TANGIBLE USER INTERFACES AND SOCIAL INTERACTION IN CHILDREN WITH AUTISM

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Statement

I hereby declare that this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree

William John Farr

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Summary

Tangible User Interfaces (TUIs) offer the potential for new modes of social interaction for children with Autism Spectrum Conditions (ASC). Familiar objects that are embedded with digital technology may help children with autism understand the actions of others by providing feedback that is logical and predictable. Objects that move, playback sound or create sound – thus repeating programmed effects – offer an exciting way for children to investigate objects and their effects.

This thesis presents three studies of children with autism interacting with objects augmented with digital technology.

Study one looked at Topobo, a construction toy augmented with kinetic memory. Children played with Topobo in groups of three of either Typically Developing (TD) or ASC children. The children were given a construction task, and were also allowed to play with the construction sets with no task. Topobo in the task condition showed an overall significant effect for more onlooker, cooperative, parallel, and less solitary behaviour. For ASC children significantly less solitary and more parallel behaviour was recorded than other play states.

In study two, an Augmented Knights Castle (AKC) playset was presented to children with ASC. The task condition was extended to allow children to configure the playset with sound. A significant effect in a small sample was found for configuration

of the AKC, leading to less solitary behaviour, and more cooperative behaviour. Compared to non-digital play, the AKC showed reduction of solitary behaviour because of augmentation. Qualitative analysis showed further differences in learning phase, user content, behaviour oriented to other children, and system responsiveness.

Tangible musical blocks (‘d-touch’) in study three focused on the task. TD and ASC children were presented with a guided/non-guided task in pairs, to isolate effects of augmentation. Significant effects were found for an increase in cooperative symbolic play in the guided condition, and more solitary functional play was found in the unguided condition. Qualitative analysis highlighted differences in understanding blocks and block representation, exploratory and expressive play, understanding of shared space and understanding of the system.

These studies suggest that the structure of the task conducted with TUIs may be an important factor for children’s use. When the task is undefined, play tends to lose structure and the benefits of TUIs decline. Tangible technology needs to be used in an appropriately structured manner with close coupling (the distance between digital housing and digital effect), and works best when objects are presented in familiar form.

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“All these children [with Autism] often show a fascination for objects and machines which they prefer to people. We too wished to capitalise on this feature, and similarly, we wanted the child to be more active in the environment so that whatever happens he can say: ‘I did it and my doing it made a difference’ (Emanuel & Weir, 1976, p. 122, insertion mine).”

1 Introduction

Autism is a lifelong disorder with onset prior to the age of three (Jordan, 2001). Time of diagnosis can be varied, occurring as early as 18 months or as late as adulthood, but one aspect is clear: autism affects the social mind, and causes a ‘triad of impairments’ in social interaction, communication and imaginative activities (Wing, 1981; Wing & Gould, 1979). There is currently no known ‘cure’, and there is a growing concern among modern researchers that it is useless to even try and search for a single cure due to the conglomeration of possible genetic and environmental factors that may contribute to the disorder (Happé, Ronald, & Plomin, 2006). However, there is a growing body of research that suggests genes such as NLGN4X will most likely be mutated further in autistic individuals through protein structures at the glutamate synapse (Perche et al., 2010). The very notion of a cure is debatable amongst many theorists who point to a continuum of existence stretching from the autistic to the typical population, positing that cognition within the autistic population offers skills and ways of being that have positive as well as negative social consequences (e.g. Baron-Cohen, 2009).

To reach the autistic mind, the variety of treatments and therapies provide structure, low-impact environments, and/or intensive tuition (e.g. see Parsons et al., 2009; Schopler & Mesibov, 1984). The degree of intensity, as well as the relative success of the method, varies from child to child (Parsons et al., 2009). Without a clear understanding of what causes the disorder, we are left to deal with observable behaviour, informing both the tuition of individual children, and providing a window into the world of the social and cognitive impairment that makes up Autism and its associated spectrum of disorders (Bettelheim, 1967).

One of the ways forward – addressed in this thesis – is through the use of tangible user interfaces (TUIs) that couple and/or embed digital data within real objects (Ishii & Ullmer, 1997). Actions on physical rather than virtual objects enable users to manipulate data in new ways (Jorda, Julia, & Gallardo, 2010). TUIs are ‘out here’ in the real world and so provide potential multi-sensory access (Dourish, 2004). The TUIs, used in these series of experiments, were still in prototype form. Three main branches of TUIs are addressed within this thesis as indicated by Shaer and Hornecker (2010). These are: radio frequency identification technology (RFID), computer vision, and microcontrollers, sensors and actuators (Shaer & Hornecker, 2010). The aim is to investigate the overall effect that tangibles will have on social interaction for children with Autism Spectrum Conditions (ASC). Results are suggestive of a link between ‘coupled’ aspects – how physically close the digital effect is to the object – of a TUI and its social coherence by children with Autism. The degree of coupling (full, nearby, environmental and distant) is explored within the three studies.

Little research in the field of psychology has so far looked at tangibles in relation to autism. Tangibles designed for autistic children are often found in small-scale case studies (e.g. Brok & Barakova, 2010; Sitdhisanguan, Chotikakamthorn, Dechaboon, &

Out, 2008; van Rijn & Stappers, 2007) with little or no psychological and statistical assessment. Heterogeneity in research with children with autism is not without difficulty, as pointed out by Picard et al. (Picard, 2009; Picard & Goodwin, 2008) who claim that '[i]f you've have met one person with autism, then you have met one person with autism (Picard & Goodwin, 2008, p. 38). It is therefore difficult to provide a simple 'one-size fits all' answer when developing possible interventions for children with autism. Diagnosis in comparison appears to have the potential to become easier but ultimately what to do after diagnosis provides a significant challenge (Ecker et al., 2010).

Additionally, researchers have been calling for an analysis of different tangible interaction styles as well as the various ways in which tangible interfaces allow users to manipulate data (Fernaeus & Tholander, 2006; Marshall, 2007; Marshall, Price, & Rogers, 2003; Shaer & Hornecker, 2010). For example, more empirical work on the variety of 'mappings'– how tangibles reflect certain physical or cognitive activities – could show how digital feedback aids or hinders children's interaction (Antle, 2007). Long-term research is still required, as the effects of TUIs may decline over time simply due to novelty (Hinske, Lampe, Yuill, Price, & Langheinrich, 2009; Shaer & Hornecker, 2010). However, this thesis does not address that issue, rather it seeks to discover what tangible interaction occurs with, around, and through TUIs with children who have autism. Interventions were short in time scale, usually over the period of a week. As a result, this thesis could and should be considered exploratory work, testing and establishing whether TUIs and autism is a significant branch that deserves further investigation.

Section 1 of the thesis is an introduction to the theory behind TUIs. This is followed by a theoretical look at autism and how TUIs could help children with this impairment.

We briefly trace the history of TUIs, but the main argument is how the field of computer science, in particular the theory of embedded interaction has similarities in the field of psychology in work conducted on object interaction and autism. Impaired object interaction in autism rests on sensorimotor, symbolic, and functional limitations in understanding objects, yet learning and interaction in autism relies heavily on proximal, hands-on interaction with objects (Rowland & Schweigert, 2009; E. Williams, 2003). Both bodies of literature argue for a view of action grounded in the world; objects embedded with digital technology and closely coupled effects help children with autism socially interact by allowing multiple points of entry.

In section 2 (Article I) we look at autism and social interaction with a TUI possessing 'full coupling' (discussed in section 1.2.3 below). This study focuses on how a tangible construction kit can impact on children's social play and whether it promotes more cooperative forms of play. Play and TUIs is additionally discussed. Parten's (1932) play state codes are used to analyse play.

Section 3 (Article II) highlights how control, and configurability of a novel augmented storytelling environment creates – as in section 2.1 – more social interaction and less isolated behaviour. Here the coupling (as discussed in section 1.2.3) between input and output is 'nearby' rather than full. Output is heard through speakers embedded in buildings and the base of a unit – but not directly from figurines.

Section 4 (Article III) looks at a computer vision system – the d-touch. The coupling of the system is 'environmental' as sound is heard from speakers that are not embedded as part of the system. Blocks are abstractly linked to cubes by placement on a computer marker sheet of paper on an x/y axis. Social interaction is again investigated and the coding scheme used in Articles I and II is re-used. The coding scheme is extended here to look at children's symbolic and functional understanding of the d-touch.

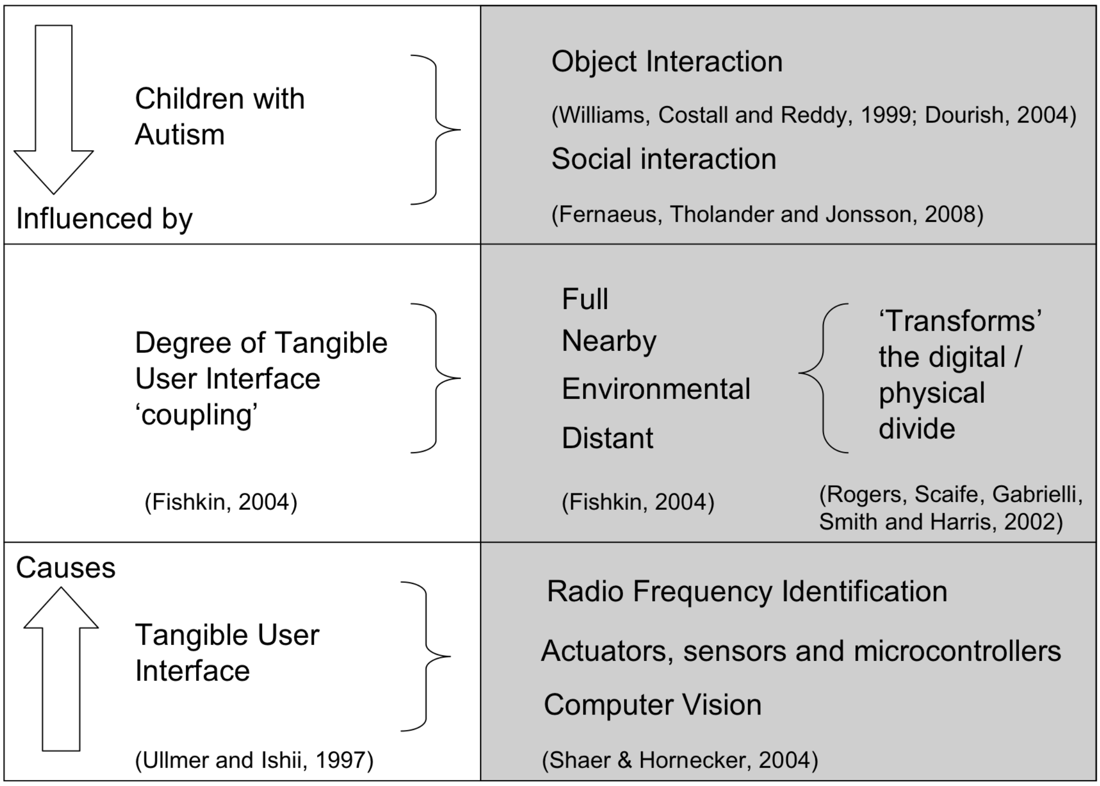

Figure 1. Overview of thesis

1.1 Overview of Thesis

Interaction with objects for children with autism is problematic and indicative of the developmental disorder (E. Williams, Costall, & Reddy, 1999) but provides beneficial insight for TUI use and design. The interrelationship presented in this thesis between social and object interaction in children with autism, and tangible user interfaces (Figure 1) depends largely upon the degree of coupling that exists between the TUIs actual appearance and its digital effect (Fishkin, 2004). Further, the transformation (Rogers, Scaife, Gabrielli, Smith, & Harris, 2002) of digital to physical effects, and vice versa, will have an impact on children's play, as will multiple points of entry that allow for subjective interpretation by users (Fernaeus, Tholander, & Jonsson, 2008). In this series of studies, the less obvious the link between the TUI's appearance and digital effect, the harder it is for children with autism to comprehend the TUI, and ultimately be drawn together to socially interact with and around the TUI.

1.2 Tangible User Interfaces

1.2.1 Concepts driving the development of TUIs

TUIs emerged from a special issue of the Communications of the Association for Computing Machinery (ACM) in 1993 on 'Augmented Reality and Ubiquitous Computing'. This was in contrast to the accepted virtual position predominant in computer science at the time (Dourish, 2001). Shortly before, Mark Weiser, head of the Computing Research Lab at Xerox Parc in California, in a short article for Scientific American in 1991, argued that computers should be woven into the fabric of daily life – and disappear – so that they do not require conscious attention (Weiser, 1991). For Weiser, human psychology mattered more than human technology. Computers would adapt their behaviour so interaction with computers would become more of a place than an interface (Weiser, 1991). The world needed to be augmented with digital functions, rather than with virtual reality which demanded more immersion and attention by human users (Shaer & Hornecker, 2010). Weiser's own work at XEROX Park reflected 'Ubiquitous Computing' (UbiComp) by the 'foot, inch and yard', in interactive name tags, digital tablets, and early prototypes of interactive whiteboards (Dourish, 2004).

Early prototypes were such items as the 'ActiveDesk' (Fitzmaurice, Ishii, & Buxton, 1995), an interactive architectural tool that used implements enhanced with digital technology on its active surface (see section 1.2.4 for description). Developed at the University of Toronto in the 1990s it "grew out of both the ubiquitous perspective and the media space tradition, an approach to supporting collaboration and interaction through a combination of audio, video and computational technology" (Dourish, 2004, p. 18). Work conducted in this joint UbiComp and media space emphasised how people now needed to work with computers as resources for action bringing digital computation into the physical world (Fernaeus et al., 2008).

Paul Dourish's 'Where the Action Is: The Foundations of Embodied Interaction' (2004) stated the case for the field of Human Computer Interaction (HCI) to move toward a more refined interpretation of Weiser's view, and lay philosophical groundwork for much of the TUI field, in particular tangible interaction. Dourish's notion of 'embodied interaction' suggested that much of our present-day interaction with computers developed as a direct result of the trajectory of computer development. A trade-off between usability and time (and therefore cost) efficiency meant that for most of the period of computer use in human history, the computer has stood around doing nothing for 95% of the time (Dourish, 2004). The computer did computation, as access to mainframes and networks was incredibly expensive. Computer-use via procedures and computation came to matter more than computers and interaction, as early forms of computing were concerned with resistors and electrical equipment, before eventually becoming 'high level' symbolic languages such as binary (Dourish, 2004). This led computing to continue along a trajectory where it became an abstract area, with computation alone being the sole purpose of computing. For Dourish, with computer technology being more powerful than ever before, computers were still essentially separated from real interaction in the environment. Dourish suggests that computers should instead inhabit our world, not the other way around. To "exploit our familiarity with the everyday world", the natural understanding of objects, and the "world of social interaction and physical artifact is the place computer technology should be inhabiting" (Dourish, 2004, p. 17). The environment in Weiser's vision would be able to detect who came into what room, and what temperature different people liked (Weiser, 1991). Human Computer Interaction (HCI) theorists were concerned that

Weiser's vision would make us passive recipients of computer data (e.g. Rogers, 2006). Computers should not do everything for us, meaning that we still need to engage – cognitively at least – with the environment. Dourish suggested that what is more important is not what a computer *does*, but what it *conveys* and *how*, which must therefore change the way we interact with computers (Dourish, 2004). Dourish does not completely explain the field of TUIs or tangible interaction, rather that phenomenologically, the use of artifacts enhanced or embedded with digital technology makes more sense than desktop computers when placed in particular cultures, times, or environments. This world of social interaction and physical artifact is now referred to as 'tangible computing', 'tangible interaction' or 'embedded interaction'. This thesis is to some degree concerned with the cultural factors that come along with the use of tangible interaction with children who have autism, as understanding the 'culture' (Mesibov et al., 2005) and behaviour of this user group enables us to understand the value of TUIs for children with autism. Some of these values include: use of physical objects, motivating toys, a fascination for computers, and multiple access points that allows for heterogeneity. However, we are primarily concerned with the use of physical artifacts, or objects enhanced with digital technology with children with autism, and whether social interaction is enhanced in any way when TUIs are used.

In this section we have tried to pursue some of the underlying conceptual factors behind TUIs. We have shown that TUIs developed from the vision of Mark Weiser's Ubiquitous Computing and was altered by Dourish to include the messy world of social interaction, people, objects, cultures and artifacts. We now turn to a more specific discussion of the trajectory of TUI development.

1.2.2 Origins of tangible user interfaces

TUIs aim to move away from 'painted bits' or representations of information on screen-based systems, to 'tangible' or 'graspable' interfaces, and take advantage of human interaction with multiple senses, and multiple-sensory information (Fitzmaurice et al., 1995; Ishii & Ullmer, 1997; Shaer & Hornecker, 2010). Since Ishii and Ullmer's discussion of 'tangible bits' in 1997 there has been a growth in the field of tangible user interfaces (Ishii & Ullmer, 1997). The original term'graspable' was dropped when it was later thought that the word tangible offered a better description of these new interfaces (Ishii & Ullmer, 1997). Grasping itself was not essential, rather tangibility and transparency of purpose in the form of data or physical representation was now deemed to be more important (Ishii & Ullmer, 1997; Shaer & Hornecker, 2010). For example, in the ambientROOM (Ishii et al., 1998), whilst information was meant to be understood and relayed in a physical architectural space, physical objects such as bottles and clocks were still employed as primary activity controllers. AmbientROOM explored boundaries between foreground and background awareness with tangible controls managing activity in a clear manner (Ishii et al., 1998). For example, whilst using the ROOM users would be given information in an immediate way with digital information on the interactive desk, or through moving tangible objects on the desktop such as pens and rulers, other information such as time was conveyed in a subtler way via projections or the changing height of a ball to indicate time passing.

The vision for TUIs was that computer technology would become increasingly embedded or coupled with objects and direct manipulation with the object ultimately would become direct data programming (Jorda et al., 2010). In place of the 'WIMP', (the window-icon-menu-point) interface introduced by the XEROX Park research and development teams, would be the grasp, move, point, swipe of normal physical interaction (Dourish, 2004; Jorda et al., 2010). Theorists believed that the usability and natural interaction of TUIs outperformed – or had to outperform – the mouse and keyboard based interface (van den Hoven et al., 2007). Interaction with a digital object was directly enhanced by natural engagement as proximal senses could now be used to explore, a distinct advantage to children with autism who favour interaction in this manner (Dourish, 2004; Rowland & Schweigert, 2009; Sitdhisanguan, Chotikakamthorn, Dechaboon, & Out, 2007; E. Williams, 2003). Various examples show this to possibly be the case as completing tasks using Graphical User Interfaces (GUIs) takes longer, due initially to the constraint of manipulation only ever being in two-dimensions (Sitdhisanguan et al., 2007; Xie, Antle, & Motamedi, 2008). This is discussed at more length in section 1.3.4 in Table1, but the primary differences between GUIs and TUIs is to be found in the physical embodiment of data that allows users to interact directly with the interface.

However, TUIs are not only places for sharing digital information through physical means, they are tools that enable control of shared activities and actions (Dourish, 2004; Fernaeus & Tholander, 2006; Jorda et al., 2010). This view emerges from user-centred studies emphasizing that the form of a tangible artifact would imply its function and that subsequent actions could be carried out upon it as a result (Fernaeus & Tholander, 2006). Tangible interaction occurs as TUIs provide ambiguity of access with multiple ways available in how to use them (Fernaeus et al., 2008; van den Hoven et al., 2007). Human action with TUIs therefore becomes more important than the transformation of information from the physical to the digital (Fernaeus & Tholander, 2006).

1.2.3 Frameworks used to describe tangible user interfaces

The basis of the two main frameworks that have emerged for TUIs not surprisingly come from the technical developers' point of view, as well as that of researchers interested in the user-group. Technical developer's interests are focused on what makes a good TUI and how to represent various digital occurrences (e.g. Fishkin, 2004). The user group view focuses instead upon what the user experiences (Dourish, 2004; Fernaeus & Tholander, 2006). The developers' point of view is vital though to understanding the backdrop to tangible interaction.

Fishkin's precise taxonomy for tangible interfaces argues that the way to understand tangibles is through the use of the terms 'embodiment' and 'metaphor'. Embodiment describes how closely digital computation is within the object, referred to as 'coupling'. Coupling is divided into four subgroups:

- *Full* (the input device is the output device) e.g. Topobo (Raffle, Parkes, & Ishii, 2004) used in this thesis (paper 1). The object has digital technology directly embedded within the framework of the object itself.

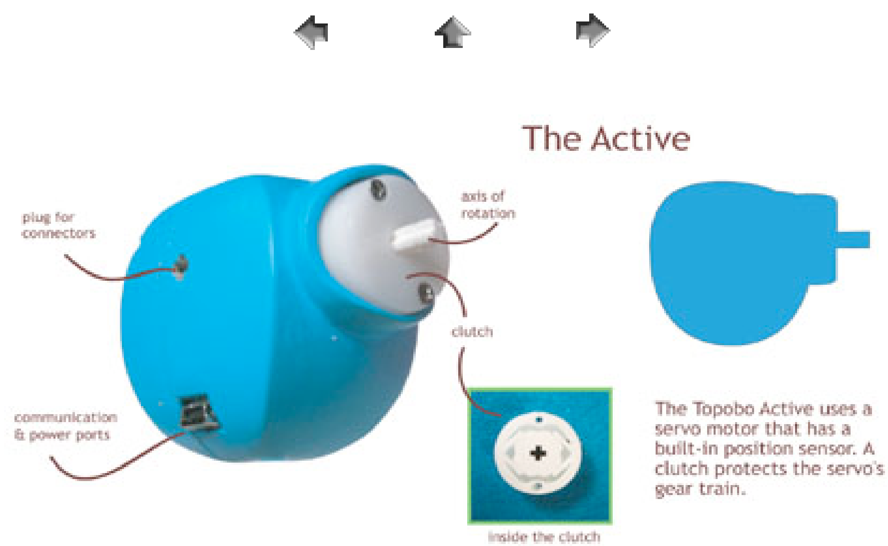

Figure 2. Image showing full coupling of technology within Topobo (copyright Media Lab, Massachusetts Institute of Technology)

- *Nearby* (i.e. it is tightly coupled) e.g. the Augmented Knights Castle (Lampe & Hinske, 2007) is an augmented Playmobil™ set (paper 2 in this thesis). Sounds are produced for figurines so that they 'speak'. However in this instance sound comes from castle base units as opposed to directly from the figurines themselves. The feedback technology does not therefore come directly from the figurine itself.
- *Environmental* (i.e. around the user) e.g. Stepstone, an interactive floor application for the hearing impaired (Iversen, Kortbek, & Aargaard, 2007). The application literally surrounds the user. AmbientROOM (Ishii et al., 1998) is closer to the tangible vision suggested by Fishkin as TUIs are an integral part of the system.
- *Distant* (i.e. on another screen, or in another room) e.g. 'Chick-clique' an application produced for mobile phone use by teenage girls to encourage girls to exercise. This allowed individuals to exchange information with one another remotely so digital feedback and interchange occurred remotely (Toscos, Faber, An, & Gandhi, 2006). D-touch, (Constanza, Giaccone, Kug, Shelley, & Huang, 2010), reported in article III of this thesis was initially conceived as a distant TUI as play and activation of the d-touch was remote, users were required to log onto the d-touch server to access the application.

Metaphor describes the importance of the physical properties of the object. This Fishkin divides into the categories of *none*, where a command line interface would be used which has only an abstract relationship to an object; *noun*, where an analogous link is made between the shape of the object and what it does; to *verb* where an analogy is made more to gesture than anything else and object shape does not matter. Lastly *noun* *and verb* is where “<X>ing something in an <A> in our system is like <X>ing something <A>ish in the real world” (Fishkin, 2004, p. 351). An example of this would be the Nintendo Wii system where swinging a virtual baseball bat with the Wiimote is approximate to the same movement as swinging a real baseball bat, and can in fact be better as it is more assistive than the reality (for example see Yong et al., 2010).

