avoid playing with the TUIs, especially when no child interacted with them. However, we noticed they were still keen to prompt children to wait during AA. In Study 2 (Olly), it was found that i.e. Alice and Tom were prevented by Alice's TA from playing freely and spontaneously with Olly and that some TAs were constantly playing (too much) with Olly. The aim of these play sessions was to create better opportunities for the children to understand the cause-effect interaction and for spontaneous intentions beyond adult interventions. The sessions' start and end were shortened, per the dance teacher's initial suggestions, i.e., shorter hellos and goodbyes.

Table 5. Profiles of children who participated in Study 3

OLLY MAZI						
Anna 5	**Elodie 5**	**Selina 5**	**Tula 5**	**Steve 5**	**Theo 5**	**Ray 5**
Clear, consistent routine, holding a small toy, Snacks, Playing, Running, Being outdoor, Adults attention, Tickles, New things	Having a clear routine, Songs and music, Bubble, Sensory play, Feathers, Foam, Relaxing, Dance	Knowing my routine, Bubbles, Music, Dance, Singing, Being outdoor, Musical toys, Dance and drama, Repeating things, actions twice	Warm water bottle, Snacks, Clear routine, Songs, music, Dance, sitting on vibrating cushion, play time/climbing, Nap when tired	Clear consistent routine, holding small stretchy toy, Snacks, Playing, running, Being outdoor, Adults attention, Tickles, New things	Clear routine, Singing, Music, Outdoors activities, Climbing, Legos, Dance	Adult's attention, Straws and strings, clear routine, Singing, Music, Outdoors activities, Climbing, Interaction with others

6 DATA ANALYSIS AND EVALUATION

We based our analytical approach on video interaction analysis and the evaluations of the dance teacher and the TAs. With the dance teacher, we co-designed an evaluation framework to be used by her and the TAs after each play session. The mixed approach used for developing the framework was inspired by tenets of embodied interaction and nonverbal communication [135, 136, 133, 137], evidence-based assessment tools (SCERTS), and the teacher's assessments and the children (more details can be found in Nonnis [2021]). The teaching assistants provided written evaluations of each of the children they worked with individually. At the same time, the dance teacher evaluated all the children individually, following our evaluation framework's criteria (see Table 6). The dance teacher advised us to define only a few criteria for their observations to minimise memory overload. In Study 1 (Mazi), the criteria they evaluated were 5 (Themes 1 to 5). Still, they became 7 from Study 2 onward, as we realised from the video analysis of the first study that we wanted their opinions on children's emotional responses and levels of attention.

By the time Study 2 (Olly) finished an extra criterion, Theme 8 (T8) called 'Play types' was added to the analysis carried out by the first author on the video recordings as we wanted more details on the types of play children engaged in. Therefore, by the end of Study 3, we evaluated 8 main criteria (T1 to T8), plus 23 sub-themes in total (see Appendix A) [4]. We triangulated the first author's video interaction analysis and the teacher's observations and comments to form the quantitative and qualitative results reported in detail in the findings of each study [85, 88, 90] and the first author's thesis [89], briefly summarised in the section below.

[4] Children exhibited interactions with Olly and Mazi that went beyond the digital affordances of the TUIs, and used them in personalised ways. We feel important to highlight them in appendix (B) as they inform insights for TUI designs

Table 6. The final evaluation framework used to assess the TUIs

Themes	Definitions	Analysis
Theme 1 (T1)	**Introduction to TUI**. Show interest in the presentation of the TUI (teacher Attention Autism)	Time each child spent: showing signs of interest towards the introduction of Olly by looking at it
Theme 2 (T2)	**Approach** the TUI	Time each child spent: approaching Olly independently (I), or receiving gestural/verbal (GP/VP) and/or physical prompts (PP)
Theme 3 (T3)	**Touch 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 personalised use of TUI** (i.e., for else than playing notes such as deep pressure, climbing, squeezing, patting etc.)	What types of personalised uses, what parts of TUIs are of interest, and the 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)	**Share attention:** Attentional focus towards other peers interacting with the TUI	Instances of common focus of attention.
Theme 8 (T8)	**Play Types**	Time each child spent: exhibiting different types of social play such as those in A1

7 BRIEF REFLECTIONS ON FINDINGS OF PLAY SESSIONS

As we previously mentioned, the below reflections on findings are summaries of the previously published papers about the first authors' three PhD research studies (Mazi) [85, 86], (Olly) [88, 87], and (Olly Mazi) [90, 89].

7.1 MAZI: Reflections on findings

This study (Study 1), called Mazi, found that this group of autistic children who liked music responded well to sonic e-textile playful TUIs. Key factors for effective tangibles included but were not limited to the robustness of the design, its versatility defined by its ambiguous form and openness, the sensory stimulation provided, its configuration, size, and possibly its mobility. As demonstrated by the children's behaviours, the mobility aspect of the tangible might have been crucial for encouraging socialisation and collaborative or competitive activities as the physical affordances of Mazi intuitively prompted children to i.e., move it by sliding it on the floor across the space or lifting it from the floor. Additionally, this provided children with a weight-bearing activity and opportunities to self-apply deep pressure onto their bodies. For example, the dance teacher reported that Pete "engaged with Mazi immediately. Sliding across the floor, manouvering [sic] Mazi' to different parts of the studio (laying-sitting-standing on Mazi)" and Joshua's TA said that "He also requested deep pressure from Mazi and lifted Mazi onto his legs, as though to attain deep pressure and to create a blanket/ a form of comfort." Children played with Mazi in various ways i.e., Alice explored it with feet while Tom's TA reported that he "enjoyed climbing on Mazi".

Children were regulated i.e., as reported by the dance teacher about Alice, "motivated. Switched on. Vocal. Happy. Engaged. Alice was enriched by Mazi… is able to express herself in this session enabling her to develop confidently" or about Joshua "at ease in the situation. He has formed a relationship with Mazi and he's able to touch engaged naturally- organically". At the end of the play, session 5 – the last session, the dance teacher said that Joshua "did not have an object (as he always requests), so what he achieved today was amazing". This suggests that the design and the context provided some regulatory opportunities that enabled the child to feel regulated without needing a ribbon as he generally did in other schools' lessons, i.e., the classroom, P.E., and dance lessons.

Further studies are needed to discern whether the sonic element influenced the children's experiences. It seems that most of them used the TUI more for personalised (T5) purposes and to satisfy their deep-pressure touch-seeking behaviours, rather than to play sounds together. However, it was reported that they all played music and listened attentively, and the sonic features might have supported sharing attention behaviours. For example, the dance teacher noted that Tom was "looking at Mazi from a distance. He stood several times and listened to the music being played", and Joshua "was listening attentively". Children, therefore, exhibited participation in activities in the Onlooker modality, even if Parten defined onlooker as a non-social activity [93]. This demonstrates to us that sociality between autistic children can take different forms [78, 26].

The open-ended nature of the design allowed the children to appropriate aspects of the TUI as they wished, and the open-ended nature of the study structure, with the minimal support provided by adults, left freedom and encouraged children's spontaneous explorations. Teachers reported children's level of engagement with Mazi beyond their facilitation, as in i.e., "[Joshua was] moving in the space with his ribbon he independently approached Mazi requiring no prompts".

7.2 OLLY: Reflections on findings

Study 2 demonstrates that using stretch sensors facilitated children's social interaction with and around Olly, the TUI. For example, Isaac TA commented, "He pulled the cloth. Placed his body inside the cloth. Isaac explored the cloth with Ben running around Olly". Some children went inside the ribbons, others pulled them from standing outside, and others manipulated them with their fingers or feet. The dance teacher explained that Pete "wrapped the Lycra around his feet the same time as Joshua" and that "watching this brief interaction was wonderful" for her. She added that the stretch ribbons offered the children more sharing opportunities than Mazi because "if you were laid on it [Mazi], it was a bit difficult to play". Therefore, it seems that Olly's affordances, such as its size and types of sensors, offered more space and opportunities when played together by more children. Ben's TA observed that "pulling was good for [Ben] [..] because he likes the pull he likes the actual motions of doing things […]it was quite good because he could go back a bit". For children who like to be on the move, such as by rocking, the use of stretch sensors might facilitate those actions.

The stretch materials also seem to have afforded opportunities for self-regulatory strategies to take place through deep pressure, as noted by the dance teacher: "Isaac really liked that because he loves the ribbon in dance, 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", and

“[Joshua] likes to stretch. He liked the feeling”. Olly offered a wider variety of interaction styles. The combined use of textiles, such as felt, elastic lycra, and music, provided rich multisensory feedback and a soothing experience all the children and TAs appreciated. Isaac’s TA observed that “[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 the song. As a shape, as a something, there was no gender of this. There were no very harsh colors [sic]. It was just like a nest. It was accessible. It was really good”.

The absence of music in session 4 has affected all the children. The dance teacher noticed that “Alice was very engaged and calm on arrival-ready to play with Olly” but added that “Once she realised there was no music […] she became unhappy”. Alice left the room after crying very loudly, as the lack of sound seemed to upset her. Joshua went to the cupboard where the music is usually played by the stereo during Dance as if to indicate that they wanted it on. Isaac made the music himself by drumming on Olly’s body with a TA. He pushed Pete off Olly’s top, which is something they had never done before, while Pete displayed over-excited behaviours. Interestingly, the dance teacher stated that the “collaborative play was much more [with Olly] than with than with Mazi. In a different way. The fact that how it sounded it was different [..] it was like they were creating music. Whereas with Mazi um the creative. Creating music was something. Well, like with Joshua with Mazi. Once he got the hang of it, he would come back and do it. But it was more like cause and effect”.

However, children did not interact with the TUI just by manipulating the ribbons. Many enjoyed other features, such as its round shape and wobbliness. For example, Pete also “enjoyed laying over the top and rocking”, and Ben’s TA said that “[Ben] Lays on Pete’s back listening to the speaker. – v calm”. When “Pete became quite overstimulated” during the last play session, the teacher said that “the vibrations from the music calmed him down” and “he was singing, calm and relaxed”. Alice also enjoyed singing and replicating similar melodies to those played with Olly during the sessions. Joshua’s teacher noted, “He was also really interested in the vibration of the speaker because he was always putting his feet on top.” The bigger speaker, therefore, seems to have provided somatic feedback that the smaller speakers in study 1 did not provide.

Furthermore, children did not lift or move Olly around as they did in Mazi. However, Joshua did use its base to cover his legs. He slid it around the floor by pulling the ribbons (on day 4 – but that could have been an indication of the child trying to make music with it), indicating perhaps that the mobility aspect found to be enjoyed with Mazi in study 1, might be a design feature that needs more exploration.

As in our previous iteration, enabling children to be Onlookers was also seen to be beneficial to their regulation and participation. Staff reported that children used these moments to regulate their energy and sensory levels, which in turn is believed to have enabled them to access the ongoing activity. For example, the dance teacher said that Alice “has to go away and process it because she gets so I think it just becomes so much,” and her TA said that she “was exploring the area around the Olly by walking, running and making sounds" implicating that she was participating in her way. Similarly, Joshua's TA said, "he was like looking like that, you know, like I'm looking to see".

Once again, the semi-structured environment was considered important by the dance teacher: "You have to have a clear structure for our children to be able to have that moment to explore because they know that when it's starting, and they do know when it's finishing and in the middle it can be that freedom". Contrarily to cycle 1, however, where the supporting TAs offered minimal support and encouraged children's explorations, it was found that one TA in this study might have negatively affected the experience of some children. For this reason, i.e., Alice's TA was asked not to accompany Alice in session 5, as both the dance teacher and the first author thought that she was working against some children at times e.g., as noted by the dance teacher, "she didn't make a relationship with anybody" and "I think at the beginning she overpowered Alice". This issue, albeit it might seem irrelevant, highlights the importance of designing for the whole ecology and not just the technology.

7.3 OLLY MAZI: Reflections on findings

In Olly Mazi (Study 3), we found that generally, most children played more with Olly than with Mazi. Furthermore, Olly was also the TUI that children used the most in personalised ways. Children adopted similar interaction styles and approaches when using the TUIs in personalised ways, meaning that both offered similar affordances. Olly, however, might have facilitated a more varied sensory experience than Mazi, as it was reported by the dance teacher that "the material that covers Olly is very tactile and sensory. The shape is inviting for pupils to sit on, lay on, or stand on. Embracing and cuddling Olly is easy (shape). The size is appealing to young children as they can see over the top – a view of all of the shapes. The ribbons are bright and colourful and soft to the touch". Perhaps Olly, being bigger and wobbly, required a more overt interaction, i.e., laying or sitting on it. Because these children were small, they laid more on Mazi as it afforded this action better than Olly, providing them with immediate somatic feedback. However, Ray enjoyed Olly's wobbliness and spent much time balancing on its top while standing on it, and Tula liked rocking on it. Elodie's TA reported that "For sure the shape of olly and mazi [sic] was fun because it was round, so they all were laying back and jumping on top [..] Material was good because it was soft and fluffy for them to kick push pull jump" and Selina and Theo's TA observed that "It was very [sic] nice experience to see how children explore new object with so many different sounds, shape and texture. I could see Olly and Mazi make big impression on them. Students like to touch it (even pull the textures out), touch it, lie down on it and swing." The dance teacher added, "Mazi was more popular due to design the pupil can receive a response quicker with their Body ex. [sic] Sit on, lay on, stand". She generally observed that "the experience was very positive, well-pitched and age-appropriate. Bumblebee students have an innate curiosity, and your prototypes fully caught their attention. Olly and Mazi enable students to use different senses to explore according to their abilities. Students who sought pressure found it by pulling strings with their legs or back; those who were more active were able to jump on the prototype and press buttons and those who were more sensory received feedback from the material used by touching or stroking their body against it. All in all, it seemed that both prototypes suited their different needs in many ways."

It was further expanded by Tula's TA that "the round shape was inviting. The size was their size, they could reach it, and it could hold them (especially Olly). The material was soft, they probably liked it because they (Tula, Ray, Selina, Theo, and Steve) laid on it. Most of them tried the ribbons; they liked the elasticity of this, especially Ray and Tula, she might also liked [sic] the colour of the ribbons". Competitive play was also observed and happened mainly with Mazi. Perhaps children competed more over Mazi than Olly because Mazi is slightly smaller and easier to move around, or maybe because it lacks a carpet around its base, which might have discouraged Olly's mobile attributes and encouraged more chilling and social activities. However, most of the competitive play, when using Mazi, mainly emerged due to one child, Theo, who became very protective of Mazi from session two and as his TA noted, he did not like to share it.

All children approached the TUIs predominantly when the sound was on, confirming that the music had a positive influence on children's interactions and worked well as a honey-pot effect, even though it was observed by Selina and Theo's TA that "Some of the textures where more motivating for them then the cause-effect of the Mazi [sic] Olly technology". Overall, children played music with Olly and Mazi for about the same amount of time. However, children played music together more by using Mazi. The dance teacher believed that this happened because, with Mazi, it is "easier to create sound", and perhaps a simpler sonic interaction might be best to elicit social musicking behaviours between younger autistic children (aged 5 or younger).

Self-regulation was enabled by a few factors, such as the sessions' open-ended structure, the TUIs' open-ended design, and the freedom and agency left to children. For example, Anna and Steve' TA thought that they were regulated because "The room has space enough for them to join [sic] or be apart whenever they want. The technologies don't require constant interaction, they are not very demanding and respect the rhythm of the children". The dance teacher thought that "children were very motivated with Mazi and Olly and the sensory input they received was meaningful and fulfilling". Even Tula's TA said that she "used less prompt as she was regulated throughout the sessions" suggesting that allowing children to be independent and free not just empowered them but also enabled them to self-regulate. The dance teacher thought that "Children self-regulated [also] by moving to the perimeter of the area when Olly and Mazi was crowded – working things out". She appreciated that the children were given the opportunity "to explore an interactive musical toy using their body, in a relaxed and unprompted environment so they could use their initiative to enjoy and relax" which she said, "made the experience more child-led". When the dance teacher compared the play session with Olly Mazi to the dance lessons, she explained that "In dance it is different interactions as we move quite quickly between activities – more direction. Mazi and Olly move at a slower/ relaxed pace which enables more time for the children to find a peaceful place". Theo and Selina's TA confirmed this point: "Children were more able to reacted [sic] spontaneously to Olly and Mazi, and they have more chance to interact with another students then looking for an adult hand".

Once again, during the study, it was observed that onlooker play enabled some children to develop social awareness and access the ongoing activity. This is confirmed by i.e. Tula's TA, who said that she "monitor(s) from a distance […] looking at Olly Mazi plus the others from a distance" or by Anna's "she observes from different places of the room and smiles". Around 4 months after the study was terminated, due to the spread of COVID-19, the first author was contacted by one of the TAs via WhatsApp messages: "Just to let you know that Ray is asking for Olly Mazzi everyday [sic]. And he makes me write it on a piece of paper so that he can carry it with him", indicating that the child was missing Olly Mazi. The dance teacher said that both Olly and Mazi were "A place to gather – an object of reference [..] Social interaction has definitely been facilitated as Mazi and Olly are motivating objects, and the children gather and share space, which helps them communicate with each other".

8 CONTRIBUTIONS

In the following section, we reflect on the insights gained from the three iterative cycles described above and highlight the contributions of this manuscript by presenting some research and TUI design principles that guided our playful and inclusive explorative research approach.

8.1 INSIGHTS FOR RESEARCH DESIGN

Reciprocity. Gernsbacher [2006] suggests that non-autistic people could and should increase their reciprocity behaviours towards autistic people. We held onto several values to establish a reciprocal relationship with the children and stakeholders we collaborated with:

- ***Challenge the deficit narrative***. Researchers should be attuned to a neurodiverse world, including the autistic way of being. Echoing Spiel and Gerling [2020], in our opinion, this can only happen when autistic children's being in the world is appreciated and embraced and when there is a genuine interest in their well-being guiding the research. Although in conflict with the insider/outsider dichotomy, as explained in the positionality section of this paper, we started cycle 1 of this research feeling somehow part of the community we were collaborating with, that of the Garden school (not the autistic embodiment of being an insider [81] – albeit we do consider ourselves allies). The first author started this journey with a good understanding of autism, having more than 10 years of experience working with disabled and neurodiverse children both in playground and educational settings. She also had the honour of bonding with many of the children she encountered in her life and has always tried to engage in a relationship of true reciprocity [43]. However, we believe that our level of understanding of autism and TUI designs for nonverbal autistic children has increased throughout the three iterative cycles, thanks to the children's expertise and that of their parents, teachers, therapists and the broader autistic community. During this journey, we learned about ourselves, the children, autism, and technologies. Children's spontaneous ways of playing inspired us to explore novel materials and interactions, revealing interesting insights for researching and designing with and for this population. These cycles have fuelled our expanding interest in and understanding of critical autism studies and led us to review works on autism written by autistic scholars and people. This, in our opinion, has enabled us to consolidate our view of how we see autism and of the message we want to portray moving on, that "Autistic experience needs acceptance and societal accommodation and support, not intervention or "cure" [original emphasis]" [26]. We suggest that to enable better transfer of knowledge and understanding [79 and 81] of autistic children, researchers working within a scholastic environment should learn from the experts, that is, the autistic children and their stakeholders (parents/carers, teachers, therapists), and the autistic people that produce knowledge about autism. Therefore, we argue that HCI researchers who work with autistic children should abstain from having preconceived ideas based on deficit narratives portrayed by an averagely neurotypical society and be open to *learning from the children* and *challenge their preconceptions*.

- ***Understand the context and culture***. It is therefore important that, as researchers, we get to know the community of people we work with if we are to reinforce a positive (autistic) identity and overall message in the children we work with and in the research that we produce [26]. Our ethnographically informed design approach, based on the first author's prior experience and her knowledge of the Garden school, the teachers and some of the children, allowed us to develop an understanding of the context of the research before the research started. As we've seen, this understanding improved throughout the research. However, our appreciation and understanding of differences enabled us to be open and willing to understand the children's ways of being from the start. The iterative process offered by RtD enabled us to constantly feed children's needs and preferences (together with our design and research knowledge) into research and design decision-making processes. This collaborative approach enabled us to develop designs that children enjoyed interacting with. We encourage researchers to collaborate with stakeholders and children by using their knowledge and expertise and to spend time with autistic children and communities to understand better and appreciate neurodivergent ways of being humans before starting any research. The first author spent many years with autistic children before deciding to start a PhD to work with them. This level of contact and experience might not be easily achievable during a 3-year PhD research. However, researchers could i.e. spend some time shadowing professionals working at the institutions they collaborate with to gain deeper knowledge and understanding around best practices and support, do some casual or voluntary work, employ immersive observational approaches where they spend time with the children by observing and living what they like doing while following their lead, talk to autistic people. Researchers should stand in a position of learning from, not teaching to, the people we collaborate and design with and for. In doing so, we can perhaps challenge the dominant and "authoritarian" way of being in the world that we so much celebrate as the norm and impose on others and ourselves [80, 94].
- ***Follow the children's rhythm***. We used two main strategies to enable children to take the lead in the design decision-making process and of the play sessions: 1) by designing two tangibles to reflect children's likes and preferences, and 2) by providing the right amount of adult support. Where opportunities for agency and spontaneity are prevented instead of enabled, such as happened in study 2 with Alice's TA, researchers should 1) be able to recognise that and 2) not be afraid to intervene and request support from highly qualified staff members. To be able to recognise that, researchers must understand what they observe. The institution we worked with offers highly specialised provisions for autistic individuals and all staff is regularly trained in child protection, safeguarding and evidence-based approaches to Special Education Needs. However, albeit with the children's best intentions, some adults in educational contexts can still be overpowering as they seek a sense of control of the children, which in turn might disable them instead of enabling them [130]. This is when practice, i.e., spending a considerable amount of time with different autistic children before starting a study which involves them, becomes useful. In our studies, and particularly in study 3, where teachers were requested not to intervene, if not when asked by the children, they were happy, relaxed, and in need of little adult support, if any. This made a difference in how children autonomously played and took ownership of the play sessions, compared to i.e., cycles 1 and 2.

Semi-structure the activity but leave freedom within. Following Makhaeva et al. concept of Handlungsspielraum, Frauenberger et al. [2020] reflect on the paradox of being open while offering structure. We found several ways to enable freedom within structure in our play sessions.

- ***Provide the right level of support***. In our three cycles, we used educational approaches such as TEEACH, PECS and OoR to semi-structured the sessions and enable children to understand them. For example, *enabling* children's *understanding* of where they are going when transitioning from their routine scholastic lessons to our play activity (through i.e., "now and then" cards), hence giving them agency and power of choice (i.e., whether they want to be in the activity or not), is of paramount importance. Therefore, children in our study could show disapproval even before they came to the sessions if they did not want to come, for example, by refusing to come. The same can be said for enabling an understanding of the sessions' structure. As remarked by the dance teacher in study 2, we aimed to do that using identifiable starts and endings. Wood [2022] explains that though the adults might still be "in charge [..], following the child's lead results in more, not less compliance and co-operation".
- ***Enable spontaneous participation***. We found that participation in our studies happened twice: 1) during design and 2) play. Modes of participation during design included observing children's communication "with their whole body" [104], that is, through their bodily movements and verbal utterances, even if nonverbal [128]. Being attuned to how autistic children exhibit their ways of being is of help when designing and evaluating the technologies, and the lack of understating or attunement might hinder children's participation and research outcomes. The modes of participation during play can involve interaction with tech, interaction with people/peers, interaction with both, and *non-interaction*. We want to reflect on the importance of the *non-interaction* mode of participation for our three groups of autistic children. *Onlooker* play is often seen as a non-social play type [93]. In all our studies, children exhibited participation in activities also in onlooker modality, hence through non-interaction, perhaps showing a more "outsider" form of "social experience and expression of social agency" compared to the more dominant ways of being social [81], but participation was, nonetheless. For example, in Study 1, Tom was "looking at Mazi from a distance. He stood several times and listened to the music being played", and Joshua "was listening attentively". In study 2, Alice had "to go away and process it because she gets so I think it just becomes so much", but she "was exploring the area around the Olly by walking, running and making sounds". Joshua's TA said, "he was like looking like that, you know, like I'm looking to see". In study 3, Anna was reported to be observing her peers playing with the TUIs "from different places of the room and smiles," and Tula "went away sometimes from Olly and monitor from a distance [...] looking at Olly Mazi plus the others from a distance". Through onlooker play, children demonstrated that technology becomes not just an object for them to interact with but one that supports different levels of sociality between them. Farahar [2022] explains that some autistic people are happy to silently inhabit space while still being "a vital part of it" or hiding but still wanting to be part of it. Therefore, considering different ways of *participation* is important to understand children's experiences with technology better.

Provide opportunities for socio-emotional and sensory regulation. As we have seen in the literature, self-regulatory behaviours help us balance our arousal and stress levels [21] and allow autistic children to express their emotions [63]. The feeling of being judged for their stimming actions and behaviours [101, 107] (alongside environmental factors such as lights, space, temperature, and noise levels [138]) might impact children's perception of a playful experience. As in [124], we should embrace and understand children’s different behaviours and ways of “Self-expressing”. This is one way to enable them to develop a positive identity while enjoying a playful activity. In turn, it allows designers to develop meaningful technologies for the children’s experiences. Fostering a positive identity is good for children’s well-being [26]. By i.e. letting the children take full control of the sessions in Study 3 - Olly Mazi, they “were more able to reacted [sic] spontaneously”. Children were reported to self-regulate also “by moving to the perimeter of the area when Olly and Mazi were crowded”. Therefore, enabling children to balance personal and social space contributed to children’s regulation and improved the play experience. This echoes the concept of *solitary detours* proposed by Frauenberger et al. [2020], which only reinforces the need to offer a balanced proportion of solitary and social interactions in groups of autistic children. Anna’s TA, in study 3, also emphasised this aspect: “The room has space enough for them to join [sic] or be apart whenever they want”. By looking at the children holistically (i.e., considering the socio-emotional, sensorial, individual and contextual spheres as part of a whole), we can therefore study our prototypes in a holistic way i.e., as part of a whole design which includes the people, the technology, the context, and the situation at hand [109].

We found that reflecting both on the research and the design processes through an ecological lens, focusing hence not just on the technologies but on the people that use them, the space where they are deployed (i.e., the size and its configuration), the people supporting the people that use them, the environment (such as lights, noises, temperature etc), and the social practice taking place (i.e., the play activity) is particularly relevant when designing social play TUIs for autistic children [113].

8.2 INSIGHTS FOR TUI DESIGNs

The three research cycles also helped us outline design principles that guided our design processes. In Studies 1 and 2, the children led the design decision-making process but did not participate in the physical making of the designs, the first author made them; a few design decisions were reinforced by the first author’s design knowledge and the literature. This has led us to uncover a few guidelines that we think can help other researchers wanting to explore the space of e-textile sonic TUIs for social play and minimally verbal to nonverbal autistic children. We propose a few ways that TUIs can be designed to foster positive social play experiences:

Not requiring constant interaction. We found that technology needs to allow children to move away from it to regulate their emotional state without major “issues” happening if they move away, such as i.e. the technology switching off or not working anymore or playing on its own to demand children’s attention. In contrast to Frauenberger et al. [2020], who used *Impulses to Interpret*, such as actions autonomously initiated by technology to attract children’s attention, we found that following the children’s lead was important to respect their times. One of the TAs in Study 3 highlighted this: “The technologies don’t require constant interaction; they are not very demanding and respect the rhythm of the children”. Children should be able to interact when they want without feeling the demand to do so.

Sensory qualities matched to preferred regulatory actions/qualities. The sensory qualities of a TUI should be matched to the children's preferred regulatory and expressive actions. Objects that *enable soothing activities* such as rocking, swinging, stroking, touching, twisting, pulling, pushing, sitting, laying, pressing, patting, etc.. enabled our groups of children to interact with the technologies using a range of body movements that resonated with them. For example, Pete rocking on Olly in Study 2 or lying on Mazi in Study 1, Alice lying on Olly's base whilst playing with the ribbons in Study 2 or exploring Mazi with feet in Study 1 or stroking it, Joshua twisting and pulling Olly's ribbons in Study 2, Isaac playing music by standing inside the ribbon and moving back and forth in Study 2, Theo, Elodie and Ray hugging Mazi in study 3, Selina pressing her hands against it, or Tula rocking on Olly and Ray balancing on it while being very focussed. Some of these actions or behaviours were similar to those we observed during P.E. and dance lessons (i.e., by using the bouncing balls in P.E., patting hands with adults or on their own, rolling their body parts onto objects or the floor, manipulating fabrics, twisting materials, balancing on the mirror's bar of the dance studio etc..). In Study 2, Ben's TA observed that "pulling was good for him [..]because he could go back a bit". Considering that, as we mentioned above, children were also self-regulated by moving at the perimeters around the TUIs, this could indicate that this type of sensor offered the children the chance to pull away from the main body of the toy, where it was more crowded if children were sitting or lying on the base, and left opportunities to gain some personal space while still being around the TUI. This, however, needs further exploration. Children might have liked the pressure of pulling the ribbons. We believe that the actions afforded by the two TUIs enabled children to communicate and interact using their whole bodies and on their terms. The mix of materials used, including the stretch and soft components, enabled openness and ambiguity. Unlike other digital devices, TUIs exist beyond their digital allure as they can be enjoyed when the power is off, but to be enjoyed, they need to be meaningful for the people who use them. As observed by the dance teacher in Study 3, "children were very motivated with Mazi and Olly, and the sensory input they received was meaningful and fulfilling". By creating rich sensory experiences that resonate with children's lives and interests, the open nature of the designs and their ambiguous aspects can inspire children to experience, create and communicate freely. We suggest researchers create TUIs that allow multiple means of engagement to enable appropriation – using e-textiles and soft components (and music) allowed us to do that.

Ambiguity. To achieve ambiguity, we balanced openness of interpretation and specificity [41]. Gaver et al. [2010] outline that "systems are often 'open' within a constrained space of possibility". We chose to design a *non-figurative* shape that did not resemble anything children had seen beforehand so that they could interact with Mazi and Olly without needing any preconceived formed knowledge. Non-figurative forms, such as the fluid forms we chose for Mazi and Olly, combined with using novel e-textile materials, music, and interaction paradigms, allowed the design to be *open* and accessible [67]. For instance, when looking at Mazi, this TUI mainly allowed one modality of digital interaction, i.e., touching the bubble and playing one note once. However, its affordances went beyond the digital feedback, as children explored it in many other ways, such as by climbing on it, pressing their hand on its main body, stroking it, sliding it across the room

(See Appendix B) i.e., where they could reflect their images on the mirror, or where they could move away from their peers, laying on its top and/o rocking on it, leaning their heads on its five bubbles, balancing on the top bubble and so on. The same happened with Olly. Its modality of digital interaction allowed children to pull the elastic ribbons to play one note, and it invited them to continue pulling to play a sequence of notes, which created "soothing" melodies, as reported by the dance teacher. Children playing with Olly, however, displayed similar behaviours as those exhibited when playing with Mazi beyond playing sounds, such as jumping on Olly's top, standing on it, laying and rocking, pressing their hands on the ball and patting it, etc. This indicates that the TUIs were used in various ways and left openness to interpretation. However, Mazi and Olly are also constrained somehow by the topic they address, which is scaffolding a spontaneous socially engaged play experience while offering opportunities for self-regulation between groups of nonverbal autistic children. If we imagine that Mazi and Olly were designed to teach children how to play music instead of eliciting free social play and self-regulation, the focus would be on the musical aspect. The TUIs would probably foster less spontaneous or playful behaviours and be centred around timing, timbre, rhythm, amount of pressure, focus, etc. These constraints, therefore, "are important in making systems that are 'about' something, suggesting initial possibilities for interaction, and avoiding clichéd forms of engagement with topics and devices" [41]. Consequently, we believe that the soft materiality of the designs, including the use of textile, inflatable objects, padding materials, foam, and e-textile sensors, alongside the TUIs shapes and sizes, and the quality of physical and sonic feedback increased the ambiguous characteristics of the technologies. We invite researchers to explore these aspects of ambiguous TUI designs further.

Shareability. Researchers are encouraged to consider the two core components of shareability when designing TUIs for social play: entry points and access points. *Entry points* are part of the environmental structure, defined as a cue to "invite people into engagement with a group activity and entice them to interact" [77]. These are, for example, the aesthetic qualities of a TUI, including a device's overall configuration and appeal. They allow people to plan their approach by providing an overview of the system and entice them with a point of attraction or *honey pot effect* to stimulate active interest and *minimise barriers to access*. *Access points* instead are part of the interface and its actual content, defined as characteristics that enable and sustain interactions 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 enable access points, we followed the configuration of the O-space, specific to human-human interactions. We designed two large-scale round sonic e-textile TUIs to resemble Kendon's F-formation within the designs of our systems. To *minimise physical barriers,* we considered the designs' type and elevation. A non-elevated design, alongside its round shape, size, number and positions of sensors, provided the children in our studies with equitable opportunities for participation [134]. A*esthetic barriers* can be minimised by the overall designs if they are based on the children's likes, needs and preferences. In our studies, the types of sensors and materials used, the colours and sizes and non-figurative fluid shapes, alongside the sonic outputs, created a *honeypot effect* and enticed the children. We used harmonic sounds to enable social musicking activities to take place even between untrained musicians (similar to those they listened to during P.E.) and a mix of salient vs. non-salient design features for both Olly and Mazi, such as colours around the bubbles or coloured ribbons vs neutral colours for the main bodies, to balance the number of visual stimuli received by the children and attract their attention.

9 LIMITATIONS

Some limitations have emerged that highlight the challenges of designing TUIs with and for nonverbal autistic children. Firstly, the institution we worked with offers highly specialised provisions for autistic individuals and all staff are regularly trained i.e., in child protection, safeguarding and evidence-based approaches. The first author worked there before starting her PhD research, which could have affected the outcome of our study. Secondly, striking the right balance between the support adults give and the freedom left to the children is challenging but of great importance. We found that asking adults in Study 3 not to intervene unless they were asked to by the children enabled pupils to be more in control and independent, creating a genuine, playful atmosphere. Another point is that we wanted to have a holistic picture of the children's experiences, and the framework for analysis offered us that. However, this meant that we had to deal with lots of data, which was overwhelming at first and time-consuming. Unfortunately, other frameworks for observations within the HCI and CCI are specific to certain domains, such as tangibles for learning [77, 4, 139], musical abilities [140], or VR [141]. They are used to inform the design of TUIs rather than to evaluate the experience of the children [5] or to support participatory design processes (i.e. IDEAS used in [8]). We think that the criteria for observations, or themes, used for the video analysis could be reduced to further optimise the process, such as T5-Personalised uses, T6- Share emotions, T3-Touch to activate sounds, and T4-Music making together, could be included as part of a more detailed analysis of T8-Play types, to reduce the number of observations. The framework could then be used as a guide to conduct observations during play sessions with technologies to examine children's verbal and nonverbal interactions qualitatively.

Additionally, the technologies were tested with small groups of children, and the aim was not to generalise findings to the wider population. A further limitation was that the first author was Mazi and Olly's designer, maker, and programmer. Coming up with these two big design solutions was a time-consuming and resource-intensive process. It required us to think thoroughly about what we observed from the children to experiment with different materials to make two meaningful artefacts. However, certain opportunities emerged by pure chance. For example, we thought that having compromised Olly's stability by using the inflated ball might have been an issue. Nonetheless, children liked its wobbliness, and they enjoyed rocking on it by laying with their belly on its top, sitting on it, or standing and balancing on it. Hence, perceived design challenges might turn into opportunities for children. Combining electronic textiles with off-the-shelves equipment took time. Buying and experimenting with the new materials was a costly process that ate into the budget we had available over the years (£1000 for 3 years). That is also why, for example, we used an inflated therapy ball to make Olly instead of using another soft-play dome like the one we used for Mazi (or even bigger than that).

However, making two novel, playful e-textile sonic tangibles that are large-scale is also rewarding. Designing the TUIs was an enriching process that emphasised the importance of going through an explorative phase to achieve the best possible outcome for the children we worked with. Lastly, while the first author provided a neutral analysis and discussion of the findings, clearly supported by evidence drawn from triangulating data from the video analysis and the teacher and TA's feedback, some of the positive comments of the dance teacher could be biased due to her involvement in all the three studies.

10 CONCLUSIONS

To date, there is little research that explores the space of social play activities mediated by shareable e-textile TUI designs led by nonverbal autistic children's preferences and needs. It is necessary to develop ecological approaches and designs that understand, accommodate, value, and embrace a diverse variety of people; this requires careful consideration. Embracing children's socio-emotional and sensory needs, enabling them to be their authentic selves and providing interaction opportunities that they find meaningful is one way we found to challenge the normalisation agenda. The double empathy problem is a challenge that we must recognise, reflect, and act upon as neurotypical researchers and designers working with neurodivergent children. We found that through this journey of discovery, our understanding of autism has strengthened. Our work shows that looking at factors that influence children's social play, such as attitudes toward autism and children's sensory and socio-emotional needs and different ways of expressing and communicating, helped us develop technologies with and for nonverbal autistic children that expand current participatory design approaches, and to craft experiences that were meaningful to the children that led the design decisions but also applicable to different groups of children with similar interests and needs. This is important as our research practices need to be sustainable. We conducted and described three explorative cycles and studies with three groups of nonverbal autistic children and illustrate how the designs of two sonic e-textile shareable TUIs, called Mazi and Olly, led by the children's interests, preferences and needs, have scaffolded social play and enabled children to be their authentic unmasked self.

We found that to create opportunities for children to be themselves and to design play objects that resonate with them, researchers should a) increase their reciprocity behaviours towards autistic children by challenging the deficit narrative, understanding the context and culture, and following the children's rhythm, and b) semi-structure the environment and play experiences but leave freedom within by offering children the right level of support, enabling spontaneous participation, and providing opportunities for emotional and sensory regulation. To enable children to join the social play experiences, TUI designs should a) not require constant interaction, b) provide opportunities for self-regulatory and expressive actions by matching the TUI's sensory qualities to those expressive and regulatory actions preferred by the children, c) be ambiguous by balancing openness of interpretation and specificity, d) and shareable. We do not claim that we have unlocked the key to making TUIs and research with and for autistic children. On the contrary, we think that designing TUIs to foster children's social play needs careful consideration, and it is a challenging but rewarding endeavour. We only scratched the surface of how the research and design of novel e-textile shareable TUIs following a neurodiversity narrative could be beneficial to develop intrinsically motivating social play with and for nonverbal autistic children. We invite other researchers to expand this ongoing conversation further.

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REFERENCES

[1] Allen, R., Heaton, P. (2010). Autism, music, and the therapeutic potential of music in alexithymia. Music Percept. 27, 251–261. https://doi.org/10.1525/mp.2010.27.4.251

[2] Almon, J. (2003). The Vital Role of Play in Early Childhood Education, The Developing Child: The First Seven Years. Waldorf Early Childhood Association of North America 285 Hungry Hollow Road, Spring Valley, NY 10977.

[3] Andrews, C., Endert, A., & North, C. (2010). Space to think: large high-resolution displays for sensemaking. In Proceedings of the SIGCHI conference on human factors in computing systems (pp. 55-64).

[4] Antle, A.N., (2007). The CTI framework: Informing the design of tangible systems for children. TEI'07 First Int. Conf. Tangible Embed. Interact. 195–202. https://doi.org/10.1145/1226969.1227010

[5] Antle, A.N., Wise, A.F., (2013). Getting down to details: Using theories of cognition and learning to inform tangible user interface design. Interact. Comput. 25, 1–20. https://doi.org/10.1093/iwc/iws007

[6] Autistic Self Advocacy Network., (2023). About autism. Retrieved from ASAN: Autistic Self Advocacy Network: https://autisticadvocacy.org/about-asan/about-autism/ on the 17th June 2023.

[7] Bentley, R., Hughes, J.A., Randall, D., Rodden, T., Sawyer, P., Shapiro, D., Sommerville, I., (1992). Ethnographically-informed systems design for air traffic control. Proc. Conf. Comput. Coop. Work 123–129. https://doi.org/10.1145/143457.143470

[8] Benton, L., Vasalou, A., Khaled, R., Johnson, H., & Gooch, D. (2014, April). Diversity for design: a framework for involving neurodiverse children in the technology design process. In Proceedings of the SIGCHI conference on Human Factors in Computing Systems (pp. 3747-3756).

[9] Bhattacharya, A., Gelsomini, M., Pérez-Fuster, P., Abowd, G.D., Rozga, A. (2015). Designing motion-based activities to engage students with autism in classroom settings. Proc. 14th Int. Conf. Interact. Des. Child. - IDC '15 69–78. https://doi.org/10.1145/2771839.2771847

[10] Boso, M., Comelli, M., Vecchi, T., Barale, F., Politi, P. (2009). Exploring musical taste in severely autistic subjects: Preliminary data, in: Annals of the New York Academy of Sciences. Blackwell Publishing Inc, pp. 332–335. https://doi.org/10.1111/j.1749-6632.2009.04853.x

[11] Bottema-Beutel, K., Kapp, S.K., Lester, J.N., Sasson, N.J., Hand, B.N., (2021). Avoiding Ableist Language: Suggestions for Autism Researchers. Autism in Adulthood. https://doi.org/10.1089/aut.2020.0014

[12] Brown, J., Murray, D., (2001). Strategies for enhancing play skills for children with autism spectrum disorder.pdf. Educ. Train. Ment. Retard. Dev. Disabil. 36, 312–317.

[13] Brownlow, C., O'Dell, L., Abawi. D. (2022). Critically contextualising 'normal' development and the construction of the autistic individual from: The Routledge International Handbook of Critical Autism Studies Routledge

[14] Burdette, H.L., Whitaker, R.C. (2005). Resurrecting Free Play in Young Children. Arch. Pediatr. Adolesc. Med. 159, 46. https://doi.org/10.1001/archpedi.159.1.46

[15] Cappelen, B., Andersson, A.P., 2012. Musicking tangibles for empowerment. Lect. Notes Comput. Sci. (including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics) 7382 LNCS, 254–261. https://doi.org/10.1007/978-3-642-31522-0_38

[16] Cappadocia, M., Weiss, J., and Pepler, D., (2012). Bullying experiences among children and youth with autism spectrum disorders. Journal of Autism and Developmental Disorders, 42(2), pp. 266–277. DOI: 10.1007/s10803-011-1241-x239

[17] Case-Smith, J., Weaver, L.L., Fristad, M.A. (2015). A systematic review of sensory processing interventions for children with autism spectrum disorders. Autism 19, 133–148. https://doi.org/10.1177/1362361313517762

[18] Chang, W.-L., Šabanovic, S., and Huber, L. (2013). "Use of seal-like robot paro in sensory group therapy for older adults with dementia," in Proc. of the 8th ACM/IEEE HRI. IEEE Press, 2013, pp. 101–102

[19] Cibrian, F.L., Peña, O., Ortega, D., Tentori, M., 2017. BendableSound: An elastic multisensory surface using touch-based interactions to assist children with severe autism during music therapy. Int. J. Hum. Comput. Stud. 107, 22–37. https://doi.org/10.1016/j.ijhcs.2017.05.003

[20] Cook, A., Ogden, J., and Winstone, N. (2016) 'The experiences of learning, friendship and bullying of boys with autism in mainstream and special settings: A qualitative study', British Journal of Special Education, 43(3), pp. 250–271. https://doi .org /10 .1111 /1467 -8578 .12143

[21] Di Paolo, E., Buhrmann, T., & Barandiaran, X. (2017). Sensorimotor life: An enactive proposal. Oxford University Press.

[22] Dow, S., Ju, W., Mackay, W. (2013). Projection, place, and point-of-view in research through design. SAGE Handb. Digit. Technol. Res. 266–285. https://doi.org/10.4135/9781446282229.n19

[23] Duvall, J.C., Dunne, L.E., Schleif, N., Holschuh, B. (2016). Active "hugging" vest for deep touch pressure therapy. Proc. 2016 ACM Int. Jt. Conf. Pervasive Ubiquitous Comput. Adjun. - UbiComp '16 458–463. https://doi.org/10.1145/2968219.2971344

[24] Edelson, S.M., Goldberg, M., Kerr, D.C.R., Grandin, T. (1999). Behavioral and Physiological Effects of Deep Pressure on Children With Autism: A Pilot Study Evaluating the Efficacy of Grandin's Hug Machine. Am. J. Occup. Ther. 53, 145–152

[25] Farahar, C., and Bishopp-Ford, L., (2020). Stigmaphrenia: Reducing mental health stigma with a script about neurodiversity. In D. Milton (Ed.), The neurodiversity reader: Exploring concepts, lived experience and implications for practice (pp. 48–66). Shoreham by Sea, UK: Pavilion Publishing and Media.

[26] Farahar, C., (2022). Autistic identity, culture, community, and space for well-being. Routledge Int. Handb. Crit. Autism Stud. 229–241. https://doi.org/10.4324/9781003056577-23

[27] Farr, W., Yuill, N., Raffle, H. (2010). Social benefits of a tangible user interface for children with Autistic Spectrum Conditions. Autism 14, 237–252. https://doi.org/10.1177/1362361310363280

[28] Fisher, M., and Taylor, J., (2016). Let's talk about it: Peer victimization experiences as reported by adolescents with autism spectrum disorder. Autism, 20(4), pp. 402–411. DOI: 10.1177/1362361315585948

[29] Francis, G.A., Mareva, S., Farr, W., Gibson, J.L. (2018). Do Tangible User Interfaces promote social behaviour during free play? A comparison of autistic and typically-developing children playing with passive and digital construction toys. https://doi.org/10.31234/osf.io/vz83a

[30] Frauenberger, C., Spiel, K., Makhaeva, J., (2019a). Thinking Outside The Box – Designing Smart Things with Autistic Children. Int. J. Hum. Comput. Interact. 35, 666–678. https://doi.org/10.1080/10447318.2018.1550177

[31] Frauenberger, C. (2019). Rethinking assistive technologies with autistic children [Professorial Dissertation, Technische Universität Wien]. reposiTUm. http://hdl.handle.net/20.500.12708/159449

[32] Frauenberger, C., Spiel, K., Scheepmaker, L., Posch, I., (2019b). Nurturing Constructive Disagreement Agonistic Design with Neurodiverse Children 1–11. https://doi.org/10.1145/3290605.3300501

[33] Frauenberger, C., Kender, K., Scheepmaker, L., Werner, K., Spiel, K., (2020). Desiging Social Play Things. ACM Int. Conf. Proceeding Ser. https://doi.org/10.1145/3419249.3420121

[34] Frost, J.L. (2006). The dissolution of children's outdoor play: Causes and Consequences. Common Good Conf. 1–26.

[35] Frost, J.L. (1998). Neuroscience, Play, and Child Development. IPA/USA Trienn. Natl. Conf. (Longmont, CO, June 18-21, 1998) 18

[36] Gates, G., (2019). Trauma, stigma, and autism: Developing resilience and loosening the grip of shame. London, UK: Jessica Kingsley Publishers.

[37] Garfinkel, H. (1967). Studies in Ethnomethodology. Prentice Hall.

[38] Gaver, W., Dunne, T., and Pacenti, E. (1999). Design: Cultural probes. interactions, 6(1):21–29, jan 1999

[39] Gaver, W. (2002). Designing for Homo Ludens. I3 Mag. 3–6. https://doi.org/10.1145/2207676.2208538

[40] Gaver, W.W., Beaver, J., Benford, S., (2003). Ambiguity as a resource for design. Conf. Hum. Factors Comput. Syst. - Proc. 233–240

[41] Gaver, W., Blythe, M., Boucher, A., Jarvis, N., Bowers, J., & Wright, P. (2010, April). The prayer companion: openness and specificity, materiality and spirituality. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 2055-2064).

[42] Gaver, W. (2012). 'What Should We Expect from Research Through Design?' In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. CHI '12. New York, NY, USA: ACM, pp. 937–946

[43] Gernsbacher, M. A. (2006). Toward a behavior of reciprocity. The Journal of Developmental Processes, 1, 138–152

[44] Ginsburg, K.R. (2007). The_importance_of_play_in_prom.PDF. Pediatrics 119, 182–191. https://doi.org/10.1542/peds.2006-2697

[45] Gumtau, S., Newland, P., Creed, C., Kunath, S., (2005). MEDIATE: A Responsive Environment Designed for Children with Autism. Proc. Access. Des. Digit. World Conf. 1–8.

[46] Hampshire, P.K., Hourcade, J.J., (2014). Teaching Play Skills to Children with Autism Using Visually Structured Tasks. Teach. Except. Child. 46, 26–31. https://doi.org/10.1177/004005991404600303

[47] Hardy, M.W., LaGasse, A.B., (2013). Rhythm, movement, and autism: using rhythmic rehabilitation research as a model for autism. Front. Integr. Neurosci. 7, 1–9. https://doi.org/10.3389/fnint.2013.00019

[48] Harris, A., Rick, J., Bonnett, V., Yuill, N., Fleck, R., Marshall, P., & Rogers, Y. (2009). Around the table: Are multiple-touch surfaces better than single-touch for children's collaborative interactions?. In CSCL (1) (pp. 335-344)

[49] Heinzel, T., & Stewart, R. (2021). Introduction: Textile Intersections-Textile Discipline at Cross-Roads. Journal of Textile Design Research and Practice, 9(1), 1-8

[50] Hendrix, K., van Herk, R., Verhaegh, J., Markopoulos, P. (2009). Increasing children's social competence through games, an exploratory study. Proc. 8th Int. Conf. Interact. Des. Child. - IDC '09 182. https://doi.org/10.1145/1551788.1551823

[51] Hill, E. L. (2004). Evaluating the theory of executive dysfunction in autism. Developmental Review, 24, 189–233.

[52] Hochhauser, M., Engel-Yeger, B. (2010). Sensory processing abilities and their relation to participation in leisure activities among children with high-functioning autism spectrum disorder (HFASD). Res. Autism Spectr. Disord. 4, 746–754. https://doi.org/10.1016/j.rasd.2010.01.015

[53] Hochhauser, M., Weiss, P.L., Gal, E., (2015.) Negotiation strategies of adolescents with high-functioning autism spectrum disorder during social conflicts. Res. Autism Spectr. Disord. 10, 7–14. https://doi.org/10.1016/j.rasd.2014.10.022

[54] Holistic. (2023). https://dictionary.cambridge.org/dictionary/english/holistic (accessed on 11/07/2023)

[55] Hornecker, E., (2012). Beyond affordance: Tangibles' hybrid nature. Proc. 6th Int. Conf. Tangible, Embed. Embodied Interact. TEI 2012 175–182. https://doi.org/10.1145/2148131.2148168

[56] Hornecker, E., Marshall, P., Rogers, Y. (2007). From entry to access: How shareability comes about, Designing Pleasurable Products and Interfaces. https://doi.org/10.1145/1314161.1314191

[57] Hoven, E. v. d., J. Frens, D. Aliakseyeu, J. B. Martens, K. Overbeeke and P. Peters (2007). 'Design research & tangible interaction'. In: Proceedings of the 1st international conference on Tangible and embedded interaction, pp. 109–115

[58] Ishii, H., & Ullmer, B. (1997, March). Tangible bits: towards seamless interfaces between people, bits and atoms. In Proceedings of the ACM SIGCHI Conference on Human factors in computing systems (pp. 234-241)

[59] Jarvis, P., Newman, S., Jarvis, P., Newman, S., Swiniarski, L. (2016). On 'becoming social': the importance of collaborative free play in childhood. https://doi.org/10.1080/21594937.2013.863440

[60] Jeong, S., Breazeal, C., Logan, D., Weinstock, P. (2018). Huggable: Impact of embodiment on promoting verbal and physical engagement for young pediatric inpatients. RO-MAN 2017 - 26th IEEE Int. Symp. Robot Hum. Interact. Commun. 2017-Janua, 121–126. https://doi.org/10.1109/ROMAN.2017.8172290

[61] Jensenius, A.R., Voldsund, A., (2012). The Music Ball Project : Concept , Design , Development , Performance. Proc. Int. Conf. New Interfaces Music. Expr. 300–303.

[62] Kapp, S.K., (2022). Models of helping and coping with autism. Routledge Int. Handb. Crit. Autism Stud. 255–269. https://doi.org/10.4324/9781003056577-25

[63] Kapp, S.K., Steward, R., Crane, L., Elliott, D., Elphick, C., Pellicano, E., Russell, G., (2019). 'People should be allowed to do what they like': Autistic adults' views and experiences of stimming. Autism 23, 1782–1792. https://doi.org/10.1177/1362361319829628

[64] Karana, E., Barati, B., Rognoli, V., Zeeuw van der Laan, A., (2015). Material driven design (MDD): A method to design for material experiences. Int. J. Des. 9, 35–54.

[65] Kossyvaki, L., Curran, S., (2020). The role of technology-mediated music-making in enhancing engagement and social communication in children with autism and intellectual disabilities. J. Intellect. Disabil. 24, 118–138. https://doi.org/10.1177/1744629518772648

[66] Krauss, K.E. (1987). The Effects of Deep Pressure Touch on Anxiety. Am. J. Occup. Ther. 41, 366–373

[67] Larson, C. L., Aronoff, J., Sarinopoulos, I. C., & Zhu, D. C. (2009). Recognizing threat: a simple geometric shape activates neural circuitry for threat detection. Journal of cognitive neuroscience, 21(8), 1523-1535.

[68] Laurent, A.C., Fede, J. (2021). Leveling Up Regulatory Support Through Community Collaboration. Perspect. ASHA Spec. Interes. Groups 1–18. https://doi.org/10.1044/2020_persp-20-00197

[69] Lazarus, R.S., & Folkman, S. (1984). Stress, Appraisal, and Coping. New York: Springer.

[70] Libby, S., Powell, S., Messer, D., Jordan, R. (1998). Spontaneous Play in Children with Autism: A Reappraisal. Autism Dev. Disord. 28, 487–497. https://doi.org/0162-3257/98/1200-0487

[71] Lillard, A.S. (2015). The Development of Play. In Handbook of Child Psychology and Developmental Science, R.M. Lerner (Ed.). doi:10.1002/9781118963418.childpsy211

[72] Locke, J., Shih, W., Kretzmann, M., Kasari, C., (). Examining playground engagement between elementary school children with and without autism spectrum disorder. Autism 20, 653–62. https://doi.org/10.1177/1362361315599468

[73] Lounds Taylor, J., Adams, R., and Bishop, S., (2017). Social participation and its relation to internalizing symptoms among youth with autism spectrum disorder as they transition from high school. Autism Research, 10(4), pp. 663–672. DOI: 10.1002/aur.1709

[74] Malinverni, L., Mora-Guiard, J., Padillo, V., Mairena, M.A., Hervás, A., Pares, N. (2014). Participatory design strategies to enhance the creative contribution of children with special needs. ACM Int. Conf. Proceeding Ser. 85–94. https://doi.org/10.1145/2593968.2593981

[75] Mastrangelo, S. (2009). Harnessing the power of play: Opportunities for children with autism spectrum disorders. Teaching Exceptional Children, 42(1), 34-44.

[76] Marshall, P., Fleck, R., Harris, A., Rick, J., Hornecker, E., Rogers, Y., ... & Dalton, N. S. (2009). Fighting for control: Children's embodied interactions when using physical and digital representations. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 2149-2152)

[77] Marshall, P., Rogers, Y., & Hornecker, E. (2007). Are tangible interfaces really any better than other kinds of interfaces?

[78] Milton, D. (2014b) Embodied sociality and the conditioned relativism of dispositional diversity. In: Theorising Normalcy and the Mundane, 26th-

27th June 2012, Chester, UK. (Unpublished). Retrieved on the 18th June 2023 from https://web.archive.org/web/20180422105654/http://www.larry-arnold.net/Autonomy/index.php/autonomy/article/viewFile/AR10/pdf

[79] Milton, D.E.M., (2012). On the ontological status of autism: The "double empathy problem." Disabil. Soc. 27, 883–887.

[80] Milton, D., & Sims, T. (2016). How is a sense of well-being and belonging constructed in the accounts of autistic adults? Disability and Society, 31(4), 520–534. https:// doi .org /10 .1080 /09687599 .2016 .1186529

[81] Milton, D.E., (2014a). Autistic expertise: A critical reflection on the production of knowledge in autism studies. Autism 18, 794–802. https://doi.org/10.1177/1362361314525281

[82] Miller D., Rees J., Pearson A. (2021). 'Masking is life': Experiences of masking in autistic and non-autistic adults. Autism in Adulthood, 3(4), 330–338. https://doi.org/10.31219/osf.io/t6vp2

[83] Mora-Guiard, J., Crowell, C., Pares, N., Heaton, P. (2017). Sparking social initiation behaviors in children with Autism through full-body Interaction. Int. J. Child-Computer Interact. 11, 62–71. https://doi.org/10.1016/j.ijcci.2016.10.006

[84] Morris, B. A., Havlucu, H., Oldfield, A., & Metatla, O. (2023, April). Double Empathy as a Lens to Understand the Design Space for Inclusive Social Play Between Autistic and Neurotypical Children. In Extended Abstracts of the 2023 CHI Conference on Human Factors in Computing Systems (pp. 1-7).

