Can Computer-Assisted Training of Prerequisite Motor Skills Help Enable Communication in People with Autism?

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***Abstract*—Our and others' research indicates that in fully a third of people with autism who lack communicative speech, the communication deficit may actually be a deficit in motor skills necessary to move the mouth and the vocal tract. These individuals have difficulties in fine, gross and especially oral motor skills, and a disparity between impaired expressive language and relatively intact receptive language: that is to say, they can listen but not speak. Because involvement in research and receipt of the fullest educational, occupational and other services demands ability to interact verbally and to control one's movements and actions, these people get the short end of the stick when it comes to scientific enquiry and pedagogic and therapeutic practice.**

Point OutWords, tablet-based software designed in collaboration with autistic clients and their communication therapists, exploits the autistic fascination with parts and details to motivate attention to learning manual motor and oral motor skills essential for communication. Along the way, autistic clients practise pointing and dragging at objects, then pointing at sequences of letters on a keyboard, and even speaking the syllables represented by these letters. Whereas many teaching and learning strategies adapted from methods for non-autistic people end up working against autistic cognition by asking people with autism to do what they cannot easily do, Point OutWords works with autistic cognition, by beginning from the autistic skill at manipulating parts and details. Users and their parents or guardians can opt into collection of data on motor interactions with Point OutWords; these internal measures of motor skills development are complemented by external, standardised tests of motor, oral motor and communicative development. These quantitative measures are collected alongside reports on Point OutWords's acceptability to users, and users' fidelity to a recommended treatment regime, so as to evaluate feasibility of a larger randomised controlled trial.

Keywords—Autism; Social Communication; Technology; Motor Learning

I. Introduction

Autism spectrum disorders are common, lifelong conditions, affecting approximately 1% of the population, with about a quarter of those affected nonverbal or minimally verbal

[1-3] - that is, producing either no words at all, or some words but no phrases other than non-communicative compulsive vocalisations. Our and others' research has demonstrated strong association between autistic language delay and motor dysfunction [4-10]. In our own clinical sample, fully one third of autistic children who lack communicative speech manifest a distinctive pattern in which motor, particularly oral motor skills are impaired whilst expressive language is impaired disproportionately to more intact receptive language [6].

UK National Institute for Health and Care (NICE) guidance for pædiatric autism support and management (CG170) broadly recommends "psychosocial interventions" and, recognising economic reality, suggests that these be mediated by parents, caregivers, teachers or peers. Most clinics operationalise this guidance as a combination of social skills groups, occupational therapy and speech/communication therapy, most children receiving just 6-8 sessions. Nonverbal patients use the Picture Exchange Communication System [11], which is effective [12, 13] albeit limited by its inability to convey abstract concepts [14]. Behavioural therapies in general are only modestly effective at treating symptoms [15], do not address developmental causes, and have "no discernible effect" on language development [16]. Applied Behaviour Analysis [17] and early social communication intervention [18] are effective but not routinely provided in most jurisdictions as their labour-intensive nature presents an economic barrier. Sign-language training in autism seems not to lead to further language development [19]; rather, baseline verbal imitation skill is the major predictor of any language development beyond signing [20]. Typing, unlike signing, is asynchronous [21] and therefore can be less cognitively demanding [22]; it has spurred communicative development in some autistic individuals [23]. NICE guidance does not address motor symptoms.

Our work suggests that the high-level deficits in social communication so overtly characteristic of autism may emerge developmentally from interaction of lower-level, more subtle, fundamental traits in three general areas: social motivation and reward, cognitive and motor control, and sensory perception [24], and thus implies that early training directed towards such lower-level skills – in the case of this new intervention, motor control and sequencing – might exert a knock-on effect on the development of communicative skills. This approach is novel and significant because it 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 – tend to fall short [25, 26].