Fishkin’s taxonomy was aimed at moving gradually away from the computer-to-human interface towards human interaction. A second designer framework that has moved TUIs as resources for shared action within tangible interaction is the tokens and constraints system. Tokens are physical objects that represent information that is digital, and constraints are the physical limitations placed upon those tokens (Shaer, Leland, Calvillo-Gamez, & Jacob, 2004). Introduced by Ullmer (2002), the token and constraint system is based on the MCRit framework of Model, Control, Representation (intangible/tangible). This framework sought to put the computing control system of a TUI into its physical representation, therefore providing an illusion of direct control (Bennett, 2010; Shaer et al., 2004). Musical TUIs have for example put rhythm, pitch, volume, tempo and order into various representations in tangible objects (e.g. the ReacTable of Jorda, Kaltenbrunner, Geiger, & Bencina, 2005). For Ullmer, physical constraints provided by tokens were a means by which objects could successfully become TUIs (Ullmer, 2002). Additionally, Ullmer talks of the temporal importance of representations and the pace of use with TUIs in “a space of slowness” which is predominantly “physical” (Ullmer, 2002, p. 214).

Ullmer’s MCRit model was extended in the Tangible And Computing (TAC) paradigm where tokens and constraints were defined by the amount of function that could be applied to either a token or constraint (Shaer et al., 2004). In this sense, tokens could be coupled, defined, associated, computationally interpreted or manipulated

(Shaer et al., 2004). A part of a tangible may relate to the rest of the system either fully or partially in terms of its physical or digital manipulation and in terms of “recursive and/or temporary relationships” (Shaer et al., 2004, p. 368). In the TAC paradigm there was lastly and most importantly a definitive split between what were called ‘lexical handlers’, those who dealt with the user and the physical objects, and the control component itself. Therefore both the MCRit and TAC models took computational solution and design with TUIs and turned it increasingly toward physical and human action. Early examples of this are storytelling technologies for young children (Benford et al., 2000), interactive bricks (Fitzmaurice et al., 1995), digital toys (Resnick et al., 1998) and even wearable computers discussed by Ishii et al. in their seminal paper ‘Tangible Bits’ (Ishii & Ullmer, 1997).

This increased focus on the physical as a separate realm or conduit to digital manipulation has led in turn to ‘tangible interaction’ as ‘here and now’ became more important in the way in which humans interacted with computing systems (Dourish, 2004). Face-to-face interaction with tangibles is easily observable, multiple access points allow for a variety of users and the organization of social settings focuses more on user experience. Hard to reach user groups thus begin to enter the picture as the potential for planning and creating TUIs and TUI use for children with autism becomes a reality. For Hornecker and Buur (2006), tangible interaction means three main areas of focus, that of *data-centred* views – such as that of Fishkin – *expressive movement* views, and *space-centred* views. The data-centred view is predominantly that of the human-computer interaction field where TUIs are used as a form of mediating the digital with the physical. The expressive movement view looks to focus on expressive bodily interaction, such as that suggested by Dourish (2004). Lastly, the space-centred view according to Hornecker and Buur developed from arts and architecture and aimed to create interactive spaces, which Fishkin refers to as ‘environmental embodiment’ and is to a degree occupied by Ullmer whose background was in the school of Architecture at MIT. The space-centred view also moves toward more temporal relationships in TUIs and immersive environments such as the ‘ActiveDesk’, discussed in section 1.2.4. Hornecker and Buur suggest that the design of a TUI and tangible interaction therefore consists of:

- Tangible manipulation – understanding the direct tactile qualities of objects
- Spatial interaction – how object interaction occurs in real space
- Embodied facilitation – how the configuration of objects in space affects behaviour
- Expressive representation – how digital/material representations are clear and useable

Hornecker and Buur suggest that the space provided by TUIs allows users to interact by structuring, especially when locus of control is allowed with configurable computers - via actions that occur in space. Hornecker and Buur (2006), as well as Fernaeus and Tholander (2006), make the point that the wider social experience in and around TUIs offers as much to the development and classification of TUIs as the more traditional ‘data-centred’ view suggested by Ishii and Ullmer, and elaborated upon by Fishkin, (discussed in more depth below in section 1.3.4).

The tangible interaction view, focusing on user experience has been extended and clarified further in the work Marshall (Marshall et al., 2003), O’Malley (O'Malley & Stanton-Fraser, 2004), Rogers (Rogers, 2006; Rogers, Scaife, Harris et al., 2002) and Price (Price, 2008) and deepens the meaning of tangible use by analysing and exploring learning benefits. The value of TUIs extends beyond both the data-centred and expressive-movement view toward ‘action-centric’ views (Fernaeus et al., 2008) with more fundamental value, where TUIs may assist learning, and ultimately become assistive technologies (Blasco, Cerro, Elena, & Uceda, 2009).

Rogers et al. brought the focus to the human realm with the notion of transforms (Price, Rogers, Scaife, Stanton, & Neale, 2003; Rogers, Scaife, Gabrielli et al., 2002). Tranforms describes changes that occur to states within the world, and how people experience these habitually in daily life (Price et al., 2003). In particular how these perceptual changes occur in action and cognition. Changing information from digital to physical and vice versa will highlight issues of understanding and representation of effects. For children with autism this transformation is even more important as it will need to be explicit. The theory of transforms focuses on four dimensions; action and effect occurs along one axis, and the physical and digital occurs along another. This clearly flags the coupled effects of a TUI, as well as the TUI as a resource for action.

This action/effect, physical/digital divide is further explored by Marshall (2007) who asked whether tangible interfaces enhanced learning. Marshall argues that the importance of the concreteness and sensory directness of manipulative objects has been exaggerated and should in fact be considered separate to the effects of physicality when discussing TUIs. This suggests a more fundamental framework based on educational theory in terms of:

- The representation of the form of the TUI and its related function
- The effects of the physicality in the actual size, shape, weight, colour of an object

An example of both of these features are present in the third paper used in this thesis – the ‘d-touch’ – where there is a distinct difference in the sound feedback provided by the system and the wooden blocks used as interactive tools.

Further, form and representation within TUIs gives value to an object in terms of real and practical benefits (e.g. Dewey, 1916). For a user group such as ASC children the practical benefits of TUIs are clearly vital. For example, the practical value of TUIs reflects the history of children's objects as in the educational work of Friederich Froebel whose twenty 'gifts' provide the underlying framework and inspiration to most physical toy shapes and interactive learning manipulatives since the middle of the nineteenth century (Brosterman, 1997).

Froebel developed and gathered together many disparate aspects of children's objects, for example, wooden building blocks (gifts number 3, 4, 5, and 6), connecting systems known as 'peas work' where spheres can be joined to rods (gift 19) and interlacing shapes and 2-D objects (gifts 7, 8, 9, 15, 16, 17) (Brosterman, 1997). These objects are still reflected in many of the TUIs subsequently created such as Topobo, discussed in this thesis, and so TUIs are part of a wider history of toy development with practical value.

TUIs are not only grounded in the real world, but are practically useful for learning object use as they can in effect 'disappear' providing a mode whereby learning objects become tools. TUIs become a resource for action that can prompt new modes of communication. Marshall et al. (2003), echoing Dourish (2004) points to the work of the philosopher Heidegger (Heidegger, 1962) who suggested that objects as tools need to be thought of in terms of 'ready at hand' and 'present at hand'. Heidegger – along with other phenomenologists such as Husserl, Schutz, and Marleau-Ponty – presented a new view on philosophy in the early twentieth century that was in opposition to the rationalist, reductionist view that had until that point been dominant (Dourish, 2004; Heidegger, 1962). Their view was that action and understanding are unequivocally linked to what an individual does. Rather than the Cartesian view of the ghost in the machine, where mind and body exist as separate entities, the view of Heidegger was that action is situated in the real world, with knowledge emerging from real experiences (Dourish, 2004). Heidegger suggested that whilst objects may exist in our environment – present at hand – when they are used and fulfill their function well they become a part of the user and become ever-present at hand (Heidegger, 1962). This Heidegger called 'ready-to-hand' as an object, especially a tool thus disappears as it becomes more useful. Disappearing tools later form the backdrop to 'ubiquitous computing' (Weiser, 1991). Yet a tool with tangible qualities only becomes revealed when the tool or object breaks (Heidegger, 1962).

The user-centric view suggests that the meaning, representation, and value of what actions can be done with tangibles are as important as how they function (Marshall, 2007; Marshall et al., 2003). For example, exploratory activities occur when questions about what a TUI does create more of a focus on how to interact with the TUI rather than what the TUI represents. Antle (2007) shows that when children play with interactive objects, feedback causes children to raise questions about how to play, which subsequently prompts social interaction as children discuss play outcomes. In opposition, expressive activity occurs when a TUI allows individuals to represent new meaning by creating new structure with the TUI in the form of a story, or a model such as with 'Telltale' (Ananny, 2002) and 'Topobo' (Raffle et al., 2004). A TUI can equally be thought of in terms of present-at-hand and ready-to-hand. Topobo prompts children to initially explore how the system works, what digital effects occur, and how the parts of the system go together. Discussion and activity revolves around how to use the system. Once this has occurred children move on to become more expressive making creatures and moving creations.

In the next section, we will see look at some exemplars of TUIs that highlight the development of TUIs to their present state, and in particular point the way to their use for special needs and children with autism. Only recently have attempts been made to use TUIs with children who have special needs, as the “[g]radual incorporation of a wider range of human skills and abilities” has occurred (Dourish, 2004, p. 14).

1.2.4 Implementation of TUIs

In this section we will look at three TUIs and use them to explain the wide variety of social interaction and interaction with physical artifacts that can occur with TUIs. These are separate from the TUIs used in the three main studies of this thesis but they seek to keep to the three main areas of TUIs as defined by Shaer and Hornecker (2010) of RFID, computer vision, and actuators, sensors, and microcontrollers. The examples used are not specific to children with autism, as these are assessed and addressed in section 1.3.4.

The Marble Answering Machine

The most famous and oft-cited early tangible system was Durrell Bishop’s marble answering machine, developed between 1982/3. This would today in Shaer and Hornecker’s (2010) classification system straddle actuator, sensor and microcontroller TUIs and RFID TUIs. When messages were recorded, an object, in this case a marble, represented the message. Marbles fell down a chute where they were collected to indicate the number of messages received. Replaying messages was a matter of placing a marble in a play section of the machine. Dialing an individual back was a matter of using the same marble that the message had been received upon. Messages therefore could be moved out of order, stored and deleted without the need for the difficult understanding of a system (Dourish, 2004; Shaer & Hornecker, 2010). This concept sketch was never made, but was inspirational in terms of ‘object mapping’ messages onto the marble, and in its use of tokens (Shaer & Hornecker, 2010; Shaer et al., 2004). Either solution for the use of actuators, sensors and microcontrollers, and RFID technology could have been used for its creation. For tangible interaction what was important here was “’re-training’ their [people’s] perceptions of, and associations with objects” (Abrams, 1999, p. 7, insertion mine). What is most important for Bishop’s original design is that it established a new connection between objects, microelectronics and users. Additionally Bishop was wise enough to develop the answering machine so that it looked like a conventional machine (Abrams, 1999). As we will see in section 1.3.4, the retention of and use of habitual and conventional objects provide opportunities for children with autism to learn how to functionally use objects as they choose and use those that are motivating.

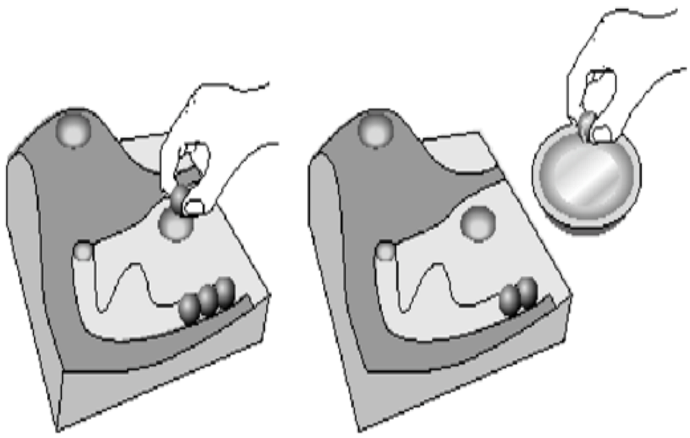

Figure 3. Image concept of Durrell Bishop’s marble answering machine (from http://interactionthesis.wordpress.com/2007/02/01/marble-answering-machine/)

'ActiveDesk'

The 'ActiveDesk' (Fitzmaurice et al., 1995) was modeled on a drafting desk and used a rear-projected LCD computer screen onto the drafting surface. This was a computer vision TUI and a sensors, actuators and microcontrollers TUI prototype. A transparent tablet lay as the drafting surface. On the drafting surface GraspDraw, a simple drawing application allowed users to draw and graspable objects, in this case 'bricks' made from Lego™ were used to 'anchor' objects together and interact on the surface. In this way transparent setsquares, rulers, and objects such as Lego bricks were used to map-out shape and space for architectural purposes.

Figure 4. The Active Desk (from http://www.billbuxton.com/ActiveDesk.html)

In terms of TUIs and tangible interaction the ActiveDesk and its prototype development is important for a number of reasons:

- The use of input was capable of identifying objects on an x/y coordinate
- The interaction time span allowed for quick manipulation and feedback
- Objects used on the desk encompass the span of 'coupling' from tight to remote (see section 1.2.3) as some objects had technology directly housed within the

object, others relied on a response from technology housed elsewhere (for example through passive radio frequency identification)

- Spatial awareness was now an inherent part of design as people could now work alone, or in groups developing “mutual awareness” of other ideas, objects and occurrences developed by others (Fitzmaurice et al., 1995)

‘Curlybot’

‘Curlybot’ (Frei, Su, Mikhak, & Ishii, 2000) is an educational toy aimed at children aged four and up. Curlybot used microcontroller technology. Curlybot was a two-wheeled vehicle with embedded technology that could record and play back motion. Curlybot was a palm-sized semi-circular device – often made in bright colours – which when placed on a flat surface could be programmed to move using a record/playback button. The programming aspect of curlybot was based on LEGO™ mindstorms (see Article I), programmable bricks, and LOGO™ turtle (discussed below in section 1.3.3). The inspiration for Curlybot was that of Friederich Frobel’s twenty inspired physical objects for children (Brosterman, 1997). Interaction with children with curlybot tended to focus on ‘gesture and narrative’ as it captured the trajectory of movement, with expressive gestures such as shaking, pausing, and accelerating as programmed by children. Control was specifically oriented to repetition, with feedback occurring in the order it was programmed. This allowed children to see Curlybot as an ‘object-to-think-with’ where multiple styles of play and learning would be captured by interaction with and around curlybot (Frei et al., 2000).

The three TUIs mentioned in this section cover an extremely broad church of design types, technological solutions and potential interaction patterns that could occur with and around interfaces. These multiple points of entry to interaction open the potential for hard-to-reach user groups (Fernaeus et al., 2008). The marble answering machine set the standard for altering the way in which we view our interaction with simple objects and new capabilities were mapped onto old objects in new ways. With ActiveDesk the use of bricks with a rear-projected screen as a drafting table, took an already familiar tool and added a new dimension, showed how graspable interfaces could be developed further simply by changing our relationship to objects. Lastly, curlybot showed the potential for purposeful design for children so that a) the relationship with the object, a toy in this case, was new and unexpected, creating a new mapping b) the object was graspable so that tactile interaction of picking-up, shaking, moving was a part of the tangible interaction and c) allowed for multiple access points for children. As confidence has grown in the development of TUIs technologically as can be seen in the ActiveDesk, tangible interaction has appeared as a new mode of interaction with and around TUIs. Children could now be included much more readily as part of the design process, and most significantly, this has paved the way for TUIs to now be used with children who have special educational needs, and developmental disorders. We now turn to a discussion of one of these disorders, autism, to establish the potential value of TUIs.

1.3 Autistic Spectrum Conditions and TUIs

1.3.1 Autism definitions and impairments

Kanner in the early 1940s wanted to show that an impairment existed that differed from childhood schizophrenia (Kanner, 1943). This ‘autism’ was marked by a “powerful desire for aloneness and sameness” (Kanner, 1943, p. 249). Today, according to the Diagnostic and Statistical Manual (DSM-IV) Autism is a Pervasive Developmental Disorder “characterized by severe and pervasive impairment in several areas of development: reciprocal social interaction skills, communication skills, or in the presence of stereotyped behaviour, interests and activities" (APA, 1994, p. 65). In particular for 'Autistic disorder' the "impairment in reciprocal social interaction is gross and sustained" (APA, 1994, p. 67). The International Classification of Diseases ICD-10, (WHO, 2007) additionally characterizes autism under section F84 'Pervasive Developmental Disorder', yet continues to organize the disorder further than DSM-IV along the following lines:

- Childhood Autism (F84.0): manifests before the age of three, with abnormal functioning in "reciprocal social interaction, communication and restricted, stereotyped, repetitive behaviour (WHO, 2007)"
- Atypical Autism (F84.1): differs from childhood autism in that it fails to fulfill all three sets of criteria of that impairment
- Rett's syndrome (F84.2): occurs so far only in girls where social and play development are arrested, stereotyped behaviours, along with partial or complete loss of speech, and poor motor skills
- Other childhood disintegrative disorder (F84.3): Normal development is followed by an unexplainable loss in a previously acquired skill
- Overactive disorder associated with mental retardation and stereotyped movements (F84.4)
- Asperger's syndrome (F84.5): Similar to childhood autism but there is no delay in language or cognitive development

Broad heterogeneity in the diagnostic criteria for autism along with differing prevalence and epidemiological rates continue to cause concern today (Knapp, Romeo, & Beecham, 2009; Laidler, 2005; Shattuck, 2006; J. H. G. Williams, Higgins, & Brayne, 2004; Wing & Potter, 2002) as more cases of autism are detected. The reason for prevalence rates being on the rise is unclear; yet the economic cost, and the impact autism and autism spectrum disorders is having on communities and nations is only now being understood. Whilst detection is becoming better and faster (Ecker et al., 2010) a clear genetic understanding of the condition remains elusive (Happé et al., 2006). This is in part due to co-morbidity that is often found in autism, with additional problems such as attention deficit disorder, epilepsy or bipolar disorder presenting in addition to the autism (Happé et al., 2006; Isager, Mouridsen, & Rich, 1999; Mouridsen, Bronnum-Hansen, Rich, & Isager, 2008).

1.3.2 Current theories of object and social deficits for autism

The fundamental debate amongst theorists' of children with autism is what in the particular social constructs of the child – or adult – leads them to view the world in the way that they do. The overarching view is that of meta-representation, which suggests that individuals with autism are impaired in their ability to be able to produce cognitive representations of what is observed or experienced (e.g. Hobson, Chidambi, Lee, & Meyer, 2006).

For children with autism the normal path of development normally becomes arrested, and the development of mental constructs may not even occur or are cut off before they are properly constructed (Frith, 1989). A variety of theoretical models have suggested how this may actually occur. Baron-Cohen (1997) suggests that children with autism possess a faulty set of 'Mind-reading' components. Baron-Cohen's theoretical stance as to the origins of autism has deepened since 1997. For example there have been investigations into prenatal testosterone (Baron Cohen, Lutchmaya, & Knickmeyer, 2004). Suggestions of the extreme male brain as an impairment concerns Baron-Cohen (Baron-Cohen, 1999, 2004). An autism test 'could hit maths skills' resulting in eradication of genetic anomalies that lead to specialist knowledge such as mathematics, or computer science ability which have been implicated in the autistic brain (Baron-Cohen, 2009) Even so, Baron-Cohen's theoretical structure has remained essentially the same. The mind-reading system consists of an intentionality detector (ID), an eye direction detector (EDD), a shared attention mechanism (SAM), and the Theory of Mind Module (ToMM). Each of these aspects means that children with autism could fail to understand the intentions of others by not focusing on, for example, eye gaze (e.g. Tomasello, Carpenter, Call, Behne, & Moll, 2005). Triadic representations build up in the mind of the observer as to what another individual is looking at, and assumptions about the other persons' intentions occur (Baron-Cohen, 1997). Goal detection and facial processing becomes confusing for individuals with ASC, and uncertainty is only increased by attending to eye gaze (Baron-Cohen, 1997).

Views such as Baron-Cohen's, and others such as the theory of 'central coherence' and 'executive function' (Happe, 1998) focus on some sort of underlying cognitive structure which may simply suggest only part of the answer to autism.

Yet the environment should dictate an autistic individual's view of the world. This bridge between the field of TUIs and psychology is to be found in the work of Loveland (1991; 2001). Loveland's work follows in the tradition of Gibson's (Gibson, 1979) theory of ecological perception. A fundamental aspect of this theory is the notion of affordance. Affordance describes how perceptual cues and clues are 'given off' by a particular object, person, or place in our environment that enable us to implicitly grasp how things should be used. Both humans (and animals) are built to be able to tune into these affordances. This theory has been highly influential in computer science via the work of Norman (Norman, 1988, 2007). Norman's 1988 'Design of Everyday Things' discusses everyday objects from kettles, to door handles to telephones in an attempt to grasp what is wrong about design from the point of view of its implicitly understood use.

Loveland's work on affordance attempts to explain autism through the notion of ecological perception. The relationship, according to Loveland, between perceiver and perceived is based on the ultimate perception of a meaningful environment. Creation of a meaningful environment is dependent on objects in our environment 'making sense' because of their preferred affordance. Preferred affordance is based on three aspects for Loveland: "affordances for physical interaction with the environment, culturally determined affordances that reflect preferred but not necessary interactions, and social and communicative affordances that reflect the meaning of human activity" (Loveland, 1991, p. 99). Loveland suggests that for children with autism, physical interaction with an environmental object (for example) may be possible, but a child with autism may misuse that object as they simply do not understand its culturally preferred affordance i.e. that which is most commonly displayed. If this is the case then all social and communicative activities with that object then become equally impaired. This explanation suggests that what is wrong with a child with autism may derive more from shared cultural perceptions of how objects, people and environments are interacted upon, and environmental objects have multi-layered meaning which children with autism may simply never understand.

The intuitive use of the physical, cultural and social environment if impaired in autism leads to a multiplicity of problems with object interaction, which TUIs could help with multiple points of entry.

1.3.3 History of tangible-type computers for children with autism

As is discussed further in the studies below, the widespread use of computers for children with autism has been slow to evolve (Jordan, 2001). The main reason for this is that researchers have been concerned that the 'monotropic' or tunneled atmosphere that surrounds the computer could make the isolated behaviour of children with autism worse (Jordan, 1995; Murray, Lesser, & Dawson, 2005).

Computer-based instruction as a method of intervention has been tried since the early 1970s. A variety of researchers have tried to establish that using computer technology was useful as computers were logical, non-threatening and consistent in response (Emanuel & Weir, 1976; Panyan, 1984). Colby's (1973) work on seventeen non-speaking autistic children found that encouraging exploratory play with a keyboard-controlled audio visual display enabled some of the children (as four participants did not respond) to overcome a 'dyssymbolic' difficulty or the understanding of symbols. Autistic children who responded began to socially interact and communicate.

The earliest recorded use of a tangible-type system with children with autism was in the work of Emanuel and Weir (1976). This work aimed to use the LOGO language to try and catalyse communication in an autistic child. The child was gradually taught how to use a LOGO turtle to move using a programmable interface. The initial motivator for Emanuel and Weir was in the observed "fascination for machines shown by autistic children" (Emanuel & Weir, 1976, p. 118). Observed effects were twofold: in the sudden use of spontaneous language, and in the "active seeking out of social interaction" (Emanuel & Weir, 1976, p. 118). The use of objects during interpersonal interaction and 'perception' additionally showed for Emanuel and Weir "our interpersonal schemata", or how well children subsequently represent object use in their minds (Emanuel & Weir, 1976, p. 120).