[85] Nonnis, A. and Bryan-Kinns N. (2019a). Mazi: Tangible Technologies as a Channel for Collaborative Play. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19). ACM, New York, NY, USA, Paper 440, 13 pages. DOI: https://doi.org/10.1145/3290605.3300670

[86] Nonnis, A. and Bryan-Kinns N. (2019b). Mazi: a Tangible Toy for Collaborative Play between Children with Autism. In Proceedings of the 18th ACM International Conference on Interaction Design and Children (IDC '19). ACM, New York, NY, USA, 672–675. https://doi.org/10.1145/3311927.33253402

[87] Nonnis, A. and Bryan-Kinns N. (2020). Όλοι: music making to scaffold social playful activities and self-regulation. Proc. New Interfaces for Musical Expression (NIME '20), Royal Birmingham Conservatoire, Birmingham, UK. DOI: 10.5281/zenodo.4813186

[88] Nonnis, A. and Bryan-Kinns N. (2021). Olly: A tangible for togetherness, International Journal of Human-Computer Studies, 2021, 102647, ISSN 1071-5819. DOI: https://doi.org/10.1016/j.ijhcs.2021.102647

[89] Nonnis, A. (2021). Playful E-textile Sonic Interaction for Socially Engaged and Open-Ended Play Between Autistic Children. Ph.D. thesis. Queen Mary University of London, UK. Retrieved from https://qmulprod-my.sharepoint.com/personal/acw322_qmul_ac_uk/Documents/Attachments/Thesis_SIGNED_Antonella%20Nonnis_revised%20final_1%201.pdf

[90] Nonnis, A. (2022). Olly Mazi: Un Nuovo Approccio al Design di Interfacce Tangibili per il Gioco Sociale. Autismo 20 (3), 233-268. Edizioni Erickson. DOI: https://doi.org/10.14605/aut2032202.

[91] Ochs, E., & Solomon, O. (2010). Autistic sociality. Ethos, 38(1), 69–92.

[92] Parés, N., Masri, P., Van Wolferen, G., Creed, C., (2005). Achieving dialogue with children with severe autism in an adaptive multisensory interaction: The "MEDIATE" project. IEEE Trans. Vis. Comput. Graph. 11, 734–742. https://doi.org/10.1109/TVCG.2005.88

[93] Parten, M.B. (1932). Social participation among pre-school children. J. Abnorm. Soc. Psychol. 27, 243–269. https://doi.org/10.1037/h0074524

[94] Pearson, A., Dr, & Rees, J. (2020). 'Masking is Life': Experiences of Masking in Autistic and Non-Autistic Adults. https://doi.org/10.1089/aut.2020.0083 https://doi.org/10.1080/09687599.2012.710008

[95] Pearson, A., and Rose, K., (2020). A conceptual analysis of autistic masking: Understanding the narrative of stigma and the illusion of choice. OSF Preprints, pp. 1–25. DOI: 10.31219/osf.io/6rwa5

[96] Pellicano, E. (2022). Annual Research Review: Shifting from 'normal science' to neurodiversity in autism science. Journal of Child Psychology and Psychiatry, 63(4), 381-396. https://doi.org/10.1111/jcpp.13534

[97] Perner-Wilson, H., & Buechley, L. (2010a). Making textile sensors from scratch. In Proceedings of the fourth international conference on Tangible, embedded, and embodied interaction (pp. 349-352).

[98] Perner-Wilson, H., Buechley, L., & Satomi, M. (2010b). Handcrafting textile interfaces from a kit-of-no-parts. In Proceedings of the fifth international conference on Tangible, embedded, and embodied interaction (pp. 61-68).

[99] Piaget, J., Inhelder, B. (1969). The Psychology of the Child, (H. Weaver. ed. (H. Weaver, Trans.). New York: Basic Books. https://doi.org/10.1097/00005053-194408000-00051

[100] Porayska-Pomsta, K., Keay-Bright, W., Kossyvaki, L., Lemon, O., Mademtzi, M., Menzies, R., Pain, H., Rajendran, G., Waller, A., Wass, S., Smith, T.J., Alcorn, A.M., Avramides, K., Beale, S., Bernardini, S., Foster, M.E., Frauenberger, C., Good, J., Guldberg, K., (2018). Blending Human and Artificial Intelligence to Support Autistic Children's Social Communication Skills. ACM Trans. Comput. Interact. 25, 1–35. https://doi.org/10.1145/3271484

[101] Rice-Adams, E., (2022). Autistic young people's sense of self and the social world: A challenge to deficit-focused characterisations. Routledge Int. Handb. Crit. Autism Stud. 130–149. https://doi.org/10.4324/9781003056577-13

[102] Rodgers, J., Wigham, S., McConachie, H., Freeston, M., Honey, E., Parr, J.R. (2016). Development of the anxiety scale for children with autism spectrum disorder (ASC- ASD). Autism Res. 9, 1205–1215. https://doi.org/10.1002/aur.1603

[103] Rogers, Y., Lim, Y. K., Hazlewood, W. R., & Marshall, P. (2009). Equal opportunities: Do shareable interfaces promote more group participation than single user displays?.Human–Computer Interaction, 24(1-2), 79-116

[104] Rosqvist, H.B, Brownlow, C., & O'Dell, L. (2015).'What is the point in having friends?' reformulating notions of friends and friendship for adults with autism. Disability Studies Quarterly, 3(4). https://doi.org/10.18061/dsq.v35i4

[105] Rosqvist, H.B., Milton, D., O'Dell, L., (2022). Support on whose terms? Competing meanings of support aimed at autistic people. Routledge Int. Handb. Crit. Autism Stud. 182–193. https://doi.org/10.4324/9781003056577-18

[106] Salimpoor, V.N., Zald, D.H., Zatorre, R.J., Dagher, A., McIntosh, A.R. (2015). Predictions and the brain: How musical sounds become rewarding. Trends Cogn. Sci. https://doi.org/10.1016/j.tics.2014.12.001

[107] Sasson, N.J., Faso, D.J., Nugent, J., Lovell, S., Kennedy, D. P. and Grossman, R.B. (2017) Neurotypical peers are less willing to interact with those with autism based on thin slice judgments. Scientific Reports 7(1): 1–10

[108] Scheepmaker, L., Frauenberger, C., Spiel, K. (2018). The Things We Play with Roles of Technology in Social Play 451–462. https://doi.org/10.1145/3242671.3242695

[109] Sein, M. K., Henfridsson, O., Purao, S., Rossi, M., & Lindgren, R. (2011). Action Design Research. MIS Quarterly, 35(1), 37–56. https://doi.org/10.2307/23043488

[110] Shaer, O. (2009). Tangible User Interfaces: Past, Present, and Future Directions. Found. Trends® Human–Computer Interact. 3, 1–137. https://doi.org/10.1561/1100000026

[111] Sinclair, J. (2010). Cultural commentary: Being autistic together. Disability Studies Quarterly, 30(1).

[112] Small, C., (1999). Musicking — the meanings of performing and listening. A lecture. Music Educ. Res. 1, 9–22. https://doi.org/10.1080/1461380990010102

[113] Smith, R.C., Iversen, O.S., Hjermitslev, T., Lynggaard, A.B. (2013). Towards an ecological inquiry in child-computer interaction. ACM Int. Conf. Proceeding Ser. 183–192. https://doi.org/10.1145/2485760.2485780

[114] Spiel, K., & Gerling, K. (2021). The Purpose of Play: How HCI Games Research Fails Neurodivergent Populations. ACM Transactions on Computer-Human Interaction (TOCHI), 28(2), 1-40

[115] Spiel, K., Frauenberger, C., Keyes, o., and Fitzpatrick, G. 2019. Agency of Autistic Children in Technology Research—A Critical Literature Review. ACM Trans. Comput.-Hum. Interact. 26, 6, Article 38 (December 2019), 40 pages. https://doi.org/10.1145/3344919

[116] Steward, R. L. (2015). Repetitive stereotyped behaviour or 'stim- ming': An online survey of 100 people on the autism spec- trum. Paper Presented at the 2015 International Meeting for Autism Research. Retrieved from https://insar.confex.com/ insar/2015/webprogram/Paper20115.html

[117] Suarez, M.A. (2012). Sensory processing in children with autism spectrum disorders and impact on functioning. Pediatr. Clin. North Am. 59, 203–214.https://doi.org/10.1016/j.pcl.2011.10.012

[118] Tam, V., Gelsomini, M., Garzotto, F., 2017. Polipo - a Tangible Toy for Children with Neurodevelopmental Disorders. Proc. Tenth Int. Conf. Tangible, Embed. Embodied Interact. - TEI '17 11–20. https://doi.org/10.1145/3024969.3025006

[119] Tager-Flusberg, H., & Kasari, C. (2013). Minimally verbal school-aged children with autism spectrum disorder: The neglected end of the spectrum. Autism research, 6(6), 468-478.

[120] Tavory, I. (2022). A theory of intersubjectivity: experience, interaction and the anchoring of meaning. Theor Soc (2022). https://doi.org/10.1007/s11186-022-09507-y

[121] Toth, K., Munson, J., Meltzoff, A.N., Dawson, G. (2006). Early predictors of communication development in young children with autism spectrum disorder: Joint attention, imitation, and toy play. J. Autism Dev. Disord. 36, 993–1005. https://doi.org/10.1007/s10803-006-0137-7

[122] Stahmer, A. C. (1995). Teaching symbolic play skills to children with autism using pivotal response training. Journal of Autism and Developmental Disor- ders, 25, 123-141

[123] Vandenberg, N.L. (2001). The Use of a Weighted Vest To Increase On-Task Behavior in Children With Attention Difficulties. Am. J. Occup. Ther. 55, 621–628

[124] Van Horen, F., Mussweiler, T., (2014). Soft assurance: Coping with uncertainty through haptic sensations. J. Exp. Soc. Psychol. 54, 73–80. https://doi.org/10.1016/j.jesp.2014.04.008

[125] Vazquez, V., Cardenas, C., Cibrian, F.L., Tentori, M., (2016). Designing a Musical Fabric-Based Surface to Encourage Children with Autism to Practice Motor Movements. Proc. 6th Mex. Conf. Human-Computer Interact. - MexIHC'16 1–4. https://doi.org/10.1145/2967175.2967384

[126] Vygotsky, L.S., (1967). Play and Its Role in the Mental Development of the Child. Sov. Psychol. 5, 6–18. https://doi.org/10.2753/rpo1061-040505036

[127] Wade, J., Sarkar, A., Swanson, A., Weitlauf, A., Warren, Z., Sarkar, N., 2017. Process Measures of Dyadic Collaborative Interaction for Social Skills Intervention in Individuals with Autism Spectrum Disorders. ACM Trans. Access. Comput. 10, 1–19. https://doi.org/10.1145/3107925

[128] Wilson, C., Brereton, M., Ploderer, B., Sitbon, L. (2019). Co-Design Beyond Words: 'Moments of Interaction' with Minimally-Verbal Children on the Autism Spectrum. CHI Conf. Hum. Factors Comput. Syst. Proc. (CHI 2019) 1–15. https://doi.org/10.1145/3290605.3300251

[129] Wing, L.A., (1995). Play is not the work of the child: Young children's perceptions of work and play. Early Child. Res. Q. 10, 223–247. https://doi.org/10.1016/0885-2006(95)90005-5

[130] Wood, R., 2022. From disempowerment to well-being and flow: Enabling autistic communication in schools. Routledge Int. Handb. Crit. Autism Stud. 277–287. https://doi.org/10.4324/9781003056577-27

[131] Zagermann, J., Pfeil, U., Rädle, R., Jetter, H.C., Klokmose, C., Reiterer, H. (2016). When tablets meet tabletops: The effect of tabletop size. Conf. Hum. Factors Comput. Syst. -Proc. 5470–5481. https://doi.org/10.1145/2858036.2858224

[132] Grandin, T. (1992). Calming effects of deep touch pressure in patients with autistic disorder, college students, and animals. *Journal of child and adolescent psychopharmacology*, *2*(1), 63-72.

[133] Kendon, A., (1970). Movement coordination in social interaction: Some examples described, Acta Psychologica, Volume 32, Pages

101-125, ISSN 0001-6918, http://dx.doi.org/10.1016/0001-6918(70)90094-6.

[134] Kendon, A. (1990). Spatial Organization in Social Encounters: the F-formation system. In Conducting Interaction: Patterns of Behavior in Focused Encounters, ed. A. Kendon, 209-38. Cambridge: Cambridge University Press

[135] Heath, C., Hindmarsh, J., Luff, P. (2010). Video in Qualitative Research: Analysing Social Interaction in Everyday Life 37–60. https://doi.org/10.4135/9781526435385

[136] Hall, E. T. (1966). The hidden dimension (Vol. 609). Garden City, NY: Doubleday

[137] Lewis, H. (1998). Body Language: A Guide for Professionals. Thousand Oaks, CA: Sage

[138] Wharmby, P. (2023) Untypical: How the world isn't built for autistic people and what we should all do about it. Mudlark, HaperCollins *Publishers.*

[139] Price, S., 2013. Tangibles: Technologies and interaction for learning, in: The SAGE Handbook of Digital Technology Research. pp. 307–325. https://doi.org/10.4135/9781446282229.n21

[140] Kaur, D., Alias, A., Mohamad, M., 2019. The Sounds of Intent Framework for Autism Intervention: A Conceptual Paper. Creat. Educ. 10, 1953–1964. https://doi.org/10.4236/ce.2019.108141

[141] McVeigh-Schultz, J., Kolesnichenko, A., Isbister, K., 2019. Shaping pro-social interaction in VR an emerging design framework. Conf. Hum. Factors Comput. Syst. - Proc. 1–12. https://doi.org/10.1145/3290605.3300794

[142] Raffle, H.S., Parkes, A.J., Ishii, H., 2004. Topobo: A constructive assembly system with kinetic memory. Conf. Hum. Factors Comput. Syst. - Proc. 6, 647–654.

[143] Baudelaire, C. [1853] (1995). The philosophy of toys. In I. Parry & P. Keegan (Eds.), Essays on dolls. London: Syrens

[144] Eco, U. (1997). Opera Aperta, IV edizion. ed, Bompiani. Tascabili Bompiani, Milano.

[145] Luff, P., Jirotka, M., Yamashita, N., Kuzuoka, H., Heath, C., Eden, G. (2013). Embedded interaction. ACM Trans. Comput. Interact. 20, 1–22. https://doi.org/10.1145/2442106.2442112

[146] Schopler E., Mesibov G.B., Hearsey K. (1995) Structured Teaching in the TEACCH System. In: Schopler E., Mesibov G.B. (eds) Learning and Cognition in Autism. Current Issues in Autism. Springer, Boston, MA

[147] Bondy, A. (1994). The picture exchange communication system. Focus Autistic Behav. 9, 1–19

[148] Zissermann, L. (1992). The Effects of Deep Pressure on Self-Stimulating Behaviors in a Child With Autism and Other Disabilities

[149] Centers for Disease Control and Prevention. (2020). Signs and Symptoms of Autism Spectrum Disorders. Retrieved from https://www.cdc.gov/ncbddd/autism/signs.html

[150] Fletcher-Watson, S., De Jaegher, H., Van Dijk, J., Frauenberger, C., Magnée, M., Ye, J. (2018). Diversity computing. Interactions 25, 28–33. https://doi.org/10.1145/3243461

[151] Ringland, K.E. (2019). A Place to Play: The (Dis)Abled Embodied Experience for Autistic Children in Online Spaces. In Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems (CHI '19). Association for Computing Machinery, New York, NY, USA, Paper 288, 1–14. DOI: https://doi.org/10.1145/3290605.3300518

[152] Kapp, S. K. (2020). *Autistic community and the neurodiversity movement: Stories from the frontline* (p. 330). Springer Nature.

[153] Zachariou, A, Whitebread, D, 2015. Musical play and self-regulation: Does musical play allow for the emergence of self-regulatory behaviours? International Journal of Play 4 (2), 116–135. https://doi.org/10.1080/21594937.2015.1060572

[154] Prizant, B.M., Wetherby, A.M., Rubin, E., Laurent, A.C. (2003). The SCERTS Model: A transactional, family-centered approach to enhancing communication and socioemotional abilities of children with autism spectrum disorder. Infants Young Child. https://doi.org/10.1097/00001163-200310000-00004

[155] Davies, G., (2017). Practical help with autism – Gina Davies Autism Centre. Retrieved from: http://ginadavies.co.uk/.

APPENDICES

A THEME 8 – PLAY TYPES

The following table summarises the different types of play types analysed in the video interaction analysis by the first author used from study 2 onward.

Table 7. Theme 8 showing the types of play analysed by the first author and sub-themes

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

Categories of Play (Adapted from Parten 1932)	Definitions
	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 adult's 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.

B THEME 5 – PERSONALISED USES

The following table shows children's "personalised uses" (theme 5), i.e., when they used the TUIs beyond the digital affordance during the testing sessions (or play sessions) of the 3 studies.

Table 8. Personalised uses. Types and frequency (FRQ) of interactions with the TUIs beyond their digital affordances throughout the three studies

BEYOND DIGITAL (INTER)ACTIONS							
MAZI STUDY 1	**FRQ**	**OLLY STUDY 2**	**FRQ**	**OLLY STUDY 3**	**FRQ**	**OLLY MAZI STUDY 3**	**FRQ**
Lays on it	53	Lay belly on top	51	Lay belly on top	83	Lay belly on top	70
Sits on it or next to it	48	Sit on top	26	Sit on top	11	Sit on top	64
Slides across the floor	29	Bonce on top	62	Bounce on top	31	Bounce on top	13
Presses	27	Ribbon's manipulation	61	Ribbon's manipulatio n	39	Leans against	132

BEYOND DIGITAL (INTER)ACTIONS							
MAZI STUDY 1	**FRQ**	**OLLY STUDY 2**	**FRQ**	**OLLY STUDY 3**	**FRQ**	**OLLY MAZI STUDY 3**	**FRQ**
Climbs/Jumps on it	24	Sit/step/lay on base	56	Sit/lay on base	69	Pulls/manipulate wool	9
Using with feet	23	Leg under base	14	Leg under base	5	Press bubble	4
Shows interest in speaker	23	Touch speaker	36	Touch speaker	46	Speaker	20
Strokes	9	Pat body	11	Pat body	20	Pat body	17
		Touch felt	7	Touch body	40	Touch body	38
		Ribbon around waist	42	Ribbon around waist	12	Climbs	49
		Ribbon around armpit	8	Climbs	51	Foot on	16
		Ribbon around wrist	7	Press hands	86	Hug	76
		Rocks/swings on top	19	Rocks/swin gs on top	41	Touch bubble	49
		Balance on knee	29	Balance on	28	Press hands	67
		Twist/pulls ribbons	52	Jumps on	19	Jumps on	63
		Speaker cover	7	Pull ribbon	9	Balances on	22
		Feet up on Olly	26	Feet up on Olly	1	Cover with jumper	28
		Press/push top	11	Leans against	36	Head on bubble	11
		Feet tucked at base	11	Face on base	2	Thread	16
		Feet in ribbon	9	Snaps	22	Looks at circuit box	1
		Ribbon around shoulders	2	Steps/walks nd stand on base	278	Moves across floor	82
		Bites ribbon	4	Bites ribbon	1	Chin pressed on bubble	5
		Looks at circuit box	1	Box	5	Rocks on ball	1
		Moves across floor	3	Stroke ribbon on face	2	Looks under jumper	3
		Stroke ribbon on face	4	Velcro	1		
				Stands up	13		

BEYOND DIGITAL (INTER)ACTIONS							
MAZI STUDY 1	FRQ	OLLY STUDY 2	FRQ	OLLY STUDY 3	FRQ	OLLY MAZI STUDY 3	FRQ
				Hug	3		
				Foot in ribbon	1		
				Face on top	2		
				Wobble ball	11		
				Knee on	1		