Evaluations of parent-developed methods of manual motor symbolic communication [22, 27] reveal trends consistent with this back-door, 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 [28]. An alternative is to extract the essence of such methods and to implement that essence in a semi-automated manner, in which clients interact with a computer under the supervision of their aides. Previous computerised training programs have in general focused on developing social and/or communicative skills via a direct training route, have tended to result in failure to generalise skills beyond the trained context [29], and have been small, exploratory and underpowered [30]. Historically, a further issue with such skills-training software has been the very nature of desktop computer user interfaces, comprising a keyboard that demands fine visuomotor accuracy and spatial re-mapping and a display spatially distinct from that keyboard, which confounds the autistic style of iconic, concrete reference (one can't provide input by pointing at the display itself). Those whose autism is severe enough to impair motor and cognitive control have been practically barred from such technologies. The advent of tablet computers, in which keyboard dimensions are adjustable and motor output is spatially colocalised with visual cues, has changed this game.

Point OutWords, iPad software designed in collaboration with 31 autistic clients and their communication therapists [31; http://www.AutismCollaborative.org/PointOutWords/], exploits the autistic fascination with parts and details [32] to motivate attention to learning manual motor and oral motor skills essential for communication. Point OutWords develops skills in pointing and dragging at objects, then pointing at sequences of letters on a keyboard, and where possible for the individual user, speaking the syllables represented by these letters. Even in the comparatively user-friendly case of touchscreen software, mainstream user interfaces assume a typical style of motor planning and execution. In the case of autism – especially the motor-impaired subpopulation whom we have described – visuomotor interaction is not typical, and interfaces designed for non-autistic users present obstacles to interaction. Point OutWords was designed with a touchscreen interface especially adapted to accommodate autistic motor dyspraxia [33, 34] and an open-loop style of visuomotor control, in which visual feedback is not integrated into the execution of an ongoing movement [35]. Given this inability to make use of visual and proprioceptive feedback, gazing towards the target of a movement confers no advantage and in fact the perceptual load associated with direct gaze can interfere with cognitive and motor tasks necessary for successful communication [22, 36, 37]. Gaze therefore is often averted during movements, after momentary gaze fixation that precedes movement execution. Regardless of whether gaze is engaged or averted, reaching and pointing movements tend to contact the touchscreen at some distance from the intended target. In our experience many autistic users correct this targeting error after the finger has reached the touchscreen surface, by wiping the finger against the touchscreen in series of smaller movements that successively approach the intended target, and depart from the touchscreen once the target has been contacted. Touchscreen interfaces designed for non-autistic persons misinterpret such interactions by responding to the point of initial contact; we modify the interface so as to respond to the point of departure from the touchscreen.

Along with its communicative deficits, the autistic cognitive profile also includes many unusual strengths, one of which is attention to localised details. Many people with autism excel at assembling jigsaws and similar spatial puzzles because of their abnormally strong ability to match details on adjacent pieces. Whereas many teaching and learning strategies adapted from methods for non-autistic people end up working against autistic cognition by asking people with autism to do what they cannot easily do, Point OutWords works with autistic cognition, by beginning from this point of strength [38]. The software exploits the autistic fascination with parts and details to motivate attention to learning manual motor and oral motor skills prerequisite to typed or spoken communication. The design renders the communicative content spatially and temporally coincident with the most physically salient, attention-capturing stimulus [22, 39]. By pairing perception of the spatial sequences inherent in jigsaw-puzzle pictures with production of the manual motor or oral-motor sequences making up the typed or spoken words for these pictures, Point OutWords aims to develop manual motor and oral motor skills and to bootstrap the development of symbolic from iconic representations.

Point OutWords is used with a therapist, teacher, parent or caregiver (hereafter termed the 'aide') who can support the autistic client in an 'errorless learning' format, filling in responses and correcting errors when the client is unable to do so independently, and redirecting the client towards the task when attention wanders. As a parent-mediated, computer-based method, and one that accesses communicative development via motor rather than primarily social training, Point OutWords has potential to complement and to augment the psychosocial interventions that many health authorities currently provide.

II. Aims

The current feasibility study of Point OutWords intervention aims (1) to assay fidelity to the recommended treatment regime; (2) to determine the intervention's acceptability to autistic users and their parents or caregivers, and (3) to determine the acceptability of several candidate outcome measures in assessing the efficacy of the Point OutWords intervention.

Although the scope of a feasibility study does not suffice to answer definitively the crucial therapeutic question of whether or not Point OutWords can improve communicative skills, pilot data are being collected to help define a larger-scale randomised controlled trial. In addition to the efficacy of Point OutWords as an adjunct to usual clinical therapy for autism, the data acquired can address the following secondary questions: (1) whether and to what extent autistic pointing and dragging movements involve errors in visuomotor targeting, (2) whether and to what extent autistic vocalisations differ systematically from non-autistic vocalisations in spectral-temporal properties and other traits indicative of differences in oral motor performance, (3) whether and to what extent caregivers may be moving the computer in ways that could unconsciously influence the autistic user's choice of keys on the touchscreen keypad, (4) whether autistic children's use of Point OutWords alleviates stress in their parents and (5) whether any such improvements are specific to the previously identified subgroup of people with autism who have significant impairments in motor functioning.

III. Methods

A. Design

The study applies a feasibility parallel-groups randomised controlled design [40] in which participants are randomly assigned into matched experimental and control groups. Outcome is assessed blind to treatment group condition. Because of the participatory nature of the behavioural intervention, participants and parents cannot be blinded to their treatment condition.

B. Participants

Participants were recruited with the aid of teaching staff in schools serving autistic students in Nottingham; the intervention took place on school sites during school hours, under the supervision of teachers or teaching assistants. Further participants are being recruited from NHS Peterborough Neurodevelopmental Service, a regional clinic for neurodevelopmental disorders. Inclusion criteria are (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. (This restriction is a practical requirement, as non-English translations of the Point OutWords software are not yet available.) Exclusion criteria are severe visual or hearing impairment, or severe impairment distinct from autism and affecting body movement, such as cerebral palsy.

C. Randomisation

Participants are randomly assigned to equally sized experimental and control groups, subject to constraint of group-level matching for age and for developmental level as assayed by the Vineland Adaptive Behavior Scales. All baseline, post-test and fidelity measures are collected blind to group assignment. Baseline measures including fine motor scores, expressive-receptive language score differences, and Verbal Motor Production Assessment for Children scores, are used to used to construct a linear discriminant [6] classifying participants into motor-intact and motor-impaired subgroups. The possible effect of subgroup on outcome is explored both by using subgroup membership as a discrete independent variable and by using discriminant score as a continuous covariate. In our past work [6] one third of our clinical sample of nonverbal or minimally verbal autistic children were reliably classified into this motor-impaired subgroup; the current feasibility study will verify that this distinction applies in the study population as assayed by the proposed measures of motor and language function, and will identify those measures most sensitive to this distinction, whose baselines could be most predictive of outcome. The measures so identified would be carried forward into an eventual randomised controlled trial, and if this feasibility process indicates that clinical improvement is restricted to the motor-impaired subgroup, inclusion criteria for the randomised controlled trial would be adjusted accordingly.

D. Procedure

The experimental group receives at least 40 hours of Point OutWords intervention as an adjunct to typical treatment or teaching. Point OutWords therapy is administered by teaching staff in schools, or by parents in the home. These aides receive training in the use of Point OutWords and telephone follow-up and are asked to provide at least half an hour of Point OutWords contact time per day for five days a week over an eight-week period.

The control group receives equal iPad contact time via exposure to their choice of a library of iPad software packages, each of which has been a subject of at least one empirical study demonstrating positive effect on behaviour and/or skills development in autistic children. (https://www.AutismSpeaks.org/autism-apps). The control group also receives an equal level of regular contact and support. The focus of the control is not the specific nature of the iPad-based task but simply time interacting with the iPad. As the aim is to evaluate communicative development, software packages that specifically target vocabulary development are excluded from this set of control apps. Psychometric measures are collected immediately post-intervention, and members of the control group are offered Point OutWords intervention after the end of the study period.

E. Measures

An assessment of feasibility will inform whether a full-scale trial would be warranted, and will indicate any necessary adjustments to the protocol such as changes to procedures, outcome measures, data collection methods or intervention delivery.

1) Recruitment and Fidelity to the Intervention:

A key component of a feasibility study is assessment of fidelity to the intervention, for example in a recent study of horse riding intervention [41] and the PACT study of parent-mediated social communication intervention [25]. A fidelity instrument is in development using researcher observations, reports from aides, and the data logged by the iPads themselves. Components will include number of sessions using the software, time spent using the software; consistent use of errorless learning; consistent use of praise. We also employ a process evaluation comprising 'think-aloud' sessions in which aides talk through their thoughts and experiences as they conduct one of the intervention sessions, diaries addressing experiences, feelings, and children's interactions with the software, and focus groups. Data are transcribed and thematically analysed using Atlas-ti software. A partially inductive and partially deductive coding frame is developed using the analytical stages of Braun and Clarke [42]. This qualitative analysis will be evaluated using indicators of confidence and relevance [43] to ensure rigour, transparency and accountability.

2) Acceptability of the Intervention:

The acceptability of the intervention is indicated by response, dropout and completion rates, self-report questionnaires and qualitative reports from aides during focus groups/interviews and from children in response to Point OutWords. In addition, positive and negative behaviours (non-verbal) are recorded by observational coding during Point OutWords sessions. In follow-up work with a subset of participants, an eye-tracking device will be used to monitor gaze [38].

3) Outcome measures – internal:

With users' opt-in consent, Point OutWords logs all prompts and stimuli, all contacts with the touchscreen, and all movements of the iPad (using the built-in accelerometers); children's inputs will be statistically distinguished from parents' modelled responses within these logs, then used to construct internal measures of learning: Visuomotor targeting error during pointing is 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) is measured both as the temporal duration of screen contact and the spatial path length of screen contact. Anticipatory movements of the iPad by the aide during Type mode are 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. Feasibility of identifying change in these measures over time will be analysed via three exploratory analyses of covariance, one using total cumulative Point OutWords usage time as the covariate, one using number of distinct Point OutWords sessions, and one using real time. As these measures internal to Point OutWords will not exist for the control group, these assays will take place within the experimental group only.

4) Outcome measures – external:

Baseline and outcome immediately post-intervention are assayed with a range of measures selected on the basis of (1) their tapping the motor skills directly addressed by Point OutWords, the communicative skills predicted to result indirectly, and adjustment and social function that may be affected by these, (2) their wide acceptance and standardisation, and (3) their brevity and their mix of parent-survey and patient-interview measures which avoids placing a heavy time burden on patients or their parents. Some measures are 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, and there is precedent within the autism literature for applying such instruments outside their normed age ranges in cases of severe impairments where performance-based equivalent age does lie within the normed range of chronological age [44]. These external, psychometric measures are analysed via a 2x2 (motor-impaired or motor-intact subgroup, Point OutWords treatment or iPad control condition) repeated-measures analysis of variance.

Direct assessments of users are as follows: (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; (3) Verbal Motor Production Assessment for Children (VMPAC). These assessments occupy less than 30 minutes each, and are administered by a trained research assistant, in separate sessions so as to avoid fatigue. Parent interviews and checklists include the Movement Assessment Battery for Children (MABC-2 Checklist, 10 minutes);, the Social Responsiveness Scale (SRS-2, 15 minutes);, the Parenting Stress Index (PSI-4, 5 minutes) and the Vineland Adaptive Behavior Scales II (VABS-2, 20-30 minutes for this population). The total time burden is about one hour.

The Mullen Scales of Early Learning are widely used to measure cognitive and language skills in research and clinical evaluations of autistic children [44, 45]. Each subscale yields developmental age equivalents, and thus is applicable to developmentally delayed children outside the 68-month normed age range [46]. The Mullen shows good test-retest and inter-rater reliability [47] and strong concurrent validity with other developmental tests of motor and language skills, including the VABS [45].

The CELF-4 [48] subtests above comprise measures of receptive and expressive language normed for ages 5-8 but yielding raw and age-equivalent scores outside this age range. The CELF-4 has been applied as an outcome measure in previous studies of autism and developmental delay [49] (although there is some question as to whether the CELF-Preschool might present a more sensitive range of measurement in this minimally verbal autistic population).

The VMPAC assesses neuromotor integrity of the speech system and is standardised for 3-12 years [50]. Its five subscales Global Motor Control, Focal Oromotor Control, Sequencing, Connected Speech and Language, and Speech Characteristics can be interpreted independently; Focal Oromotor Control and Sequencing may be most predictive of outcome. VMPAC subtests have strong test-retest reliability (.88-.90), inter-rater reliability (.93-.99), and high validity [50]. The VMPAC is sensitive to change following speech or motor intervention [51, 52].

The SRS-2 [53] assesses social communicative competence from 2.5 years on. It is sensitive to behavioural change and widely used as an outcome measure [54, 55]. The VABS-2 [56] is a parent-interview measure of communicative, motor and social skills which complements the other tests addressing these domains, normed for all ages, widely used [57] and recommended [58] as a test-retest measure in autism treatment studies. The PSI-4 [59] is measure of family stress normed up to one year of age but valid on face for older, developmentally delayed children, and previously used at as an autism trial outcome measure [60]. The MABC-2 [61] is a quick measure of motor performance in context, normed for ages 5-12.

F. Intervention

The Point OutWords software contains five separate themes each depicting a different scene associated with activities of daily living. 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 the participant how to point and to drag within a touchscreen interface: The participant 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 that are scattered round the touchscreen. Using pointing and dragging movements, the user must assemble these pieces into a complete whole.

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 labeled with a letter in the word, 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.

For participants who are able to vocalise, Speak mode offers an opportunity to practice 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 modeled, the user is prompted to speak each one, and OpenEARS speech recognition software 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 modeled pronunciations is by design high, and can be configured by the teacher/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.

IV. Pilot Results and Discussion

The Point OutWords software has been piloted at our clinic in Bangalore, India, in clinically diagnosed autistic children aged 3 to 7 years who lack functional communicative speech [31]. This initial pilot actually was the end stage of an ongoing process of iterative, user-centred design. 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. Issues cited and refined included 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), allowance for inaccurately targeted movements in discerning users' intent (the interface was redesigned so as to register point of departure rather than the point of initial contact with the touchscreen), and the prevention of usage of predictable stimulus-response contingencies [62] within Point OutWords as an occasion for repetitive behaviours (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 software is now also being piloted in three special schools in Nottingham, England. Initial data on acceptability, feasibility, and usability are being obtained, with both qualitative and quantitative analysis, as will statistical analyses of further outcome measures including the efficacy of Point

OutWords in improving communicative skills. Initial results from interviews with parents of autistic children in the UK, discussing the usability and acceptability of Point OutWords, provided positive feedback.

In focus groups, parents commented that the design's vivid contrasts of luminance and of colours would capture or recapture their children's attention [22, 63], and that other communication apps on the market focus on picture-based communication; parents commented that although plenty of apps allow users to combine pictures there is no software for combining words. The necessity of ongoing support and guidance was a common theme; not all parents are familiar with software interfaces touchscreen hardware. 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.

Our clinical experience with Point OutWords highlights the significance of moving from Point mode to Type mode: whereas Point mode depends on an iconic style of reference in which the user manipulates objects by pointing at pictures of those objects, Type mode is essentially symbolic, depending on association of an object with an arbitrary sequence of letters or other symbols. Symbolic communication depends to a greater degree on integrative cognitive and neural functions of the sort that are most compromised in autistic brains and minds [64]. Some therapeutic communicative tools, *e.g.* the Picture Exchange Communication System [11], sidestep this symbolic impairment by depending purely on iconic reference, but such iconic systems cannot directly express abstract ideas. In our experience, users once accustomed and practised with Point mode will perseverate in attempting to interact with the device iconically: when cued to tap a keyboard symbol in order to move a puzzle piece, users will instead point at the piece itself. Overriding this prepotent tendency to iconic pointing depends on modeling and correction by aides, in an errorless-learning format. Therapeutic and pedagogic staff thus constitute an essential part of any intervention that utilises Point OutWords: the software is designed to work with teachers and therapists, rather than substituting for them.

As a supplement to such teacher-led guidance, Point OutWords has been augmented with features to redirect visual spatial attention from the puzzle pieces to the keyboard in Type mode. When a touch in the puzzle region of the touchscreen is detected, the target key within the keyboard becomes animated, repeatedly expanding and contracting, illuminating and darkening. At the same time, a bright line grows from the screen location of the touch to the target key. These luminance and spatial stimuli involuntarily and exogenously capture attention [39, 65-67], supplementing voluntary, endogenous attentional shifts that are pathologically slowed in autism [68].

The autism phenotype shows both convergence from many independent causal factors and divergence into molecular, neural, cognitive and behavioural heterogeneity [69]. Distinct phenotypic profiles will require distinct targeted therapies. Point OutWords targets the 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 [6]. Deficits in lower-level, non-social, prerequisite skills could be one amongst several developmental routes into the emergence of autistic social communicative deficits [24]. Targeting computer-based training towards such lower-level skills – in this case, motor control and sequencing – might facilitate the development of communicative skills.

In recent years a host of tablet computer applications have been developed with therapeutic aims. Easy-to-use tablet-based technologies have advantage for users with motor impairments, and can also allow interventions targeted at younger children. Early interventions heighten impact on intelligence and communicative skills in later life [70]. However, few technology-based teaching methods have yet managed to generalise 'in-game' skills to real-life situations.

A recent randomised controlled trial [71] investigated the effect of a newly designed app on social communication behaviours. Gameplay was based on a touch-and-point task, with the aim of improving joint attention. Results revealed no significant benefits to real-world social communicative behaviours. It is possible that higher-level skills such as social communication are harder to target through game-based learning methods, although some limited effects on real-world behaviours have been found in other studies targeting social communication [72, 73]. Despite these negative findings and limitations, touchscreen devices have potential as a learning and therapeutic tool, with much scope for development. Tablet devices are widely deployed and easy to incorporate into daily activity [71]. Other computer-based interventions have evoked positive results in areas such as emotion recognition [74] and communication [30, 75, 76]. Technological interventions targeting more low–level skills, such as attentional gaze [77], have shown some suggestive results. A recent study [70] investigating the effect of training joint attention skills also yielded promising results. These data suggest that in children with ASC, early pointing could have a causal effect on expressive language development, and illustrate the importance of therapeutic interventions targeting specific gestural and attentional skills early in development.

Just as there is no one single biological cause present in all individuals with autism, there is no one single most effective treatment for all individuals with autism. Different methods are applicable to different individuals in varying degrees, alone or in combination. Our back-door approach, in which social communicative skill could be developed by training non-social, prerequisite skills, is not at all necessarily exclusive of the more traditional and straightforward front-door approach in which speech and social skills are trained directly. If proven effective, Point OutWords could thus find use as a complementary therapeutic approach, while the user is also being trained directly on higher-level communicative and social skills. It can be one tool in the toolbox available to teachers and speech and language therapists, complementing and augmenting other approaches. Point OutWords may be specifically effective in a subgroup of nonverbal or minimally verbal people with autism who are distinguished by motor and especially oral motor impairment, and disparity between impaired expressive and more intact receptive language.

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