Work has since appeared to go either into the development of language communication or into social interaction with computers. Work by Tjus et al for example (Tjus, 1998; Tjus, Heiman, & Nelson, 1998) has focused on the use of desktop computers to train children with autism to understand language. The work of the Aurora project (e.g. Dautenhahn, 2000; Robins & Dautenhahn, 2007) in opposition has created robots that act as peers so that facial movement, and eye contact can become a focal point when presented at a slowed rate. Kozima, Michalowski and Nakagawa (2009) have created Keepo, a small yellow toy with eyes embedded with webcams, so that the small figure can react and turn toward younger children with autism when they look at Keepo. Virtual peers have also been used with good effect in the work of Tartaro and Cassell (2008) who have used them to teach language and mimicry of facial expression. The use of facial expression, and autistic children's interest in machines has also led to the Transporters, where six minute cartoons focus on different emotions through characterized machines such as cars, trains and lorries (Baron-Cohen, Golan, Chapman, & Granader, 2007). An extension of expression has also occurred in the use of individual's affective states so that children with autism can use feedback on their current state that enables reflection and increases the ability of users to act on their own emotional and physical state. (el Kaliouby, Picard, & Baron-Cohen, 2006; Goodwin, 2008; Picard, 2009)

The use of TUIs for children with ASC has only happened within the last five years, as far as we know, as the growth of user-centric, tangible interaction views have promoted more collaborative and shareable interfaces (Fernaeus et al., 2008). The Sides project used a Mitsubishi diamond-touch tabletop computer to create a puzzle that demands Aspergers users collaborate together to achieve an overall aim (Piper, O'Brien, Morris, & Winograd, 2006). Research by Barakova and Chonnaparamutt (2009) used a participatory model to create intelligent tangibles that interact together and can be used collectively by children with ASC to interact. Other work has also used a participatory approach such as the LINKXX project (van Rijn & Stappers, 2007, 2008) to create interactive devices for children with ASC to encourage social interaction. The Reactickles project (Keay-Bright, 2007) has used tangible qualities that children with autism are motivated by to create software for interactive whiteboards that encourage social interaction with shapes. We now turn to a discussion of the benefits TUIs may explicitly offer to children with ASC.

1.3.4 Sensory and social benefits of TUIs: How TUIs might help children with autism

Jordan and Powell (1995) list the following elements which are involved in autistic children's thinking within school-based situations and here have particular relevance to way in which TUIs could become resources for action:

1. Inconsistent reaction to perceptual stimuli so intensity may change on a daily basis
2. Problems planning movement so proprio-receptive perception may lead to a dependence on visual cueing
3. Learning to be motivated, by taking control of situations for themselves
4. Provide a structure for making decisions. Unstructured spaces need structure to make them manageable
5. Tunneled attention
6. The importance of feedback, so that the child's own role is known within task
7. Challenge without penalty i.e. allowing for non-threatening experimentation
8. Reflecting on enjoyment

9. Making meanings accessible e.g. through explicit and clear guidance

The ability of a resource then to be open to wide interpretation, allowing for individualized adaptation within a structured setting, is vital to children with autism (Jordan & Powell, 1995; Mesibov et al., 2005). These aspects are some of the ways in which the heterogeneous ASC population may think and interact with environment, which multiple entry points will allow for. TUIs then become resources for a variety of actions such that a “representation thereby only becomes meaningful for a person through the way it manifests itself to that person” (Fernaeus et al., 2008, p. 255). Some of these aspects are discussed in this section, but they all appear throughout the three studies, for example in article III children have the opportunity to reflect on how to use the d-touch. Feedback is explored and is shown to be important for children’s comprehension in how to use the TUI in article III. Structure is provided in article I as children are given a clear task to carry out with the TUI. The subjective nature of social interaction with TUIs (Fernaeus et al., 2008) allowing children to take control appears in article II.

Objects themselves are an external stimulus that could disrupt the poor play cycle of children with autism as they struggle to understand both people and play objects (E. Williams et al., 1999). In addition, children with autism have fluctuating knowledge about objects. (E. Williams, Kendall-Scott, & Costall, 2005). However, multiple points of entry may allow each child with autism the opportunity for subjective interpretation of TUIs (Fernaeus et al., 2008).

A comparison between GUIs and TUIs in table 1 (below) shows the difference in access points available to TUI users. The table indicates that physicality, multiple degrees of freedom and possible number of users are key differences TUIs offer when compared to GUIs. Multiple degrees of freedom in the tangible interaction framework mean that TUIs should be considered as resources for action such as physical manipulation, perception and sensory experience, referential, social and contextual action, and digitally mediated action (Fernaeus et al., 2008). This view emphasizes physical and social contexts for action with bodily and subjective experience (Fernaeus et al., 2008).

Children with autism find TUIs easier to use as opposed to graphical user interface based systems (Sitdhisanguan et al., 2007). But TUIs divide physical representation of an object and how the object exists as a digital representation that may be of dual benefit (Antle, 2007; Marshall, 2007; Uttal, O'Doherty, Newland, Liu-Hand, & DeLoache, 2009). The hands-on response afforded by either familiar or motivational objects, and what the object could represent or do through digital enhancement increases the number of ways in which children could use TUIs as resources for action.

The use of tangible objects enables users to think with external representations that “provide a structure that can serve as a shareable object of thought” (Kirsch, 2010). Cognition extends to processes beyond the mind and body, and flows quickly to places where they are easiest to organise (Kirsch, 2010). The persistence of visual or tangible structures supports exploration and endures rather than ebbing away as thought processes do (Kirsch, 2010). The use of external representations means that physical constraints and visual hints help individuals know what to do with particular objects or representations literally becoming a “better object of thought”. External representations then take advantage of ‘rearrangement’, or the fact that they can be moved, re-organised and re-evaluated (Kirsch, 2010).

Aspect of Interface	Interface	
	Graphical user interface	*Tangible user interface*
Where action takes place	In two dimensions (virtual)	In three dimensions (physical)
Correspondence to physical attribute	Loose correspondence to physical movement (size, scale, surface)	Real correspondence to physical movement (size, weight, scale, surface, texture)
Representation type	Intangible e.g. video projection, digital shadow. Output only (Ishii, 2008)	Tangible e.g. building model. Input and output (Ishii, 2008) Slows down interaction speed as objects are physical (Hengeveld, Hummels, & Overbeeke, 2008)
Mode selection	Graphical representation of data e.g. window-icon-menu-point (Dourish, 2001; Jorda et al., 2010).	Physical embodiment of data, bodily interaction, (Dourish, 2001)
Physical to Digital 'transforms'	Digital information changed via intangible representation from digital to physical e.g. typing transforms the physical to the digital (Ishii, 2008)	Digital information changed via tangible representation of physical control (Ishii, 2008)Physical interaction heightens control for user (Hengeveld et al., 2008)
Mapping	Perceptual coupling between physical object mediated as intangible representation such as an icon (Fernaeus et al., 2008) leading to reliance on symbols (Hengeveld et al., 2008)	Perceptual coupling between physically mediated tangible object such as 'Phicons' -physical icons (Ullmer & Ishii, 2001) leading to reliance more on explorative and multi-sensory interaction (Hengeveld et al., 2008)
Degrees of freedom	Limited - Single graphical representation of data e.g. window-icon-menu-point. (Jorda et al., 2010)	Multiple - allows users to be flexible interacting with TUI (Hengeveld et al., 2008). Ambiguous meaning in how to use TUI allows for multiple interaction styles (Fernaeus et al., 2008)
Skills Required	Cognitive, linguistic (Hengeveld et al., 2008)	Perceptual-motor, linguistic, social, emotional (Hengeveld et al., 2008)
Number of users	Best suited to solitary use (Hengeveld et al., 2008)	"Physical input material allows for a more flexible interaction style and opens up opportunities for collaborative use" (Hengeveld et al., 2008, p. 161)

Table 1. Comparison of GUI and TUI systems

Sensory experience with TUIs may be more beneficial for children with autism because they allow for hands-on play, and often projects choose as their inspiration objects that children already love (e.g. Jordan, 1995; Keay-Bright, 2007). If an object or TUI is linked to popular culture this can equally provide more motivation (e.g. Baron-Cohen et al., 2007). Many therapeutic methods are based on children's motivation, so if a child likes certain cartoon or television characters then these are used as part of the intervention (Baron-Cohen et al., 2007; Jordan, 2001). This is especially important as "much of [ASC] play involves manipulating objects, parents, teachers, siblings and friends can begin reciprocal interaction with objects that are of salience to the child" (Mastrangelo, 2009, p. 26).

Objects that children have played with in a home setting – habitual objects – additionally benefit children with autism compared with objects that are unfamiliar or may require symbolic understanding. Parents teach their children with autism how to use everyday objects such as cups or forks (Rowland & Schweigert, 2009; E. Williams et al., 2005). However, children who experience difficulties in object perception and learning prefer objects that are familiar to them and require minimal processing (Jones & Smith, 2005). Processing of complex stimuli for children with autism is additionally aided by presentation in a slow manner (Gepner & Feron, 2009).

Toys, such as sensori-motor toys, and toys with obvious uses are important (Dominguez, Ziviani, & Rodger, 2006; E. Williams et al., 1999). Toys that elicit a variety of responses either in sensori-motor play, functional play or symbolic play are also important. Dominguez et al. (2006) found that in younger children with autism 30% of all play was given to play with construction toys, dolls and action figures as opposed to typically developing children who played with the same objects for approximately 50% of the time. Children further tended to play more with a Thomas the

Tank Engine™ playset accounting for a further 20% of the time whilst typical children only played with the playset for 5% of the time.

TUIs therefore provide a multi-modal way for children with autism to play and interact. A digital level compliments a physical level of understanding. Physical understanding allows for hands-on play and TUIs may be in the motivating form of familiar toys. Digital feedback may or may not be familiar but may also be motivating.

Article I looks at Topobo and shows how a TUI with full coupling can produce greater cooperation amongst children with autism, and less solitary play. Article II looks at the Augmented Knights Castle and how control afforded to children with autism whilst configuring a TUI embedded with digital technology show less solitary activity and more cooperation. Article III shows that when coupling is environmental and distant, multiple access points decline, raising the necessity for appropriate help to alleviate this shortfall.

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I was the sole investigator for this work. Dr. N. Yuill was my supervisor. Dr. H. Raffle was the primary designer of Topobo.

2 Article I - Social Benefits of a Tangible User Interface for Children with Autistic Spectrum Conditions

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2.1 Abstract

Tangible User Interfaces (TUIs) embed computer technology in graspable objects. This study assessed the potential of Topobo, a construction toy with programmable movement, to support social interaction in children with Autistic Spectrum Conditions (ASC). Groups of either typically-developing (TD) children or those with ASC had group play sessions with Topobo and with Lego. We recorded the extent and sequence of different categories of play during these sessions. For both participant groups, there were more social forms of play with Topobo than with Lego. More solitary play occurred for Lego and more parallel play occurred with Topobo. Topobo was also associated with more time in onlooker and cooperative play. Finally, we observed differences in play sequences between TD and ASC children, and discuss how different play materials might produce specific patterns of play in these two groups.

2.2 Introduction

Autistic Spectrum Conditions (ASC) affect an individual's ability to understand the mental states of other people (Happe, 1998). This impairment has far reaching consequences for social interaction, communication, and imagination (Wing & Gould, 1979). Children with autism show less interaction in free play situations, and rarely initiate social interaction (Yuill, Strieth, Roake, Aspden, & Todd, 2007) .

There are a large number of treatments and intervention therapies for autism (e.g. Green et al., 2006). Technological interventions include robotic children that mimic facial movements (e.g. Dautenhahn, 2000) and the use of interactive whiteboards (e.g. Keay-Bright, 2007) and multi-touch surfaces such as the Mitsubishi DiamondTouch (Piper et al., 2006). In this study we focused on a Tangible User Interface (TUI) to examine the impact of technology when embedded in objects that children with ASC find motivating and interesting to play with. We hypothesized that the technology used would support childrens' social interactions, and assessed how the properties of the technology might influence the form and sequence of play in ASC.

2.2.1 Autistic Spectrum Condition and Play

Play is an integral part of typical development that occurs during early childhood. Children with ASC experience a deficit in their ability to play with others (Jordan, 2003). This is caused in part by impairment in their ability to respond to and extend reciprocal exchanges (Tager-Flusberg & Anderson, 1991). Play exhibited by children with ASC is often limited, repetitive, and obsessive. Placed in a situation with typically-developing (TD) peers, children with ASC can become more isolated because their patterns of play do not attract play partners (Jordan, 2003). Parten's (1932) ground-breaking work found that play in TD children is often solitary or in association with other children prior to becoming parallel or cooperative. This sequence depends not only on the play environment, but also on the materials available to interact with. Parten's scheme to code children's play has been used extensively, and has been applied to those with ASC in integrated playgroups (Wolfberg & Schuler, 1993). At around 7 to 8 years of age, play in TD children becomes more imaginative (Rowland & Schweigert, 2009). A child with ASC, however, may be incapable of imaginative play and not understand the subtlety brought about by pretend play situations.

2.2.2 Autistic Spectrum Condition and Computers

Computer responses contrast with human behaviour because of their predictability. For example, they do not react to atypical behaviour such as rocking or screaming as a human would (Powell, 1995). Therefore, computers may be advantageous for children with ASC because the stress and unpredictability caused by interpreting the human face in social situations is largely removed (Murray, 1997). Further, a branch of intervention known as 'affective computing' attempts to tackle exactly these types of stressors through wearable technology that provides feedback to the user on an individual's present affective state, based on bodily functions such as heart rate or galvanic skin response (e.g. el Kaliouby et al., 2006; Goodwin, 2008; Picard & Goodwin, 2008). Computer use provides a window of opportunity where children with ASC can encounter tools and symbols that could be used to support and enrich social interactions (Jacklin & Farr, 2005).

Many technologies have been designed to motivate and support social interaction in children with ASC by providing predictability and following this population's interests (e.g., trains, Lego, television characters). For example, the Transporters CD-ROM (Baron-Cohen et al., 2007) uses human faces superimposed on trains and cable cars in a didactic fashion to teach emotions. The predictable element of the machines appears to encourage facial emotion recognition by virtue of a well-liked medium. The SIDES project (Piper et al., 2006) is a cooperative game designed for users with ASC that incorporates a digital, multi-touch surface table. Users' actions are contingent on each other, and the system enforces turn-taking by preventing a user access when it is not their turn. Utilizing a different approach, Reactickles (Keay-Bright, 2007) provides colourful flowing patterns via interactive whiteboards. It does not teach skills explicitly, but is meant to draw users into playful communication with the screen, and then with other co-located users. As articulated by Powell (1995), technology can therefore provide the potential "to begin to put the individual with autism into situations which are *custom built* to provide learning about human thinking and behaviour" (p. 131).

While these projects aim to encourage social skills, awareness of others, and the reading of facial expressions through visual interface technology, they suffer from a common criticism: that individuals with ASC may come to prefer computers over humans, thereby decreasing interaction with other people. However, there are other technologies beyond single-user PCs that offer the possibility to increase predictability, support joint interaction, and encourage collaboration through the use of shared interfaces (Harris et al., 2009). Tangible objects are an example of this alternative technology and potentially have an advantage over tabletops or interactive whiteboards in that they can be shared and passed between multiple users while adhering to systematic principles (e.g. see Hinske, Langheinrich, & Lampe, 2008; Raffle et al., 2004). Tangible user interfaces may provide a fruitful avenue for supporting social interaction in children with ASC.

2.2.3 Tangible User Interfaces

Tangible user interfaces (TUIs) are a branch of the field of Human-Computer Interaction (HCI) that embed digital technology into graspable forms, allowing users to access computer technology in novel ways (Ishii & Ullmer, 1997). Developers of TUIs seek to give meaning to objects through technology by building in the possibility of manipulating digital or physical actions (Ullmer & Ishii, 2001). For people with special needs, the mediation of a tangible interface may promote co-located cooperative work (Ullmer & Ishii, 2001). For instance, graspable TUIs may encourage users to reflect on and talk about how they created an object and what it means to them. Digital and physical effects in TUIs can often be recorded, and this record of change has been shown to help individuals focus in on their activities (Hornecker & Buur, 2006). The TUI used in the current work allows participants to create and play back animated toy actions through programmable movement. Thus, what begins as an imagined movement becomes a physical recording that can be repeated, altered, and shared.

The present study used a TUI called Topobo, a 3-D constructive assembly system embedded with programmable kinetic memory (Raffle et al., 2004). Topobo allows the creation of 'creatures' through interconnected plastic blocks similar to the Lego system. The blocks are passive in and of themselves, but when connected can be programmed to move. For instance, a leg, arm, and/or torso can be combined and move in an automated pattern defined by the user. This programmed movement can be recorded at the time of construction and replayed autonomously. Sections such as legs, arms, or long bodies can be produced without compromising the strength of the structure, unlike Lego where a similar creation would fall apart. Qualitative analysis of a small case study of Topobo has suggested that Topobo may encourage interactive play in TD children (Parkes, Raffle, & Ishii, 2008). The present research aims to explore Topobo's potential for encouraging play in children with ASC.

Passive construction systems, notably Lego, have previously been used with children with ASC. LeGoff (2004) found that Lego play reduced behaviour typical of ASC and improved social responses over an eight-week period. In this study, social responses were measured in terms of motivation to interact with peers, manner in which interactions were sustained, and whether aloof and rigid behaviours were overcome. These responses were assessed using a structured rating scale over 12 and 24-week periods. We propose that Topobo has the benefits of Lego[1], but may be even more motivating and interesting for children with ASC to play with given its ability to have movements programmed by the user. Thus, we compare and report in detail the play patterns of TD children and children with ASC while they interact with Lego and with Topobo.

Table 1. Comparison of features of Topobo, LEGO™, and LEGO Mindstorms™

Construction Toy	Topobo	LEGO	LEGO Mindstorms
Programming potential	Programmable, using simple movements	Not programmable	Programmable, using servo motors, sensors, desktop computer interface and intelligent programmable brick
Prior experience necessary	None	None- already familiar to many children	Some
Time to construct	Quick (7 – 20 min.)	Quick (10 -20 min.)	Slower: 30 min. upwards

[1] We compare Topobo with passive Lego, rather than Lego Mindstorms, as the latter is dependent on a graphical user interface. Table 1 contrasts these three construction sets.

Degree of difficulty	Simple construction, large pieces.	Simple construction, large pieces.	Lego tecnic hard for ASC users in our sample – small, need dexterity to assemble
Typical models constructed	Movable creatures	Buildings, machines	Robots
Prior research	Raffle et al. (2004), Parkes et al. (2008)	Legoff (2004)	Papert (1980)
Participants in research	ASC children, 7 yrs +	Low functioning ASC to children with high functioning autism (HFA), 7 yrs+	HFA or people with good technical abilities, 12 yrs+

Given the findings of LeGoff (2004), we expected some level of social interaction with Lego but predicted that Topobo, a TUI, would promote greater social interaction in children with ASC. We also investigated play sequences - how one form of play leads to another - of different play patterns to gain insight into how different play materials might influence social play. However, we make no predictions about these sequences other than we expect little play differences in TD children across play materials since their play is likely to be appropriately sociable.

2.3 Method

Design

There were two participant groups: TD children and children with ASC. We experimentally manipulated Lego and Topobo toy construction (see *Procedures*) across both groups. Groups were randomly assigned to order of toy conditions.

Participants

Six boys (age 8-11 years, M = 10.6, SD =1.51) with a diagnosis of ASC confirmed by paediatric assessment were recruited from a special unit for ASC in southeast England. Six TD children (age 7-9 years, M= 8.16, SD = 0.752, 1 girl, 5 boys, in school years 5-7) from a mainstream school in southeast England also participated. Children were chronologically age-matched with a two-year lag to account for developmental delay (see Rowland & Schweigert, 2009). The children with ASC were selected by teachers based on their interest in technology, challenges with reciprocal cooperation and group work, and educational targets to increase collaboration with other students. Parent and child consent was obtained for all participants. Children were grouped by teachers in threes (see Figure 1) as other work suggests this group size works well for encouraging and studying collaboration (e.g. Harris et al., 2009)

National Curriculum Speaking and Listening (S&L) assessment levels were used to indicate baseline ability (Qualifications, Curriculum, & Authority, 1999). Levels ranged from 1a to 4c (ASC) and from 3c to 3b (TD children). The overall mean S&L was 3c, appropriate to the 3-4 year age group (age 7 and 8). The mean S&L score of the ASC group was lower (2B) and more variable and is equivalent to age 6. The TD group mean (3B) is equivalent to age 8. These scores are not psychometric assessments rather they are educational levels of attainment meant to provide some basic information on the children's competence.

Apparatus

Sessions were video-recorded in a separate room of the school, with children seated in groups of three at a $1m^2$ table. Topobo assembly materials consisted of connectors, one active module, connector rods, a pair of pliers, for the removal connector rods, and instructional photos of assembled and unassembled Topobo creatures (see Figure 2 for an example). Lego materials consisted of pieces for a 20-unit model of a car and similar photo instructions.

Procedure

All children involved in the study were familiar with the experimenter. Both groups were informally exposed to Topobo for approximately two hours in total over a period of two weeks before the experiment. This initial exposure time was suggested by the inventors of Topobo in an effort to offset the familiarity children might have with Lego.

Children were told, “I am going to give you a plan of a (creature/model) you can make with (Topobo/LEGO). I would like you to make it together.” After making the model, children were asked to “make your (creature/model) move the length of a ruler” and finally “to make another (creature/model) of your own choosing, and… make a little story with those (characters/models).” All children also participated in a play session with unrestricted materials, but this data is not presented here as it is beyond the scope of the current study.

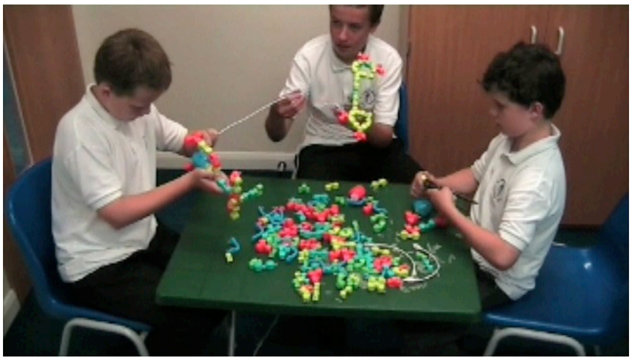


Figure 1. Children with ASC playing with Topobo during experiment

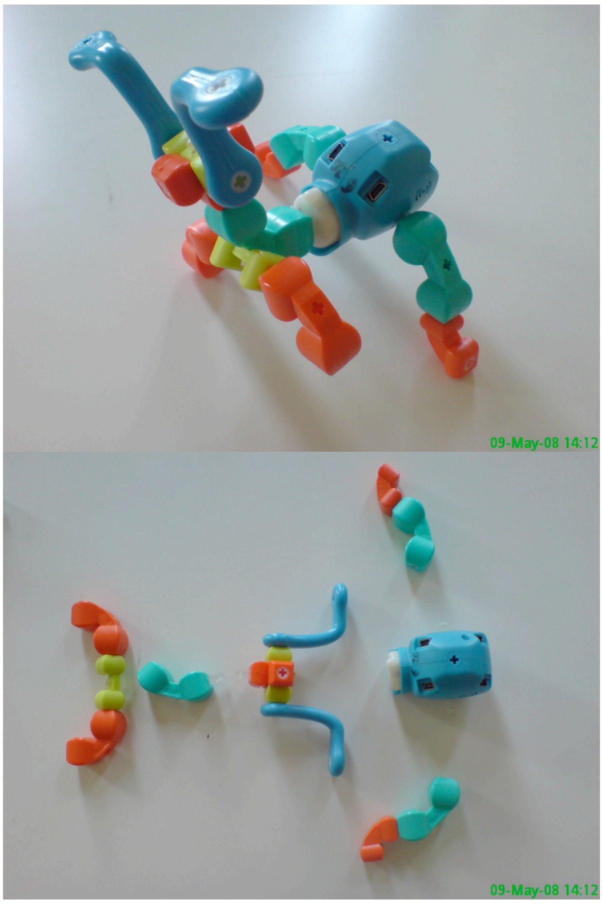


Figure 2. An example of an assembled and unassembled Topobo creature. Photos such as these were provided as assembly instructions for Topobo and Lego

Coding

Videotapes were coded with Mangold Interact software, using a coding scheme modified from Parten (1932), and shown in Table 2. This coding schema was modified to accommodate children with ASC, for example, we added a 'repetitive behaviour' code (e.g see Jordan, 2001). The coding scheme provides a descriptive account of play patterns suitable for both groups of children. Inter-rater reliability on the coding scheme was assessed by two trained coders analysing six randomly selected 10-minute sections, totaling approximately 30% of collected video which is above the normal 10% specified for video coding (e.g. Haidet, Tate, Divirgilio-Thomas, Kolanowski, & Happ, 2009). Inter-rater reliability yielded a kappa of .78.

