Journal of Behavioral Education
https://doi.org/10.1007/s10864-024-09568-2

ORIGINAL PAPER

A Precision Teaching Framework for Training Autistic Students to Respond to Bids for Joint Attention

Athanasios Vostanis[1] · **Rianna Ritchie**[2] · **Peter E. Langdon**[3,4]

Accepted: 30 September 2024

Abstract

Precision teaching has historically been primarily applied to academic skills. This study aimed to show how precision teaching could enhance the application of existing evidence-based interventions focused on crucial pre-academic skills, such as joint attention. Joint attention is typically broken into two categories: responding to bids for joint attention (RJA) and initiating joint attention (IJA). This study developed RJA using precision teaching and play-based, natural environment teaching. Four autistic students, aged between 5 and 6, attending a special education school in England participated. Six prerequisite skills were trained in two triads during 15-min sessions for three weeks. RJA was then targeted, and participants needed three, four, five, and seven days, respectively, to master it. A concurrent multiple baseline design across participants was used for all skills. Participants improved across all skills with moderate effect sizes that were maintained five weeks post-intervention. Moreover, participants demonstrated steep learning rates measured via celeration, low variability measured via the bounce metric, and a maintenance of performance improvements during the assessment of endurance, stability, and generalization. The results suggest that autistic students can quickly improve their RJA skills and demonstrate fluency in them. However, the results are tentative and require replication while addressing the limitations that have been identified. Integrating precision teaching and naturalistic approaches could offer practitioners additional information about the impact of existing evidence-based interventions on developing RJA and related skills.

Keywords Precision teaching · Standard Celeration Chart · RESA · Fluency · NDBIs

Extended author information available on the last page of the article

Published online: 17 October 2024

Introduction

Precision teaching (PT) is a system for monitoring progress designed to be embedded in other instructional procedures and curricula to help practitioners optimize their instructional outcomes across various skill areas through its five-step framework, namely pinpoint, practice, chart, decide, and try again (Evans et al., 2021). The system empowers professionals to maximize instructional time by offering continuous, precise feedback on the effectiveness of their instruction, while emphasizing mastery of skills that enable students to advance successfully through the curriculum.

Pinpointing.

In the framework's first step, titled pinpoint, precision teachers (PTers) opt for pinpointing over traditional operational definitions as it has been shown to increase detection accuracy during data collection (Kubina et al., 2022). Specifically, PTers use movement cycles, context, and learning channels to create concise definitions of the skills or behaviors to be measured. A movement cycle indicates the smallest repeatable response that can be measured (e.g., aims finger, says word, or writes digit; Kubina & Yurich, 2012). Learning channels allow PTers to specify the instructional modality or how students perceive the antecedent event (i.e., sensory in) and respond to it (i.e., behavioral out). For example, a Hear-Say learning channel set suggests that the student will hear and respond vocally to the antecedent event (Kubina & Cooper, 2000). Therefore, through pinpointing, PTers identify precisely the skills they want to target while also considering whether the instruction provided is adequately varied across learning channel sets (Vostanis et al., 2022).

Component–Composite Analysis

The pinpointing process has been linked with another strategy that has stemmed from PT but is not considered a core part of its five-step framework, namely the component–composite (aka element–compound analysis). This procedure allows practitioners to identify all the basic prerequisite skills (i.e., components) that should be mastered to fluency before the primary skill can be targeted (i.e., composite). By using this approach, PTers can ensure that their students have the foundation to succeed (Johnson & Layng, 1996; Johnson & Street, 2013; Kostewicz et al., 2020). For example, before targeting addition skills, PTers will conduct a component–composite analysis to identify essential underlying skills that should be developed to fluency first, such as being able to say and write numbers, label mathematical symbols (e.g., + and =), and count (Kapoor et al., 2023). By combining the component–composite analysis with pinpointing, PTers are able to thoroughly and precisely map a student's repertoire and provide instruction in ways that will lead to optimal outcomes.

Stages of Learning and by-Products of Mastery

In the framework's second step, titled practice, PTers arrange instruction in ways that address both primary stages of learning, namely acquisition and fluency (Jimenez et al., 2021). The acquisition stage refers to introducing new skills to students and focuses on developing accuracy, typically measured via percent correct (Johnson & Layng, 1992). The fluency stage focuses on developing effortless performance at one's natural pace that is typically measured through frequency (aka rate) and is considered essential to achieving functional mastery of a skill (Binder, 1996). Contrary to mainstream approaches that tend to stop instruction once accurate performance has been demonstrated, PTers design instruction and monitor its effect until fluency has been achieved (Johnson & Layng, 1996). Specifically, they evaluate fluency through a series of by-products historically presented via different acronyms, such as REAPS, which stands for retention, endurance, application performance standards, or RESA, which stands for retention, endurance, stability, and application (Fabrizio & Moors, 2003). Those by-products are typically evaluated at the end of the intervention through a series of short assessments. Specifically, retention focuses on one's ability to perform proficiently after a period of no practice. Endurance focuses on one's ability to perform proficiently for longer durations. Stability focuses on one's ability to perform proficiently in the presence of distractions, while application focuses on one's ability to recruit mastered skills when engaging in more complex ones. These assessments are considered the gold standard in PT as they allow PTers to empirically evaluate whether their students have achieved fluency and, therefore, functional mastery.

Visual Analysis and Behavioral Metrics

In the third step (i.e., chart), a family of standardized visual displays is used, known as the Standard Celeration Charts (SCCs). There are four primary SCCs, the daily, weekly, monthly, and yearly (Calkin, 2005). These displays offer information on a micro-, meso-, and macro-level. They are considered essential for PTers, as they have been built to optimize visual analysis and make possible the calculation of behavioral metrics, such as celeration or bounce, among others. Celeration provides a true measure of learning. Notably, PTers make a clear distinction between performance and learning. Performance is defined as an individual's ability to engage in a skill at a specific time, measured by its frequency. On the other hand, learning is the change in performance over time, quantified through celeration (Graf & Lindsley, 2002). Celeration is depicted as a trend line on the SCCs and is followed by a value indicating its direction and magnitude of change. A multiplication symbol (x) indicates acceleration of learning, while a division symbol ($\div$) indicates a deceleration of learning (Kubina & Yurich, 2012). Using celeration, PTers can accurately measure how quickly or slowly students' skills develop, offering a genuine measure of learning as a process, which is something typically missing from mainstream educational and behavioral approaches. This enables them to set goals based on students' learning rate and make more precise decisions about students' progress, as they rely on evaluating the celeration values generated during instruction rather than solely on visual analysis of performance data (Johnson et al., 2021; Vostanis et al., 2021). In other words, instead of having to determine whether a trend line is ascending steeply or moderately to determine whether the intervention is having the intended effect, they evaluate celeration values produced, such as × 1.40 vs. × 1.90, with the latter demonstrating more rapid learning, which has been shown to lead to more accurate decision making due to its more objective nature (Kubina et al., 2023). Similarly, through the bounce metric, PTers quantify variability, allowing them to objectively determine whether students' performance is adequately stable. For example, instead of relying solely on visual analysis, they can also compare bounce values across conditions, such as × 2.00 bounce vs. × 5.00 bounce, with the latter indicating more variable performance.

Dynamic Decision-Making and Recursive Problem-Solving

In the fourth step (i.e., decide), PTers evaluate progress and determine whether instruction should be continued, amended, or completed (Evans et al., 2021). The final step, titled try again, is used when instruction is unsuccessful. PTers evaluate the reasons behind the lack of progress, redesign their instruction, and re-implement it without placing blame on their students (Lindsley, 1990).

Precision Teaching's Applications

The core framework of PT has been successfully applied to various skill areas, such as reading (Ragnarsdóttir, 2007; Beverley et al., 2016; Carl Hughes et al., 2007), mathematics (McTiernan et al., 2018; Vostanis et al., 2021, 2022), gross motor (Lokke et al., 2008), fine motor (Twarek et al., 2010; Vascelli et al., 2020), and imitation skills (Lin & Kubina, 2015), and has produced encouraging outcomes. However, a closer look at PT's different applications shows that it has traditionally combined its core framework with various tactics and curricula derived from education, behavior analysis, and instructional design. These include, among other things, Direct Instruction (Ragnarsdóttir, 2007), frequency-building to a performance criterion (Datchuk & Kubina, 2014), discrete trial teaching (Malabello, 1998), and self-monitoring (Patterson & McDowell, 2009). One strategy that has yet to be used in the PT literature is natural environment teaching (Sundberg & Partington, 1998). This procedure is used widely in early childhood programs and has influenced intervention packages that fall under the more modern umbrella term naturalistic developmental behavioral interventions (Tiede & Walton, 2019).

Joint Attention Skills

Natural environment teaching is often used to train joint attention skills. Joint attention is defined as the ability to share a common point of reference with another person and refers to a cluster of behaviors that can take place across senses leading to tactile, auditory, or visual joint attention, to name a few (Monlux et al., 2019). Joint attention can be divided into two elements, responding to bids for joint attention (RJA) and initiating bids for joint attention (IJA; Bruinsma et al., 2004). In the first case, individuals respond as listeners; in the second case, they act as speakers. In typically developing children, joint attention can emerge between 6 and 12 months of age and is well established by 18 months of age. In autistic children, joint attention is a skill that might be missing from their repertoire and is considered one of the earliest indicators of a potential diagnosis of autism (Dawson et al., 2004; Murray et al., 2008; Roos et al., 2008).

Joint attention is considered a crucial developmental milestone from which new social and communicative skills emerge, such as imitation, social referencing, and language skills, to name a few (Jones et al., 2006; Pelaez & Monlux, 2018). Most importantly, joint attention skills have been linked to increased cognitive outcomes (Gabouer & Bortfeld, 2021; Mundy et al., 2007; Smith & Ulvund, 2003). Despite the various ways one can engage in joint attention, the focus is typically on its visual aspect, which includes eye gaze sharing, eye gaze alteration, gesturing, or object presentation (Monlux et al., 2019). As a result, interventions have historically focused on explicitly developing eye contact (Fonger & Malott, 2019; Hamlet et al., 1984; Jeffries et al., 2016), which has been heavily criticized as an ableist target. Various valid arguments have been made about the need to avoid explicitly targeting eye contact for autistic individuals who might find it particularly aversive (Jaswal & Akhtar, 2019). Therefore, training should focus more broadly on developing skills related to eye gaze. These skills should be cultivated to help autistic individuals maximize naturally occurring learning opportunities rather than forcing them to conform to neurotypical social norms.

Due to its importance and the significant impact on development, joint attention has been targeted widely, using various procedures. These include script-fading (MacDuff et al., 2007; Pollard et al., 2012), video modeling and augmented reality (Pérez-Fuster et al., 2022; Rudy et al., 2014), in vivo modeling and prompting (Isaksen & Holth, 2009), parent training (Rocha et al., 2007; Schertz & Odom, 2007), discrete trial training, and pivotal response training (Whalen & Schreibman, 2003). However, PT has not been embedded in existing programs used to train either RJA or IJA. As a result, to our knowledge, there is no evidence demonstrating the by-products of fluency in relation to joint attention skills, nor any data on celeration values generated during instruction on these skills—an area where PT could significantly contribute to the literature.

An evaluation of PT's existing literature suggests that despite its various applications, the primary focus has historically been on academic skills (Gist & Bulla, 2022; Martinho et al., 2022; McTiernan et al., 2022). As a result, to a certain extent, PT and fluency training have become synonymous with academic skills training and have not attracted adequate attention as to what it could offer practitioners developing other repertoires. What is more, its focus on fluency has been, at times, misinterpreted. For example, Heinicke et al. (2010) conducted a review of the evidence on fluency training for autistic individuals. Their review discussed that building high response rates might not be conducive to certain EIBI targets, such as manding. However, behavioral fluency does not necessarily mean high response rates. It means performance that is accurate, effortless, and has a natural pace (Binder, 1996). Therefore, certain skills might be performed at high-performance frequencies while others in lower frequencies, and they would both be considered fluent if the by-products of fluency were demonstrated (Fabrizio & Moors, 2003). To a certain extent, we believe this misinterpretation of fluency results from the PT literature primarily focusing on monitoring the effects of fluency training on academic skills (e.g., reading and mathematics) that lend themselves to high-performance frequencies. Therefore, there is a need for more examples of diverse applications of PT for practitioners interested in adopting the system and embedding it into their practice. One application that is lacking in the PT literature is natural environment teaching. Calls have been made to integrate naturalistic approaches with PT (Weiss, 2001), but to this day, this research gap seems to remain.

This Study's Aims

Therefore, this study aimed to expand the evidence on PT's application beyond academic skills, emphasizing fluency in other areas and highlighting underutilized concepts such as celeration. Specifically, this study focused on teaching RJA to autistic students in special education, as this is the first type of joint attention to emerge in one's repertoire (Isaksen & Holth, 2009). The research questions developed were:

(1) Will a functional relationship be demonstrated between an intervention utilizing a component–composite analysis, play-based natural environment teaching, and fluency-focused instruction and the development of RJA?
(2) Will participants demonstrate the by-products of fluent performance at the end of the intervention?
(3) What learning rates, quantified via celeration, will participants demonstrate when engaging in a play-based natural environment teaching focusing on fluency?

Method

Participants and Setting

Prior to approaching potential participants, we obtained ethical approval from the University of Kent ethics committee. Once ethical approval was provided, we requested parental consent and subsequently recruited five autistic students in the study. They all had English as their first language and had an Education Health Care Plan issued by the local authority (see Table 1). Participant 2 (PT2) was withdrawn from the study following baseline due to high rates of behaviors described as challenging that needed to be addressed. In addition, three typically developing students, labeled as comparison participants (C1–C3), were included in the study. Using convenience sampling, the students were recruited from a local mainstream education school that followed England's national curriculum. Two had English as their first language, while one had English and Swahili. These students' joint attention skills were considered fluent, so they were assessed to create performance criteria for the students who received PT.

All experimental participants attended a special education school in southern England and were supported within a unit that specialized in using educational tactics grounded in applied behavior analysis. The unit accommodated 85 students aged 4 to 19 and provided instruction across all national curriculum areas, including communication, academic, social, play, and daily-living skills. The intervention was conducted in a four by three meters room provided by the school. The room had a soft bench seat along one wall, with a mirror in the corner and a table with two chairs in the other. Additional stimuli associated with the intervention (for example, toys, books, and activities) were available but packed away in an opaque storage container.

Eligibility Criteria

For inclusion in the study, participants needed to have a diagnosis of autism and to have been reported by their teachers to be lacking joint attention skills. Students who demonstrated emerging joint attention skills or who were receiving interventions to develop joint attention skills at the time of the study were excluded from it.

Materials

Assessment Tools

A series of assessment tools were used to provide additional, descriptive information about participants' overall abilities. The Vineland Adaptive Behavior Scales-II Teacher Rating Form (VABS-II TRF; Sparrow et al., 2005) is a 233-item scale measuring adaptive behavior. The Gilliam Autism Rating Scale—2nd Edition (GARS-2; Gilliam, 2006) is a 42-item scale measuring the extent of symptoms related to autism. The Verbal Behavior Milestones Assessment and Placement Program (VB MAPP; Sundberg, 2008) is a criterion-referenced assessment tool, curriculum guide, and skill-tracking system for autistic individuals or ones diagnosed with language delays.

Table 1 Participants' Scores on the Assessment Tools Used in the Study

Participants	Sex	Age	Ethnic Group	VABS-II TRF	GARS-2	VB-MAPP	Additional Participant Information
				Standard Score	Autism Index	Level	
PT1	Male	5:6	White British	30	91	1	The student was non-vocal and had no established form of communication. At the time of the study, he was being taught a combination of signs and object mands to express wants and needs. He could lead adults by the hand to indicate what he wanted but engaged in behaviors described as challenging, if not understood. He would seek out familiar adults for physical interactions, such as squeezes and tickles, and would play in parallel with his peers if the environment was not too noisy. However, he would not show any interest in their behavior
PT3	Male	6:3	White British	27	85	1	The student was non-vocal and used some spontaneous adapted signs for actions while being taught object mands to accompany this at the time of the study. He could lead adults by the hand to indicate what he wanted. He would seek out familiar adults for physical interactions and to sing to him. He would play in parallel with his peers but would not show any interest in their behavior
PT4	Female	6:4	Asian British	36	102	1	The student would emit one to two-word vocal requests but mainly under the control of the item being present, not spontaneously. She did not seek out interaction from adults or peers but enjoyed singing with an adult and having her feet tickled
PT5	Female	6:6	White British	43	70	1	The student emitted some spontaneous picture mands. She generally had very low motivation and did not seek out interaction from others but enjoyed familiar adults engaging with her
PT2	Male	5:8	White British	31	115	1	The participant was withdrawn from the study
C1	Male	7:6	White British	–	–	–	–
C2	Female	7:3	White British	–	–	–	–
C3	Male	7:4	Black British	–	–	–	–

All assessment tools were administered to provide additional information about the participants' ability for descriptive purposes. PT2's data were reported last as they were withdrawn from the study. Typically developing students were included at the beginning of the study. They were not assessed with any assessment tools, as the focus was on assessing their joint attention skills. Age is reported as Years: Months. C1–C3=Comparison Participants. VABS-II TRF = Vineland Adaptive Behavior Scales, 2nd Edition, Teacher Rating Form; GARS-2 = Gilliam Autism Rating Scale, 2nd Edition, VB-MAPP = Verbal Behavior-Milestones Assessment and Placement Program

General Materials

Tutors were equipped with printed datasheets, pens, timers, and preferred stimuli, including toys, activities, and books specific to the student they were implementing the intervention, and backup reinforcers hidden away in a storage container. Examples of items used included building blocks, music toys, puzzles, and bubbles, to name a few. The second observer was present throughout all sessions and was equipped with datasheets for inter-observer agreement, procedural fidelity checklists, pens, and timers. Datasheets were constructed on Microsoft Word™ and included the pinpoint for each skill with a series of instructions in the form of bullet points that acted as reminders to tutors about important aspects of the training. The datasheets contained a table measuring 15×18, where one could note the date, location, and time, and collect data for each skill in the triad. It also kept track of whether participants responded correctly or not to each opportunity presented to them. Each datasheet was designed to record data for an entire week of school.

Dependent Variable

Six component skills and one composite skill were identified. The component skills were pinpointed following the PT methodology of combining movement cycles and learning channels. For example, for component skill 1, we identified the movement cycle: *Aims eye gaze*. We then added the relevant context: *toward sound and then person in proximity within 5 s*. We completed the pinpoint by adding the learning channel set: *Hear-Aim*. This led to the development of the full pinpoint: Hear-Aims eye gaze toward sound and then person in proximity within 5 s (see Table 2 for a list of all pinpointed skills). A traditional operational definition was created for the composite skill as it included a combination of learning channel sets and stimuli that led to a varying complexity that would more authentically resemble a natural context.

The dependent variable was the participants' independently emitted correct and incorrect responses per minute, plotted as separate data paths on the Standard Celeration Chart, in line with PT conventions (Kubina & Yurich, 2012). For the component skills, a correct response was defined as participants completing a full movement cycle for each targeted skill within the specified time frame. Since component skills were foundational to RJA, they involved either a single response (e.g., component 4) or a dyadic sequence of responses rather than a triadic one. For example, for component skill 1, participants needed to aim their eye gaze toward the sound and then toward the person nearby within 5 s. Completing this movement cycle constituted one correct response. If participants did not complete the full movement cycle or did so after the 5 s limit from the antecedent's presentation, an incorrect response was recorded. The composite skill, being the most complex one trained, required participants to complete a full triadic sequence. This involved aiming their eye gaze toward a stimulus while pointing at, touching, or manipulating it, depending on how RJA was presented. Next, they needed to look at the instructor, return their gaze to the initial stimulus, and if relevant, hand it to them within 5 s.

Table 2 Pinpoints for Component Skills, Operational Definition for the Composite Skill, and Correction Protocol

Skills	Pinpoint/Definition	Corrections Delivered During Instruction
Triad 1		
Component 1	Hear-Aims eye gaze toward sound and then person in proximity within 5 s	Step 1: Remove all other stimuli and re-present the sound. Differentially reinforce a correct response or proceed to Step 2
		Step 2: Position yourself next to the student, re-present the sound and exaggerate your gaze's orientation toward the source of the sound. Differentially reinforce a correct response or deliver two to three one-step directions and proceed with the session
Component 2	See-Aims eye gaze toward presented object and then person in proximity within 5 s	Step 1: Remove all other stimuli and re-present the object. Differentially reinforce a correct response or proceed to Step 2
		Step 2: Re-present the object with an exaggerated movement, left/right/up/down, in line with their gaze. Differentially reinforce a correct response or deliver two to three one-step directions and proceed with the session
Component 3	See-Aims eye gaze toward person in proximity and then follows proximal point to object within 5 s	Step 1: Remove all other stimuli, attract the student's attention, and re-present the point. Differentially reinforce a correct response or proceed to Step 2
		Step 2: Attract the student's attention, re-present the point, starting from the student's line of sight and then direct it toward the object. Differentially reinforce a correct response or deliver two to three one-step directions and proceed with the session
Triad 2		
Component 4	Hear-Aims eye gaze toward person calling one's name within 5 s	Step 1: Remove all other stimuli, call student's name again in a neutral tone of voice. Differentially reinforce a correct response or proceed to Step 2
		Step 2: Call student's name again in a playful tone of voice. Differentially reinforce a correct response or deliver two to three one-step directions and proceed with the session
Component 5	See-Aims eye gaze toward person in proximity and then follows proximal point to picture within 5 s	Step 1: Remove all other stimuli, attract the student's attention, and re-present the point. Differentially reinforce a correct response or proceed to Step 2
		Step 2: Attract the student's attention, re-present the point, starting from the student's line of sight and then direct it toward the picture. Differentially reinforce a correct response or deliver two to three one-step directions and proceed with the session

Table 2 (continued)

Skills	Pinpoint/Definition	Corrections Delivered During Instruction
Component 6	See-Aim.Touch looks at person in proximity and then picks up object after following distal point within 5 s	Step 1: Remove all other stimuli, attract the student's attention, and re-present the point and request to pick up the object. Differentially reinforce a correct response or proceed to Step 2
		Step 2: Attract the student's attention, re-present the point starting from the student's line of sight and then direct it toward the object, and deliver the request to pick up the object. Differentially reinforce a correct response or deliver two to three one-step directions and proceed with the session
Composite Skill		
RJA	Any instance in which the child intentionally directs their gaze toward a stimulus (presented by the instructor through direct presentation or pointing), or points to, touches, or manipulates it if appropriate, then shifts their gaze to the instructor, and then redirects their eyes back to the initial stimulus. This entire sequence occurs within a 5 s time frame from the stimulus presentation. The presented stimuli should be novel and naturally encompass a variety of items, sounds, and pictures, while presented at varied distances between 1 and 5 feet	Step 1: Remove all other stimuli, attract the student's attention, and re-present the antecedent. Differentially reinforce a correct response (i.e., a full triadic sequence emitted by the student), or proceed to Step 2
		Step 2: Attract the student's attention, re-present the antecedent with the relevant prompt following the guidelines from the component skills that link to the type of antecedent presented (e.g., sound, point, picture). Once the prompt is delivered move the stimulus used to present the RJA and slowly adjust its positioning so that the student visually tracks toward the instructors and then back to its former position. Differentially reinforce a correct response (i.e., a full triadic sequence emitted by the student), or deliver two to three one-step directions and proceed with the session

RJA = Responding to Bids for Joint Attention. The six component skills (i.e., prerequisites) were broken into two triads. Each triad received training simultaneously. Triad 1 was introduced first. Once training was completed, Triad 2 was introduced. Finally, the primary/composite skill was targeted. For the composite skill, a traditional operational definition was created as participants were presented with various naturally occurring bids for joint attention of different complexity that included various combinations of component skills that were trained

Experimental Design

A concurrent multiple baseline across participants design was employed (Carr, 2005). This decision was considered essential due to various criticisms in the literature about the need for robust experimental designs to be employed within the PT literature (Gist & Bulla, 2022; Ramey et al., 2016). For the first triad of component skills, PT1 completed three days of baseline, PT3 completed seven, PT4 completed nine, and PT5 completed eleven, following the design conventions. For the second triad of component skills, PT1 completed six days of baseline, PT3 completed ten, PT4 completed twelve, and PT5 fourteen. For the composite skill, PT1 completed five days of baseline, PT3 completed eight days, PT4 completed nine, and PT5 completed ten days. As for PT2, they only completed five days of baseline with the component skills before exiting the study. All baseline sessions were conducted once a day on separate school days in line with the design's conventions. Participants' allocation to each tier was decided through a randomization process using the https://www.random.org website.

Performance Criteria

Performance criteria were not calculated for the component skills. However, we did calculate performance criteria for the composite skill. Specifically, three typically developing students (i.e., C1-C3) who were reportedly fluent in responding to and initiating joint attention bids were assessed over three sessions. During the assessment, students engaged in a 15-min play session with one of their teachers. To ensure that the teachers' experience and training would not affect the opportunities presented to students, we asked different teachers to run each session. The sequence of sessions and the corresponding teachers working with individual students were randomized using the website mentioned above. Data were separately collected on the joint attention bids initiated by the teacher and the number of subsequent responses on the students' part. Both the students and the teachers were blinded to the nature of the assessment.

This assessment aimed to evaluate how often teachers naturally initiated bids for joint attention and how many times students successfully responded to them. That way, we could set a functional criterion in terms of the minimum number of joint attention bids that would be presented to the students receiving the intervention. In other words, the assessment minimized the possibility of setting performance expectations that would be too low or too high for the students. Once the assessment was completed, we calculated the median number of the students' responses to joint attention bids and set that as the performance criterion for the students who received the intervention. Specifically, participants were expected to perform either at 14 correct and one incorrect response or 15 correct with no incorrect responses for three consecutive days. The decision to set the criteria for three consecutive days was based on the school's standard approach to setting performance criteria for their students.

Setting performance criteria by probing the performance of individuals considered fluent in the skill is one of the various ways PTers have to determine performance standards (see White, 1985, for more detail). This approach enhances practitioners' decision-making by providing a general benchmark against which they can evaluate their students' performance. However, it is worth noting that this approach is not meant to promote ableism (Bottema-Beutel et al., 2021), but rather act as a general guide. Variations in performance are not uncommon, and an individualized approach for each student is encouraged.

Procedure

This study followed three primary phases, namely the baseline assessment, the daily instruction, and the final assessment (see Fig. 1). The training was delivered on a 1:1 tutor-to-student ratio by four behavior technicians who had between three to five years of experience working in the field of applied behavior analysis within the school setting. Each tutor was supervised by the second author, who was a board-certified behavior analyst (BCBA) with nine years of experience, with oversight from the first author, who was a doctoral-level BCBA with ten years of experience. Another BCBA was available for collecting inter-observer agreement and fidelity data throughout the study and had five years of experience in the field.

Due to the nature of the skills targeted, it was not possible to arrange for instruction to be delivered in a free-operant arrangement typically employed within PT. A free-operant arrangement allows students to perform at their natural pace without any imposed limits to their performance. However, RJA (and its component skills) involves the presentation of a stimulus from another person. As a result, one's pace of RJA is dictated by how many bids to respond are provided. Evans et al. (2021) discussed how PTers arrange instruction across different degrees of restriction that transition from controlled operants (e.g., discrete trial training; Smith, 2001) to free-operant arrangements (e.g., frequency-building to a performance criterion; Kubina & Yurich, 2012). The instructional arrangements in this study would be in the middle of that range of restrictions. Although participants could not perform the skill in a free-operant format for reasons already described, they were presented with a minimum number of opportunities to respond linked to their typically developing peers' performance, who were considered fluent in the skill. In other words, how natural environment teaching was delivered ensured that any ceilings placed on participants' performance were minimized, to the extent possible, in line with PT expectations (Evans et al., 2021).

Preference Assessment

A multiple stimulus with replacement preference assessment was conducted at the beginning of the study to help us identify stimuli that could be used during the

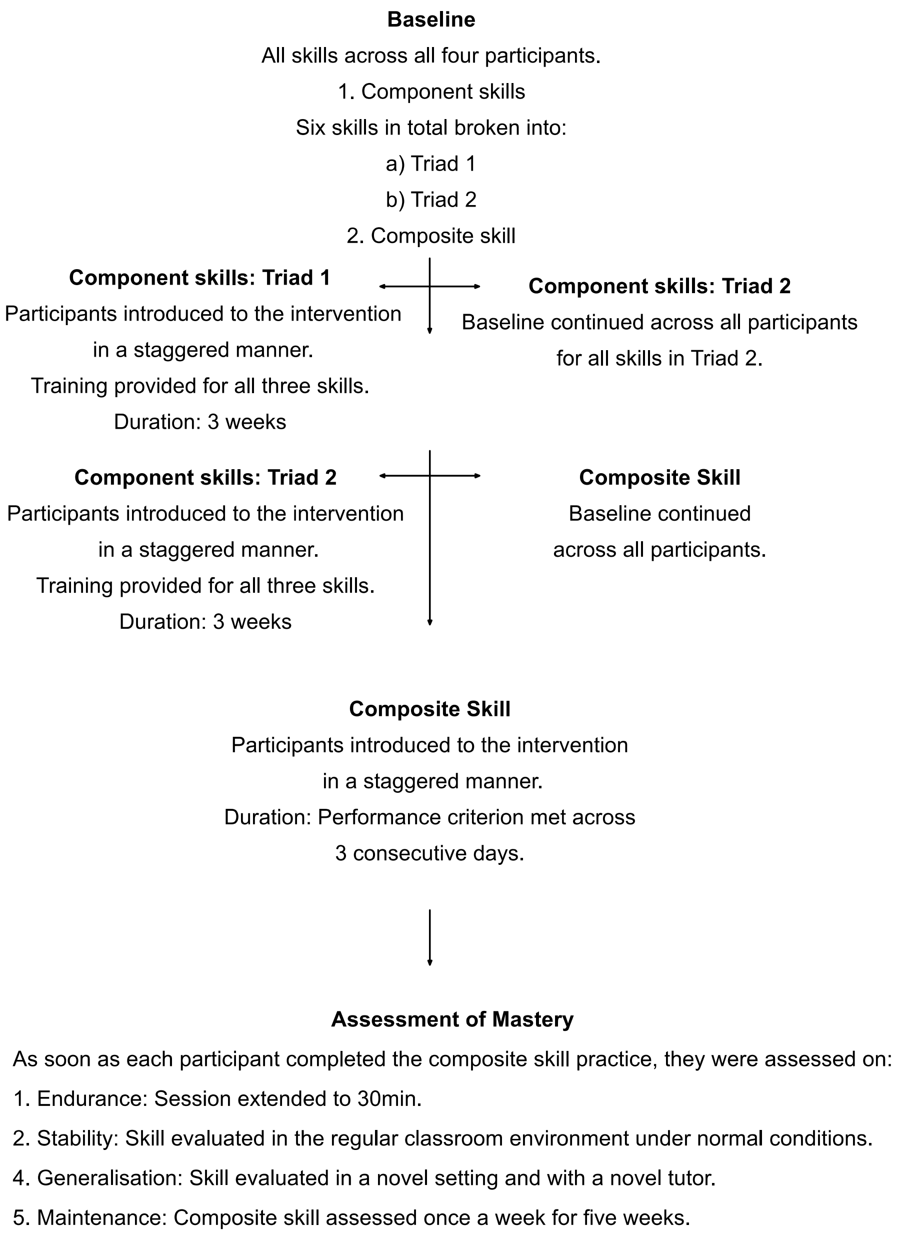


Fig. 1 Study's Steps

training. This preference assessment was chosen as it was typically used within the school setting, and contextual fit was an important consideration. However, more robust preference assessment procedures, such as the multiple stimulus without replacement method, could be used (DeLeon & Iwata, 1996). Stimuli identified as highly preferable were not used during training to evoke joint attention but were provided as reinforcing stimuli when joint attention occurred. That way, to the extent possible, we guarded against shaping a manding (i.e., requesting) repertoire during the joint attention training, which would be linked to IJA and was beyond the study's focus. Stimuli identified as moderately preferable were used to evoke joint attention to ensure that motivation was still present for the participants. Despite our efforts to avoid shaping a manding repertoire, it is important to note that using moderately preferred stimuli does not necessarily prevent the development of such a repertoire, as participants may still be motivated to access those stimuli. However, in our study, the chosen stimuli did not evoke manding behaviors and did not interfere with our procedures.

For Participant 1, the stimuli used as reinforcers for engaging in joint attention were the iPad, lanyards, slinkies, snakes, and cereal bars. For Participant 3, the musical teapot, shakers, clapping hands toys, slimes, and massage balls. For Participant 4, the iPad, blocks, alphabet puzzles, and cucumber. Finally, for Participant 5, the iPad, playdough, massage balls, slimes, and crackers. For all participants, the reinforcers were provided individually and rotated throughout each session.

Baseline

During baseline, participants were given various toys of moderate and high preference and engaged in 15-min play sessions with their tutor in a 1:1 format. Component skills were broken into two triads. Each triad and the composite skill were baselined separately. For the components, participants were provided with five opportunities to respond per skill in a randomized fashion for a total of 15 opportunities. For example, for component skill 3, the student would attend to the tutor, who would then point and look at a toy nearby. If the student did not shift their eye gaze toward the toy, the tutor would score an incorrect response and proceed with the session. No prompting or feedback was provided to participants. Similarly, the composite skill was baselined by offering 15 opportunities to respond per session without providing any prompting or feedback. At the end of each session, participants were praised for taking part, and the session was concluded.

Instruction Component Skills

Participants first received instruction on the component skills and then on the composite skill. To make practice efficient, instruction was presented simultaneously for each triad of skills. Instruction consisted of three weeks per triad of component skills for a total of six weeks.

Instruction was primarily delivered on a 1:1 tutor-to-student ratio. However, due to the nature of some of the skills being targeted, there were cases where a second tutor was involved. Specifically, any skills involving producing a sound as an antecedent, such as from a musical toy, required a second tutor positioned in the corner of the room who was responsible for producing the sound. During the instructional sessions, tutors offered practice on each of the three skills in a randomized fashion while ensuring that participants had at least five opportunities to respond for each skill for a total of 15 per session. Participants received daily instruction using natural environment teaching in a play-based format, including social and tangible reinforcement, along with corrective feedback that included response and stimulus prompts and prompt fading (see Table 2).

During instruction, participants were presented with a relevant antecedent event linked to the relevant component skill. Depending on whether they responded correctly or not, they either received confirmatory or corrective feedback. Confirmatory feedback included vocal praise and the presentation of a preferred item on a fixed ratio of one (FR1) schedule of reinforcement. Corrective feedback included two separate steps presented sequentially. The first step included removing additional stimuli from the environment and representing the antecedent. The second step involved ensuring the environment was free from distractions, ensuring that the tutor's position was adjacent to the participant, and presenting a stimulus or response prompt (see Table 2 for more information). If participants did not respond to the final step, the tutor presented 2–3 one-step directions before presenting the next opportunity to respond independently. The prompting used during corrections varied depending on the targeted skill and included gestural prompts, position, movement cues, and vocal prompts. For example, when practicing the first component skill, participants were engaged in natural play and presented with a sound (e.g., a musical toy). Depending on whether they looked at the source of the sound and then their tutor or not, they received praise and a highly preferred item or a correction in the form of stimuli being removed from their immediate environment and the sound being represented. If they did not respond after this first correction, the second observer would represent the sound, and the primary tutor would exaggerate, directing their gaze toward it to prompt the student to shift their gaze toward the sound and then back to the primary tutor. If the participant still failed to respond after this second correction, the primary tutor would present 2–3 mastered one-step directions, natural to the play they were engaging in, before providing a novel opportunity to respond independently. Once practice was completed, tutors plotted the data on the Daily per Minute SCC (see section titled: Data Repository).

Instruction Composite Skill

Instruction on the composite skill was similar to the one used to train the component skills and followed the same sequence of confirmatory and corrective feedback. However, there were some critical differences. First, instead of using moderately preferred items as with the component skills, we used novel items. Second, rather than training a simple or dyadic response, we instructed participants to engage in a full triadic sequence. This involved presenting bids of varying complexity, incorporating visual, auditory, and tactile stimuli to simulate natural conditions. During training, participants were guided to shift their gaze to the stimulus, then to their tutor, and back to the original stimulus—a triadic sequence not required during component skills practice. Given the diverse presentations of RJA, participants were sometimes expected not only to gaze at the stimulus but also to point to, pick up, manipulate, or hand it to their tutor. For instance, during practice, a tutor would point and say, ‘Look at (name) jumping so high on the trampoline,’ referring to someone a few feet away. Participants were instructed to observe the person on the trampoline, return their gaze to the tutor, and again to the person jumping. At times, participants might have been playing with a car track that was missing a piece, in which case the tutor would point to the piece across the carpet so that participants could go and pick it up and complete the track. In this case, as well, participants were trained to look where the tutor pointed, then at the tutor, and finally go and pick up the piece. