A tablet computer-assisted motor and language skills training programme to promote communication development in children with autism: development and pilot study

*E.J. Weisblatt[1,2], C.S. Langensiepen[3], B. Cook[3], C. Dias[2], K. Plaisted Grant[1], M. Dhariwal[4], M.S. Fairclough[1], S.E. Friend[1], A.E. Malone[1], B. Varga-Elmiyeh[1], A. Rybicki[5], P. Karanth[6], M.K. Belmonte[6,7,8]

1. Department of Psychology, University of Cambridge, UK
2. Peterborough Integrated Neurodevelopmental Service, Cambridgeshire and Peterborough NHS Foundation Trust, UK
3. Computing and Technology Team, Nottingham Trent University, UK
4. Laboratory for Social Machines, Media Lab, Massachusetts Institute of Technology, USA
5. University of Birmingham, UK
6. The Com DEALL Trust, Bangalore, India
7. Centre for Autism, School of Psychology and Clinical Language Sciences, University of Reading
8. Division of Psychology, Nottingham Trent University, UK

*corresponding author ejw44@cam.ac.uk, tel: +44 1733 777939

Abstract:

Autism is a heterogenous condition, encompassing many different subtypes and presentations. Of those people with autism who lack communicative speech, some are more skilled at receptive language than their expressive difficulty might suggest. This disparity between what can be spoken and what can be understood correlates with motor and especially oral motor abilities, and thus may be a consequence of limits to oral motor skill. Point OutWords, tablet-based software targeted for this subgroup, builds on autistic perceptual and cognitive strengths to develop manual motor and oral motor skills prerequisite to communication by pointing or speaking. Although typical implementations of user-centred design rely on communicative speech, Point OutWords users were involved as co-creators both directly via their own nonverbal behavioural choices and indirectly via their communication therapists' reports; resulting features include vectorised, high-contrast graphics, exogenous cues to help capture and maintain attention, customisable reinforcement prompts, and accommodation of open-loop visuomotor control.

doi: 10.1080/10447318.2018.1550176

1. Introduction

1.1 Theoretical background and motivation

Autism spectrum disorders (ASD), including autism, are common, lifelong conditions, affecting approximately 1% of the population, with about a quarter of those affected nonverbal or minimally verbal - that is, producing either no words at all, or some words but no phrases other than non-communicative compulsive vocalisations (Anderson et al., 2007; Norrelgen et al., 2015). Our and others' research has demonstrated a strong association between autistic language delay and motor dysfunction (Amato & Slavin, 1998; Belmonte et al., 2013; Bhat, Galloway, & Landa, 2012; Leonard et al., 2014; Leonard, Elsabbagh, Hill, & BASIS Team, 2014; MacDonald, Lord, & Ulrich, 2013; MacDonald, Lord, & Ulrich, 2014). In some children with autism, oral motor skills are limited and receptive language is greater than would be suggested by the level of expressive language (Belmonte et al., 2013) i.e. this group of children understand more than they can say. Although the trajectory of language development in autism can show a variety of patterns, including advanced expressive language structurally (Lord, Risi, & Pickles, 2004), our proposed intervention addresses specifically those children with less developed expressive than receptive language function, particularly those who show difficulties with motor development in addition.

It is important to note that there are many strengths as well as difficulties experienced by people with an autism spectrum diagnosis, for example excellent attention to and memory for detail, focus and high achievement in areas of interest, honesty, loyalty and some sensory processing strengths. In addition, many characteristics are only “deficits” in the context of “typical” functioning, such as conversational style, eye contact, “unusual” or “excessively intense” interests, and difficulties in noisy environments. When the social and physical environment take a person’s autism into account, many “deficits” disappear. However, for people with limited or absent verbal and other communication, there are real deficits and difficulties in daily life and activities even when the environment is optimised and others are making every effort to interact in a way helpful to the person with autism. A severe lack of communication ability can thus lead to frustration, unhappiness, and other means of communication such as physical outbursts, biting, and self-injury. Adults who experienced difficulties with communication as children report that they found this frightening and immensely frustrating and would have welcomed any help with developing their language skills when younger (Mukhopadhyay, 2008). Carers also report the evident frustration of their children who are unable to communicate their needs, and they prioritise very highly being able to understand their children’s needs better. We therefore focus here on the indisputable deficit in spoken communication experienced by some people with autism, while acknowledging that many other “deficits” are determined by societal response and others’ lack of understanding, and that autism equally is associated with many strengths. Throughout this paper we refer to “autism” to include autism and any related diagnoses or conditions, though in practice there is little consensus amongst people on the autistic spectrum about what they prefer it to be called (Kenny et al., 2017).

Our work and that of others suggests that the high-level difficulties in social communication so characteristic of autism may emerge developmentally from interaction of three more fundamental domains: (i) social motivation and reward; (ii) cognitive and motor control; and (iii) sensory perceptual organisation (Valla & Belmonte, 2013). Early training directed towards such lower-level, prerequisite skills (Karanth, Shaista, & Srikanth, 2010) – in the case of our new intervention, motor control and sequencing – thus might exert a knock-on effect on the development of communicative skills. This approach aims to develop social communicative skills by training non-social, domain-general skills – implementing what is in a sense a 'back door' route to autism therapy. Strategies that knock on the front door exclusively – as exemplified by the many techniques that aim to train social and/or communicative skills – show some encouraging results for some children but by no means all, with wide variation in outcome measures (Green et al., 2010; Green et al., 2015).

The current intervention thus arose from the idea that improving motor skills can be helpful for communication. UK National Institute for Health and Care Excellence guidance (NICE 2011, updated 2017) at the time of writing does not directly address motor symptoms in autism, which have not until recently been considered primary characteristics worthy of investigation and intervention. Although sign-language training in autism seems not to lead to further language development (Shield, Pyers, Martin, & Tager-Flusberg, 2016), typing, unlike signing, is asynchronous (Forsey, Bird, & Bedrosian, 1996) and therefore can be less cognitively demanding (Chen, Yoder, Ganzel, Goodwin, & Belmonte, 2012), For some individuals, then, spelling out words using sequences of alphabetic symbols may come easier than speaking sequences of phonemes or signing sequences of ideograms. Indeed, typing has spurred communicative development in some autistic individuals (Mirenda, 2003). We therefore hypothesise that computerised game-based training of motor skills may enable a manual-motor medium of symbolic communication in individuals who have not developed the rapid motor control and sequencing capacities prerequisite to spoken or sign language. In these individuals typed communication may thus be a first step towards more flexible and general symbolic communication.

Evaluations of parent-developed methods of manual motor symbolic communication using eye-tracking and attentional models (Chen, et al., 2012; Grayson, Emerson, Howard-Jones, & O'Neil, 2012) reveal trends consistent with this sensorimotor route to skills development. However, such parent-developed therapies demand extensive training for those who implement them, are labour-intensive, and can be difficult to subject to controlled testing (Cardinal, Hanson, & Wakeham, 1996). Parent-delivered therapies overall have shown some promising results over recent years but full evaluation and potential acceptance of such methods will depend on framing their practical insights within theoretical knowledge of autism, and evaluating them in high-quality studies that apply appropriate clinical trial methodology, outcome measures, and measures of fidelity and treatment adherence (Fletcher-Watson et al., 2016; McConachie & Diggle, 2007; McConachie, Fletcher-

Watson, & Working Group 4, COST Action 'Enhancing the Scientific Study of Early Autism', 2015). Point OutWords has been developed to meld the insights of autistic people and their parents and caregivers with amenability to such rigorous evaluation, giving voice to these insights within a field that historically has developed without their full participation. It formalises users' and caregivers' insights and input in a format that provides quantitative usage data suitable for gauging learning. In this sense Point OutWords simultaneously and synergistically is a training device (from the perspective of autistic users and their families), an intervention (from the perspective of clinical therapy), and a research tool (from the perspective of clinical science).

1.2 Existing Computerised Interventions

One way to make such training more broadly accessible and simultaneously to obtain quantitative outcome measures is to implement it in a semi-automated manner, in which clients interact with a computer under supervision. Previous computerised training programs have usually focused on direct training of social and/or communicative skills, and have tended to result in failure to generalise skills beyond the trained context (Wass & Porayska-Pomsta, 2014). Although small studies such as these can be statistically underpowered, that is, lacking sufficient numbers of users to identify statistical patterns of change within the user group as a whole, they nevertheless can yield pilot data and experiences to drive further investigations and improved design, and provide an essential basis for later expansion, up to and including clinical trials.

A further obstacle to previous interventions has been the desktop computer user interface, with a keyboard that demands fine visuomotor accuracy and does not use iconic, concrete reference (i.e. one cannot provide input by pointing at the display itself but has to remap a response to an arbitrary, separate spatial location). Those people with autism who have difficulties with motor control and/or the use of symbolic referents spatially and visually distinct from the iconic reference thus have been practically barred from such keyboard-based technologies. Keyboardless technologies such as tablet computers introduced within recent years have made technology more accessible to many users. These interfaces have so far been used in a number of ways, including allowing people with autism to give instructions, access preferred stimuli, and use the device to generate speech (Kagohara et al., 2013). Computer-based interventions have produced some positive results in areas such as emotion recognition (Serret et al., 2014) and communication (King et al., 2014; Waddington et al., 2014; Xin & Leonard, 2015), and a recent study (Fletcher-Watson, et al., 2016) used an iPad app with pictures of social situations to attempt to enhance social communication by the 'front door' of using social stimuli. This study showed that the app was enjoyable and accessible, but did not find any positive change in real-life play or social communication. Touchscreen devices do clearly have potential as a learning and therapeutic tool and are already widely used by many children and easy to incorporate into daily activity (Fletcher-Watson, et al., 2016).

People with autism tend to orient towards the veridical sensory-motor world as it is, rather than towards spatially, temporally, conditionally, or symbolically displaced communicative referents. Touch-screen technologies feature adjustable keyboard dimensions, and their visual sensory input and motor output are spatially coincident and hence directly and immediately related. Such technologies are therefore particularly amenable to the style of iconic rather than symbolic reference demonstrated by people with autism, and have potential to be of great use. This adaptability of touchscreen technologies to autistic perceptual style has been under-explored in the literature so far.

The confluence of these new technologies with the recognition of motor contributions to autistic communicative impairment thus begs therapeutic application in which users' interaction with *icons* can bootstrap them into learning to interact with *symbols*. This approach is one of enhancing more fundamental skills, such as visuomotor coordination and other motor skills, to reference both iconic and more symbolic visual stimuli using an iPad. Development of such a tool is best approached as an iterative design process with autistic users, their parents, carers, therapists, computer scientists and clinical and academic researchers using a variety of methodologies. Point OutWords (http://PointOutWords.online/) is the result of such a process, specifically aimed at the visuomotor abilities hypothesised to underlie communication difficulties in some children with autism, particularly those who are nonverbal or minimally verbal.

This paper focuses primarily on the design, development and evaluation of Point OutWords through the three phases completed so far, accomplished with parents, carers, therapists and children with autism with very limited conventional communication abilities. These include an iterative development phase with autistic users as co-creators and testers, a focus group and feedback phase addressing the feasibility of practical use by children and families, and a pilot study for initial assessment of real-life acceptability and usefulness of both Point OutWords itself and candidate outcome measures to assess whether it achieves the desired effect of improving motor and communicative skills; quantitative data from this most recent phase provide empirical validation of Point OutWords' design and highlight the potential for future evaluation of its efficacy.

2. Design and methodology

This was essentially a user-centred design (UCD) process with elements of co-design (participatory design), as outline requirements were generated from background research to scaffold the design options and choices evaluated with co-creators. This context is somewhat different to a business process, where there is often a very specific problem to solve and users can be involved very early because of their workplace experiences with existing software. Here, the research indicated certain high-level goals but there was no existing workflow or task to improve. Because of the communication difficulties of the target user group, the UCD process was, of necessity, rather fluid, but still ensured that the key aspects of usability, workflow, environment and user characteristics were fully explored and addressed.

2.1 Initial Design Features/Requirements

Five principal features of the design were proposed based on previous research and theoretical perspectives. These provided a framework within which to elicit feedback from co-creators during Phase 1 of the development process (*vide infra* 2.3); in short, theory informed specific questions to be asked and issues to be highlighted, and responding to these questions and issues was the subject of the co-creative process:

> ***Engage autistic cognitive strengths.*** Too often, methods adapted from those for non-autistic learners end up working against autistic cognition by asking people with autism to do what they cannot easily do. The most effective teaching and learning strategies in autism build from autistic and individual cognitive styles, for instance turning visual sensory preoccupations to advantage as a medium for instruction (Quill, 1997). The goal here is to work with autistic cognition, beginning from autistic enjoyment of visual object-based structured activities centred on parts and details. Accordingly, Point OutWords begins with "Point mode", in which interactions with the device are purely iconic, and users practise visuomotor skills by pointing and dragging to assemble jigsaw puzzles piece by piece. Section 2.3 provides details of the use of a behavioural choice paradigm to allow users to indicate preferences for different stimuli by non-verbal actions, e.g. choosing between pairs of stimuli. Enjoyment and engagement were also assessed non-verbally by noting which stimuli were chosen and by observing which visual formats proved more or less distracting, or produced more or less accurate and efficient performance on the task.
>
> ***Open-loop motor control.*** For people with autism – especially for the motor-impacted subpopulation– visuomotor interaction is atypical, and conventional interfaces present barriers to interaction. The application would employ a touchscreen interface adapted to accommodate autistic motor dyspraxia (Miller, Chukoskie, Zinni, Townsend, & Trauner, 2014; Sampath, Agarwal, & Indurkhya, 2013). The first requirement was to accommodate an open-loop style of visuomotor control, in which visual feedback is not integrated into the execution of an ongoing movement (Haswell, Izawa, Dowell, Mostofsky, & Shadmehr, 2009). This design goal takes account of the known difficulty of many people with autism in making use of sensory feedback, such that gazing towards the target of a movement confers no advantage and can interfere with cognitive and motor resources necessary for successful communication (Chen, et al., 2012; Doherty-Sneddon, Riby, & Whittle, 2012; Doherty-Sneddon, Whittle, & Riby, 2013). People with autism often fixate only briefly before movement and then avert their gaze. Because motor execution is not updated with ongoing visual feedback, movements tend to accumulate spatial error and the finger may initially contact the touchscreen at some distance from the intended target. Once in contact with the touchscreen, the three-dimensional visuomotor targeting problem becomes a two-dimensional problem and many users apply a strategy of successive approximation, wiping the finger in contact with the touchscreen in steps until the target is contacted. Touchscreen interfaces

designed for non-autistic persons misinterpret such movement sequences, responding only to the point of initial contact. An interface adapted for autistic users must respond to the point of departure from the touchscreen, rather than the point of initial contact. This crucial modification can eliminate a major source of users' frustration. Open-loop processing is thus well-established in people with autism and this evidence was used to guide the initial parameters based on existing knowledge. Section 2.3 (Phase 1, Stage 3) details the assessment of actual open-loop versus closed-loop behaviours using direct observation of users' movements as part of the ongoing iterative design process, corroborating and instantiating to this particular user group the neuroscientific finding of visuomotor dyspraxia in autism.