Table 2. Coding Scheme

Play State (Code)	Definition
Co-operative	Student works with another person by turn-taking or discussing play outcomes when tasks are distributed. Individual works together with somebody, e.g., hands on something at same time or discussing outcome together.
Associative	Borrowing and loaning of play material – no division of labour and no organization. Individual acts as s/he wishes. Individual may act with another.
Parallel	Individual chooses to work alongside another participant but does not influence or modify other people's work, and plays beside rather than with.
Onlooker	Participant is watching what the other individuals within the group are doing but does not actively take part.
Solitary	Participant is taking part in the task but is working alone and individually rather than with others.
Disengagement	Participant is not attending to the task or other individuals within the group.
Repetitive	Odd and repetitive behaviour typical of children with ASC. For example, a child with autism may repeatedly play or manipulate an object in the same way over an extended period. This action may not make sense in terms

of the object, such as repeatedly looking closely at a coloured pencil.

2.4 Results

The total duration of each type of play state was compared using Wilcoxon two-tailed tests to compare differences between Topobo and Lego in each participant group. We also conducted descriptive analyses on play state sequences in each condition.

Overall Topobo produced more cooperative play than Lego, ($Z = 2.82$, $p < .005$), more onlooker behaviour ($Z = 1.961$, $p < .05$) and less solitary play than Lego ($Z = -2.201$, $p < .05$). More parallel occurred with Topobo than Lego ($Z = -2.032$, $p < .05$).

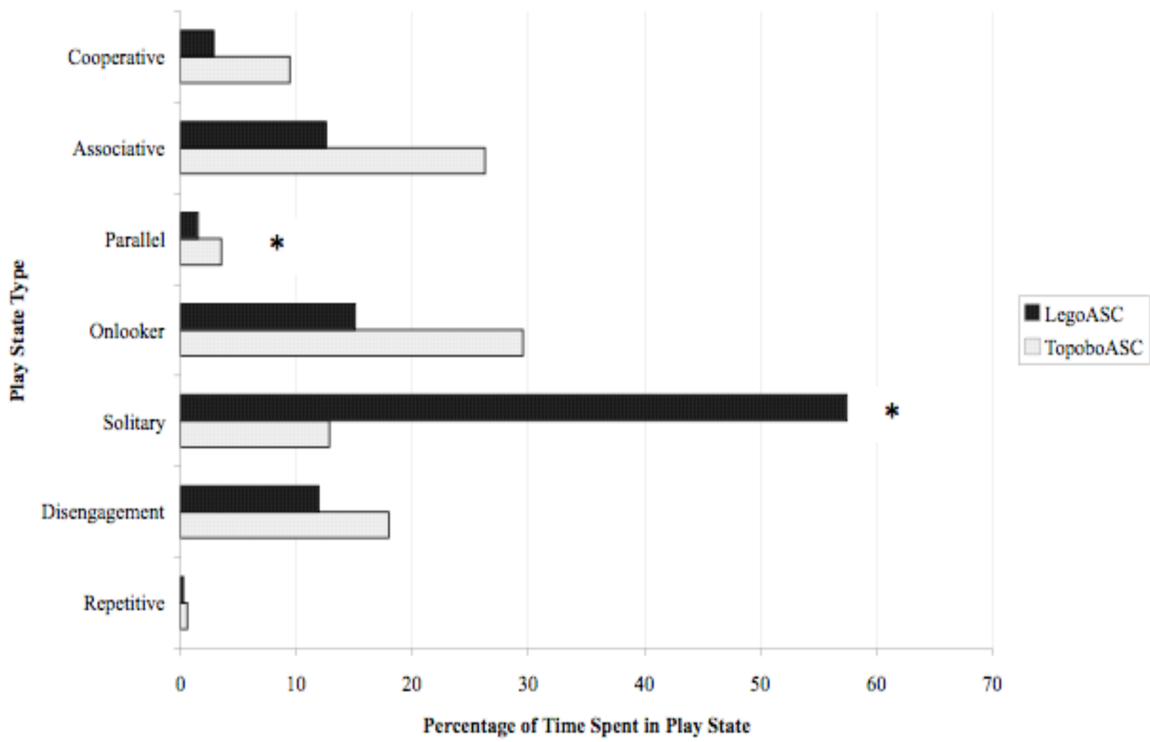


Figure 3. Play state percentage duration for ASC Children in Lego and Topobo conditions

Social interaction with Lego and Topobo for ASC group

Figure 3 shows the durations of each play state as a percentage of total session time for Topobo and Lego in children with ASC. Compared to Lego, Topobo produced more parallel play ($Z = 2.34$, $p < .05$), and less solitary play ($Z = -2.667$, $p < .01$). There were no significant differences in associative, cooperative, onlooker, disengagement, and repetitive behaviors.

Social Interaction with Lego and Topobo for TD group

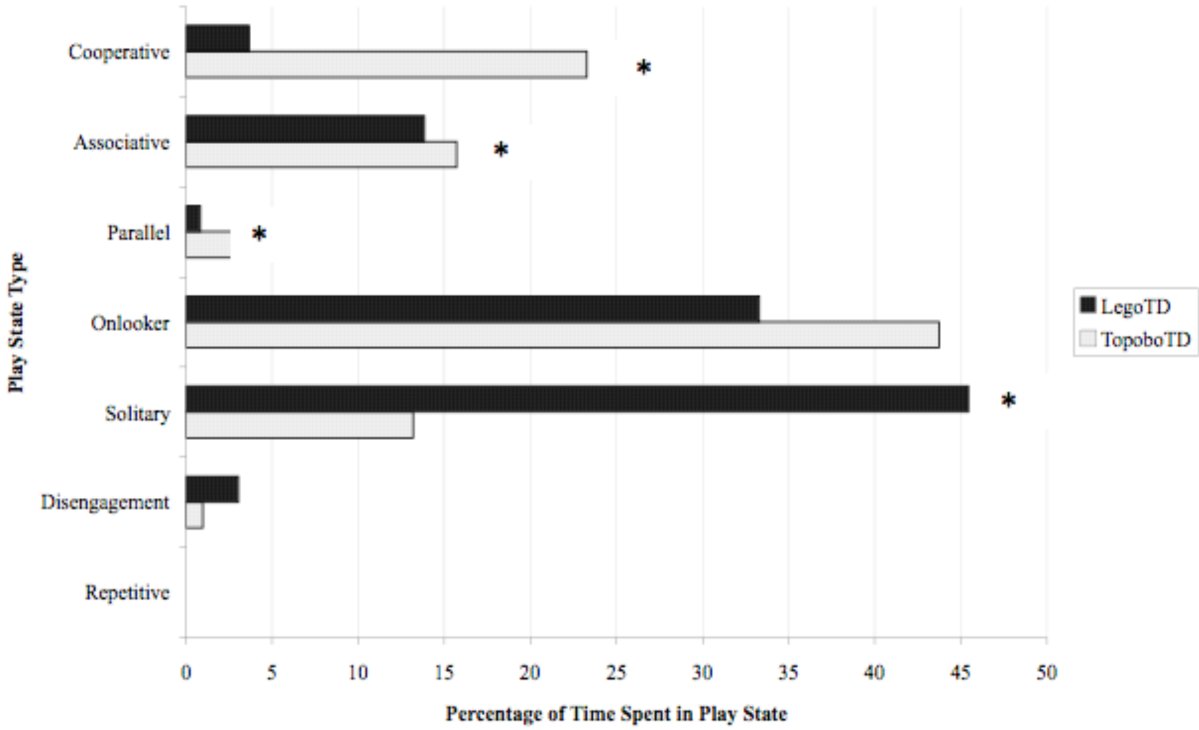


Figure 4. Play state percentage duration for TD children in Lego and Topobo conditions

Play states for the two sets of materials in TD children are shown in Figure 4. There was significantly more cooperative ($Z = -2.201$, $p < .05$), associative play ($Z = -2.201$, $p < .05$), and parallel ($Z = -2.201$, $p < .05$), and less solitary play ($Z = -$

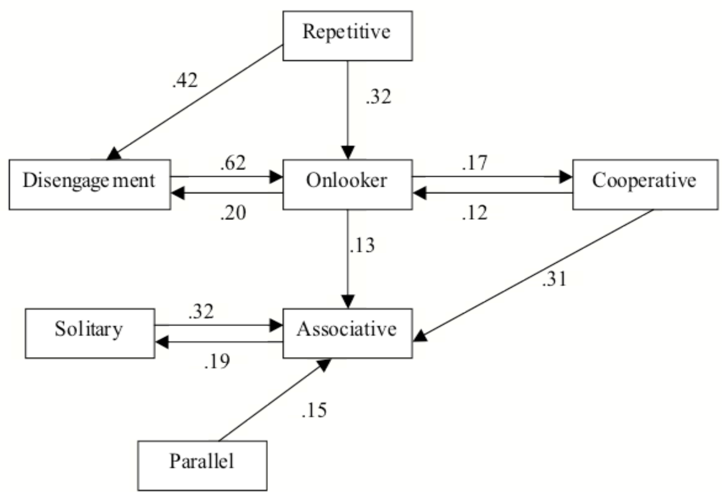
2.824, $p < .05$) with Topobo than Lego. There were no significant differences in onlooker, disengagement, and repetitive behavior.

Play sequences

In an attempt to understand processes of children's interaction with play materials, we also studied sequential patterns of play in each group using contingency analysis. In this context, a contingency analysis provides the raw frequency of one play state following another. To assess the likelihood of one state occurring after another, raw data was converted to a D'Mello score (D'Mello, Taylor, & Graesser, 2007). This statistic is similar to Cohen's K and shows the probability that movement from one state to another given the probability of the previous state will occur when compared to a baseline frequency of a particular play state (Rodrigo et al., 2008). For example, a +0.8 score of A-B transition is equivalent to an 80% likelihood that play state B will follow play state A. We adopted a 10% (0.1) cut off point to determine meaningful sequences of play patterns so that positive interactions were reported.

Topobo/Lego in ASC

(a) Topobo



(b) Lego

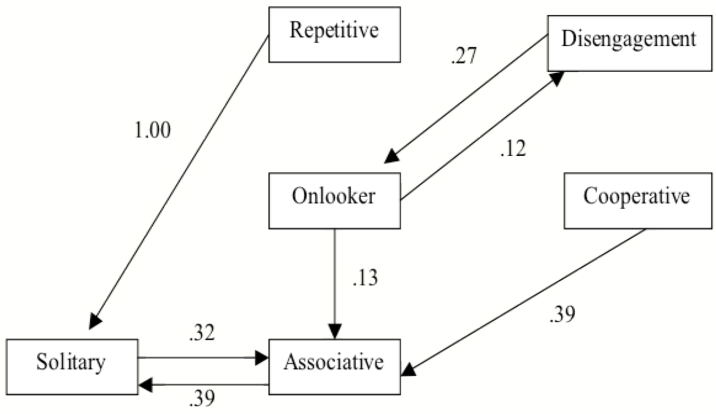


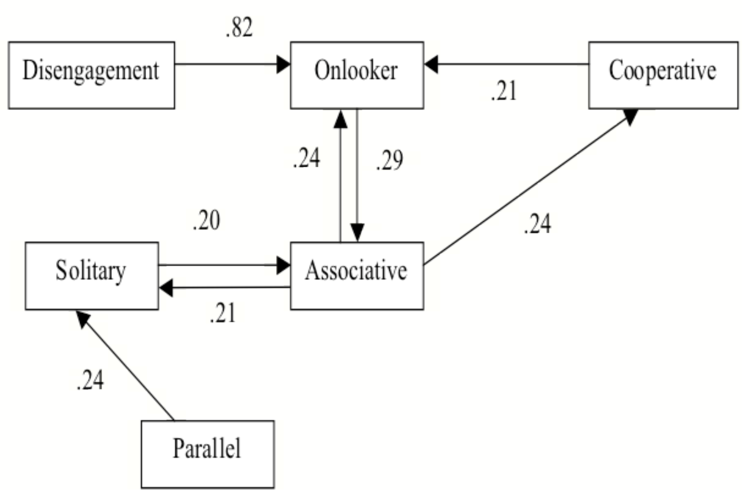
Figure 5. Sequences of play for ASC children using (a) Topobo and (b) Lego

Figures 5 and 6 show all transitions exceeding 10% between play states for Topobo and Lego in the ASC and TD groups, respectively. Transition values are shown next to each arrow.

As indicated in Figures 5 and 6, our results show a bidirectional loop between solitary and associative play regardless of play material in both participant groups. A similar relationship was found between onlooker and disengagement behavior in the ASC group, but not in the TD group where disengagement only precedes onlooker behavior. With the exception of directionality between cooperative and associative play, sequences of play were found to be very similar regardless of play materials in TD children, while play materials seemed to make more of a difference in the ASC group. In particular, the ASC group seemed to function differently according to play material in that cooperative play, despite being infrequent, tended to lead only to associative play in the Lego condition. In contrast, with Topobo, cooperative play led to onlooker states, and then through its link to associative play, back to cooperative play. Solitary play was more common in the ASC group with Lego than Topobo. This form of play seemed to result in something of a social ‘dead-end,’ wherein associative play tended to lead back to solitary play. In contrast, solitary behaviour leads to associative and cooperative play in the ASC group when using Topobo. Repetitive behaviour was quite infrequent in both ASC and TD groups, however, it seemed to function differently between the two materials: for Lego, it always led to solitary play, but with Topobo it lead to onlooker and disengaged behaviour, and from there to other play states.

There appear to be some core similarities in the way the two groups of children play. Onlooker and associative play occurs for both Lego and Topobo. However, the cycle between onlooker and associative play states was only evident in the TD group. In the ASC group, play cycled between solitary and associative, and onlooker and disengaged states. Also, unsurprisingly, only the ASC group showed repetitive behaviour.

(a) Topobo



(b) Lego

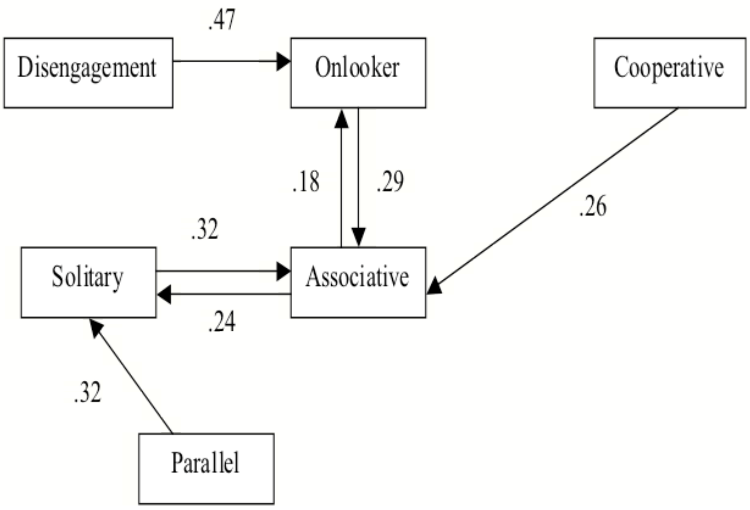


Figure 6. Sequences of play for TD children using (a) Topobo and (b) Lego

There were, however, some consistent differences associated with play materials in both groups. Associative and solitary play appears to function as a bidirectional loop when interacting with Lego. Further, with Lego there is little likelihood that a child's cooperative play will lead to onlooker play; cooperative play only ever seemed to lead to associative play. Taken together, Topobo appears to provide more opportunities for children, regardless of whether they are TD or have ASC, to move into more interactive play states. For example, higher occurrences of disengaged play leads to onlooker play, and associative play leads to cooperative play with Topobo in both groups.

2.5 Discussion and Conclusion

Similar to LeGoff's (2004) findings, we found that children with ASC show some degree of social interaction when playing with Lego. However, relative to Lego, we found greater parallel play, and less solitary play when children with ASC used Topobo. Interestingly, some similar but less marked effects were observed in the TD group who showed more cooperative, solitary and parallel play with Topobo than with Lego.

Our common play sequence findings suggest that playing with Topobo offers more opportunities for social interaction in children with ASC than Lego. Considering the sequence data as a whole, the patterns observed also suggest more pathways to social forms of play when children interact with Topobo than Lego. Topobo seems to offer children with ASC more potential for interactive behaviours such as cooperative and associative play states, whilst lessening solitary and disengaged behaviour.

These findings suggest that embedding toys with programmable digital technology may support more pathways to social interaction. Children manipulate, adjust, and turn active sections of Topobo when programming, enabling a physical action to become translated into a digital one, which can be a compelling addition to a play set (Marshall, Rogers, & Hornecker, 2007). In comparison to more traditional construction systems such as Lego, Topobo also possesses more degrees of freedom in the way pieces of the toy can be turned and manipulated. As a result, there are possibly more ‘entry points’ for engaging and continuing play with Topobo than with other toys (Hornecker & Buur, 2006).

The current study is clearly limited given the very small sample size and heterogeneous nature of ASC. However, despite these limitations, analysis of play sequences suggests Topobo encourages more socially interactive play relative to Lego. It is unclear whether the results reported here would generalize to other play materials and conditions. Nevertheless, as cited elsewhere (Rowland & Schweigert, 2009), when children with ASC are engaged in a task in a more structured setting, levels of symbolic and functional play increase. Tangible devices continue to develop, and integrating them with newer devices such as tabletops may provide novel and effective play-based interventions for children with ASC. Such multi-dimensional ‘ecology of devices’ (Rogers, 2006) could extend the possibilities for tactile or proximal engagement if that is a preferred choice for the user (Rogers, 2006; E. Williams et al., 1999). Additionally, in terms of designing newer technologies, it seems likely that incorporating digital effects that extend well from objects (e.g., a toy soldier that can talk), can be used in goal-oriented ways, and give users the ability to customize play materials and actions may be especially promising.

Future work could follow LeGoff’s (2004) work with Topobo as a programme of sustained therapeutic intervention for children with ASC. Research could also investigate digital versus non-tangible toys to isolate what in particular makes TUIs produce differential play patterns in this population. Contingency - the ability to predict what will occur as a result of an action in the future – may be an especially important toy feature for sustaining play in children with ASC, and should be studied further. Finally, future research might also consider the affects that integrated play environments have on play patterns in children with ASC when interacting with TUIs in the presence of TD children.

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A shorter version of this paper has appeared as: Farr, W., Yuill., Hinske, S. *(2010)* In My Own Words: Configuration of Tangibles, the Augmented Knights Castle and Social Interaction in Autism, *IDC'10 Proceedings of the 9th International Conference on Interaction Design and Children*, Barcelona, Spain. ACM press: New York, 30 -34.

I was the sole investigator for this work. Dr. N. Yuill was my supervisor. Dr. S. Hinske built the Augmented Knights Castle.

3 Article II – An Augmented Toy and Social Interaction in Children with Autism

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3.1 Abstract

An Augmented Knights Castle (AKC) play set was adapted so that children with autism configured programmable elements. This is compared with a non-configurable AKC. When the system is configurable, and when it is switched on, less solitary play and more cooperative play occur. Digital toys, and their configurability are key factors in design for children with autism allowing greater individual control and more socially-oriented behaviour. We suggest that tangibles provide a safety net for encouraging social interaction as they allow for a broad range of interaction styles.

*Figure 1***.** The Augmented Knights Castle play set (Lampe & Hinske, 2007)

3.2 Introduction

Digital technology for individuals with special needs plays an important supporting role (e.g. Baron-Cohen, 1997; Baron-Cohen et al., 2007). For children with autism technology can be a 'compensatory mechanism', that is, a psychological tool that can "transform…natural abilities into higher metal functions…" (Vygotsky & Luria, 1994, p. 344). As children with autism experience a divergence between their natural and social developmental paths, equipment, tools, and objects highlight social and interaction use and offer ways of mediating and improving development (Kozulin & Gindis, 2007).

Technology offers compensatory mechanisms that can support children in their abstract reasoning, logical memory, voluntary attention, and goal-directed behaviour (Kozulin & Gindis, 2007). Interactive technologies in particular can play a further role in the development of social skills by socially mediating interaction and aiding peer-to-peer relations and collaboration (Marti, Pollini, Rullo, Giusti, & Grönvall, 2009).

Digital technology often appeals to individuals with autism, and can help redress some social deficits (e.g. see Baron-Cohen et al., 2007). Computers allow children with autism a chance to encounter tools and symbols that can support social interactions, help direct behaviour, and help motivation within activities. One of the reasons why this may be the case is that computers contrast with human behaviour as they do not react to the odd behaviour typically found in autism (Powell, 1995). The stress and unpredictability caused by social interaction is largely removed during computer interaction (Murray, 1997). Tangible user interfaces (TUIs), and in particular augmented toys (ATs) – which are a branch of computer science – may be beneficial as manipulation presents the individual with an opportunity to interact directly with data.

Here we investigate the hypothesis that a digitally-augmented playset that can be configured by children with autism will increase social interaction. We also look at the system when digital elements are switched off to see if differences in play are due to augmentation. Augmented toys allow children to trigger and configure digital content (Hinske et al., 2009). The AT in this current study allows toy figures that speak to be played with, and also allows these figures to be programmed with children's own voices. The Augmented Knights Castle playset (Lampe & Hinske, 2007) was used to see whether configuration of the AKC increased children's social engagement when children with autism controlled feedback and could program where, when, and what RFID figures said. If the configurable element is important, there should also be a difference between the augmentation and non-augmentation. Children's play should be enhanced with the augmented version.

In the following sections we look at the field of tangible user interfaces, and object interaction as an impairment in autism. This dual look at TUIs from the field of Human Computer Interaction (HCI) and psychology sets up our reasoning behind looking at an augmented toy as a means of promoting social interaction in children with autism. We then turn to a description of the system used and our method of investigation, present the results and discuss our findings.

3.2.1 Augmenting toys and tangible user interfaces

Tangible user interfaces (TUIs) are objects with embedded digital technology (Ishii & Ullmer, 1997). Augmented toys (ATs) are a subset of TUIs and are toys that are enhanced with digital technology (e.g. see Hinske et al., 2009; Hinske et al., 2008). TUIs are graspable, and allow users the opportunity to directly manipulate data input through objects (Ishii & Ullmer, 1997). The possibility of manipulating objects through digital and physical actions introduces a novel element into user action (Ullmer & Ishii, 2001). A variety of feedback mechanisms can occur such as visual engagement, kinesthetic interaction, or audio and haptic feedback (Hinske et al., 2008; Lampe & Hinske, 2007). Tangible user interfaces allow for a variety of 'mappings' between physical and digital space (e.g. Shaer et al., 2004). In this case the impaired ability to predict change in human behaviour in autism relates directly to behavioural mapping, or the cause and effect of a tangible (Antle, 2007; von Hofsten, Uhlig, Adell, & Kochukova, 2009).

A tangible interface for children with autism may also promote co-located cooperative work as shown with work using Topobo (see Farr, Yuill, & Raffle, 2010; Ullmer & Ishii, 2001). TUIs encourage reflection and discussion about the objects as they are used (Hornecker & Buur, 2006). Interaction with tangibles allows other people to be identified as intentional agents, especially with the addition of goals such as configuration (Passerino & Santarosa, 2008). Digital and physical effects in TUIs can often be recorded, and this record of change has been shown to help individuals focus on activities (Hornecker & Buur, 2006). For the TUI used here – described below –

programming is by demonstration, and control of input/output is user controlled (Edge & Blackwell, 2006). This is often referred to as ‘end-user’ programming and is a system method where building, constructing and playback of programmed elements occur via the construction or interaction with an object. The user programs the interface during interaction. Users are given the “[a]bility to redefine what actions are used at what time” (Edge & Blackwell, 2006). This extension of being able to manipulate TUIs means the manipulation itself directly becomes the programming. This system factor enables the user to control when and how feedback on programmed aspects occurs.

Multiple entry points are therefore present in an activity with a TUI as they are made by physical manipulation, manipulation of data, observation of digital effects, listening, talking, and playback of digital features. This clear functionality allows children to observe cause and effect, which can be both motivating and help reinforce attention to objects through tangible interaction (Fernaeus & Tholander, 2006). Further, meaningful manipulation and control of digital information enable multiple and subjective interpretation to occur as TUIs become shareable resources for action (Fernaeus et al., 2008). These multiple entry points, both data- and socially-oriented could be beneficial for children with autism (Antle, 2007; Marshall et al., 2003).

3.2.2 Object interaction and autism

Autistic children are additionally affected not only by social difficulties but are impaired in their understanding of object interaction (Powell, 1995; Tager-Flusberg & Anderson, 1991; E. Williams et al., 1999). Therefore predictable cause and effect in tangible systems has the potential to support person-to-object-to-person interaction.

Most object use for children occurs during play. As play is an important indicator of the quality of children’s lives, tangibles and augmented toys can be used to extend object function and appearance, and can provide a high-quality experience, whilst minimizing confusion, with predictable digital effects (Antle, 2007; Marti et al., 2009; Tager-Flusberg & Anderson, 1991). Objects can provide fixed or flexible cues, and those that require little cognitive negotiation become easier to use (Norman, 1988). Objects, when created in an appropriate manner, become tools, moving from being objects which are simply present to useful objects, so much so that they almost 'disappear' as they become unconsciously used thus moving the object beyond the realm of simple tool to psychological tool (Heidegger, 1962).

Toys are play objects that are familiar, and with the addition of digital technology can provide high-quality materials for play. For example, Topobo (Raffle et al., 2004) when linked together, forms objects that look like animals and insects, and when programmed can play back movement. The digital playback in Topobo extends logically from its functional use. If a creature is constructed then programming enables the creature to move. When Topobo is used in a structured play setting, children with autism are significantly more likely to play with others in parallel, and less likely to play in a solitary manner (Farr, Yuill, & Raffle, 2010).

Children with autism experience difficulties in understanding how to use objects flexibly in social situations (E. Williams et al., 1999). Object use is often a social process which children with autism find difficult (E. Williams et al., 1999). Functional or sensori-motor use of an object is easier for a child with autism to understand than that of symbolic use (Rowland & Schweigert, 2009). Symbolic use of objects occurs when children play and develop imaginary situations (Leontyev, 1981). Playing with objects is repetitive and often inflexible with low levels of exploratory behaviour (Jordan & Powell, 1995). Proximal senses such as touch with the hand or mouth are favoured to gather information as opposed to auditory or visual means (E. Williams, 2003). Without a clear understanding of the functional use of an object, features and aspects often become fixated upon, (von Hofsten et al., 2009).

For children with autism, frequency and quality of object play depend on the type of object and the structure of the situation (Tiegerman & Primavera, 1981; E. Williams, 2003). Pairing children with severe autism with an adult playing with an object in parallel increases interaction during positive imitation (Tiegerman & Primavera, 1981). Greater frequency and duration of play also occurs depending on the play material and structure employed (Tiegerman & Primavera, 1981). If object interaction changes with situation and context, especially if objects are similar and are placed within an environment that promotes play in parallel, tangible interaction should promote social interaction in children with autism.

To summarise this section:

- An ability to predict the flexible way in which objects can be used is impaired in autism
- The structure, presentation and type of object interaction can positively influence interaction in children with autism by reducing solitary behaviour and encouraging parallel play
- Tangible systems give feedback that supports an understanding of cause and effect in autism
- Technology can provide compensatory mechanisms for children with autism, whilst minimising confusion during social interaction

3.2.3 The Augmented Knights Castle

The Augmented Knights Castle (AKC) is an augmented toy environment consisting of three base units that are wirelessly connected to a system server. An earlier version consisted of one centralized play set (Lampe & Hinske, 2007). The base units are equipped with radio frequency identification (RFID) readers and antennas, which allow location and identification of individual Playmobil figures. The figures have RFID tags attached to the base of the feet, inside the head and into the back section of the figure. As the tags used in this experiment were very small (i.e., between 0.9 and 1.5cm in diameter), the tags could almost be invisibly integrated.

Figure 2. The Augmented Knights Castle showing dragon tower, castle, and magic pool

Figure 3. AKC internal RFID technology, antennae (right hand side), multiplexers, and surround sound inside main housing (Lampe & Hinske, 2007; Hinkse, 2009)

When figures are placed into one of three base units (a castle, a dragon tower, and a magic pond play area – see Figure 1), antennas detect RFID tags and readers then relay the tag-specific information of that figure back to the laptop. Pre-recorded sounds are then played. A read cycle checking for figures in range occurs almost in real time.

Investigations with typically developing children have already been extensively conducted with the AKC (Hinske, 2009; Hinske et al., 2009) and found positive results for the AKC when compared to a Knights Castle playset in children's play when content can be chosen. The importance of controlling content for children is well documented (Papert, 1976, 1980), but is especially important for children with autism as a powerful method for motivation and learning (Keay-Bright, 2008; Murray, 1997; Panyan, 1984). A variety of iterations were attempted during the creation of the AKC (Hinske, 2009) but allowing users with autism the chance to make content offers exciting potential for tangibles user interfaces.

3.3 Method

Participants

A sample of children (N=12) with a medical diagnosis of autism (mean age=11.2) from a special needs school for moderate learning difficulties were used. Children participated in groups of three. Three groups were made up of boys (two groups aged 12-13, and one group aged 9-10), and one group of year 5 girls (aged 9-10). Consent was obtained from children, parents and the school.

The child's severity of autism was screened through the use of the Childhood Autism Rating Scale (Schopler, Reichler, DeVellis, & Daly, 1980). The CARS rating scale is made up of 15 questions covering questions from children's social skills to object interaction. Scores are compiled through observation and discussion. The child's teacher made the judgement on CARS score. The mean score was 31.04 (SD = 8.87), listed on the scale as moderate autism, but with variance in scores from moderate to severe autism.

Design

A two group (N=12), two condition (configuration, non-configuration), between-subjects design was used (see Figure 4). All groups in session one were presented with the Knights Castle, with the AKC then switched on for five minutes at the end. In session two, two groups entered the configuration condition, while the other two groups were presented with the AKC in non-configurable format. Children in the configuration condition could place figures in a 'magic box' that contained an RFID reader. The reader scanned figures, and the laptop server recognized each figure using RFID tags. The option to speak into a microphone and program each figure's speech was available. The researcher programmed the location where a character would speak, initially from child direction, but children eventually learnt this.

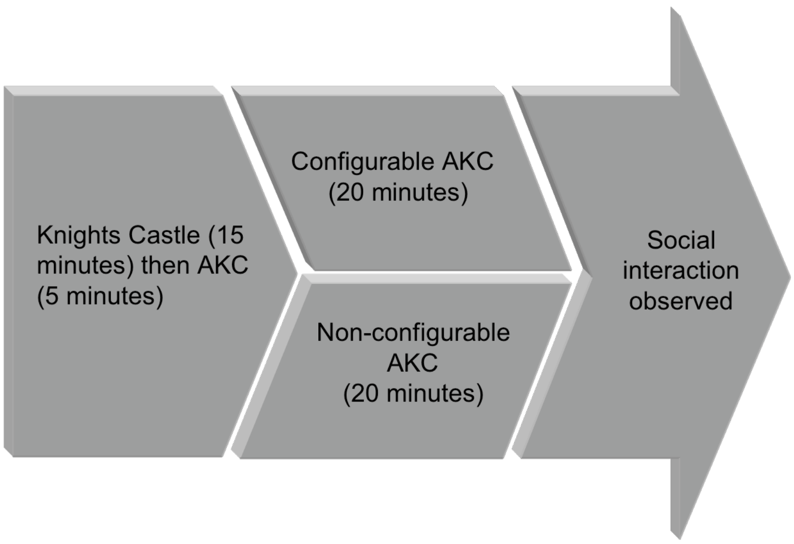

Figure 4. Experimental method

Stimuli and apparatus

Children's play sessions were recorded using a digital video camera. Sessions took place in a room $4m^2$ normally reserved for computer work. Children were given 10 Playmobil™ figures in the configuration condition and 20 Playmobil figures in the non-configuration condition. These numbers were to offset learning time required to configure characters due to observations made during pilot research, otherwise children may have taken more time simply learning how to configure characters. A timer was on display for the children to know how much time was left in their play session.

Procedure

Play sessions were conducted over one week. One day elapsed between each play session. Play sessions were twenty minutes in length. Standardised instructions were given across the two conditions. These were:

Session 1

KC to AKC session: This is a Playmobil set. You can play with it how you like. There is no right or wrong way of playing with the set; it is up to you how you play with it. After 15 minutes the AKC will be switched on: The set says things. Look at this character. If I put him here this happens (demonstrate placing a character in the AKC).

Session 2

Non-configurable AKC condition: You have twenty minutes to play with the set again. Remember, if I put a figure here then this happens (demonstrate figure talking by placing in the AKC). You will have twenty minutes again to play with the AKC.

Configurable AKC condition: You have twenty minutes to play with the set again. Remember, if I put a figure here then this happens (demonstrate figure talking by placing in the AKC). The magic box will let you make characters say different things. I can make it do this (demonstrate by recording a sound and placing in the AKC set). You will have twenty minutes again to play with the AKC.

Coding

Videotapes were coded using Mangold Interact™ software, using a coding scheme shown in Table 1 (modified from Parten, 1932; Robinson, Anderson, Porter, Hart, & Wouden-Miller, 2003). Modifications were made to accommodate children with autism with the inclusion of a code for repetitive behaviour. Children with autism often get caught in a cycle of repeated action that is unrelated to the functional use of an object (e.g see Tiegerman & Primavera, 1981). This coding scheme provides a descriptive account of play suitable for both typical and autistic groups of children in clear play patterns. This coding scheme has been used before (Farr, Yuill, & Raffle, 2010) but was modified to include recent developments and clarification on particular codes such as solitary and parallel behaviour (see Holmes & Procaccino, 2009; Rowland & Schweigert, 2009). Inter-rater reliability yielded a κ of .73 on a coding sample of 33% of all video.

Table 1. Coding Scheme

Play State (Code)	Definition
Co-operative	Subject works with another person by turn-taking, or discussing play outcomes but where tasks are distributed. Individual works together with somebody e.g. hands on something at same time or discussing outcome together

Associative	Borrowing and loaning of play material – no division of labour and no organization: individual acts as he wishes, group play. These actions are usually swift and may include passing, giving, exchanging of objects
Parallel	Child chooses to work alongside another participant but does not influence or modify other person's work. Plays beside rather than with. This may include imitation. The child acts on an object and remains aware of what other individuals are doing in relation to an object
Onlooker	Participant is watching what the other individuals within the group are doing but does not actively take part
Solitary	The child is taking part in the task, or constructing an object but is working alone rather than with others. The child acts on an object alone
Disengagement	Participant is not attending to the task or other individuals within the group
Repetitive	Repetitive, ritualised or odd behaviour typical of children with autism that has no impact on other children; cycle of action with no functional relevance to the object used

3.4 Quantitative results

Quantitative data is now presented on video-coded data. A discussion of methods used for analysis, followed by data comparing children's play states and sequential play patterns for the AKC compared to the Knights Castle is discussed. This is followed by data comparing the configurable with the non-configurable AKC. Lastly, additional data is presented on RFID figure usage.

3.4.1 Autistic Children's play with the AKC

All individual data from analysis was broken down according to play state frequency and duration. All reported data is from the twenty-minute play session, and is raw transitional data for one type of behaviour to another. All interaction figures are for children grouped in threes, each diagram consisting of total scores for four groups (Figures 5 and 6) and two groups (Figures 7 and 8). All children were presented first with the KC switched off, before the AKC was switched on. In the second session children were then allocated to either the configurable or non-configurable condition. Total amounts of raw play by type are not presented, as these do not show clear interaction patterns.

We studied sequential patterns of play in each group using contingency analysis. Contingency analysis provides the raw frequency of one play state following another. To assess likelihood of one state occurring after another, raw data was converted into a D'Mello score (D'Mello et al., 2007). This has been used before with tangibles and children with autism (see Farr, Yuill, & Raffle, 2010). Here an augmented environment broadens the scope of this earlier work. The overall effect of using the D'Mello score is to highlight how children with autism play with tangibles by isolating play patterns. The D'Mello statistic, similar to Cohen's K, shows the probability that movement from one state to another given the probability of a previous state will occur when compared to a baseline frequency of a particular play state (Rodrigo et al., 2008). For example, a +0.8 score of an A-B transition is equivalent to an 80% likelihood that play state B will follow play state A. We adopted a 10% (0.1) cut off point to determine meaningful sequences of play patterns so that positive interactions were reported. Figures 5 to 8 show these results for all conditions. The thickness of the bars linking behavioural states shows the strength of the likelihood of an interaction occurring. Where there is no arrow between the types of behaviour, interaction was not associated and so not included.

3.4.2 Knights Castle compared to Augmented Knights Castle

A Wilcoxon non-parametric test of all durations of behaviour for the AKC showed that solitary behaviour was significantly lower in duration whilst playing with the AKC ($Z = -2.237$, $p = .02$) than with the KC. Frequency of solitary behaviour was also significantly less with the AKC ($Z = -2.197$, $p = .02$) than with the KC. Frequency of onlooker behaviour was more with the KC than with the AKC ($Z = -2.118$, $p = .03$). Comparisons of each social interaction picture (see figures 5 and 6 below) show that more likely transitions of a play state may not indicate quality interaction when compared to varying play states. For example, play breaks down when children cooperate with the Knights Castle as they are likely to move back to solitary behaviour (see Figure 5).

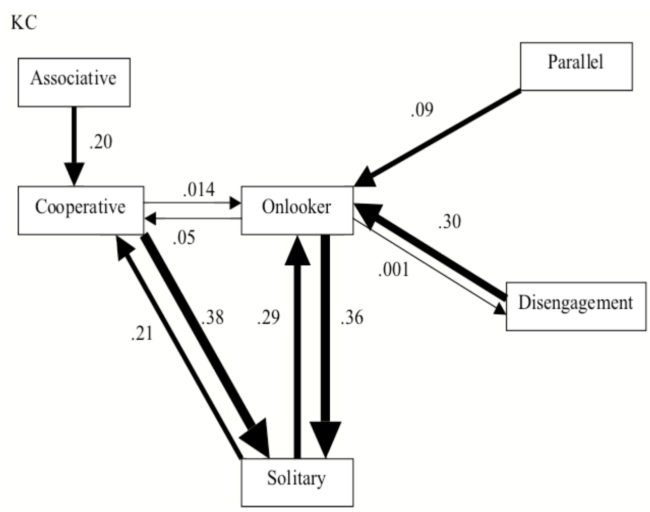

Figure 5. Interaction of children with autism with the Knight's Castle

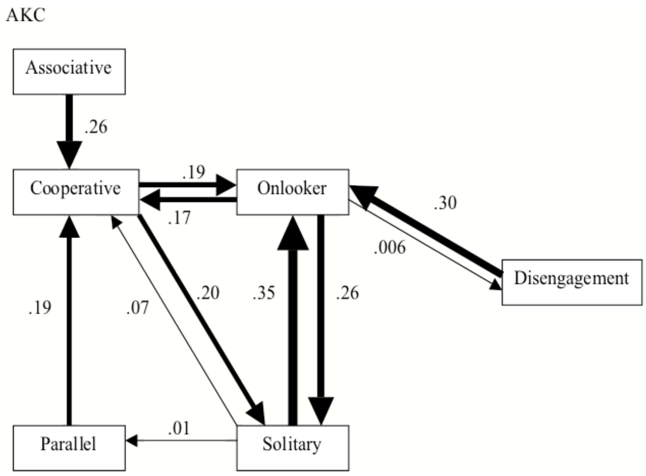

Figure 6. Interaction of children with autism with the Augmented Knight's Castle

In effect, once children are playing cooperatively they move on the whole to solitary play (figures 5). Although children exhibited more overall onlooker behaviour with the KC, the quality of interaction appears to be less than with the AKC (Figure 5). Solitary behaviour with the KC leads back to onlooker or cooperative states but this is without the clear cycle of onlooker to cooperation loop that occurs more readily with the AKC. Parallel play leads to onlooker behaviour with the KC, but to cooperative behaviour with the AKC. When the AKC is switched on, children with autism appear to have more ways in which to get back to playing cooperatively again.

Onlooker behaviour works differently for the AKC and KC; with the KC it can lead to disengagement, cooperation or solitary play. With the AKC onlooker play state leads to disengagement, cooperation and solitary play, but the likelihood of onlooker action leading to cooperation is greater. Children on the whole must go via onlooker behaviour to cooperation. The likelihood of solitary behaviour leading back to onlooker behaviour also appears to be greater with the AKC than the KC.

3.4.3 Configurable compared to non-configurable AKC

AKC data from session 2 was analysed using the coding scheme in relation to the experimental condition of configurable versus non-configurable AKC. A one-tailed

Mann-Whitney two independent samples non-parametric test was used. Significantly less amount of time was spent in solitary behaviour with the configurable AKC (Z = -2.326, p < .01) when compared to the non-configurable AKC. Significantly more time was also spent in cooperative behaviour with the configurable AKC (Z = -2.882, p < .01) in comparison to the non-configurable AKC.

The non-configurable AKC allows for interaction between cooperative and onlooker behaviour (see Figure 7). The strongest interaction is the loop between onlooker and solitary interaction.

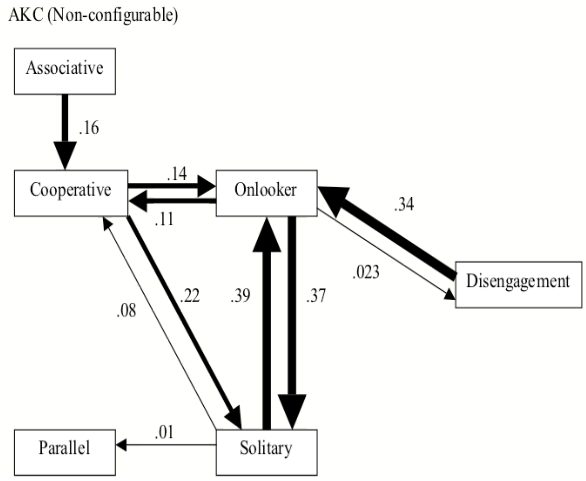

Figure 7. Non-configurable AKC interaction

Disengagement leads positively back to onlooker behaviour, and onlooker behaviour does not lead necessarily to disengaged behaviour. Associative behaviour has a likelihood of leading to cooperation (.16). Solitary behaviour has a likelihood of leading to parallel behaviour (.01).

For the configurable AKC (CAKC) disengaged behaviour is strongly linked to heading back toward onlooker behaviour (see Figure 8). There is a strong cycle for CAKC between cooperation, onlooker and solitary behaviour, but this is stronger for cooperation in the non-configurable condition. The likelihood of cooperative behaviour leading to onlooker behaviour and back accounted for almost half of all potential transitions (.53). Associative behaviour also has a higher likelihood (.31 with CAKC as opposed to .16 with the NCAKC) of leading back to more positive social interaction of cooperation. The more even distribution of interactions in the configurable AKC condition - shown by thinner bars - indicates a greater variety of ways children interacted.

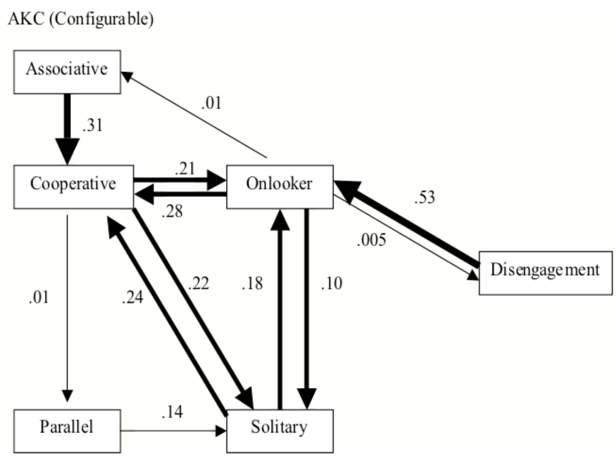

Figure 8. Configurable AKC interaction

3.4.4 RFID figures

Data was additionally collated on the number of times children used RFID figures to speak. An RFID figure was deemed to have ‘spoken’ when a child picked up a character and placed the character in a part of the AKC, and the AKC responded by playing a pre-recorded sound. Examples of what characters said include dragons roaring, or the knight saying “I need a weapon, where is my lance?”. When comparing the configurable with the non-configurable AKC the frequency characters were used to produce speech was 78 (NCAKC) compared to 229 (CAKC). The number of times the characters were used when the play set was configurable suggests that the ability to be able to configure made play with figures happen more often.

3.4.5 Object interaction, ability and children's play

An interesting significant effect was found for CARS scores between the CAKC and NCAKC conditions. This may have been a possible hidden variable that may explain differences in the quality and quantity of children's play. A significant result showed for children's 'Object Use' ($Z = -2.351$, $p < .02$, non-configurable-configurable), so children in the non-configurable condition were more likely to show as stated on question 5 "mildly inappropriate interest in objects". If this is the case children's play behaviour may be explained by object ability, and not the configuration of the AKC. The data for this question was analysed further using a one-way ANOVA and showed the same significant effect ($F = (1,10)$ 9,474, $p < .01$) but when CARS 5 was included as a covariate, this was no longer significant for children's play states in either condition (e.g. solitary play between conditions $F = (1,12)$ .740; $p = .41$). A multivariate analysis confirmed this ($F = .440$; $p = .77$). Whilst it appeared that children's ability to play with objects impacted on play behaviour, when this was controlled for, it was not the case here. Whilst not impacting on this data, this is an interesting aspect of autistic children's interaction with the AKC, in that initial object ability may point toward children's initial abilities with tangibles.

Although the ability to use an object had no significant impact on either group, the difference in use of the RFID figures between groups is large. In the configurable condition children interacted with figures more often.

Overall the CAKC and the AKC:

- Seem to offer multiple entry points to play states (i.e. a wider variety of states for interaction)
- Led to greater character use, but it is unclear if this is symbolic or functional use
- Allowed for more opportunities for play to become more cooperative

3.5 Qualitative results

Here we discuss four key qualitative findings with examples taken from transcripts of children's play. The four areas are organized as user content, learning phase, behaviour oriented to other children and system responsiveness. Findings here focus on key discoveries during the configured play sessions that captured interaction features found to be important during children's play.

3.5.1 User content

The opportunity to input own content onto the AKC provided children with a powerful interactive tool. When the system worked as intended with immediate user content, this prompted more interaction within groups as children then looked to their peers for approval and discussion about the effect. This was especially so in the configurable condition where users discussed what to programme onto characters. In the following example, children are reaching the point where they understand how the system works and so start to think about the type and placement of user content as a group with little prompting. A dragon has just been programmed with user content:

[00:05:18.16] Child 1 “Arrghh” [Recording dragon on AKC]

[00:05:21.18] Adult 1: That was it yeah?

[00:05:21.18] Child 1:Yeah

[00:05:21.18] Adult 1: Where's it going to be? [Referring to where the dragon content is to be played]

[00:05:24.10] Child 1: At the dragon's tower [Nods toward tower]

[00:05:25.20] Child 3: [Interrupts] Inside it or..? [Gestures to place in the dragon tower]

[00:05:27.29] Child 2: [Interrupts] He wants [Referring to Child 1] to just play with the dragon [Dragon figure growls]

[00:05:32.24] Child 1: [Tries out dragon, but this time dragon does not work]

[00:05:32.24] Adult 1: Oh it did not work we're going to have to do it again

[00:05:36.19] Child 1:I don't mind doing it [Referring to programming the figure by himself with the laptop and the magic box]

[00:05:36.19] Child 3: I'll do it [Walks up to magic box to join in] Can I try again? [Referring to wanting to program another figure].

Children's motivation with the AKC was equally influenced when they could hear or show their own content (see extract in section 3.5.4). The impact of using and making content produced joy and excitement amongst users far more than preconfigured sounds. However, characters in the NCAKC were more likely to be seamlessly played with in the castle setting, which led to more symbolic play where children played imaginatively and made up stories of characters interacting. With configuration, children were more interested in programming as part of play. Configuration may have reduced children's symbolic play, as children diverted imaginative activities to establishing user content.

3.5.2 Learning phase

Children learnt to use the AKC at the end of session 1, and in session 2 this was either extended or added to in the form of the configured or non-configured AKC. Results found during the second play sessions may be due to the effect of learning to configure. Variance in quantitative interaction may equally have grown or lessened if there had been a third session. Yet children's attempts to configure were dependent on learning the system. In this example the child is being taught how to configure:

[00:00:05.10] Adult 1: You got one? Right so if you put that in the box. Now… can you see that there? It's the black knight

[00:00:23.09] Child 1: Yeah

[00:00:21.09] Adult 1: Now what we are going to do is we are going to program the knight to say something. What do you want the knight to say? When I say start you speak into there (points to microphone) something that you want the knight to say. Okay? Go.

[00:00:47.14] Child 2: (Laughs then says) "Die all of you"

[00:00:50.14] Adult 1: Okay? So this is what it will sound like. Listen? (Plays back "Die all of you")

[00:00:52.24] Child 1: (Laughs)

[00:00:54.09] Adult 1: I am going to store that. Now where do you want that to actually happen?

[00:01:10.25] Child 2: (Puts toy in front of the cave)

Toward the end of sessions children needed far less guidance:

[00:17:51.15] Adult 1: Where is this going to happen? Where is the laugh going to happen? (The dragon had been programmed with user content)

[00:18:02.12] Child 3: Up there up there (points to top of dragon tower)

[00:18:02.12] Adult 1: On top of the dragon tower

Even though children were learning to configure in session 2, interaction was not affected. Children were able to learn how to configure within the first five minutes of the play session. The learning phase was steep but quickly achieved.

3.5.3 Behaviour oriented to other children

Children often took on roles whilst playing with either the CAKC or NAKC, and often these roles were interchangeable. With the CAKC if one child lost interest in play, another child would try and encourage that child to become involved again by taking and showing them a Playmobil character and/or demonstrating an effect with the AKC, possibly due to user content driving play. Roles also extended as far as to who led play if children were inventing a story. This storyteller role was also interchangeable. With the AKC demonstration of programmed effects became a key part of the configured AKC as showing and sharing caused laughter and amusement as children tried to install exciting and interesting effects within figures. This demonstration often led to that child being the focus of interaction around the AKC. With the non-configurable AKC this type of role-changing occurred less, so children were more likely to assert themselves in the configured condition. Here in the CAKC child 3 draws the attention of child 1 as he is programming content onto the red dragon, child 2 becomes involved at the end as he tries to gain the other children’s attention by making the sound of an animal, which he subsequently programs on to the AKC:

[00:16:59.09] Adult 1: Okay what are we going to have said. What's it going to be: "I'm the big red dragon"

[00:17:20.06] Child 3: No no it's "ha ha hah"

[00:17:20.06] Child 1: No no it's " Mwah hah hah"

[00:17:23.09] Adult 1: Ready

[00:17:23.09] Child 3: Ready

[00:17:23.09] Adult 1: Okay. Steady

[00:17:25.08] Child 3: Wait wait

[00:17:27.29] Adult 1: Do you know what you are saying? What is it you are saying?

[00:17:29.29] Child 3: Mwah hah hah "

[00:17:30.25] Adult 1: Yeah okay 1,2,3

[00:17:34.26] Child 3: Mwah hah hah

With the non-configured AKC it was often less about demonstrating effects than about placing the effects within a story scenario. If anything the configured aspect of demonstrating programmed effects shows that children needed time to investigate the novel elements of the technology.

3.5.4 System responsiveness

Feedback of the AKC occurs on a 2.5-second cycle that has been reported elsewhere (Hinske, 2009). Whilst this is as fast as possible within the current design, there is a time lag between children placing figures and receiving feedback. Any lengthy lapse in feedback always produced problems for children in that they were disappointed if the effect was slow. They were also equally disappointed if the feedback given was not what they had individually programmed. Figures programmed are given a probability of playing from 1 to 10. In the configured condition all programmed characters were given a probability of 10 but sometimes preconfigured sounds still played. This produced confusion, but not frustration. When sounds were played children's reactions varied from laughing, to high-fives, to wanting to do more programming, as in this example from session 2 of the configurable condition:

[00:02:46.15] Child 1: Do I have to say it first?

[00:02:49.03] Adult 1: No. We'll just do it. Are you ready to record?

[00:02:55.19] Child 1: " I am going to suck your blood"

[00:02:58.00] Child 3: What? (Looks over at what child 1 is doing) What did you say?

[00:02:59.25] Adult 1: Okay now where is this going to happen?

[00:03:05.10] Child 1:At the top of this

[00:03:12.17] Adult 1: At the top of the...

[00:03:12.17] Child 1:You know the cave…at the top of the...(points)

[00:03:12.17] Adult 1: At the top of the cave

[00:03:12.17] Child 1: Yes at the top of the cave

[00:03:30.16] Child 1: (Places RFID character) "I am going to suck your blood"

[00:03:32.19] Child 1: laughs

[00:03:32.19] Child 3: looks up and also laughs - looking at child 1

[00:03:35.01] Child 1 and Child 3 (High five between the two children)

[00:03:36.21] Child 1: laughs

However, even delay between placement and feedback created an opportunity for social interaction as when the system was deemed not to be working, answers were sought from the experimenter.

The four areas of qualitative finding show that a) user content prompted interaction by users b) children needed to learn how to configure, but this did not impact on the amount of interaction c) behaviour became more oriented toward others with the CAKC as children sought each others attention and d) that system response provided immediate feedback which motivated children to continue to interact.

3.6 Discussion

In this study one aim was to see whether allowing configurability of the AKC for children with autism changed their social interaction. This was also compared to when the AKC was switched on as well as off for all children to see if there was a difference in the quality of interaction. Children with autism appeared to benefit from an extension of object affordance with tangibles through digital effects. Predictable and personal content playback created a better quality experience. Whilst the KC alone is still an important and good toy as shown in Figure 5, the addition of digital effects raises the quality of interaction. Inputting user content appears to create more opportunities for interaction amongst users. Other research has demonstrated the importance of user content with tangibles, but with the deliberate purpose of storymaking such as Picture This! (Vaucelle & Ishii, 2008). Here we have sought to allow children the freedom to play with a toy environment with no particular end goal in mind. However, in terms of compensatory mechanisms, configuration could be seen as a task or a goal, and so may have helped the children's behaviour with the AKC. More orientation, more motivation, and more positive social interaction in the form of cooperative behaviour may have focused play sessions toward 'configuring' as opposed to playing. Nevertheless, goal orientation provided a task focus to play and gave children the opportunity to be more cooperative and less socially isolated.

Typically-developing children when playing with the AKC report that they would equally like additional control over content by switching on or off (Hinske et al., 2009). In this study we went further than simply discussing digital versus non-digital but sought to ask whether personal content would increase control over the augmented toy and increase interaction. Whilst interaction such as cooperation increased, and solitary behaviour decreased, the AKC appears to provide more entry points for play when allowing for configured user content. Results in earlier work using Topobo are similar to the AKC in that social interaction increased whilst solitary play decreased (Farr, Yuill, & Raffle, 2010).

Social interaction that occurs around tangibles shows a future for TUIs as a compensatory mechanism for children with ASC. Children with ASC can play with TUIs as they wish, especially as a screen or physical limitations do not hinder them. Tangibles appear to provide a safety net of multiple entry points, helping children who may be at different developmental stages and may prefer digital toys. One element of this, end-user programming, allows children to program as they go, giving choice and freedom as to when this occurs (Edge & Blackwell, 2006). Children who are challenged by speech as well as by object manipulation have an equal chance of playing with the AKC in an involved way. The lack of reliance on one type of access point allows broader access than research where digital effects are only virtual or rely entirely on speech (Tartaro & Cassell, 2008). Exploratory contexts can be better for social interaction when less reliance is on computational activity (Shaer et al., 2004). Touch and manipulation through haptic interaction is not new to TUIs, but has only recently become a priority for medicine and is clearly an important way forward (Vaucelle, Bonanni, & Ishii, 2009).

Exploration of objects that have digital effects can in certain circumstances, such as the AKC, map on to deficits present in disorders such as autism through behavioural mapping, allowing children the chance to observe predictable effects, and control these effects. These TUIs would on the whole need to be familiar in form to children, and less abstract, and take advantage of experiences through habituation (Jones & Smith, 2005). Digital effects should extend logically from the form of the object to maximise possible benefits. A key question remains as to whether the effects found in this study would continue over time or if they were simply due to the novelty of the equipment. Longitudinal studies would address this shortfall in findings.

3.7 Conclusion

Overall results found that the AKC prompted:

- Greater occurrence of behaviour which was oriented to others when the AKC was configurable
- Individual user content increased interest in the system and other children
- System responsiveness has positive as well as negative effects, and children may want to switch off all digital aspects
- More parallel and cooperative play, and less solitary play with the configurable AKC

- More activity with Playmobil figures when children used the configurable AKC

If children with autism struggle to understand the world around them, then control over their own environment must present them with daily challenges (E. Williams, 2004). Presenting an opportunity for increased configuration may well offer new avenues to children with autism through an increased sense of control (Rotter, 1989). Tangibles with multiple access points, when coupled with personally configurable elements, lessen isolation for children with autism. There is potential then for systems such as the AKC to be used in a therapeutic way. Diagnostic evidence could be compiled for children with disabilities and be appropriately compared to a typically developed baseline. Borderline diagnosis and confusion over the triad of impairments could perhaps be avoided, as harvested data could then be used in addition to observable reports.

This paper has been submitted for peer review in the journals *Computers in Human Behaviour*, and *Interacting with Computers.*

I was the sole investigator for this work. Drs. N. Yuill and P. Romero were my supervisors. Dr. E. Constanza built the d-touch.

4 Article III – New Kids on the Block: Enabling Understanding of a Distant-Coupled Tangible User Interface in Children with Autism

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4.1 Abstract

Disparity between a tangible user interface's (TUIs) form and digital feedback can impact on children with autism and their comprehension of TUIs. This is in contrast to typically developing children for whom abstract and unexpected feedback often creates greater interest. Groups of autistic and typically developing children played with a musical tangible that changed sounds when wooden blocks with fiducial-like markers were moved within an active area. Disparity between form and feedback was manipulated by altering the amount of guidance presented to children. Children who experienced more guidance with the tangible were less solitary in their play patterns, showed more expressive play – particularly in the typically developing group – and displayed actions that showed understanding of the system. Problems with distant coupling can be alleviated somewhat by guidance and task-elicited structure.

4.2 Introduction

Tangible User Interfaces (TUIs) have the capacity to engage users across multiple perceptual boundaries such as sight, sound, and especially touch (Antle, 2007; Ishii & Ullmer, 1997; Shaer & Hornecker, 2010). A variety of mappings can occur between what the tangible is and how it is understood as a digital artifact by children (Antle, 2007). The closer an object's digital effect is to its design the closer its 'coupled' understanding (Shaer & Hornecker, 2010). Coupling occurs through metaphor, the importance of the physical property of the object, and embodiment, which describes how closely the user thinks the digital computation is actually within the object (Fishkin, 2004). For example, the Augmented Knights Castle (Lampe & Hinske, 2007) uses RFID-embedded antennae and tags in Playmobil figures. When characters are placed in different areas of the castle, speech or sound (depending on the character) is played accordingly. Autistic children are able to interact with the castle set and understand how to use the system (Farr, Yuill, & Hinske, in press). The manner of the coupling between digital effect and physical effects transforms the way in which virtual and physical worlds interact (Rogers, Scaife, Harris et al., 2002). However, coupling may establish limits to the possibilities for action with a shared TUI resource (Fernaeus et al., 2008).

Correspondence in the objects' coupling in this experiment was close as digital technology was placed within the object itself (see section 4.2.1 below). But if there is a disjuncture between physical form and digital effect, can a lack of seamless affordance be alleviated by guidance during the use of a TUI. This study uses a TUI with distant coupling to explore this question.

4.2.1 The d-touch

The d-touch (Constanza et al., 2010) is a tangible system that makes music via simple wooden blocks that have fiducial-like markers attached to three of the six faces. The system uses a webcam to analyse marker location, which is then translated into particular sounds played through speakers. Blocks are placed on an interactive surface and read using x and y location, the x-axis representing time, and the y-axis representing type of sound (see Figure 1). The webcam scans from left to right on the page and repeats every twelve beats. Sounds are therefore played and made in a similar way to written music, left to right. The d-touch consisted of one workspace page with dimensions 60 x 40 cm (see figures 1 and 2 for experimental setup). Eleven blocks each 5 cm square with a printed pattern on three of the six sides caused software to play a particular percussive sound, when placed in the workspace.

Figure 1. Showing typical user setup of equipment, and experimental setup in school

4.3. Affordances, Transforms, Coupling, Play, and Guidance

Comprehension of form relies on cues that an object presents to us (Gibson, 1979). Comprehension is based on elements inherent in design and form that ‘afford’ particular uses (Norman, 1988, 2007). Loveland’s (1991) theory of affordances and ecology for autism proposes that the environment and the individual have a mutually interdependent relationship. Building on Gibson's (1979) action/perception theory Loveland suggests that children with autism will struggle to understand the nature of objects' affordances. Children with autism will simply be unable to perceive how objects can be used in relation to other people (Loveland, 1991).

The addition of digital effects to objects transforms how individuals experience the nature of objects' affordances. The theory of transforms (Rogers, Scaife, Gabrielli et al., 2002) explains that with the addition of digital effects, individuals experience the world along two new axes, digital to physical, and action to effect. The location of action – the interface – occurs from the purely digital, like a desktop computer screen, to completely physical such as with a tangible user interface. The action and effect locates how and where an action changes that may be immediate, slow, or predominantly based on physical action as found within tangible user interfaces.

The change between these digital and physical effects, and the subsequent comprehension of affordance relies most importantly on coupling. Coupling refers to the link between input events, a computer system sensing this event, and an output event occurring (Fishkin, 2004). These types of events occur according to embodiment and metaphor (Fishkin, 2004). Embodiment refers to the distance between the input and output events, and how closely they physically occur to one another. For example Topobo (Raffle et al., 2004), a 3-D modelling device with kinetic memory, would have 'Full' embodiment as the input device is the output device. Metaphor refers to the effect the system is producing in terms of how close it is to something similar happening in the real world. Topobo would be classified as having 'Full' metaphor as "the virtual system is the physical system: they manipulate an object and the world changes in the desired way" (Fishkin, 2004, p. 351). Another example is the Augmented Knights Castle, (Lampe & Hinske, 2007) placing a figurine in the Knights Castle produces sound that character might make, so a dragon might roar and a person might speak. Here a speaking character is like a speaking character in the real world, as it depends on situation, as well as other characters around that character. This, in the Fishkin taxonomy, would be described as possessing a ‘Noun and verb’ metaphor because “the object being manipulated is itself physical”, yet the “physical and virtual objects differ” (Fishkin, 2004, p. 351). In the context of the Augmented Knights Castle (AKC) the physical object is the figurine and virtual object is the audio sound.

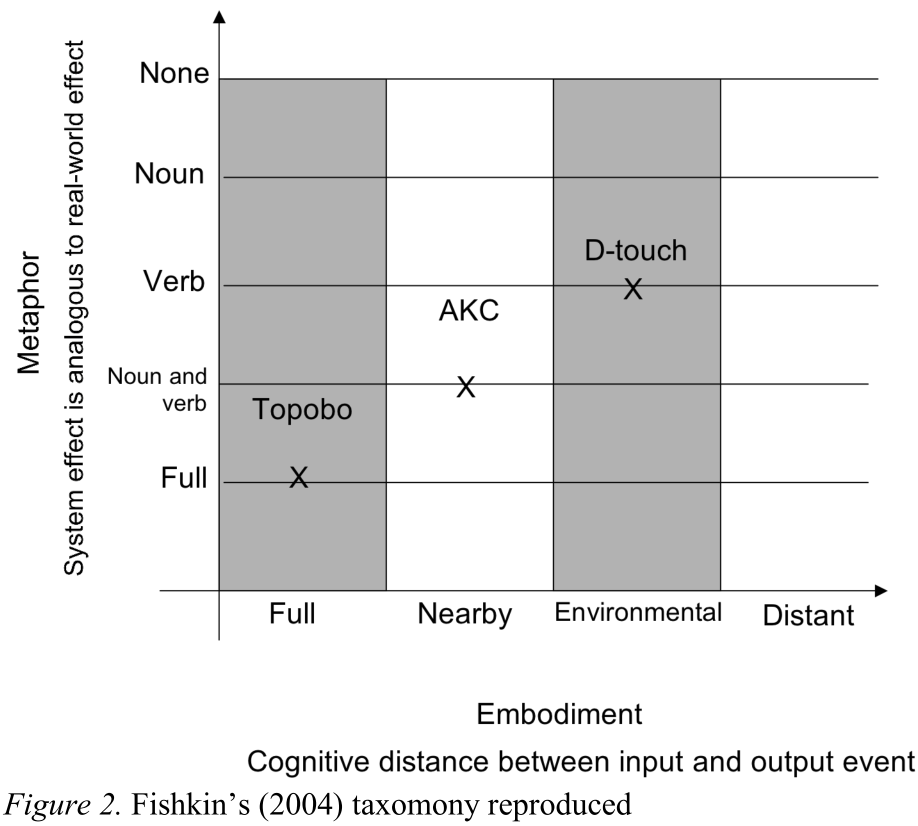

Figure 2. Fishkin’s (2004) taxomony reproduced

The d-touch system in this taxonomy would be classified as having environmental embodiment. The d-touch is environmental because the “output is ‘around’ the user, typically in audio...there is a tenuous link between the input object and output” (Fishkin, 2004, p. 349). In this sense, wooden blocks are used to represent sound, as opposed to in the AKC where figures make sound (i.e. a figure speaks) that would be an expected effect. The metaphor for d-touch is represented as verb as the "analogy is to the act being performed (the "verb") largely independent of the object it is being performed on" (Fishkin, 2004, p. 351). The d-touch is distant in terms of embodiment, and the metaphor level remains complex.

For children with autism their experience of embodiment and metaphor is based upon difficulties in symbolic play. Symbolic play is a behaviour that is simulated, where an action occurs "'as if' something is the case when in reality it is not" (Jarrold, Boucher, & Smith, 1993). Symbolic play demands that children hold a separate image of whatever is being played with to enable that object to be manipulated in a way not directly linked to how that object may actually look or feel (Baron-Cohen, 1987). Playing with an object in a situation that demands symbolic play in particular leads to confusion for children with autism (Baron-Cohen, 1987). As a result, children with autism prefer to manipulate objects in isolation and in terms of function rather than any pretense that may be present in social play (Holmes & Procaccino, 2009). We draw on Leslie (1987) as we refer to symbolic play as substitution, where one object – in this case a wooden block – represents something else, in this case a sound. Children then need to take a leap in logic if they are to grasp that moving a block relates to and can be represented by sound.

Regular object use, for example when a child uses an object having been trained or habitually exposed to its use, results in functional play. Functional play involves appropriate or conventional use of objects (Jarrold et al., 1993). For example the handle of a mug has a function of being picked up, or a key is put in a lock, similar to the theory of affordance. Baron-Cohen (1987) found no difference in typically developing children and those with autism in functional play. Other research has found that children with autism can have significant problems with functional play (E. Williams et al., 2005). Williams et al. (2005) report that children with autism compared to typical children and those with Down's syndrome use objects inexpertly. Williams et al. (2005) also found that children with autism are not interested in objects that relate to activities such as brushing teeth, and have problems using objects in relation to other people, as suggested by Loveland (1991). Further, parents employ strategies such as placing hands over their child's hand, verbally and physically reinforcing by repeating actions, or may even perform a part of the action as a prompt (E. Williams et al., 2005).

For typically developing children, functional and symbolic play are taken for granted, especially with technology as showed by the Hunting of the Snark (Rogers, Scaife, Gabrielli et al., 2002) which investigated how children would react to a novel interface. Children had to discover items that a Snark – a mythical and digital creature – would like through a variety of technological methods. What was found was that a high degree of novelty through abstract metaphor and distant embodiment promoted more collaborative reflection in typically developing children (Price, 2008; Price et al., 2003).

4.3.1 Guidance

Systems with distant embodiment and a lack of metaphor may therefore require other methods, such as guided structure to allow accessibility for children with autism. In many cases help must be appropriate to make up any difference in the shortfall present in technology (Luckin, Connolly, Plowman, & Airey, 2003). Structure can vary, and may take the form of guidance to support learning, which can help a child move from one realm of knowledge to another (Wood, Bruner, & Ross, 1976). Support may often be put in place by adults for children with autism (Jacklin & Farr, 2005), for typically developing children may involve showing or helping a child with how a task can be carried out (Siegler, DeLoache, & Eisenberg, 2010). Yet for children with autism, structure, predictability and repetition are vital to enable understanding (Jordan, 2001). Therapies and interventions for autism often readily employ guidance through structure, predictability, and repetition to the point where all interactions, behaviours and classroom practices are incredibly specific and guided such as with the TEACCH (Schopler & Mesibov, 1985) and Applied Behavioural Analysis programmes (Lovaas, 1987). In the TEACCH method for example, classroom layout, timetabling, and task procedure are all clearly used within a set structure. A sand-timer might be used for example so that children can see visually how long a task will last for.

Task guidance with computers in particular provides meaningful opportunities for the exploration of experiences in complicated forms and in addition to language, as they can be visual, auditory or kinaesthetic in phenomena (Touminen, Kangassalo, Hietala, Raisamo, & Peltola, 2008). Children with disability may need guidance up to and including scaffolded situations where the amount of support is gradually diminished over time (Addison Stone, 1998; Addison Stone & Wertsch, 1984).

Many claims have been made about the benefits of TUIs alone with no guidance. For example Barakova, Gillsen and Feijs (2009) show that when metaphoric meaning is presented in tangible objects, greater understanding can occur within an autistic group. Autistic children took care of cuboids that were embedded with colour-changing capacity. The colour of an object changed and as they did blocks symbolized states of being in animals such as hunger, thirst, and tiredness. These objects possessed full embodiment with verb metaphor, so the extent of how far the embodiment/metaphor can be pushed with children with autism is as far as we know yet to be explored. We have attempted to address this gap.

We have implemented guidance during this experiment with tangible user interfaces to support the process of comprehending symbolic substitution, and the subsequent social interaction of children with autism with the d-touch (Farr, Yuill, & Hinske, 2010; Farr, Yuill, & Raffle, 2010; Pontual Falcão, 2010; Pontual Falcão, Meira, & Sandro Gomes, 2007). To test embodiment/metaphor we used two conditions. One condition used the TUI with blocks only present beside the active area, this we termed non-guidance. The other condition had blocks already present within the active area upon children entering the test room. Guidance given was therefore minimal, and low impact, with the set-up of the TUI changing across two conditions, and two populations (typically developing and autistic). Additionally, adults gave no guidance so all interactions that occurred with the d-touch were because of a change in set-up, pinpointing the TUI's coupling (embodiment/metaphor alone) and guidance. Embodiment and the metaphor may be insufficient for children with ASC, therefore guidance may be necessary to alleviate this shortfall.

4.4 Method

Design

Two participant groups took part, a group of eight typically developing (TD) children, and eight children with Autism Spectrum Conditions (ASC). The independent variable was guidance/non-guidance, and child (autistic, typically developing).

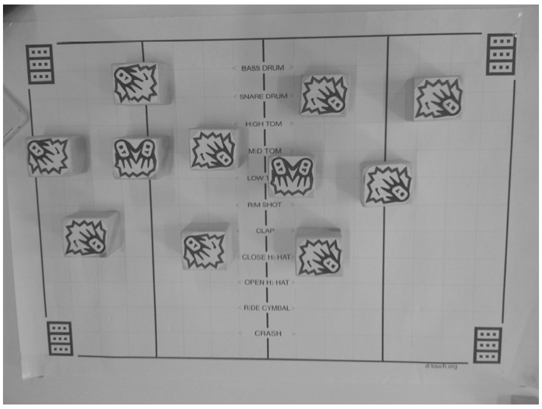

Figure 3. User setup for guided condition

The dependent variables were the number of interactive states displayed in the paired user condition (see Table 1 below). Two coding schemes were used – discussed below – one looking at children's interactive play states, the second looking more closely at children's symbolic and functional understanding of the d-touch using subsets of the initial code scheme. Qualitative observational data of children's behaviours and interaction was also gathered during experimentation to look for broader patterns that may be missed with coding. Children were randomly assigned to either a guided or non-guided group. Instruction was the same for both groups (see procedure below).

Participants

Eight boys (MA = 13.4 years, SD =1.6) with a diagnosis of Autism Spectrum Condition (ASC) confirmed by pediatric assessment took part, recruited from a special needs school for autism in southeast England. The children with autism presented severe autistic behaviour with repetitive speech patterns and impairments in social communication (in line with behavioural patterns found in Wing & Gould, 1979). Eight TD boys (MA = 11.2 years, SD =0.4) from a mainstream school in southeast England also participated. Children were assessed using Raven's Coloured Progressive Matrices (Raven, 1962). This was used to assess a basic level of cognitive functioning to establish baseline data. The ASC group (M = 17, SD = 3.2) had a marginally larger spread of scores with a lower mean compared to the TD group (M = 20, SD = 1.99). Children were paired by raw score on Raven's Matrices across year groups with a two year lag to account for developmental delay (e.g. see Rowland & Schweigert, 2009).

Child and parental consent was obtained for all participants. Children were free to drop out of the experiment at any time.

Apparatus

Sessions were video-recorded in a separate room of the school, with children seated in pairs at a 1msq table. Based on an initial pilot study seating was preferred over standing so that children focused on the task at hand, as children might have moved away from the experimental area if allowed to stand. Sitting was additionally replicated, as this is how most children engage with a task in most classroom situations. The number of blocks to be used was investigated during a pilot study and it was found that eleven blocks between two people was a good number that would not result in overwhelming feedback or a cluttered active area. The developers also suggested during a broad investigation of logged data that the likelihood of using more than ten blocks was very small (Constanza et al., 2010). Children in the guided condition were provided with a set-up of musical blocks on entering the room (see Figure 3). A web camera was positioned over the workspace area, which picks up the position of blocks that are then read by software to produce sounds (see Figures 1 and 3 for setup of experiment). Two digital cameras were stationed around the participants, one looking at the workspace from above, a second showing children from the front, to capture hand, body, and face.

Procedure

Children in paired conditions were given the following instructions: “This is a drum machine. You can sit here and play for 10 minutes. You can play, move the blocks however you like as they are similar to wooden blocks you might have played with as a child”. In the guided condition for paired children, they were additionally presented with a preconfigured layout to prompt children to move blocks and see how sound was being made (see Figure 3). Sounds were therefore playing as children entered the testing room. The non-pattern condition had no layout presented upon entering the testing room.

Coding

The videotapes were coded using Mangold Interact™ software, using a modified segment of coding scheme from Parten's play participation definitions (Parten, 1932) adapted for the d-touch and which focuses on individual children's play comprehension (see Table 1 below). Parten's definition of cooperative and solitary play have been taken and extended from solitary independent play meaning "[t]he child plays alone and independently with toys…[h]e pursues his own activity without reference to what others are doing" (Parten, 1932, p. 250). In Parten's original code this type of play included playing with toys completely different to other children but for the purpose of this study as the children are already in front of the same system, this refers to children acting entirely independently of their partner. For cooperative play "[t]he child plays in a group…[t]he goal as well as the method of attaining it necessitates a division of labor, taking of different roles by the various group members and the organization of activity so that the efforts for one child are supplemented by those of another" (Parten, 1932, p. 259).

These initial codes were extended into four subsets of cooperative and solitary activity to capture when children understood the d-touch in physical form (cooperative or solitary functional activity) or when the digital effect was understood as being an extension of activity with the blocks (cooperative or solitary symbolic).

Table 1. Coding scheme

Play State (Code)	Definition
Cooperative Functional (Cf)	Plays together (taking turns). The child engages with

	their partner whilst playing with blocks. Blocks may be stacked together or simply moved about the active area with no relation to the symbolic nature of blocks, but in relation to partner
Cooperative Symbolic (Cs)	The child realises that the blocks and sound are linked. Blocks generally face upwards towards webcam as children realize that markers trigger sounds. Making and changing tunes is done together by alternating movement of blocks placed by partner. Block location changes because of sound created by partner. Hand may hover initially over the block once placed and will listen to the sound indicating relationship between block and sound
Solitary functional (Sf)	Child plays alone, pays no attention to what other child is doing. Child may play with blocks by separating the active area and dividing the blocks so that they can play alone. May be random movement of blocks within the active area, or piling up of blocks to make a tower. Blocks may be stacked with no relation or pause to sounds heard
Solitary symbolic (Ss)	Plays alone but child realises that block and sound are linked. Blocks generally face upwards towards webcam as children realize that the markers trigger sounds. Blocks may be moved in accordance to sounds heard

All videos were spliced so that views of the board from above as well as children's interactions from the side were captured. The coding scheme of cooperative and solitary functional and symbolic play were tested by inter-rater reliability on a randomly selected 15% sample of 5-minute clips which is above the accepted 10% for video-coding (Haidet et al., 2009). This coding scheme achieved an inter-rater reliability kappa of .89 (cf , .75; cs, 1.00; sf, 0.85; ss, 0.66 respectively). In addition, to capture children's overall play activity a coding scheme shortened form of Parten's play participation codes (Parten, 1932) was adapted for the d-touch. The scheme was modified to allow for two children sitting in front of a shared space, which meant the exclusion of the parallel code. This scheme has been previously subjected to inter-rater reliability of a randomly chosen 30% sample of all videos for typical developing and autistic children playing with tangible user interfaces (Farr, Yuill, & Raffle, 2010) scoring a kappa of .78. This was re-tested to check it was fit for purpose with the d-touch and achieved a subsequent kappa of .82 in its short form.

Table 2. Parten (1932) Modified Coding Scheme

Play State (Code)	Definition
Co-operative	Subject works with another person by turn-taking, or discussing play outcomes but where tasks are distributed.

	Individual works together with somebody e.g. hands on something at same time or discussing outcome together.
Associative	Borrowing and loaning of play material – no division of labour and no organization. Individual acts as he wishes. Individual acts with another.
Onlooker	Participant is watching what the other individuals within the group are doing but does not actively take part.
Solitary	Participant is taking part in the task but is working alone and individually rather than with others.
Disengagement	Participant is not attending to the task or other individuals within the group.
Repetitive	Odd and repetitive behaviour typical of children with Autism

4.5 Results

This section will present data from the coding scheme, with a qualitative analysis of how users interacted with the d-touch. The qualitative analysis will be presented first to show a narrative of behaviours children displayed with the d-touch and explore whether children understood the relatively distant coupling. Quantitative data follows and compares children's duration of time within particular play states shown in Table 1, as well as duration of time spent in cooperative and solitary sub-categories in Table 2. Results depended upon children being in either the guided or unguided condition, or participant (autism, typically developing). Data was non-normally distributed so non-parametric Mann-Whitney tests were carried out. Duration as a percentage of time spent within particular play states in each condition and participant group is also presented. Results for the autistic group (guided compared to unguided) will be presented; this will be followed with a comparison of results for the typically developing group (guided/unguided). Lastly, the autistic guided group will be compared to the typically developing guided group. An overall comparison of autistic to typically developing group is not included, as this does not address the main research question of how guidance might change children's ability to socially interact and comprehend a distant coupled TUI. Also, autistic unguided compared to the typically unguided group is not presented as these are presented within each participant group's data, and produced no significant findings.

4.5.1 Qualitative Data: The shape of interaction with the d-touch

Typically developing and autistic children played with the d-touch in qualitatively different ways. Figure 4 above gives an overview of how both groups played with the system. Children chose to either play with the d-touch physically (left hand side on Figure 4) or with digital effects. Physical and digital interaction led to interaction with blocks or the audio feedback which was either functional, testing the parameters of the system, or symbolic where children played with sounds and blocks. Blocks were then moved or placed in the active area from where either feedback re-occured or sometimes children further explored the system. Children's interaction is discussed further in the sections below on understanding of blocks and block representation, exploratory and expressive play, understanding of shared space and understanding of the system. These categories are highlighted with figures giving examples of children's interaction.

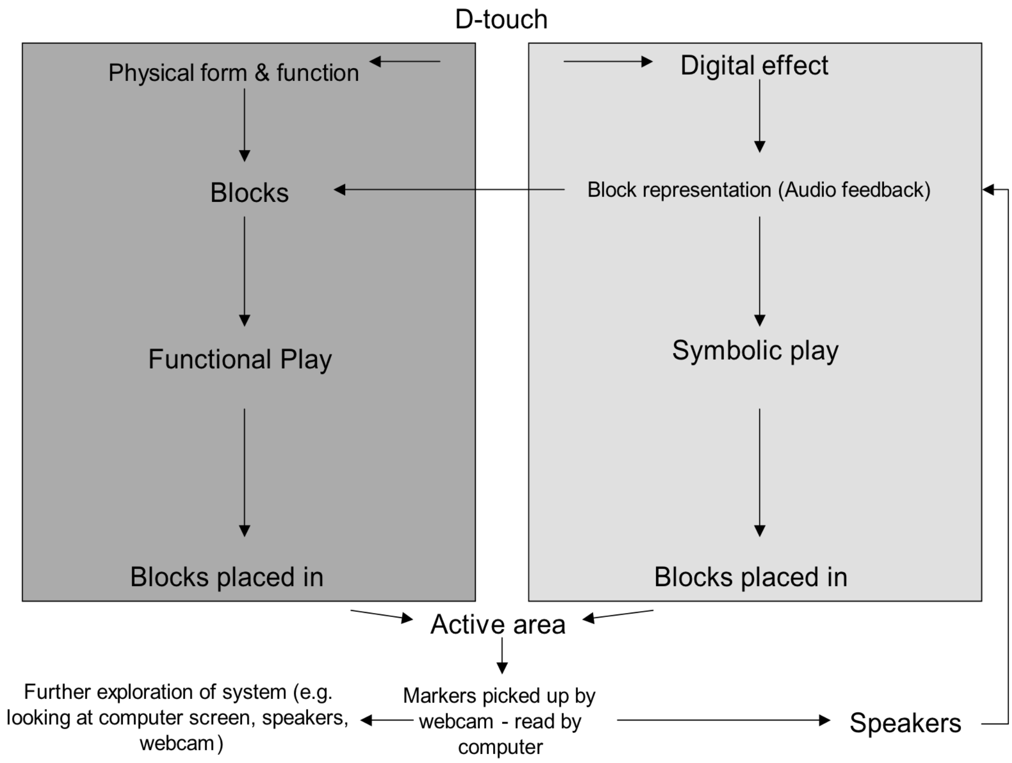

Figure 4. Diagram of how users interact with d-touch

Understanding of Blocks and Block Representation

Autistic and TD children who understood how the system worked would often start by watching and listening to sounds that objects made (see Figure 5 below). Initial movement of blocks was cautious and slow, which gave children time to explore effects of block movement. These actions were clearer in the typically developing group. As children explored more, activities moved to become more expressive as heads, eyebrows or bodies would move up and down in time to the music (Figure 6). Again, this type of action was more common in typically developing groups. Lastly, groups that understood the system surprisingly spoke very little, which was especially so in the typically developing group.

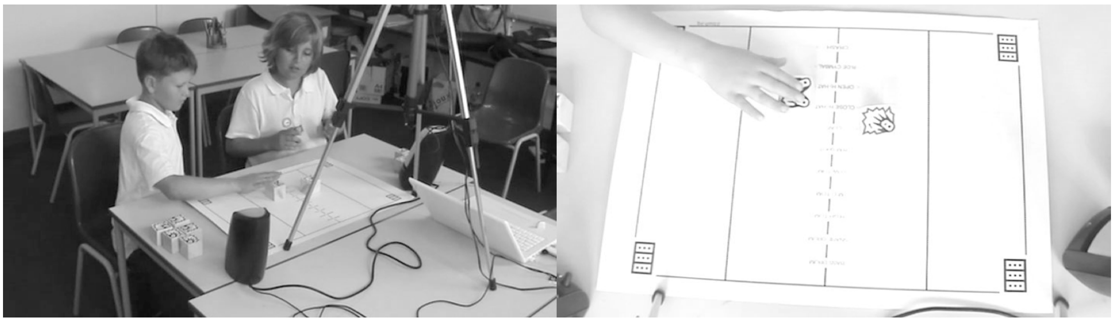

Figure 5. Children initially placing blocks and listening to feedback

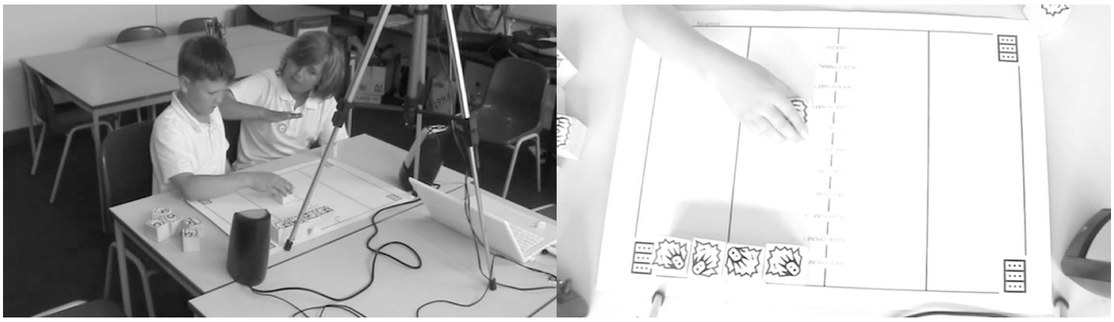

Figure 6. Children demonstrating expressive musical responses to feedback

Children in contrast who did not understand the relationship between the blocks and the sound would often treat the blocks as building blocks alone, and would pile them up, or turn the block over onto a side which did not have a computer vision marker (Figures 7a and b). Movement of blocks would be swift, so that the system never had time to respond (Figure 7c). Swift movement of the blocks occurred most often with the ASC children, especially in the unguided condition (Figure 7d) shown by greater functional activity (both solitary and cooperative) in the unguided autistic condition accounting for 38% of all functional sub-code activity compared to 20% in the guided condition. In some cases the sound of the system caused annoyance to the children and created anxiety leading to some autistic children upsetting one another as a result (Figure 7d). Here no relation was made between digital effect and physical form. No groups however needed to be stopped due to undue anxiety. Both groups in the ASC unguided condition did require prompting on occasion to keep children focused on the d-touch.

Exploratory and Expressive play

Children's physical activity with the blocks, as well as digital feedback received from the speakers highlighted children's exploration of d-touch (exploring the parameters of the system) and expressive play, where children used the d-touch as a music maker. Overall, opportunities existed for users to interact with both the blocks and the block representation in either an exploratory or expressive manner.

During exploratory activity children interacted with the TUI in an attempt to understand how to use the TUI itself. Play was either random or with intent – as mentioned in the section above – and parameters of the system (digital or physical) were fully explored. This did not always occur, as complete system comprehension did not always happen as shown in the quantitative sub-code results comparing children's symbolic and functional activity. In general, expressive activity for children often meant creating a representation of their own ideas. With the d-touch this was done through the expression of musical ideas. To do this, children developed a good understanding of how moving blocks on the d-touch directly related to audio feedback.

TD children moved beyond a state of exploratory play within the first five minutes. Play moved to expressive rhythm creation where children would mimic DJ movements, putting a hand to one ear and purposefully crafting sound until they were happy (e.g. Figure 6). TD children would often make samples of sound that would last for no more than a minute when they were content with the rhythm. However, they would then move on to create new effects often by removing all blocks from the active area and starting again. ASC children in general took longer to reach expressive play, and for some groups in the unguided condition this was never reached. For ASC groups expressive play never reached the DJ crafting stage of TD children. Sounds were altered and rythms were changed, but in a qualitatively different way to TD children. Activity for ASC children was neither as organised as typically developing children nor as explicit in its intent to create rhythm and play with sound methodically.

For ASC children, cooperative play, and cooperative symbolic play appeared to be more about turn-taking with sound rather than expressive creation of rhythm as in the typically developing group. Typically developing children intensively tested sounds as they created rhythm, leaving blocks in place that they liked, removing sounds that did not fit.

Figure 7a. Autistic Children piling up blocks with non-marker faces uppermost

Figure 7b. Autistic children piling up blocks with no relation to sound

Figure 7c. Swift movement of blocks with no regard for audio feedback

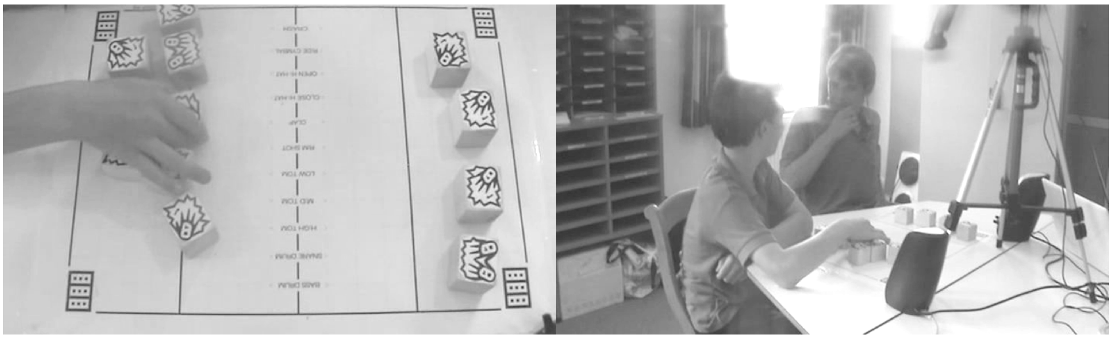

Figure 7d. Anxiety display by child with autism (right) putting his shirt in his mouth

Understanding of Shared Space

The d-touch board was often clearly marked out in autistic children’s play (see Figure 8). Arms were used to mark a central line down the middle of the board.

Figure 8. Example of ASC children dividing active area

Both groups were not explicitly informed that the active area was shared. However, children who worked together in both participant groups often came to use the active area in a shared manner. Pairs who worked together tended to use one arm within the shared space as opposed to two, indicating an allowance on the part of each user to defer the use of the other arm as the space was used jointly. Action in the active area was usually with both arms whilst moving and building blocks in children for those groups that did not work together.

Understanding of the System

Three of the four typically developing pairs, and two of the ASC pairs (guided condition) after having understood the concept of the system went beyond playing with the blocks. These groups were intrigued as to how the whole system worked. These children would get up, look at how cameras were videoing the play scene, and in particular look at the computer screen.

On the laptop screen was the image of what could be seen through the webcam that was suspended over the top of the shared play space. This showed blocks as the computer was reading them. Blocks on the screen would flash in time with the system reading each block. This effect proved interesting to all children as they sought to go beyond the music making and observe the system as it worked. This perhaps highlights the lack of coupling between the d-touch's digital effects and the blocks, which whilst confusing in some instances prompted children into more exploratory play (see Figure 9).

Figure 9. Active looking at how the whole system worked

4.5.2 Quantitative Data: Play States, and Symbolic and Functional Understanding

This analysis compared children's duration of symbolic and functional play for ASC and TD groups in unguided and guided conditions. Duration of play states was also compared for both participant groups.

ASC group: unguided and guided

Sub categories of duration for symbolic and functional play show that the guided group spent 24% of their time engaged in cooperative symbolic play which was significant ($Z = -2.033$, $p < .05$) compared to the unguided group. For the guided condition solitary functional (16%) and symbolic play (11%) were similar in the amount of time given. For the unguided condition solitary functional accounted for the largest duration of time (30%) followed by cooperative functional (7%), solitary symbolic (6%) and cooperative symbolic (2%).

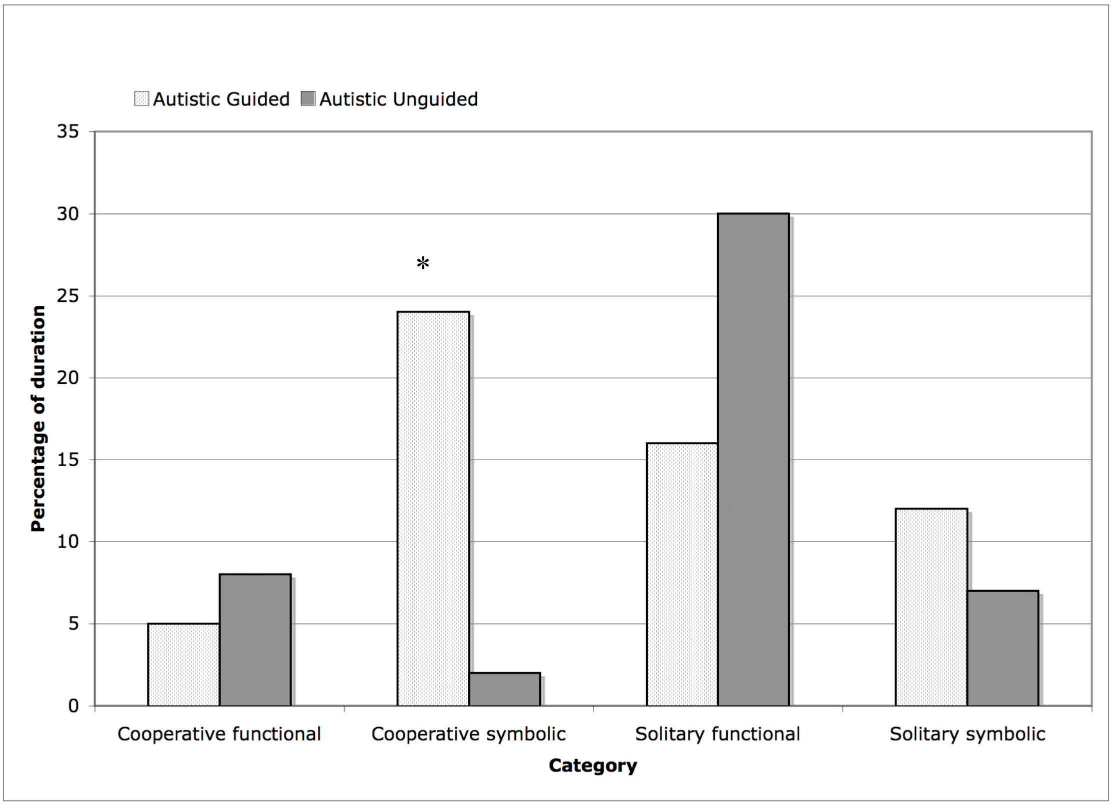

Figure 10. Percentages of sub-category duration spent by ASC children with the d-touch

For the Parten play states there was significantly more disengaged play in the unguided condition ($Z = -2.309$, $p < .01$) compared to other play states. In duration the guided condition showed greater cooperative play overall, almost three times as much as the unguided condition, with 10% unguided and 29% in the guided condition.

Children in the guided d-touch condition had 35% of their time in the onlooker play state or observing and looking directly at what their partner did (see Figure 11).

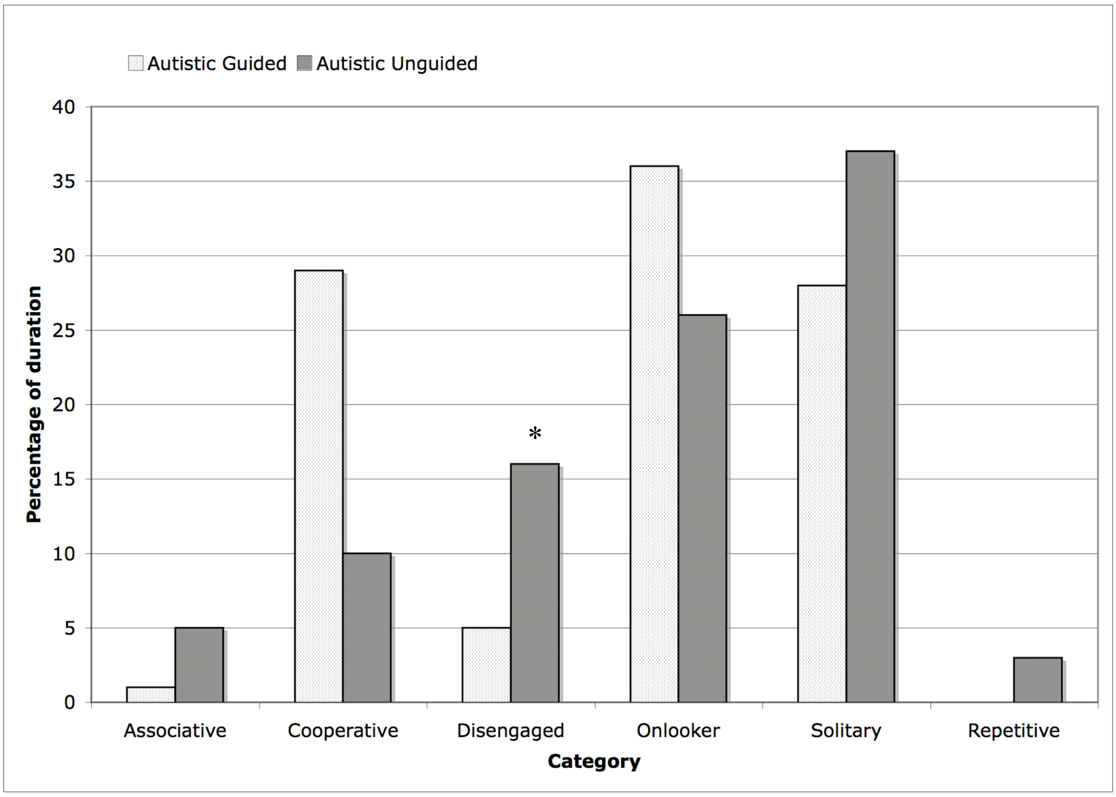

Figure 11. Percentages of play state duration spent by ASC children with the d-touch

Autistic children in the unguided condition spent 26% of their time observing their partner's actions or looking directly at their partner. Most of the unguided group's time was spent in the solitary play state (37%).

Typically developing group: unguided and guided

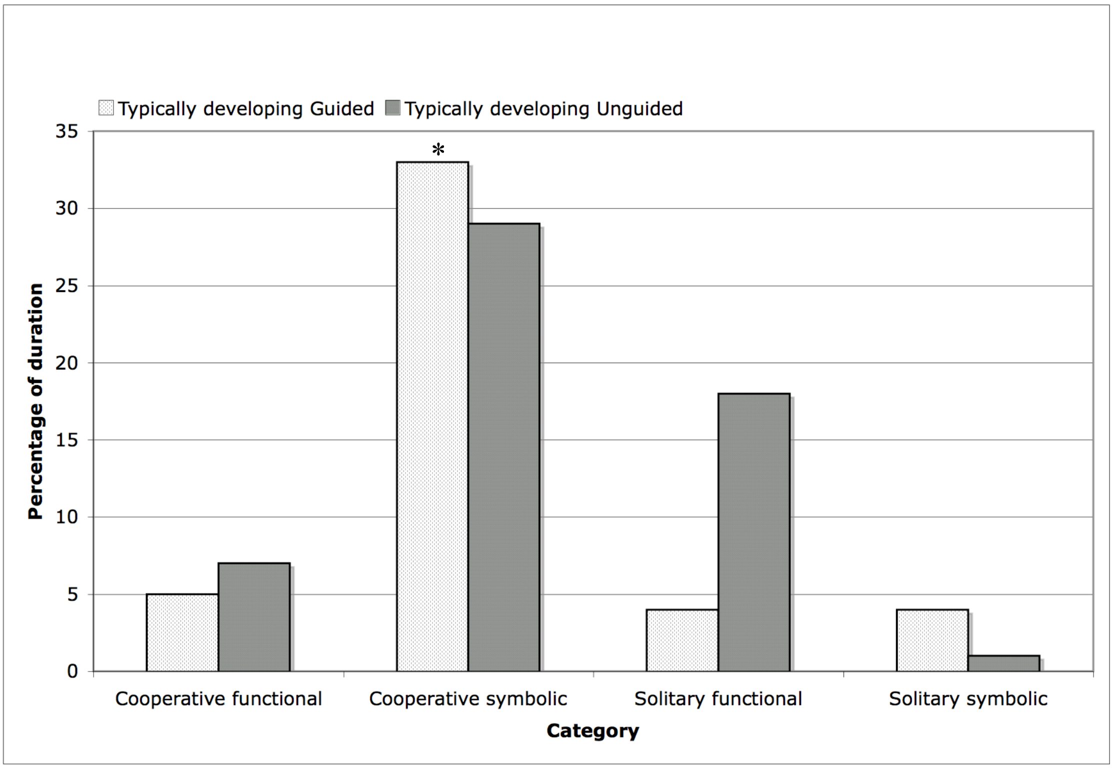

Figure 12. Percentages of sub-category duration spent by TD children with the d-touch

A significant difference was found for the sub-categories of play states (see Figure 13 below). More cooperative symbolic behaviour occurred in the guided condition ($Z = -2.201$, $p < .05$). In durational terms solitary functional in the unguided condition occurred almost three times as much within the solitary functional state, this however was not significant.

There were no significant differences in the play states of both TD groups (Table 5 below). The typically developing guided group spent their time playing mostly in cooperative (38%), onlooker (37%) play states. Total solitary play accounted for 8% of all activity, whilst associative play accounted for 3%.

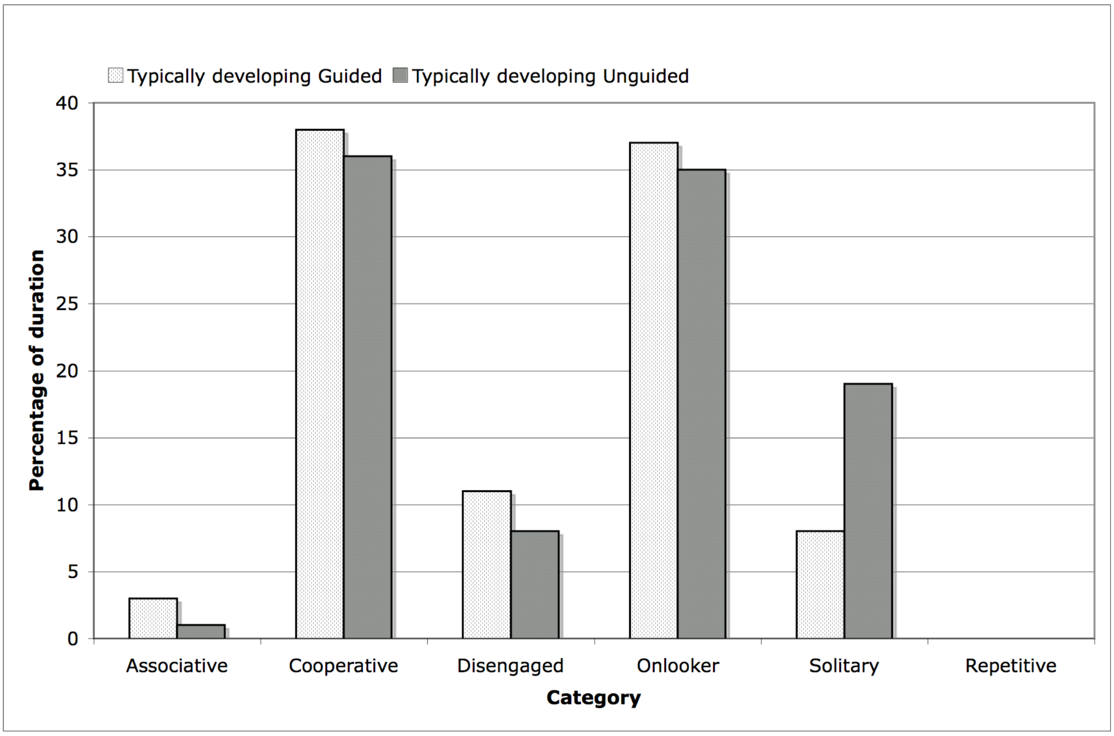

Figure 13. Percentages of play state duration spent by TD children with the d-touch

For the unguided group percentages of duration were similar except for almost 20% of their time playing in the solitary play state. Cooperative play amounted to a similar total (36%) as the guided condition (38%).

Autistic compared to Typically Developing groups

Overall (see Figure 14 below), there was a significant difference in solitary symbolic play showing a greater amount in the total ASC group (Z = -2.323, p < .05). Cooperative functional activity was between 5 – 10% of all duration across all four groups. Cooperative symbolic play was the major difference with the typically developing groups with approximately 30% of all duration occurring in this state, with 24% for the autistic guided group, and then 2% for the autistic unguided group. Solitary functional play was present mostly in the autistic unguided group (30%), followed by TD unguided (18%), autistic guided (16%) and then TD guided (4%).

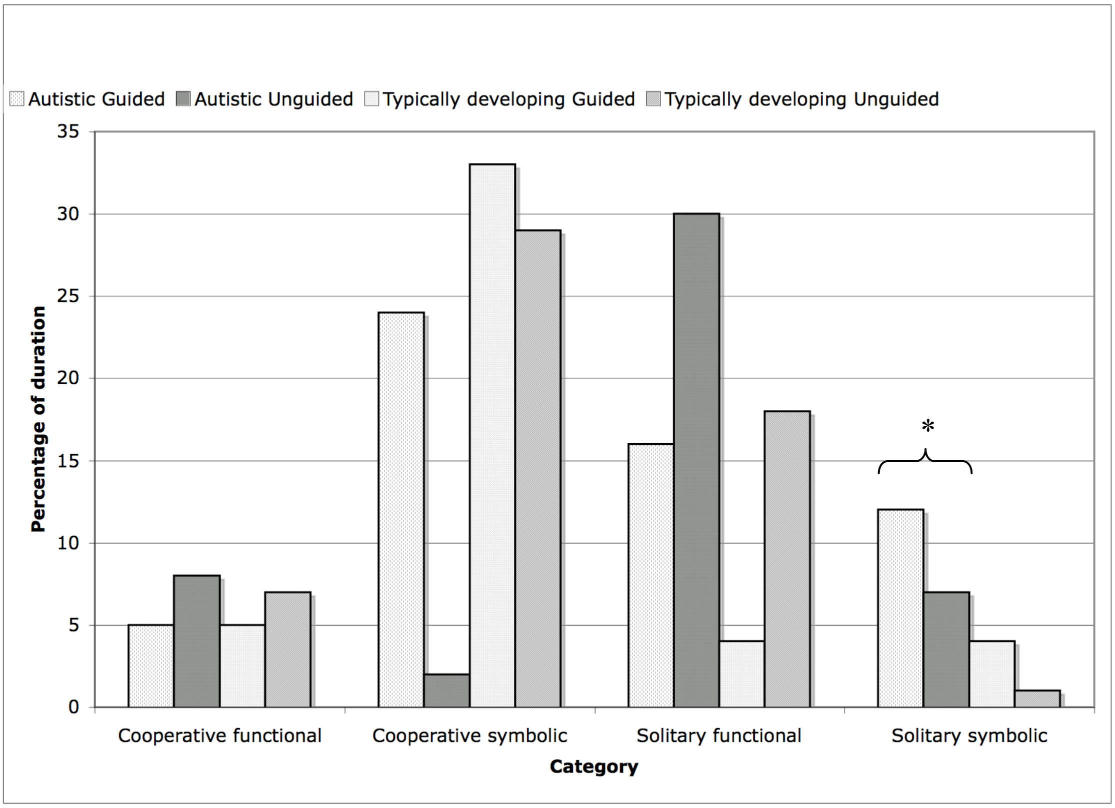

Figure 14. Percentages of sub-category duration spent by ASC and TD children with the d-touch

4.6 Discussion

The main finding here is that children with autism were able to play with the d-touch more cooperative symbolically when in the guided condition. Figure 10 shows that when children with ASC were exposed to the guided condition there was a significant difference in the amount of cooperative symbolic play. When this is placed next to the results for the ASC condition for the Parten play codes (Figure 11) we can see that children in the unguided condition also displayed significantly more disengaged activity, presumably because there was less common understanding and so became less engaged in the activity. Also, this is reinforced by the fact that the ASC unguided groups displayed more solitary functional activity, where they were just interacting with the blocks.

An overall comparison of all four groups with the subcodes showed that the ASC group in total showed more solitary symbolic activity. This is to be expected with ASC children often presenting more socially isolated behaviour. However, children with ASC were showing understanding of how the d-touch worked in solitary symbolic activity – and from Figure 10 this is predominantly with the ASC guided group – and in comparison to TD groups preferred to play with the d-touch alone when interacting with block and sound rather than interacting with their partner. In the ASC group this was again displayed more by the guided than the unguided condition.

Significant differences in cooperative symbolic activity were also found between the two typically developing groups, with the guided group also exhibiting more common understanding. A large difference was observed for solitary functional activity in the unguided TD group, but this was not significant.

These results show that the guided condition for both sample populations caused more significant cooperative symbolic play. These differences between the typical and autistic groups highlight variant play states with autistic children being more socially isolated and typically developing children showing more cooperative behaviour as would be expected.

This work suggests that a symbolic representation – a sound represented by a block in this case – can be made more meaningful by guidance for children with autism when coupling is distant in embodiment and metaphor. If coupled effects are not close in affordance children with autism are left needing further support in the form of task guidance to interact successfully with TUIs and ultimately one another. Physical representations of music could support social interaction and the externalization of thinking provided that there is the correct amount of help where necessary (Luckin et al., 2003; Price, 2008). When an object represents something else, it is not only easier with a three-dimensional object to support manipulation (Kirsch, 2010) but any shortfall in coupling can be aided by the correct amount of help, in this experiment in the form of initial guidance.

Additionally, a focus too much on technology at the expense of usability and social factors ignores tangible *interaction* focusing on “the importance of appreciating the difference between a complete scenario of interaction from the actual manipulation of tangible resources” (Fernaeus & Tholander, 2006, p. 455).

4.7 Conclusion

In tangible music systems, familiar shaped objects like “wooden blocks with geometric forms, with interactive, user-friendly application[s]” (Blasco et al., 2009, p. 342) are coupled to sounds. Children with autism understand auditory information better in the musical modality (Mottron, Peretz, & Menard, 2000). However, the close coupling of digital effects to physical representation appears to be vital for the comprehension of interactive tangible systems. The ‘transforms’ of d-touch is fascinating and expressive for TD children, but for children with ASC is difficult to understand because of a lack of seamless interchange between form and feedback. This abstraction fits music making and in many instances seems to provoke expressive play in a TD population, but for a group with cognitive difficulties appears to be too much to deal with. Even with good external representation of what is occurring i.e. moving blocks equals moving sound, this is difficult for ASC children. What does appear to be the case though is that some of the mismatch between sound and form can be helped by initially guiding the task for a special needs group. Previous research by the authors has found that when the coupled representation is close, so that the object matches the feedback such as an animate object moves, or a figurine speaks, children show greater changes in their patterns of play. Solitary behaviour is significantly less with TUIs than without, and cooperative behaviour increases with TUIs (Farr, Yuill, & Raffle, 2010). Further, if children can be in control of the type of feedback that occurs i.e. by programming sounds made, then social interaction again becomes more cooperative and less isolated (Farr, Yuill, & Hinske, 2010). Future work would attempt to make use of the limits of coupling for children with autism by extending the notion of guidance to include the rich literature on scaffolding. Tasks could be established which are longer term, and allow the gradual fading away of support to achieve deeper and more lasting understanding for children with autism. However, if relatively small changes in presentation can have an impact on ASC then tangibles are an area that has massive potential for therapy, and school-based practice.

5 General Discussion

5.1 Summary of Findings

The three studies presented draw together potential benefits of TUIs for children with autism:

1. Multiple degrees of freedom are present in TUIs which provide many potential ways to interact with a TUI such as multi-sensory play, or personal configuration
2. TUIs can lessen the amount of solitary play exhibited by children with autism, whilst increasing a variety of social interactions such as cooperative play and onlooker behaviour
3. When the coupled digital effect is physically close to the TUI this enables children with ASC to comprehend how to use the TUI
4. When the coupled digital effect is more directly linked to the affordance of the TUI e.g. a figure speaks, this is more clearly understood by children with autism

5.2 Key Implications

The findings have a number of implications for the future of TUI use with children who have autism. Children with autism choose to play with familiar objects that can be manipulated. When familiar objects are embedded with virtual data they appear to be motivating, and allow children with ASC the time and space to engage in social interaction. A fascination for repetition and predictability in machines whilst prevalent amongst individuals with autism may also extend to TUIs and require less processing, or slow down interaction as physical objects can provide a shared and external tool for thinking.

The notion of transforms may offer a way of explaining how children with autism interact across the virtual divide (Rogers, Scaife, Gabrielli et al., 2002). Transforms explains how children interact and perceive changes that occur in action and cognition, especially the boundary between action and effect. According to Rogers et al. (Rogers, Scaife, Gabrielli et al., 2002) the transform type also explains the level of children's familiarity with that transform. A physical action leading to a physical effect is highly familiar. A physical action leading to a digital effect is unfamiliar, digital action leading to digital effect is familiar and digital action leading to physical effect is highly unfamiliar (Rogers, Scaife, Gabrielli et al., 2002). Topobo (study 1) would be classified as a physical action leading a physical effect that should be highly familiar. The Augmented Knights Castle would be a physical action – moving a toy about the environment – leading to a digital effect (unfamiliar sound). The d-touch similarly would be a physical action – moving a block – leading to a digital effect (sound). However, in the work of Rogers et al. (2002) it was the unfamiliar and novel that led to increased interaction by typically developing children, a finding replicated with TD children, but possibly with a reversed trend in children with autism. The less familiar the transform, and the more distant the coupling, the more unlikely it is that children with autism will either a) understand or b) socially interact whilst playing with the TUI.

TUIs as a resource for shared action (Fernaeus, Tholander and Jonsson, 2008) may enable children with autism the opportunity to be able to interact as they allow for many potential ways to interact, as they exist in the physical world as well as the virtual. However, there may be limitations to the extent to which TUIs can help. The more distant coupling becomes – in affordance and physical embodiment – the more likely it is that appropriate help and guidance become necessary, especially when effects become more abstractly linked such as with the d-touch.

5.3 Limitations

In this thesis, all children with autism were medically diagnosed, all experiments took place on school grounds and children were removed from normal lessons to take part. Experiments were not conducted in classrooms, but did take place within school premises, improving the ecological validity of results compared to lab-based experimentation.

The tools, paediatric diagnoses, and the time period when diagnoses were confirmed were not available for participants with ASC used in this thesis. Further, diagnostic tools used here can over or even underestimate differences and abilities (e.g. see Burack, Iarocci, Flanagan, & Bowler, 2004). As a result, matching pairs of autistic children using Raven's progressive matrices, National Curriculum based assessments, or the Childhood Autism Rating Scale may produce inconsistencies in time points and score reliability. Matching typically developing children with those with ASC is a difficult issue in the construction of experimental work (e.g. see Mottron, 2004). In this thesis TD and ASC groups were compared with one another rather than in separate groups of 'diagnosed' and 'control' groups. Samples used were not clinically matched, and where tools were used to construct pairs, such as in the third article with Raven's progressive matrices, this was not used a matching tool. All these issues can damage reliability, so it is in the interests of future work in this area to have as clear a picture as possible of diagnosis, preferably triangulated with more than one diagnostic tool. However, the choices made depend upon the research questions being answered so no system of assessment or matching is perfect (Burrack et al., 2004).

Participant numbers did not exceed 20 in any of the three studies, which brings into question the reliability of results, but highlights the heterogeneous nature of the autistic population. Sample size is a limitation to the reliability of results, but future work could use 20 as a participant guideline or view 20 as a fair sample size for work of this nature. Gaining access to children with autism through school, teacher, and parental consent, and the option of dropping out of the study at any time meant that the process of acquiring participant numbers was slow and small in number. One child left the experiment of their own volition; no parents refused permission. Filtering participants by age, year group, and raw ability meant that once testing began few numbers were involved. This was usually due to age group, or timetabling pressures. Parents may have additionally let their child participate only if they thought their child was interested in technology, potentially biasing all results.

Children were typically exposed to experimental conditions that lasted from 15 minutes to half an hour. This may be too short to make substantial claims about TUIs but partly is in response to conducting work in situ in schools whilst working around school timetables, where other pressures are placed on children's time.

Children took part in studies 1 and 2 in threes to analyse overall play states whereas study 3 used pairs to get reduce some of the variability found in the earlier data. Samples were non-normally distributed and all tests were non-parametric. Effect sizes are therefore small. Tests were either Wilcoxon matched pairs (study 1) or Mann Whitney tests of significance (studies 2 and 3).

Parten's (1932) play state codes are used throughout the thesis as a measure of children's interaction. These – as discussed in paper one – have been altered somewhat by various researchers (e.g. Robinson et al., 2003) but the broad access they offer to a variety of play types exposes differing play patterns in comparison to typically developing children. Possible future work should aim to increase reliability with increased training in the specifics of coding and the coding scheme being used. This would address specific issues and problems that can arise when data is coded within a small team and triangulation is limited.

Small sample sizes show some significant levels of change because of TUIs, and it may be expected that a more reliable estimate may occur with a larger sample size.

However, significant results could have occurred because of the small sample size this would increase with larger sample sizes. Commonalities throughout the three studies in the reduction of solitary play, and increased cooperative and onlooker play states strengthen the likelihood that results are not due to chance.

5.4 Future Directions

Future work should take advantage not only of the capability of TUIs to allow wide scope of access, but should also collect data to compare groups of ASC with TD population. Future results may even allow automatically collected data – such as with RFID technology – to show percentages of play patterns. Further investigation is needed to show the link between closely coupled aspects of tangible user interfaces. One way may be through toys that possess digital augmentation and have full embodiment. For example, a ball with in-built actuators sensors that can change the colour when a ball is caught may encourage turn taking; Thomas the Tangible Tank Engine may talk and move similar to the character from the books and on television and encourage motivational factors. There is also scope for more work with TUIs and tabletops such as the Mitsubishi diamond touch to be conducted. If TUIs are used much more in conjunction with multi-touch GUIs this could then further extend multiple entry points available.

Psychological work could focus on multiple viewpoints to exhaust the digital impact of TUIs beyond novelty and multiple entry points. This work could explore cognition, gesture, verbal communication, language, attention, collaboration, peer tutoring, and motivation with only one TUI as the focus. Experiments could be longer lasting with pre and post testing. Work could also focus on the size of tangible and see whether size impacts on use. A series of nine further experiments were originally planned for this thesis using Topobo looking at numbers of participants from single user, to pairs, to pairs where one peer was more able, but as this thesis became more exploratory it was deemed more important to focus broadly to assess and compare different exemplars of tangibles.

These elements all require attention, and will not only give the wider human computer interaction field more of a handle on how TUIs are useful, but may enable the creation of specific intervention tools for children with disabilities.

In its initial iteration the AKC was explored as being potentially modular (Hinske, 2010). This meant that for different setups such as a castle or a ship different modules would eventually be purchased with sounds, and audio of that play environment. Clinically, a modular AKC then could be used to automate play tasks used in diagnosis. Clinical psychologists were observed during this thesis using playmboil toys to explore a child's possible autism. Therefore if a baseline of play using TD children could be gathered, then the use of the AKC with children with autism could increase the reliability of diagnosis as a comparative tool.

Educationally it is difficult to be pinpoint further investigation of tangibles. However, Topobo, the AKC and D-touch all seem to potentially give joint focus and attention to children with autism. Therapeutic use is possibly too soon; classroom teachers may have a particular focus such as collaboration or group work, and as a result tangibles could become part of a special needs classroom toolkit. This is particularly useful as TUIs on the whole are not generally cumbersome. However, the use of TUIs as a potential therapeutic tool may become increasingly validated.

If communication is implicit, the object itself can become a symbol; TUIs thus may offer the opportunity to open broader communication channels for children with autism. Alternative and augmented communication devices for individuals with ASC will ultimately benefit from the advances made in recent years with TUIs, enabling greater access and possibly lessening the extent to which disabled users rely on touch screens or on-screen symbols to communicate.

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