Errorless learning. Our clinical experience highlights the significance of moving from an iconic mode of reference in which the user manipulates pictures of objects by pointing at puzzle pieces of parts of the objects ("Point mode"), to a symbolic mode in which the same manipulations depend on pointing at keyboard symbols that symbolically name the object ("Type mode"). Symbolic communication depends strongly on integrative cognitive and neural functions of the sort that are most compromised in autism (Belmonte, Allen, et al., 2004). In our experience, users once practised with Point mode will initially perseverate in interacting with the screen iconically in Type mode, by continuing to point at the object rather than the letters. Overriding this tendency to iconic pointing depends on modelling and correction by a therapist, teacher, parent or caregiver in an errorless-learning format, filling in responses and correcting errors when the user is unable to do so, and redirecting the user towards the task when necessary: The software is designed to work with teachers and therapists, not to substitute for them. Indeed, we have found that when schools' resource limitations have resulted in users' merely being left alone with the iPad without human guidance, learning is displaced by repetitive behaviours (Deane & Belmonte, 2018).

Exogenous attentional capture. As a supplement to such teacher-led guidance, in Type mode the software itself must help redirect visual spatial attention from the iconic objects to the symbolic keyboard. When a touch in the puzzle region of the touchscreen is detected, the target key within the keyboard repeatedly expands and contracts, and illuminates and darkens. At the same time, a bright line grows from the screen location of the touch to the target key. These stimuli involuntarily and exogenously capture attention (Chang & Ungar, 1995; Yantis & Hillstrom, 1994; Yantis & Jonides, 1984), supplementing the voluntary, endogenous attentional shifts that are slowed in autism (Belmonte, 2000), and making a virtue of autistic learners' tendency to orient attention to the most physically (not socially) salient stimulus in their environment (Chen, et al., 2012).

Ubiquitous, transparent data logging. As a tool for skills training and therapy, Point OutWords logs rich information which can be used not only to track individual users' progress but also in research on motor and communicative functioning in autism more generally. For example, details of users' finger movements on the screen during puzzle assembly provide both evidence of change over time in skill levels (and thus an outcome measure for the motor control aspect of the intervention) and of differences in motor control between groups of users (and thus a further characterisation of autism subgroups). Both these uses require access to data on users' and caregivers' interactions with the device, to answer cross-sectional questions about which user characteristics might predict success in developing communication via Point OutWords, and longitudinal questions of how such traits might change as learning proceeds. The entire time series of interactions with the device therefore must be saved in a transparent manner that does not interfere with the user experience.

2.2 Functional Requirements

Table 1 lists the characteristics required of the software. Key data derivable from Point OutWords usage logs include (1) motor targeting error, (2) response latency, (3) multiple-choice set size, (4) any anticipatory movement of the iPad by the caregiver, and (5) with Speak mode enabled, speech data analysis *e.g.* spectral-temporal content (Sharda et al., 2010). Inputs attributable to the caregiver's modelling are separated from the user's own during analysis via statistical clustering.

The Point OutWords software contains five separate themes each depicting a different scene associated with activities of daily living, and is experienced as a game. Gameplay includes three modes of varying therapeutic focus and difficulty, each of which has settings that can be further configured to adjust difficulty and to allow for the user's level of precision in manual motor or oral motor control. Learning begins in Point mode, which teaches pointing and dragging within a touchscreen interface. The user selects an object from one of the several scenes, for instance a shampoo bottle, a cup, a birthday cake, a toilet. The object is segmented into jigsaw puzzle pieces scattered round the touchscreen, which the user must assemble into a complete whole by dragging onto a grid.

In Type mode, puzzle pieces cannot be dragged into place in an iconic style of reference, but instead must be cued by symbolic reference: each puzzle piece is labelled with a letter in the word that names it; there are as many puzzle pieces as there are letters in the spelt word, and in order to cause a piece to snap into place within the puzzle, the user must press the corresponding symbol on a virtual keyboard that appears on the touchscreen. This mode is designed not to teach children to use specific letters to read or spell, but to progress from touching the iconic representations of objects to touching symbols spatially separate from the objects themselves, cued by visual attention-eliciting features such as flashing and lines pointing to the symbol.

For participants who are able to vocalise, Speak mode offers an opportunity to practise the motor skills that support spoken communication. In this mode, the object is segmented into a number of puzzle pieces equal to the number of syllables in the word. Each syllable is modelled, the user is prompted to speak each one, and OpenEARS speech recognition software (https://www.politepix.com/openears/) is used to detect these pronunciations. Speaking a syllable causes the corresponding puzzle piece to snap into place. Tolerance for articulation errors and other slight inaccuracies of the match between actual and modelled pronunciations is high by design, and can be configured by the caregiver. The nature of this speech matching problem, combining strong prior probability (the target syllable) with high error tolerance, yields a much simpler error surface and a correspondingly much more tractable and accurate computation than the general case of speech recognition.

2.3 Development Process

Figure 1 shows schematically the design and development process, described below.

Phase 1 – User-Centred Design and Development

Inputs: Principal design features, functional requirements for game scenarios and data logging.

Process: Phase 1 development was conducted at the Com DEALL Trust, an autism clinic in Bangalore, India, with 31 clinically diagnosed autistic children aged 3 to 7 years lacking functional communicative speech (Belmonte & Dhariwal, 2013; Belmonte et al., 2016) and their communication therapists. All users contributed as testers, and six child-therapist dyads participated as co-creators. The co-creator role involved closer work between children, therapists, and developers, including explicitly selecting amongst user interface elements such as avatars and graphical styles, and implicitly demonstrating preferences via their behaviour in interactions with mock-ups and prototypes. For the more general user tester role, feedback came via the therapists' narratives of their and their clients' interactions with the software, and also objectively via measurements in the log files. Co-creators added valuable and essential specification to the design features, and user testers provided feedback in greater numbers, useful in establishing the generality of these specifications given the great degree of heterogeneity amongst individuals with autism. Designers attended the clinic and observed users' and their therapists' interactions with successive Point OutWords prototypes, and therapists gave feedback on behalf of themselves and their clients. Prototype implementations were iteratively produced, evaluated with co-creators and testers, and updated. Figure 2 shows the software in use.

Co-creators gave feedback via unstructured interviews with therapists and designers' direct observation of usage sessions of prototype versions and mock-ups of the software. A typical software requirements elicitation scenario for business systems would use structured but open-ended questions, leading to multiple viewpoints on the required system (Browne and Rogich, 2001). However here unstructured interviews were necessary because the overall requirements, as stated earlier, were very high-level, and the therapists were exploring ways in which the overall aims could be achieved. Prototypes and mockups, i.e. storyboarding, are also standard techniques for establishing user interface requirements (Landay & Myers, 1996). When working with users with profound verbal communication difficulties who cannot readily volunteer information in the ways routinely used in walkthroughs, observation of nonverbal behavior was essential. The process of iterative user-centred design and re-design was interactive to a degree to which individual iterations are difficult and not especially productive to distinguish, i.e. the iterative process was fluid (as opposed to discrete, pre-determined steps), interactive, flexible, on-going and user-led. Below we describe in more detail each stage of development, the ways in which users and caregivers contributed to development at each of these stages, and examples of the process of user-led change throughout.

Stage 1 – Basic Style of Interface, Icons and Symbols

Early prototypes featured an avatar, and users indicated their preferences for one or another avatar icon by pointing. Across several trials, avatars were rearranged on the display to control for any display location bias in pointing. Users expressed nearly even preference for a butterfly icon- perhaps preferred because of its high chromatic contrast which drew attention- and a train icon- perhaps preferred because its semantics were a match for users' special interests in transport systems. Users expressed a clear preference for vector graphics with high contrast between individual features, versus more realistic renderings; again this preference instantiates a general autistic preference for objects of high visual salience that automatically capture attention. Because endogenous control of attention is slowed in autism, autistic users often prefer to make use of stimuli that exogenously capture their attention (Chen et al., 2012). Users also selected objects for the puzzles, again preferring high contrast. It was satisfactory to see that the standard user interface (UI) process of providing options for the users to select produced definite indication of preferences, even though the standard process of users talking through their decisions was not possible (Bias, 1991) . These preferences were documented and used to make software changes through frequent iterations of user evaluation of successive prototypes, with the same group of users.

This appeal to exogenous control of attention is perhaps most effectively illustrated by a brief anecdote: during initial data-gathering sessions, the principal investigator (M.K.B.) attended the clinic and observed the interaction of one user-therapist dyad with a Point OutWords prototype. The user in question would not attend to the iPad, despite the therapist's efforts to maintain the iPad in the user's direction of gaze. The user instead consistently oriented his gaze towards the investigator—remarkable given his tendency to avoid gazing at unfamiliar people. After some minutes of this, the therapist placed a letterboard in front of the user, and the user pointed sequentially at the letters “YOU HAVE A NICE KURTA” (spaces inserted for clarity). The investigator happened to be wearing a kurta made from fabric whose pattern featured high luminance contrast and high spatial frequency. Such interactions amongst users, therapists, designers and scientific staff provided rich information as to which sorts of stimuli would command users' attention, not only within the software but in interactions more generally. For people without autism, social stimuli such as gaze, gesture, facial expression and tone of voice are privileged in terms of saliency. People with autism, in contrast, orient not to the most ***socially*** salient stimulus in the environment but to the most ***physically*** salient stimulus.

This key insight, provided directly to the design and research teams by users with autism, via nonverbal communication, is fundamental to Point OutWords' design.

Therapists also suggested that reinforcement prompts be customisable, and attentional cues adjustable for spatial and temporal luminance contrasts, as stimuli experienced as pleasant by one user might be experienced as aversive by another and there could be no one-size-fits-all reinforcer. This feature was therefore incorporated in the software, allowing families or therapists to choose prompts which they know will be reinforcing for a particular user and to tune the visual ‘loudness’ of stimuli. Customisation of the user interface to improve learning has been shown to be a useful strategy for motivation (Cha et al, 2006).

Stage 2 – Comparative Evaluation

Users were tested with other educational apps so as to identify potential pitfalls in the interaction of autistic users with typical app designs. This process allowed interface requirements to be mined from existing applications, rather than waiting for the users to discover the problems in the developed Point OutWords. Many users would press the iPad's 'home' button to exit the app, or press the app's 'settings' button to suspend the app. As a result, Point OutWords' in-app administrative controls were made to respond only to presses that continued for three seconds, allowing the therapist or caregiver time to intervene to reorient the user to the task. Many users also would latch onto certain sounds or action-response contingencies as bases of repetitive behaviours; these contingencies were eliminated by restructuring the app to minimise their occurrence, and by detecting and terminating action-response loops in the user's sequence of interactions with the app. For example, if sequences of same action (*e.g.* a button-press) and the same stimulus contingent on that action (*e.g.* the appearance or disappearance of an icon) arose repetitively, the contingent stimulus would no longer be presented (*e.g.* the icon would not appear). These key requirements are germane to other apps developed for the target group, and so provide a ‘take-home’ set of transferable usability requirements.

Stage 3 – In-Game Behaviour Evaluation

Visuomotor interactions in Point Mode and Type Mode were tested using a mock-up in which the user and therapist sat in front of a large, opaque white sheet of heavy paper to which physical puzzle pieces were affixed, using magnets on the puzzle pieces and on the back of the paper. Designers, hidden from view at the back of the paper, used the magnets to move the pieces contingently with the user's pointing actions in a ‘Wizard of Oz’ testing paradigm (Salber and Coutaz, 1993). Observations of users' interactions with this mock-up generated qualitative data on the paths through which they moved their fingers three-dimensionally into contact with the touch surface: These interactions confirmed that often open-loop control of visuomotor targeting replaced closed-loop visuomotor feedback, and that the user's initial point of contact with the touch surface thus was error-prone.

Having contacted the touch surface in three dimensions, users then faced a simpler, two-dimensional targeting problem which they tended to resolve by successive approximation, moving the finger on the touch surface closer and closer to the intended target before departing from the touch surface. The intended target thus was described more accurately by the point of departure from the touch surface than by the point of initial contact. This feature was incorporated into the design.

Interactions with the virtual keyboard in Type Mode were tested using a prototype in which reinforcing feedback was provided by an animation and sound of a popping balloon when a correct keypress was made. Although therapists reported that users were highly engaged by the balloons, this engagement did not necessarily translate to the letter symbols on which the balloons were superposed: Therapists related how the balloons became a distraction from the keys. Therapists also observed that changing the spatial layout of letter symbols on the touchscreen to accommodate the balloons tended to impair performance; users learnt to respond most accurately when keys appeared in a standard arrangement that did not change from one trial to another. Accordingly, the final keyboard arrangement eliminated the balloon reinforcers, and relied on keys in a standard QWERTY geometry. As direct observation and therapist feedback both indicated that the large number of competing response options within a full keyboard made it difficult to users to zero in on the correct key, those keys that were unused in a given puzzle were greyed out. Sizes of the letters labelling the keys, and distances between keys, also were optimised with users in a series of prototypes. In this stage, the process again revealed general patterns that could be transferred as requirements to future games or applications for the user group.

- **Summary of outcomes of Phase 1 Development:** Significant improvements and refinements were achieved during this phase that could not have been predicted without user and therapist feedback. Specific examples are given for each Stage, to illustrate the ongoing iterative process of co-creation, user testing, and therapist feedback which led to fundamental changes in the software and user interface.
- In Stage 1 the characteristics of the user interface and icons were determined by an iterative process of co-creation, testing, and development. One result was customisability of feedback prompts (some prompts intended by designers to be reinforcing actually were so loud or sudden as to be aversive for some users with auditory sensitivities).
- Prevention of repetitive usage of predictable stimulus-response contingencies (Klin, Lin, Gorrindo, Ramsay, & Jones, 2009). In Stage 2, observation of repetitive behaviours when the game was in use led directly to the introduction of systems to avoid repetitive contingencies arising, and to altering the criteria for ending the game. This issue had not been predicted in the initial design process and was only detected by observation of the software in use. A loop-detection feature was added which identifies repeated cycles of user input and software response – e.g., a user's repetitively swiping a puzzle piece to an inaccurate location so as to

hear an error tone which that particular user finds rewarding – and breaks the cycle by disallowing further response to such inputs.

- The changes made led to workflow improvement when the game was in use: Stage 3's technique of 'Wizard of Oz' user interface testing greatly improved the development team's understanding of the limitations and differences in autistic users' control, leading to changes both in the user interface and in the data collected internally.

Phase 2 – Focus Group Evaluation

Inputs: Phase 1 prototype of Point OutWords

Process: Focus groups were convened to address two topic areas – usability/acceptability and issues associated with design of a pilot study. Usability and acceptability were addressed by conducting interviews with parents of autistic children in Cambridgeshire, UK. The pilot study was developed in consultation with a focus group of 4 parents of nonverbal autistic children enrolled at the NHS Peterborough Neurodevelopmental Service, facilitated by a parent co-investigator. These meetings and demonstrations of the software generated feedback about the project's design, aims and conduct. The process of group facilitation was led by the Patient and Public Involvement (PPI) Lead for the NHS Trust Research and Development Team. This is a standardised process involving setting group rules and parameters and clarifying the purpose of the group (in this case to look at the existing software and the suggested research protocol and give feedback and thoughts about these, as well as about the theme of the research overall). An initial set of questions is used to start discussion which is then facilitated to ensure participation by everybody and a positive experience for all participants. Further questions and discussion then occur and thematic analysis of these is reported. An example of the guidance for PPI focus groups can be found at http://www.mmgconnect.com/projects/userfiles/File/FocusGroupBrief.pdf. The main outcomes of this process are summarised below:

Outcomes and how they were used to inform Phase 3:

- Parents commented that although many apps allow users to combine pictures there is no software for combining words and Point OutWords also operates at the single-word level. This feedback was taken on board as a consideration for children who achieve the single-word level using software.
- The need for ongoing support and guidance was a common theme; not all parents are familiar with software interfaces and touchscreen hardware. This outcome led us to ensure that there was sufficient time and training offered by the research team, tailored to parents' knowledge, experience and confidence. This varied in practice from 5 minutes to about an hour.
- Parents commented that in the longer term they would prefer to use Point OutWords in the home rather than exclusively in the clinic or school. This feedback led to most input being offered at home (while continuing to give families the choice of venue).

- Parents were enthusiastic about the potential for this intervention given their children's fascination with technology, although they pointed out that the very predictable stimulus-response contingencies typical of computer user interfaces might easily become occasions for unproductive repetitive behaviours (Klin, et al., 2009). This outcome had already been noted by observation in Phase 1 (and has since been verified in another pilot study (Deane & Belmonte, 2018)) and steps taken to forestall it, although it could not be completely eliminated.
- In a related issue, some parents felt that 'screen time', unless it is educational, can actually have a negative effect on social communicative skills, though previous literature suggests that overall parents are positive about the use of technology and touchscreens in particular (Clark, Austin, & Craike, 2015). This outcome will be a consideration in future studies, particularly if it is a concern for individual parents who may wish to limit screen time of any sort.
- Parents were positive about the software's use of motion and vivid contrasts of luminance and colour in capturing and recapturing children's attention (Chen, et al., 2012; Iversen, 2007), supporting the aesthetics and style co-created with users in Bangalore. This technique has been recently recognised as best practice in user interface design for autism (Alcorn, Pain, & Good, 2014). Parents also felt that the software might be effective especially for children who are active and prone to distraction. This positive outcome in Phase 2 supported the design choices made in Phase 1 (*vide supra*).
- Parents suggested that the pilot study take account of: the number of languages to which children are exposed; whether they are using computer technology already and if so, what they use; therapies that children currently receive. This outcome will be used in future clinical studies and development phases to seek any relationships between these factors and outcomes.
- Parents also suggested regular telephone contact to answer questions about using Point OutWords and to monitor progress during the pilot. This outcome was applied during Phase 3 to offer regular support and contact with parents.

2.4 Phase 3 Pilot Study

Point OutWords was developed using iterative cycles of design, feedback and parent/carer/teacher input with the aim to enhance communication by training visuomotor skills and symbolic reference using a touchscreen. Following this process a pilot and initial feasibility study was carried out in the UK (1) to assay fidelity to the recommended treatment regime; (2) to determine the intervention's acceptability to autistic users and their caregivers, and (3) to determine the acceptability of candidate outcome measures to assess the efficacy of the Point OutWords intervention. Feedback was formally collected from parents following participation in the pilot study.

Although the scope of this pilot study did not suffice to answer the question of whether or not Point OutWords definitively can improve communicative skills or family well-being, pilot data were collected to inform a more extensive feasibility study for progression to a full clinical trial. In addition, log data were acquired to begin to address the question of whether and to what extent autistic pointing and dragging movements involve errors in visuomotor targeting.

a) *Participants:*

Participants with autism were recruited via parent support groups and networks in Peterborough. Inclusion criteria were (a) clinical diagnosis of autism; (b) nonverbal or minimally verbal (lacking communicative speech); (c) aged between 3 and 15 years; (d) English as the dominant language within the immediate family (as non-English translations of the Point OutWords software are not yet available). Exclusion criteria were severe visual or hearing impairment, or severe impairment distinct from autism and affecting movement, such as cerebral palsy. Seven children were successfully recruited to the study. One participant had a known diagnosis of Attention Deficit Hyperactivity Disorder (ADHD) in addition to autism.

b) *Procedure*

The research protocol was approved by the Nottingham Trent University College of Business, Law and Social Sciences Research Ethics Committee. Members of the research team underwent training in the use of the Point OutWords software and the outcome measures used.

Participant recruitment took place through telephone conversations with the parents of prospective participants. Information on the research programme and intervention was provided verbally and in writing. Parents or therapists were also able to request a taster session and were given the opportunity to ask any questions they had before the experimental procedure began. The first meeting between the research team and participants involved obtaining signed consent, introducing the child and their parent to the Point OutWords software, and carrying out the pre-intervention baseline measurements. Assessments were staggered over multiple sessions if the child were fatigued, unable or uninterested to complete them during.

Children, their families or therapists were then left with written instructions for the software (Appendix 1) and contact details for the research team. Instructions detailed that participants should aim for 60-minute sessions using the software with as many breaks as required, occurring at least 5 days per week. Sessions were offered at the child's school, or in the family home. Consistently with the input provided by parents in Phase 2, all parents chose to use Point OutWords at home. Post-intervention measures were taken after roughly four weeks of usage and parental feedback questionnaires were distributed.

c) *Outcome measures – internal*

Internal iPad Data Processing

The data gathered from the iPad for the individual users recorded real-time finger movements when playing the game, including the initial 'pick up' of the jigsaw piece, the position on screen as the piece was moved, and the time and position of release. The data were linked to the individual puzzles, so the movements could be associated with the identity of each piece being manipulated. The target locations where the pieces needed to go were also known, though the users could release the pieces when not exactly in place and they would 'snap' into position, with the allowed snapping distance being customisable by parents. In order to compare the behaviour for different puzzles graphically, in Figure 3 the target location for each piece is fixed as the origin (x=0, y=0) and the movements calculated relative to that when displaying. This representation shows more clearly the targeting process, since all movements for all the pieces should terminate somewhere near the origin. For each of the puzzles completed by each user, the trajectories, velocities and pauses could be calculated and compared statistically.

Visuomotor targeting error during pointing was measured as Euclidean distance in screen coordinates between the point of initial contact and the nearest extent of a target object (the nearest edge of a puzzle piece in Point mode, the centre of the target key in Type mode). Visuomotor targeting error during dragging (in Point mode) or during other screen contact (*e.g.* successive approximation to a keyboard position in Type mode) was measured both as the temporal duration of screen contact, and the spatial path length of screen contact in ratio to the shortest possible drag path, averaged within each puzzle. Anticipatory movements of the iPad by the parent during Type mode were measured as magnitudes of the projection of the accelerometer vector onto the vector from the centre of the current target key to the position of the most recent departure from the touchscreen. In addition, for each puzzle undertaken to completion the following data were collected: number of failed attempts to drag pieces; overall time per piece successfully completed; variation of speed over time for each piece; variation of direction over time for each piece. These measures were used both to assess change over time for participants with autism and to compare parameters between participants with autism and those without.

d) Piloting of Outcome measures – external

An initial assessment of feasibility and acceptability of a range of measures before and after the intervention was undertaken. Validated measures previously used with autistic children and their families were selected to assess the feasibility of measuring the following areas of development which we hypothesise are targets for Point OutWords: (i) the motor skills directly addressed by Point OutWords, (ii) communicative skills, (iii) daily living skills and social functioning. A mix of parent-survey and child-interview measures was piloted to minimise the burden on children and parents and to obtain data from multiple sources. Some measures were applied outside their normed chronological age ranges; however, the subtractive, test-retest nature of the trial design makes it possible to use raw or age-equivalent scores rather than scaled scores. Children were assessed using (1) Mullen Scales of

Early Learning: Fine Motor, Receptive Language, Expressive Language; (2) Clinical Evaluation of Language Fundamentals (CELF-4): Concepts & Following Directions, Word Classes, Sentence Structure, Word Structure, Recalling Sentences, Formulated Sentences. These assessments occupy about 30 minutes each. Parent interviews and checklists were the Social Responsiveness Scale (SRS-2, 15 minutes) and Vineland Adaptive Behaviour Scales II (VABS-2, 20-40 minutes); total time for parents 45-75 minutes per child. Raw scores were calculated for the MSEL and the CELF-4; standardised scores could be calculated for the parent-report measures SRS-2 and VABS-II.

e) Usability and acceptability measures

Parent, teacher and carer involvement has been central to this project at every stage, and further feedback on the practicality and acceptability of Point OutWords was sought as part of the pilot project. Usability and acceptability of Point OutWords as an intervention were assessed using a feedback form with both specific questions and space for any further comments, distributed to parents post-intervention. The form requested an estimate of the time spent successfully using the iPad, comments on positive and negative aspects of the Point OutWords programme and their experience of the intervention programme as a whole. These responses are summarised below in the results section. Dropout and completion rates were also noted.

f) Comparison of log data between children with and without autism

Participants without autism were recruited from a state primary school, to collect data from typically-developing children matched by age to the children with autism who had provided the most log data in the intervention pilot study. Three children, aged 5-6 years, took part. Children were given a short explanation and demonstration of Point OutWords, followed by the opportunity to use Point OutWords whilst being observed to ensure that they understood. The data from this introductory session were not recorded. The application was set to display Point mode and Type mode trials equally. The children were then given the iPads for a few days to use Point OutWords independently, for 30-60 minutes in total.

For participants with and without autism, time series of the display coordinates of the finger during each drag movement were initially collected as i) speed in pixels per clock tick and ii) heading in radians relative to the zero heading which points directly from the starting point to the target location. These data were then transformed to time series of linear speed in the direction of motion, and angular speed (i.e., rate of change of the direction of motion over time). Sample variance of the linear speed and circular variance (Fisher, 1993; Mardia & Jupp, 2000) of the angular speed were derived for each individual subject, for each separate puzzle. Mixed-effects analyses were conducted (SAS PROC MIXED), with linear speed and angular speed as dependent variables, diagnosis (autism or typical) as independent variable and participant and puzzle number as random effects.

3. Results from Pilot Study

i) Participation/feasibility

Seven participants with autism (6 boys, 1 girl) were recruited. Mean age at baseline was 57.1 months, range 40-74. Of those who enrolled in the pilot study, 2 did not complete the four-week intervention, a 28.6% dropout rate. Only four participants provided log data sufficient for initial analysis. It may be that children with no communication or social interaction at all or children with rapidly-developing speech and cognition may find the task uninteresting/too difficult or too “quick and easy”, respectively. This variation in acceptability suggests that only a subset of children with autism who attempt to use the software may find it useful, but for those children it is enjoyable, interesting and potentially effective. As discussed in the introduction, children with autism and significantly limited communication have historically not been included in many research projects and intervention developments, which is a major issue for parents, funders and researchers. Point OutWords aims to fill some of this gap by its novel approach. Table 2 summarises the participant characteristics. Repeating all the measures after only four weeks was seen as burdensome by some parents and not all repeat measures could be completed in this short timescale (shorter than that which would be appropriate in a full clinical trial). This brief time frame is likely to have been a factor in at least some of the missing data. Missing data are inevitable in any treatment study and clinical trials teams use well-established techniques to address this issue (such as analysing by “intention to treat” as well as by “completed treatment” to avoid selection bias). The process of design and feedback with children and families aimed to maximise acceptability and usability.

ii) Parent feedback

Feedback by questionnaire was collected from the parents participating in the pilot study as part of the ongoing process of participation, co-design and refinement carried out throughout all phases of design and evaluation. All parents made at least one positive comment. One child did not engage with the loaned iPad at all, preferring their own familiar one— an issue that has been addressed as Point OutWords has moved from a bespoke development prototype to a downloadable App Store release. One child found the puzzles very easy and completed them quickly. Parents consistently found it hard to provide the suggested amount of input of up to 5 hours per week and suggested that 2.5 hours would be more realistic. Parents reported that even if they could find the time themselves to sit with their children for an hour at a time, the children would lose interest in a shorter time than this. Children were in practice reported to play on the iPad in short bursts and sometimes without the parent present. This tendency to use Point OutWords whilst alone limits the opportunities for scaffolding and for errorless learning, and presents a risk that Point OutWords could become an outlet for repetitive behaviours (Deane & Belmonte, 2018). Repetitive behaviours in moderate degrees can be useful as a relief from anxiety or even a reward for successful learning, but become unproductive when they displace opportunities for learning. It is also possible that parents may feel stressed if they are not meeting an expectation set for them, a pitfall which will need to be addressed in further studies.

Families overall found the software easy to use; some of the children enjoyed using it very much, while others were less interested. One parent suggested games related to the child's personal interests; although such customisation of content is highly desirable, it is currently not practical in terms of computer programming resources. Customisation of prompts and completion sounds is important as some children prefer louder sounds or music while others do not.

iii) Outcome measures – external

Means and standard deviations for the baseline measures are presented alongside the range of scores available for each measure in Table 3. The domains of functioning assessed are below. Of course, standardised assessments are a double-edged sword: they permit quantitative comparisons between individuals and groups, but at the same time reduce complex skills to a small collection of specific tasks and tests, presented in specific formats which might not be optimal or even well applicable for all of the individuals being assessed. This description of standardised measures therefore should be interpreted with this caveat. It should be noted that for the child measures (MSEL, CELF) higher numerical scores indicate greater measured skill in all of the domains assessed. For example, a higher score on the MSEL fine motor subscale indicates greater measured abilities in fine motor tasks; for the CELF domain scores, a higher score indicates more extensive measured communication skills and a lower score a lower level of communication skills in each domain. For the SRS-2 higher T scores indicate more difficulties as reported by the parent, whereas for the VABS-II higher standardised scores indicate more skills as reported by the parent.

For the SRS-2 and VABS-II, standardised scores could be computed as all children were within the age range for the measures, allowing direct estimation of the functioning of the children on these standardised measures compared to other children of the same age. For comparing pre- and post-intervention data, the issue of missing data and the large variances of the scores between individuals made exploration of patterns of change in individuals' scores more informative than comparing means; these data are presented in Figure 4 for all children and all measures.

Mullen Scales of Early Learning (MSEL)

Five children provided a complete set of pre- and post-intervention data, and six children provided full data for the fine motor domain. Post-intervention fine motor scores either increased from the baseline or stayed the same for all but one participant. One participant showed a particularly marked increase in fine motor skills, rising from a low pre-intervention score of 2 to a post-intervention score of 24. Receptive and Expressive language showed no consistent pattern of change over this brief test-retest interval.

Clinical Evaluation of Language Fundamentals (CELF-4)

Only 1 of the 7 participants yielded a full set of non-zero data for the CELF-4 measures. For the majority of participants, scores on most subscales were 0. This negative feasibility result suggests that the CELF-4 is not an appropriate measure in this population for future studies. A simpler measure focused exclusively on receptive vocabulary, such as the British Picture Vocabulary Scales, could be considered as a substitute.

Social Responsiveness Scale (SRS-2)

All the mean domain T scores were more than two standard deviations above the typical population mean, demonstrating significant difficulties in social functioning across the board. SRS-2 scores for this group of children showed particularly high levels of social communicative difficulty and restrictive and repetitive behaviours, even compared with the wider population of children with autism, but did not show a consistent pattern of change over time in this small exploratory study. Four children provided complete data both pre- and post- intervention.

Vineland Adaptive Behaviour Scales (VABS-2)

Scores were available for five participants pre- and post-intervention. Three participants showed a marked increase across all domains from pre-intervention to post-intervention, indicating higher levels of functioning in daily life. One participant exhibited score decreases across all domains after the intervention took place suggesting lower levels of functioning in daily life. One participant had no consistent pattern. There was thus no clear pattern for adaptive behaviour scores in this very small sample.

iv) Outcome measures – internal

Log data for the four participants with autism from whom a full data set was available were analysed for changes in speed and accuracy of movement during the intervention period. For three of the participants accuracy of initial reach to the target was also analysed. One participant became more accurate in two-dimensional (on the touchscreen) targeted movements: there was a significant effect of time on ratio of actual drag path length to shortest possible path length ($F(1, 972) = 30.67$, $p<.00001$). No other significant changes within individuals were identified over the short term of the study.

v) iPad data comparison between children with autism and typically-developing participants

Table 4 shows the demographics of the three typically-developing children who participated. These typically developing children and their parents commented that they enjoyed playing the game but found it easy and completed the puzzles quickly. These three typically developing children were contrasted against the three children with autism who accumulated sufficient valid data (participants 000, 002 and 004). Table 5 summarises these analyses, showing significantly greater variability within the autism users, for both linear and angular speed, on all measures. For most of the measures variability in the typically-developing children was very low indeed, showing almost constant speed following movement initiation. Figure 3 illustrates graphically the differences between the movement sequences of children with autism and typically developing children. The points on the graph indicate length of pauses and show that the children with autism were more likely to pause, assess and then move swiftly (in quite straight lines) to the next pause point. This contrasted with the typically developing children who made more continuous movements arcing towards the target location. This piecewise approach to motor planning may reflect an accommodative strategy for the constraint of open-loop motor control within each individual movement segment. The abrupt changes in speed and direction between movement segments relate straightforwardly to the aforementioned observation of heightened variance in autistic movement vectors, and are consistent with the heightened variability described in a recent comprehensive study of autistic motor behaviours measured in interaction with a touchscreen device (Anzulewicz, Sobota, & Delafield-Butt, 2016).

4. Discussion

As discussed in section 1.1, tablet-based technologies carry potentially significant advantages for users with motor impairments, who prefer direct relationships between input and output, and can also allow interventions targeted at younger children and people with less developed communication and literacy skills. Children with autism and significant difficulties with verbal communication may have all these characteristics. There is some existing work on tablet computer applications with therapeutic aims for children with autism as well as other groups, and early interventions in general have been shown to heighten impact on intelligence and communicative skills in later life (Gulsrud, Hellemann, Freeman, & Kasari, 2014). However, few technology-based teaching methods have yet managed to generalise 'in-game' skills to real-life situations. As discussed earlier, a recent intervention study found no real-life benefit to social communication from an app using social pictorial stimuli (Fletcher-Watson, et al., 2016). Higher-level skills such as social communication may be harder to target directly through game-based learning methods, although some limited effects on real-world behaviours have been found (Golan et al., 2010; Hopkins et al., 2011). Technological interventions targeting lower–level skills, such as attentional gaze and joint attention (Wass & Porayska-Pomsta, 2014; Gulsrud et al., 2014) have yielded promising results. These data suggest that in children with autism, early pointing could have an effect on expressive language development, and illustrate the importance of therapeutic interventions targeting relevant motor and cognitive skills. Many people with autism struggle with activities of daily living, education and interaction with others; improving social communication and use of symbolic communication can have a large overall impact on wellbeing and access to education and daily activities.

The lengthy process of collaborative design and iterative feedback cycles has resulted in software that provides detailed, analysable data on interaction with the iPad, and acceptability and practicability for use at home by at least a subgroup of autistic children with significant expressive language impairment. Point OutWords builds on the already established perceptual and cognitive strengths and preferences of people with autism. Outcome measures have been refined on the basis of this initial feasibility experience and earlier stages of development. These include measures of real-life functioning to assess out-of-game generalisation, a sticking point for many interventions aimed directly at enhancing social communication by the ‘front door’. These characteristics make it a candidate for a task-shifting approach (Dasgupta et al., 2016) of parent-delivered intervention with appropriate training and supervision from clinicians, rather than clinic-based intervention by clinicians. In addition to the potential benefits of being more available than resource-heavy specialised intervention, generalisations of skills learnt in the relevant environment can be hypothesised to be more likely.

Overall the process of user-centred design, as described in detail in Section 2, was shown to work very successfully with children with autism despite their limited expressive language capabilities. Both therapist and child were involved from the earliest stages. By being offered choices, the children were engaged in the process from the outset, and could express preferences nonverbally. Then by using existing apps as test beds for overall workflow and interfaces, appropriate design choices could be made in advance to avoid identified pitfalls. These processes and the UI and learning issues revealed by them could be applied to other applications for autistic learners- and the more general principles of starting from existing elements (images or apps) can be applied to other specialist groups of learners. The challenge of co-creation and testing with a population of users who have little or no spoken communication can be addressed via such approaches. Such inclusion is of crucial importance as nonverbal people with autism, of any age, are very frequently not included in research studies of all sorts, including software and intervention design and development. Our study has shown that these apparent barriers can be overcome to great effect and should not prevent participation in research, innovation and design by people with autism who lack communicative speech.

Some of the most important learning points from this process were: (i) in Phase 1 numerous changes were made to the software and the user interface in an iterative co-creation and testing process, which was necessarily more fluid and less pre-determined than some testing processes in other areas of development because of the differences in motor and sensory processing, and choices and preferences, of children with autism, and the profound limitations in verbal communication; (ii) This approach was overall highly successful in increasing understanding of issues not considered *a priori,* such as the visual salience of stimuli in the app and in the surrounding environment. For example, the absence of privileging of social stimuli (Gray et al., 2018) and resultant primacy of physically salient over socially salient stimuli in exogenous attentional cueing (Chen et al., 2012) initially posed a difficulty but then was used as a strength to help children to complete the task.; (iii) it also was clear that children could engage very usefully in 'Wizard of Oz' testing in which they demonstrated, nonverbally, their visuomotor processing style of open-loop processing, allowing the most relevant data to be logged by the app and used in the game, rather than assuming typical visuomotor processing; (iv) Phase 2 extended the software's co-creation with children and therapists by applying the methodology of 'patient and public involvment' (PPI), extracting themes of importance from parents' verbal reflections to guide both the design of the Phase 3 pilot study (particularly around the choice and number of non-iPad measures and assessments, and the length and number of sessions with the iPad) and future considerations in further software design and development; (iii) in Phase 3, feedback was gained from parents about how acceptable, easy, and enjoyable the process was for them and their children as well as how feasible it was to carry out the protocol. Common themes both positive and negative emerged amongst even this small group of parents, along with some individual comments on the software and the study. Suggestions for improvement are discussed further in the Limitations section below. The combination of direct observational and focus-group data before the pilot study, consideration of the reasons for missing data particularly post-intervention in the pilot study, and detailed feedback from parents taking part in the pilot study allowed ongoing adjustment to both the software and the overall protocol, and revealed further information about feasibility to be taken forward into future studies.

Even with the small number of participants in this study, the internal logs yielded rich data showing some overall change in skills over time, and heightened variability in motor skills in the children with autism. Specifically, analysis of the iPad logs has demonstrated significantly greater variance in velocity vectors for children with autism in contrast with typically developing children, an observation consistent with the hypothesis that the autistic users may be implementing each movement as a series of discrete, offline computations each without (much) benefit of sensory feedback, rather than as an online computation continuously updated with reference to visual feedback (Haswell, et al., 2009). The increased solution time required for each puzzle by the children with autism is consistent with this hypothesis.

Overall the design process and pilot study suggest that caregiver-delivered therapies using relatively inexpensive touchscreen technologies can usefully target fundamental processes such as motor control and symbolic reference, as a complement to more directly-targeted interventions for social communication. Interventions delivered at home using accessible, familiar technologies such as iPads, which can be used at any time when the child wishes, are welcomed by all the parents/carers/teachers involved at all stages in this project, with specialised clinical intervention and support included as needed.

5. Summary and Future Work:

The autism phenotype shows both convergence from many independent causal factors and divergence into molecular, neural, cognitive and behavioural heterogeneity (Belmonte, Cook, et al., 2004). Distinct phenotypic profiles will require distinct targeted therapies. Point OutWords targets one phenotypic subtype in whom a lack of functionally communicative speech may be secondary to a distinctive pattern of motor impairments and disparity between impaired expressive and more intact receptive language (Belmonte et al., 2013). Point OutWords has clear potential for improving motor skills, and thus - we hypothesise - communication skills. If proven effective, approaches such as that of Point OutWords may be useful as a complementary approach for children already receiving more direct training in communication and social skills.

5.2 Limitations

This paper reports an innovative potential intervention co-created with autistic users. There remain limitations to both the study and the resulting software despite the significant progress in design, and largely positive feedback from the pilot study. Firstly, although the prompts are customisable, at the current stage of development the content is not individually customisable for each user. Although Point OutWords has been designed to appeal to autistic cognitive strengths and preferences, there are always individual preferences within any group, with variation in sensory needs and subjective reward values. It is already known that “typical” rewards may not be rewarding for children with autism, and rewards in any setting need to be individualised. Full customisation for every user may be possible in future if resources allow, and if a randomised controlled trial demonstrates efficacy of Point OutWords’ current version which would warrant such further investment. Such customisation also would permit inclusion of larger numbers of exemplars in a diversity of colours to promote generalisation beyond the training context (Allen et al., 2015). Secondly, some children did not use the study iPads as they were unfamiliar, and at the time the software was a development version requiring the study team’s iPads to be used. This issue has been addressed for future work as the software is now freely available on the App Store for use on the child’s familiar device, increasing the chance they will use and enjoy it. Thirdly, we discovered during the pilot phase that some children whom we had recruited did not have sufficient interest, or possibly developmental abilities, to make use of the software at all, while others were too developmentally advanced. We have learnt from this experience that the initial assessments and trial sessions should take place in advance of recruitment for the full intervention process, so that children who are clearly too able, or are not able to use the software for any reason, do not go through the full process of assessment which does take significant time and effort on their and their family’s part. Fourthly, it would be desirable in future to be able to develop localisations for languages other than English, and for scripts other than the Roman alphabet, if resources are available. Fifthly, the external outcome measures did not (and were not designed to) in this pilot study provide enough data for quantitative analysis. We did however learn useful limitations of the piloted measures for future work: one measure, the CELF-4, provided no useful data for all but one participant. The MSEL, however, did provide potentially useful measures of communicative function in a more play-based assessment. The CELF-4 will not be included in future studies, but may be replaced by a more purely vocabulary-oriented instrument. In future studies with larger numbers of participants it may be possible to determine which pre-intervention profiles are associated with different patterns of changes in functioning, and to stratify participants by pre-intervention level and profile of functioning.

5.3 Implications and future work

Variability of outcome measures between individual users, as seen universally in studies with people with autism, suggests that analysis of change for each child, and for groups of children with particular characteristics, may be most useful. Analysis of logs has provided data consistent with the hypothesis that for this group of children with autism, movement control is an offline process, with potential for investigating motor function further using the app. Leading on from this result, performance on the simple task of dragging a cursor to a target could be measured with and without the availability of visual feedback during the movement. If the hypothesis is correct we would predict that typically developing children would perform better with visual feedback, with equal performance between groups in the condition where visual feedback during movement is not available. This use of a game-like computerised measure of temporal consistency of movement execution as a proxy for the internal motor control variables in the individual also has clear potential for further investigation of, and testing of interventions for, motor control in typically-developing people, people with autism, and other clinical groups such as those with developmental, acquired or degenerative motor disorders.

This work will be followed up by a full feasibility randomised controlled trial of Point OutWords, with the inclusion of a control-intervention group, in the NHS service in Peterborough, UK, which will address questions of recruitment, randomisation, fidelity to the intervention and full assessment protocol, and statistical power, and will use detailed qualitative analysis of feedback, focus groups and diaries. Internal log measures and a revised set of external measures will address additional questions such as whether any improvements in outcome measures are specific to the previously identified subgroup of people with autism who have significant impairments in motor functioning, and will support a complete evaluation of whether and to what extent caregivers may be moving the tablet device in ways that could unconsciously influence the autistic user's choice of keys on the touchscreen keypad.

Point OutWords is open-source software released under the Mozilla Public License 2.0, a flexible licensing scheme that permits both continued non-commercial development and commercial derivatives. Should the pending trial establish clinical efficacy, justification would exist for such further development and incorporation of new features. In particular, parents have mentioned the need for customisability and extensibility of content. In addition, scope would exist for localisations incorporating languages other than English and keyboard scripts other than the Roman alphabet, and for an Android-based implementation to complement the current iOS.

Acknowledgements

M.KB.'s work on development of Point OutWords was supported by a Fulbright-Nehru Senior Research Fellowship from the United States – India Educational Foundation, funded by the governments of India and the United States. M.K.B.'s work on preparation of this report was funded in part by the UK National Institute for Health Research: This report is independent research funded by the National Institute for Health Research - Research for Patient Benefit, "Evaluation of Point OutWords, a Motor Skills Intervention to Promote Language Development in Non-Verbal Children with Autism: A Feasibility Study", PB-PG-0816-20019. The views expressed in this publication are those of the author(s) and not necessarily those of the NHS, the National Institute for Health Research or the Department of Health.

Author Biographies

Emma Weisblatt is a consultant developmental neuropsychiatrist. She obtained her PhD in schizophrenia genetics. She is a member of the Cambridge Laboratory for Research in Autism (CLaRa) in the Psychology Department of the University of Cambridge, with research interests including perception, movement disorders and clinical phenotypes, genetics and neuropsychiatry.

Caroline Langensiepen is a Senior Lecturer in the Department of Computing and Technology at Nottingham Trent University. Her research interests include ambient intelligence, robotics and assistive systems for the elderly, as well as more general aspects of user-centred design and requirements elicitation.

Bev Cook is a Senior Lecturer in the Department of Computing and Technology at Nottingham Trent University. She teaches mobile-platform programming and studies usability of smart devices in education and healthcare, working closely with industrial partners.

Claudia Dias is a psychology student and parent of two children with autism. She has for two years been a parent partner advising and facilitating the development of Point Outwords.

Kate Plaisted Grant is a Senior University Lecturer in the Department of Psychology, University of Cambridge, and is head of the CLaRA lab. She researches cognition and perception in autism, particularly categorisation, visual perception and auditory processing.

Manuj Dhariwal is a doctoral student at the MIT Media Lab in the Laboratory for Social Machines, with a background in creating games for language learning. His master's thesis in computer science at MIT looked at children as gifted language builders; specifically, he developed an experimental and theoretical tool for studying the language of geometric concepts.

Meggie Fairclough studied Psychological and Behavioural Sciences at the University of Cambridge, graduating in 2017. She worked as a member of the Point OutWords project team in 2016-17.

Steph Friend studied Psychological and Behavioural Sciences at the University of Cambridge, graduating in 2017. She worked as a member of the Point OutWords project team in 2016-17.

Amy Malone studied Psychological and Behavioural Sciences at the University of Cambridge, graduating in 2017. She worked as a member of the Point OutWords project team in 2016-17.

Bela Varga-Elmiyeh is studying medicine at the University of Cambridge and took his intercalated BA in Psychology, graduating in 2017. He worked as a member of the Point OutWords project team in 2016-17.

Alicia Rybicki is a BBSRC-funded PhD student in Neuroscience at the University of Birmingham. Her current research investigates disorders of movement and social cognition in those with autism spectrum conditions.

Prathibha Karanth is a speech language pathologist, and Founder Director and Managing Trustee of The Communication DEALL Trust. With a longstanding interest in language disorders both in children and adults, she has worked over four decades in the areas of adult aphasias, acquired dyslexias, learning disability, specific language impairment and communication in autism / pervasive developmental disorders. Her work on clinical aspects as well as research and training has driven the development and continuous fine-tuning of the Com-DEALL programme and model.

Matthew Belmonte's research asks how domain-general cognitive capacities shape the developmental emergence of both social and non-social perception, cognition and action– giving rise to individual differences therein and autistic disorders thereof. His work in England, the United States and India has related autistic traits, cognitive sex and gender differences, individualistic and collectivistic cultures, construal level and psychological distance.

References

Alcorn, M. A., Pain, H., & Good, J. (2014). *Motivating children's initiations with novelty and surprise: initial design recommendations for autism.* In *Proceedings of the 2014 conference on Interaction design and children* (pp. 225-228). ACM.

Allen, M., Hartley, C., & Cain, K. (2015). Do iPads promote symbolic understanding and word learning in children with autism? *Frontiers in Educational Psychology, 6,* 138. doi: 10.1016/0022-0965(90)90036-8

Amato, J., & Slavin, D. C. (1998). Preliminary investigation of oromotor function in young verbal and nonverbal children with autism. *Infant Behavior and Development, 35*(2012), 838-846.

Anderson, D.K., Lord, C., Risi, S., Shulman, C., Welch, K., DiLavore, P.S., Thurm, A., Welch, K., & Pickles, A. (2007). Patterns of growth in verbal abilities among children with autism spectrum disorder. *Journal of consulting and clinical psychology*, *75*(4), 594. doi: 10.1037/0022-006x.75.4.594

Anzulewicz, A., Sobota, K., & Delafield-Butt, J. T. (2016). Toward the autism motor signature: Gesture patterns during smart tablet gameplay identify children with autism. *Scientific Reports, 6*. doi: 31107 10.1038/srep31107

Belmonte, M. K. (2000). Abnormal attention in autism shown by steady-state visual evoked potentials. *Autism, 4*, 269-285.

Belmonte, M. K., Allen, G., Beckel-Mitchener, A., Boulanger, L. M., Carper, R. A., & Webb, S. J. (2004). Autism and abnormal development of brain connectivity. *Journal of Neuroscience, 24*(42), 9228-9231. doi: 10.1523/jneurosci.3340-04.2004

Belmonte, M. K., Cook, E. H., Anderson, G. M., Rubenstein, J. L. R., Greenough, W. T., Beckel-Mitchener, A., Courchesne, E., Boulanger, L. M., Powell, S. B., Levitt, P. R., Perry, E. K., Jiang, Y., DeLorey, T. M., & Tierney, E. (2004). Autism as a disorder of neural information processing: directions for research and targets for therapy. *Molecular Psychiatry, 9*(7), 646-663. http://www.mattababy.org/~belmonte/Publications/Papers/04_Targeted_Research/

Belmonte, M. K., & Dhariwal, M. (2013). Design of a touch-screen computer application to develop foundational motor communicative skills. Abstract presented at the International Meeting for Autism Research, San Sebastián. https://InSAR.confex.com/insar/2013/webprogram/Paper14681.html

Belmonte, M. K., Langensiepen, C. S., Weisblatt, E. J., Brown, D. J., Rybicki, A., Dhariwal, M., Saxena-Chandhok, T., & Karanth, P.(2016). Can Computer-Assisted Training of Prerequisite Motor Skills Help Enable Communication in People with Autism? *2016 9th International Conference on Interactive Technologies and Games (Itag)*, 13-20. Los Alamitos, California: IEEE Computer Society Conference Publishing Services. doi: 10.1109/iTAG.2016.10

Belmonte, M. K., Saxena-Chandhok, T., Cherian, R., Muneer, R., George, L., & Karanth, P. (2013). Oral motor deficits in speech-impaired children with autism. *Frontiers in Integrative Neuroscience, 7,*47. doi: 10.3389/fnint.2013.00047

Bhat, A. N., Galloway, J. C., & Landa, R. J. (2012). Relation between early motor delay and later communication delay in infants at risk for autism. *Infant Behavior & Development, 35*(4), 838-846. doi: 10.1016/j.infbeh.2012.07.019

Bias, R. (1991). Interface-Walkthroughs: efficient collaborative testing. *IEEE Software*, *8*(5), 94-95. doi: 10.1109/52.84220

Browne, G. J., & Rogich, M. B. (2001). An empirical investigation of user requirements elicitation: Comparing the effectiveness of prompting techniques. *Journal of Management Information Systems*, *17*(4), 223-249. doi: 10.1080/07421222.2001.11045665

Cardinal, D. N., Hanson, D., & Wakeham, J. (1996). Investigation of authorship in facilitated communication. *Mental Retardation, 34*(4), 231-242.

Center for Assessment, Planning and Accountability. Methodology Brief: Introduction to Focus Groups. Retrieved from http://www.mmgconnect.com/projects/userfiles/File/FocusGroupBrief.pdf. 3/8/18.

Cha H.J., Kim Y.S., Park S.H., Yoon T.B., Jung Y.M. & Lee J.H. (2006) Learning Styles Diagnosis Based on User Interface Behaviors for the Customization of Learning Interfaces in an Intelligent Tutoring System. In: Ikeda M., Ashley K.D., Chan TW. (eds) *Intelligent Tutoring Systems. ITS 2006.* Lecture Notes in Computer Science, vol 4053. Heidelberg, Berlin: Springer. doi: 10.1007/11774303_5

Chang, B. & Ungar, D. (1995). Animation: From Cartoons to the User Interface. *Proceedings of the 6th Annual ACM Symposium on User Interface Software and Technology*, pp 45-55. doi: 10.1145/168642.168647

Chen, G. M., Yoder, K. J., Ganzel, B. L., Goodwin, M. S. & Belmonte, M. K. (2012). Harnessing repetitive behaviours to engage attention and learning in a novel therapy for autism: an exploratory analysis. *Frontiers in Psychology, 3*. doi: 12 10.3389/fpsyg.2012.00012

Clark, M. L. E., Austin, D. W. & Craike, M. J. (2015). Professional and Parental Attitudes Toward iPad Application Use in Autism Spectrum Disorder. *Focus on Autism and Other Developmental Disabilities, 30*(3), 174-181. doi: 10.1177/1088357614537353

Dasgupta, J., Bhavnani, S., Lockwood-Estrin, G., Mukherjee, D., Banerjee, A., Belmonte, M.K., Chakrabarti, B., Divan, G., Dawson, G., Johnson, M.H., McPartland, J.C., Singh, N.C. & Patel, V. (2016). Translating neuroscience to the front lines: Point-of-care detection of neuropsychiatric disorders. *Lancet Psychiatry, 3*(10):915-917. doi: 10.1016/S2215-0366(16)30186-9

Deane, R., & Belmonte, M.K. (2018). Caregiver involvement makes the difference between repetitive behaviours and engaged learning in a computer-assisted therapy for autism. *Proceedings of the 12th International Conference on Disability, Virtual Reality & Associated Technologies with Interactive Technologies and Games,* Nottingham, 4–6 September 2018.

Doherty-Sneddon, G., Riby, D. M., & Whittle, L. (2012). Gaze aversion as a cognitive load management strategy in autism spectrum disorder and Williams syndrome. *Journal of Child Psychology and Psychiatry, 53*(4), 420-430. doi: 10.1111/j.1469-7610.2011.02481.x

Doherty-Sneddon, G., Whittle, L., & Riby, D. M. (2013). Gaze aversion during social style interactions in autism spectrum disorder and Williams syndrome. *Research in Developmental Disabilities, 34*(1), 616-626. doi: 10.1016/j.ridd.2012.09.022

Fisher, N. I. (1993). *Statistical Analysis of Circular Data*. Cambridge: Cambridge University Press.

Fletcher-Watson, S., Petrou, A., Scott-Barrett, J., Dicks, P., Graham, C., O'Hare, A., McConachie, H. (2016). A trial of an iPad intervention targeting social communication skills in children with autism. *Autism, 20*(7), 771-782. doi: 10.1177/1362361315605624

Forsey, J., Bird, E. K. R., & Bedrosian, J. (1996). Brief report: The effects of typed and spoken modality combinations on the language performance of adults with autism. *Journal of Autism and Developmental Disorders, 26*(6), 643-649. doi: 10.1007/bf02172353

Golan, O., Ashwin, E., Granader, Y., McClintock, S., Day, K., Leggett, V., & Baron-Cohen, S. (2010). Enhancing Emotion Recognition in Children with Autism Spectrum Conditions: An Intervention Using Animated Vehicles with Real Emotional Faces. *Journal of Autism and Developmental Disorders, 40*(3), 269-279. doi: 10.1007/s10803-009-0862-9

Grayson, A., Emerson, A., Howard-Jones, P., & O'Neil, L. (2012). Hidden communicative competence: Case study evidence using eye-tracking and video analysis. *Autism, 16*(1), 75-86. doi: 10.1177/1362361310393260

Gray, K.L.H., Haffey, A., Mihaylova, H.L. & Chakrabarti, B. (2018). Lack of privileged access to awareness for rewarding social scenes in autism spectrum disorder. *Journal of Autism and Developmental Disorders*, *48*(10), 3311-3318. doi: 10.1007/s10803-018-3595-9

Green, J., Charman, T., McConachie, H., Aldred, C., Slonims, V., Howlin, P., Le Couteur, A., Leadbitter, K., Hudry, K., Byford, S., Barrett, B., Temple, K., Macdonald, W., Pickles, A. & PACT Consortium. (2010). Parent-mediated communication-focused treatment in children with autism (PACT): A randomised controlled trial. *Lancet, 375*(9732), 2152-2160. doi: 10.1016/s0140-6736(10)60587-9

Green, J., Charman, T., Pickles, A., Wan, M. W., Elsabbagh, M., Slonims, V., Taylor, C., McNally, J. Booth, R., Gliga, T., Jones, E. J. H., Harrop, C., Bedford, R., Johnson, M. H. & BASIS team. (2015). Parent-mediated intervention versus no intervention for infants at high risk of autism: a parallel, single-blind, randomised trial. *Lancet Psychiatry, 2*(2), 133-140. doi: 10.1016/s2215-0366(14)00091-1

Gulsrud, A. C., Hellemann, G. S., Freeman, S. F. N., & Kasari, C. (2014). Two to Ten Years: Developmental Trajectories of Joint Attention in Children with ASD Who Received Targeted Social Communication Interventions. *Autism Research, 7*(2), 207-215. doi: 10.1002/aur.1360

Haswell, C. C., Izawa, J., Dowell, L. R., Mostofsky, S. H., & Shadmehr, R. (2009). Representation of internal models of action in the autistic brain. *Nature Neuroscience, 12*(8), 970-972. doi: 10.1038/nn.2356

Hopkins, I. M., Gower, M. W., Perez, T. A., Smith, D. S., Amthor, F. R., Wimsatt, F. C., & Biasini, F. J. (2011). Avatar Assistant: Improving Social Skills in Students with an ASD Through a Computer-Based Intervention. *Journal of Autism and Developmental Disorders, 41*(11), 1543-1555. doi: 10.1007/s10803-011-1179-z

Iversen, P. (2007). The informative pointing method. Retrieved from http://www.StrangeSon.com/

Kagohara, D. M., van der Meer, L., Ramdoss, S., O'Reilly, M. F., Lancioni, G. E., Davis, T. N., Rispoli, M., Lang, R., Marschik, P. B., Sutherland, D., Green, V. A., & Sigafoos, J. (2013). Using iPods (R) and iPads (R) in teaching programs for individuals with developmental disabilities: A systematic review. *Research in Developmental Disabilities, 34*(1), 147-156. doi: 10.1016/j.ridd.2012.07.027

Karanth, P., Shaista, S., & Srikanth, N. (2010). Efficacy of communication DEALL--an indigenous early intervention program for children with autism spectrum disorders. *Indian Journal of Pediatrics, 77*(9), 957-962. doi: 10.1007/s12098-010-0144-8

Kenny, L., Hattersley, C., Molins, B., Buckley, C., Povey, C., Pellicano, E. (2017). Which terms should be used to describe autism? Perspectives from the UK autism community. *Autism,* 20(4), 442-462. doi: 10.1177/1362361315588200

King, M. L., Takeguchi, K., Barry, S. E., Rehfeldt, R. A., Boyer, V. E., & Mathews, T. L. (2014). Evaluation of the iPad in the acquisition of requesting skills for children with autism spectrum disorder. *Research in Autism Spectrum Disorders, 8*(9), 1107-1120. doi: 10.1016/j.rasd.2014.05.011

Klin, A., Lin, D. J., Gorrindo, P., Ramsay, G., & Jones, W. (2009). Two-year-olds with autism orient to non-social contingencies rather than biological motion. *Nature*, 459(7244), 257-261. doi: 10.1038/nature07868

Landay, J. A., & Myers, B. A. (1996). Sketching storyboards to illustrate interface behaviors. In *Conference Companion on Human Factors in Computing Systems* (pp. 193-194). New York: Association for Computing Machinery. doi: 10.1145/257089.257257

Leonard, H. C., Bedford, R., Charman, T., Elsabbagh, M., Johnson, M. H., Hill, E. L., & BASIS team. (2014). Motor development in children at risk of autism: A follow-up study of infant siblings. *Autism, 18*(3), 281-291. doi: 10.1177/1362361312470037

Leonard, H. C., Elsabbagh, M., Hill, E. L., & BASIS team. (2014). Early and persistent motor difficulties in infants at-risk of developing autism spectrum disorder: A prospective study. *European Journal of Developmental Psychology, 11*(1), 18-35. doi: 10.1080/17405629.2013.801626

Lord, C., Risi, S., & Pickles, A. (2004). Trajectory of language development in autistic spectrum disorders. In R. ML & a. W. S. (eds) (Eds.), *Developmental Language Disorders:From Phenotypes to Etiologies. New Jersey: Lawrence Ehrlbaum Associates, Inc., pp.7–29*.

MacDonald, M., Lord, C., & Ulrich, D. (2013). The relationship of motor skills and adaptive behavior skills in young children with autism spectrum disorders. *Research in Autism Spectrum Disorders, 7*(11), 1383-1390. doi: 10.1016/j.rasd.2013.07.020

MacDonald, M., Lord, C., & Ulrich, D. A. (2014). Motor Skills and Calibrated Autism Severity in Young Children With Autism Spectrum Disorder. *Adapted Physical Activity Quarterly, 31*(2), 95-105. doi: 10.1123/apaq.2013-0068

Mardia, K. V., & Jupp, P. E. (2000). *Directional Statistics*. Chichester: John Wiley and Sons Ltd.

McConachie, H., & Diggle, T. (2007). Parent implemented early intervention for young children with autism spectrum disorder: A systematic review. *Journal of Evaluation in Clinical Practice, 13*(1), 120-129. doi: 10.1111/j.1365-2753.2006.00674.x

McConachie, H., Fletcher-Watson, S., & Working Group 4, COST Action BM1004 'Enhancing the Scientific Study of Early Autism'. (2015). Building capacity for rigorous controlled trials in autism: The importance of measuring treatment adherence. *Child Care Health and Development, 41*(2), 169-177. doi: 10.1111/cch.12185

Miller, M., Chukoskie, L., Zinni, M., Townsend, J., & Trauner, D. (2014). Dyspraxia, motor function and visual-motor integration in autism. *Behavioural Brain Research, 269*, 95-102. doi: 10.1016/j.bbr.2014.04.011

Mirenda, P. (2003). "He's not really a reader ...": Perspectives on supporting literacy development in individuals with autism. *Topics in Language Disorders, 23*(4), 271-282.

Mukhopadhyay, T. R. (2008) *How Can I Talk If my Lips Don't Move: Inside my Autistic Mind.* New York: Arcade Publishing.

National Institute for Health and Care Excellence (2011, updated 2017). Autism spectrum disorder in under 19s: Recognition, referral and diagnosis (NICE Guideline CG128). Available at: https://www.nice.org.uk/guidance/cg128 [Accessed 25 July 2018].

Norrelgen, F., Fernell, E., Eriksson, M., Hedvall, Å., Persson, C., Sjölin, M., Gillberg, C., Kjellmer, L. (2015). Children with autism spectrum disorders who do not develop phrase speech in the preschool years. *Autism, 19*(8), 934-943. doi: 10.1177/1362361314556782

Quill, K. A. (1997). Instructional considerations for young children with autism: The rationale for visually cued instruction. *Journal of Autism and Developmental Disorders, 27*(6), 697-714. doi: 10.1023/a:1025806900162

Salber, D., & Coutaz, J. (1993). Applying the wizard of oz technique to the study of multimodal systems. In *International Conference on Human-Computer Interaction* (pp. 219-230). Berlin, Heidelberg: Springer.

Sampath, H., Agarwal, R., & Indurkhya, B. (2013). Assistive technology for children with autism - lessons for interaction design. *Proceedings of the 11th Asia Pacific Conference on Computer Human Interaction*, pp 325-333. New York: Association for Computing Machinery. doi: 10.1145/2525194.2525300

Serret, S., Hun, S., Iakimova, G., Lozada, J., Anastassova, M., Santos, A., Vesperini, S., & Askenazy, F. (2014). Facing the challenge of teaching emotions to individuals with low- and high-functioning autism using a new Serious game: A pilot study. *Molecular Autism, 5*. doi: 37 10.1186/2040-2392-5-37

Sharda, M., Subhadra, T. P., Sahay, S., Nagaraja, C., Singh, L., Mishra, R., Sen, A., Singhal, N., Erickson, D., Singh, N. C. (2010). Sounds of melody- Pitch patterns of speech in autism. *Neuroscience Letters, 478*(1), 42-45. doi: 10.1016/j.neulet.2010.04.066

Shield, A., Pyers, J., Martin, A., & Tager-Flusberg, H. (2016). Relations between language and cognition in native-signing children with autism spectrum disorder. *Autism Research, 9*(12), 1304-1315. doi: 10.1002/aur.1621

Valla, J. M., & Belmonte, M. K. (2013). Detail-oriented cognitive style and social communicative deficits, within and beyond the autism spectrum: Independent traits that grow into developmental interdependence. *Developmental Review, 33*(4), 371-398. doi: 10.1016/j.dr.2013.08.004

Waddington, H., Sigafoos, J., Lancioni, G. E., O'Reilly, M. F., Van der Meer, L., Carnett, A., Stevens, M., Roche, L., Hodis, F., Green, V. A., Sutherland, D., Lang, R., & Marschik, P. B. (2014). Three children with autism spectrum disorder learn to perform a three-step communication sequence using an iPad®-based speech-generating device. *International Journal of Developmental Neuroscience, 39*, 59-67. doi: 10.1016/j.ijdevneu.2014.05.001

Wass, S. V., & Porayska-Pomsta, K. (2014). The uses of cognitive training technologies in the treatment of autism spectrum disorders. *Autism, 18*(8), 851-871. doi: 10.1177/1362361313499827

Xin, J. F., & Leonard, D. A. (2015). Using iPads to teach communication skills of students with autism. *Journal of Autism and Developmental Disorders, 45*(12), 4154-4164. doi: 10.1007/s10803-014-2266-8

Yantis, S., & Hillstrom, A. P. (1994). Stimulus-driven attentional capture - evidence from equiluminant visual objects. *Journal of Experimental Psychology-Human Perception and Performance, 20*(1), 95-107. doi: 10.1037/0096-1523.20.1.95

Yantis, S., & Jonides, J. (1984). Abrupt visual onsets and selective attention - evidence from visual search. *Journal of Experimental Psychology-Human Perception and Performance, 10*(5), 601-621. doi: 10.137/0096-1523.10.5.601

Figure 1: Point OutWords Design and Development Summary

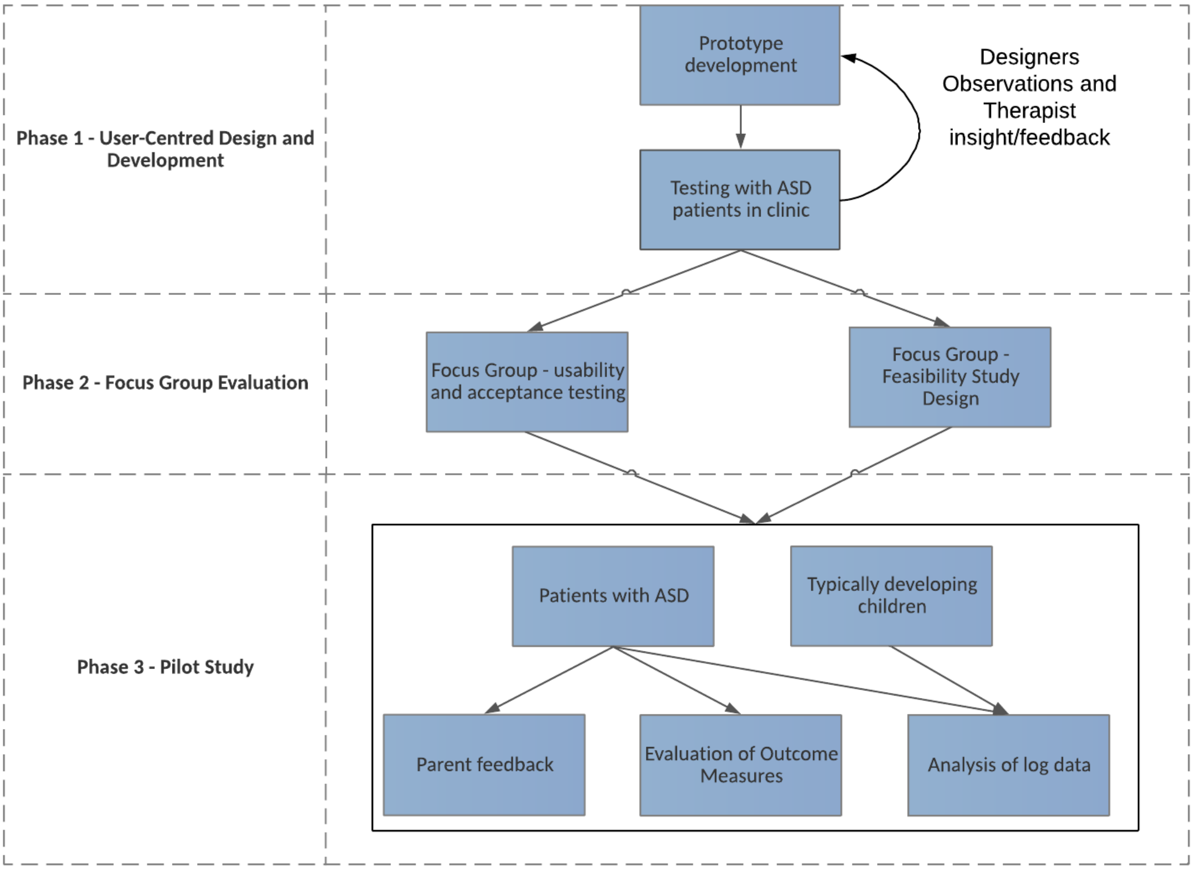


Figure 2: Examples of Point OutWords in use: child dragging pieces into a watermelon puzzle outline in “Point mode” (top); child selecting letters highlighted to signal they belong to the book puzzle in “Type mode” (bottom).

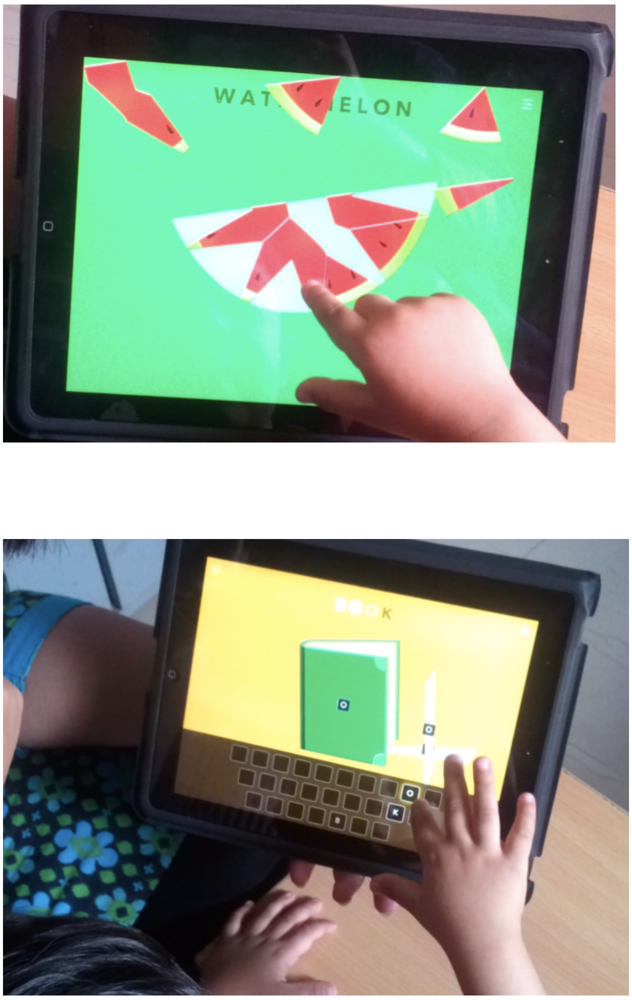
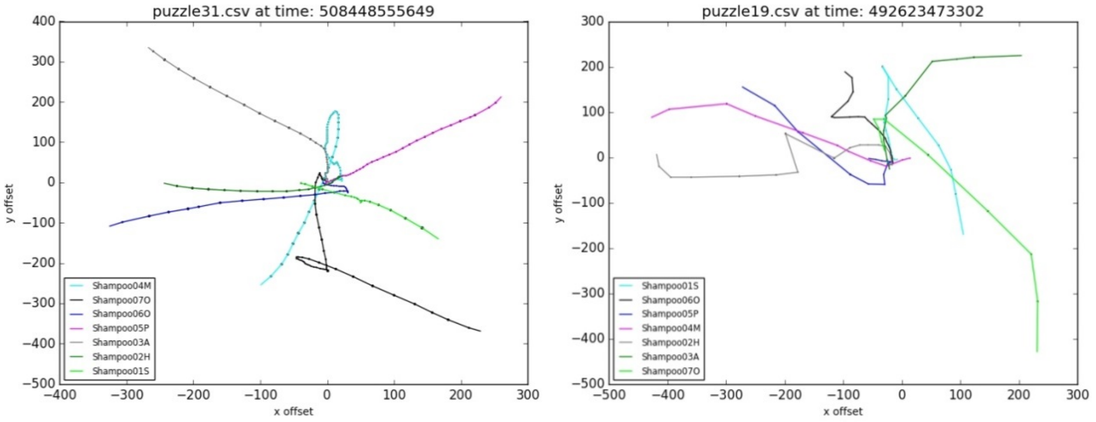
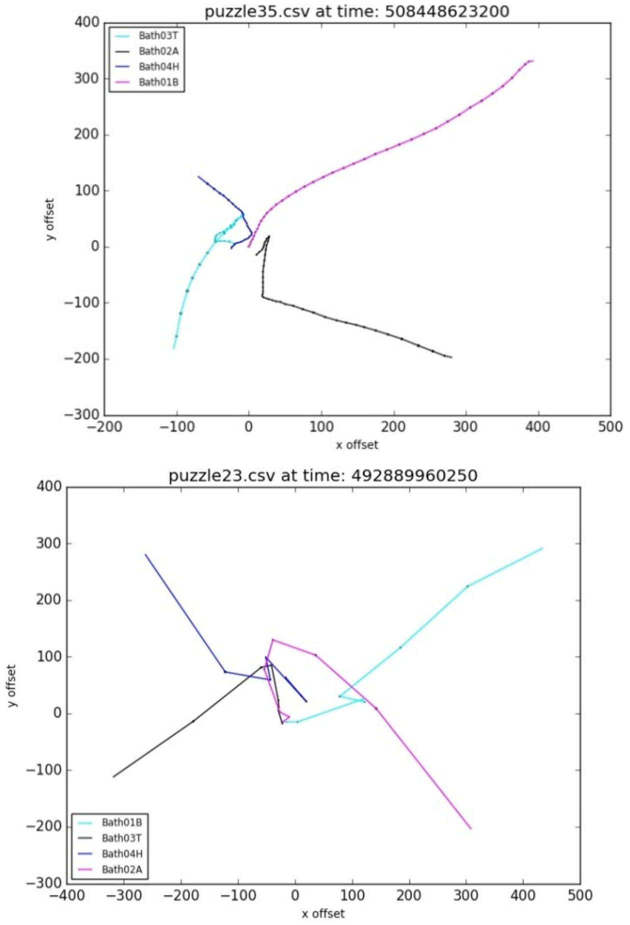


Figure 3: Examples of log data from a typically-developing user and a user with autism

3(a) Shampoo Puzzle (typically developing user on left, user with autism on right)



3(b) Bath Puzzle (typically developing user on left, user with autism on right)



3(c) Mug Puzzle (user with autism)

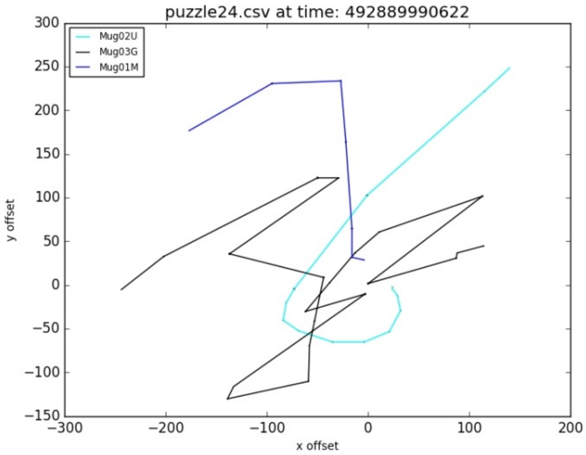
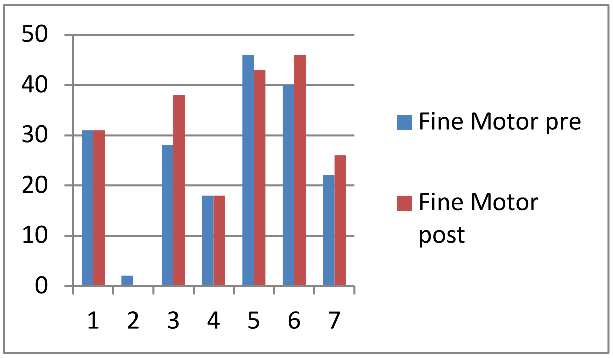


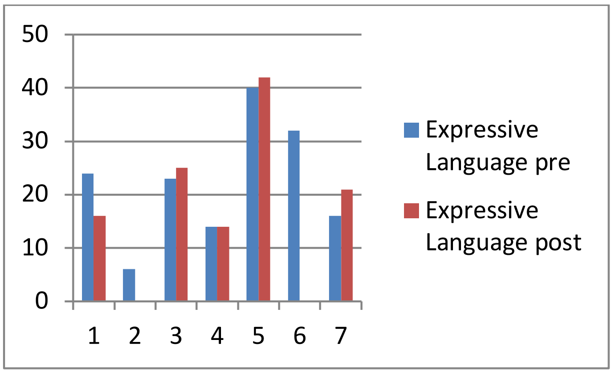
Figure 4: Pre- and post-intervention domain scores for all participants

4(a) Mullen Scales of Early Learning Raw Scores

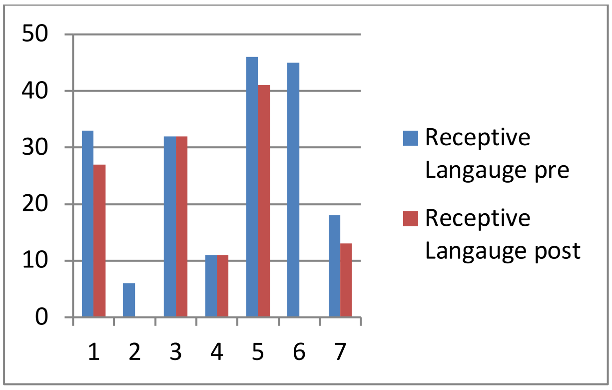
(i) Fine Motor



(ii) Expressive Language

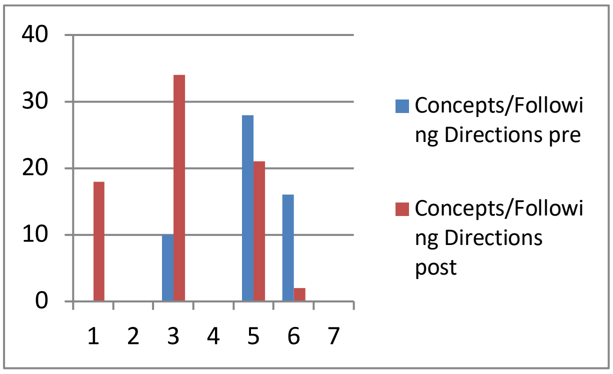


(iii) Receptive Language

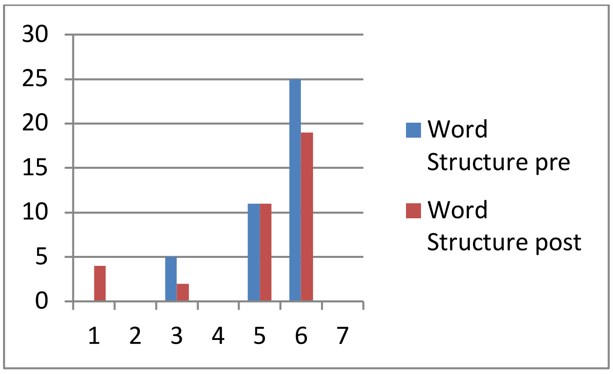


4(b) CELF-4 Raw Scores

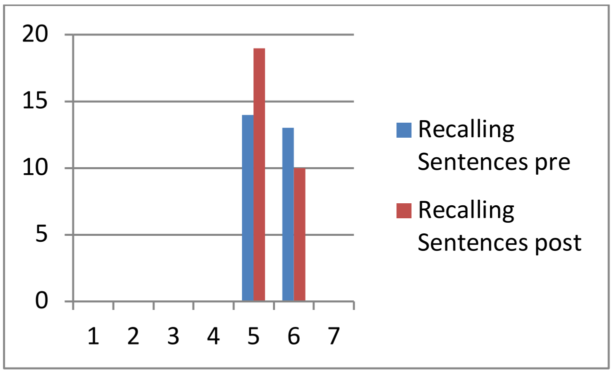
(i) Concepts and Following Directions



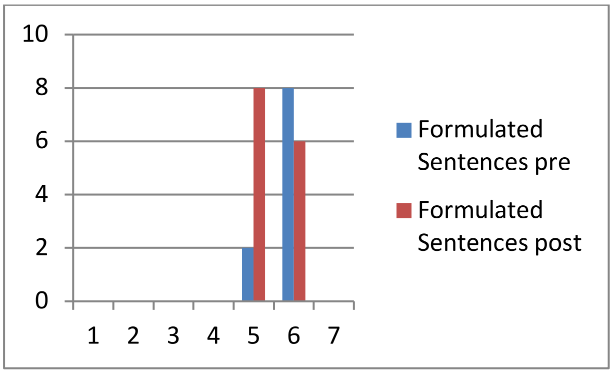
(ii) Word Structure



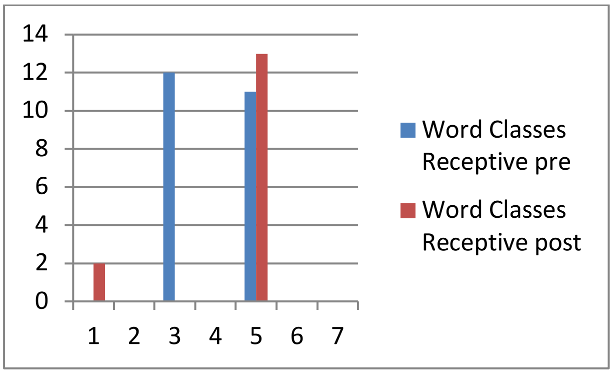
(iii) Recalling Sentences



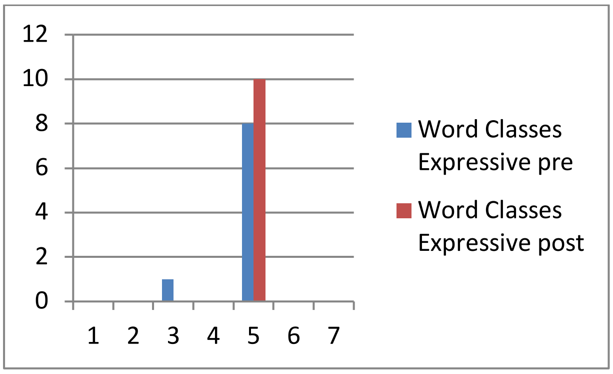
(iv) Formulated Sentences



(v) Word Classes Receptive

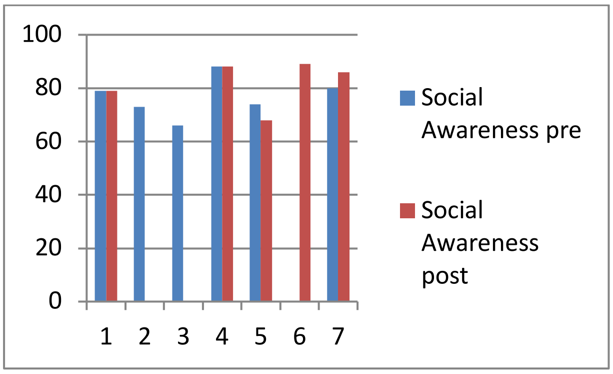


(vi) Word Classes Expressive

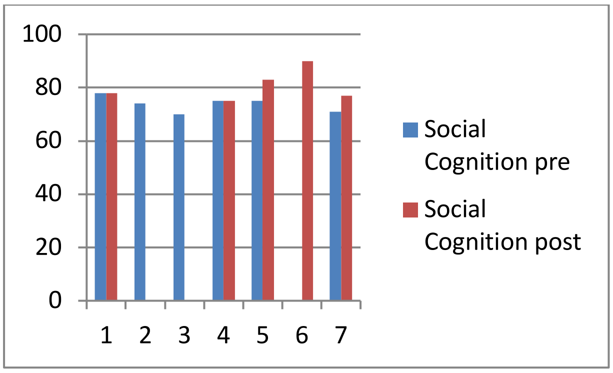


4(c) SRS-2 Standardised Domain Scores

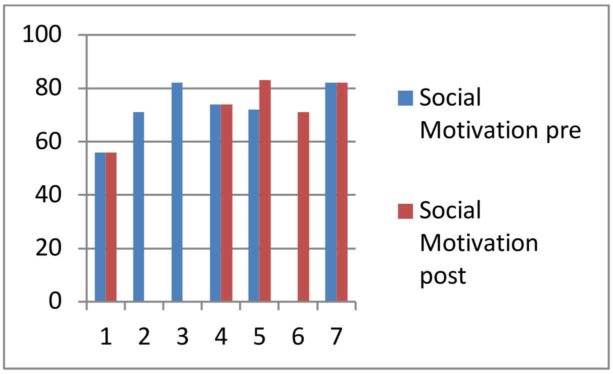
(i) Social Awareness



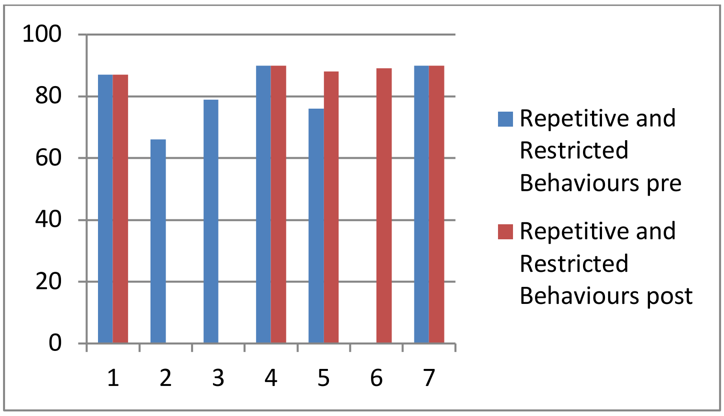
(ii) Social Cognition



(iii) Social Motivation

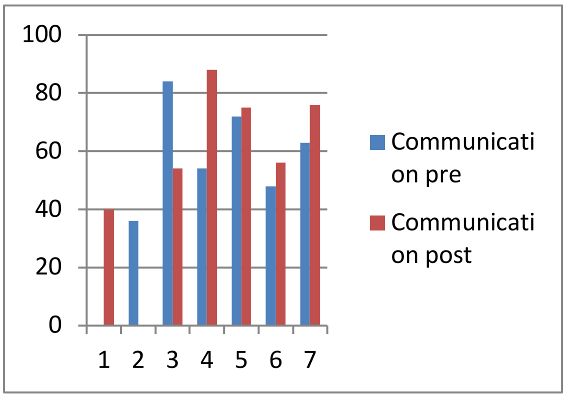


(iv) Repetitive and Restricted Behaviours

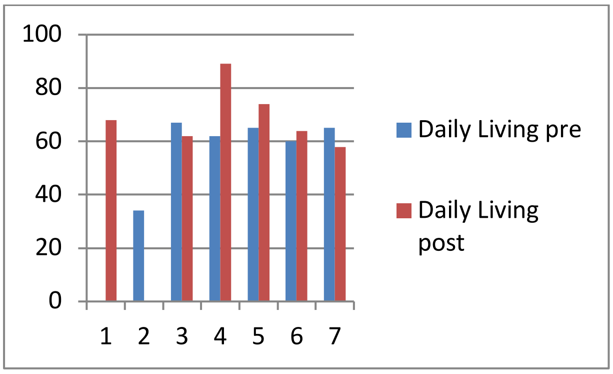


4(d) VABS-II Standardised Domain Scores

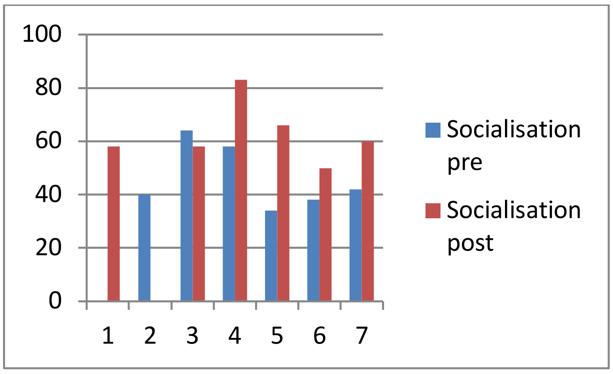
(i) Communication



(ii) Daily Living



(iii) Socialisation



(iv) Motor Skills

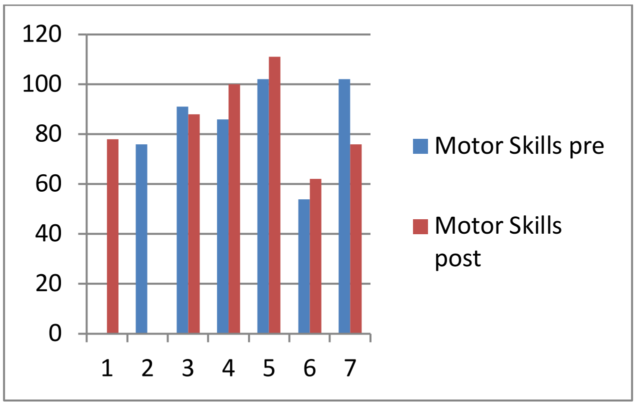


Table 1: Aims and Characteristics of Point OutWords software

AIMS - SENSORY-MOTOR	AIMS - COMMUNICATIVE
1. Develop manual motor (*e.g.* pointing to select amongst multiple response options) and oral motor skills prerequisite to typed or spoken communication 2. Adapt the touch-screen interface to autistic open-loop visual-motor control: i. Tolerate motor targeting errors ii. Tolerate lapses of contact during point-and-drag iii. If a human can discern intent from a video recording, the computer ought to be able to notice intent, too Log the time series of all stimuli and motor responses Log the time series of physical movements of the touchscreen so as to help identify any "Clever Hans" anticipation by the therapist Detect attempts to use the device as an instrument of repetitive behaviour, and shut down the reward Detect failures and advance in an errorless-learning format	1. Scaffold a transition from iconic reference (picture-based communication) to symbolic reference (communication using typed or spoken words) 2. Develop the notion of object as sequence: 3. Begin with sequence of puzzle pieces (iconic "point" mode) 4. Transition to pieces labelled with alphabet letters (symbolic "type" mode); corresponding key on a keyboard highlights to capture attention; keys must be pressed in sequence to snap puzzle pieces into place. 5. Extension to approximate speech recognition (symbolic "say" mode): Computational problem of speech recognition is facilitated by having priors (we know what syllable the user is trying to speak) and by approximate matching (we want to be very tolerant of pronunciation errors). 6. Intended for use with a parent, carer or therapist – not as a substitute.

Table 2: Characteristics of participants with autism

Participant ID	Gender	Chronological Age (Months)	Completed Study?
000	M	74	✓
001	M	73	✕
002	M	49	✕
003	M	40	✓
004	F	54	✓
005	M	66	✓
006	M	44	✓

Table 3: External measures baseline data for participants with autism

MSEL and CELF scores are raw scores, ranges given in table SRS-2 and VABS-II are standardised scores	**Pre-intervention baseline data**		**Range of scores (min-max)**
Domain measured	Mean (n)	Standard Deviation	
MSEL Fine Motor	26.7 (7)	14.6	0-49
MSEL Receptive Language	27.3 (7)	15.9	0-48
MSEL Expressive Language	22.1 (7)	11.4	0-49
CELF Concepts and Following Directions	9.0 (6)	11.4	0-54
CELF Word Structure	6.8 (6)	9.9	0-32
CELF Recalling Sentences	4.5 (6)	7.0	0-96
CELF Formulated Sentences	1.7 (6)	8.5	0-56
CELF Word Class Total	5.3 (6)	8.5	0-42
SRS Social Awareness	76.2 (5)	8.3	All SRS T scores range from 30-90, normed for age, mean 50, standard deviation 10. >60 indicates some difficulties Higher score = more difficulties
SRS Social Cognition	73.0 (5)	2.3	
SRS Social Communication	83.8 (5)	5.5	
SRS Social Motivation	76.2 (5)	8.3	
SRS Repetitive Behaviours	80.2 (5)	10.2	
VABS Communication	59.5 (6)	17.2	All VABS standardized scores range 20-150, mean 100 (normed for age) standard deviation 15 (higher number means better abilities)
VABS Daily Living	58.8 (6)	12.4	
VABS Social	46.0 (6)	12.1	
VABS Motor Skills	85.2 (6)	18.2	

VABS Adaptive Behaviour	58.5 (6)	12.6	

Table 4: Characteristics of participants without autism (typically-developing)

Participant ID	Gender	Chronological Age (Months)
100	F	72
101	F	75
102	M	83

Table 5: Comparison of iPad log data between children with and without ASD

Measure	**Group**	**Mean**	**S.E.M.**	**t value**	**Pr > |t|**	**Comparison**
Variance (simple) of scalar speed	ASD	9.2723	1.6952	5.47	<.0001	F(1,381)=6.04, p=0.0145
	TD	0.7465	3.0276	0.25	0.8054	
Circular variance of angular speed	ASD	0.001700	0.000252	6.75	<.0001	F(1,381)=7.48, p=0.0065
	TD	0.000262	0.000462	0.57	0.5712	
Circular standard deviation of angular speed	ASD	0.03426	0.002283	15.00	<.0001	F(1,381)=8.00, p=0.0049
	TD	0.02154	0.003873	5.56	<.0001	
Circular dispersion of angular speed	ASD	0.5017	0.000278	1805.75	<.0001	F(1,381)=6.98, p=0.0086
	TD	0.5002	0.000504	993.28	<.0001	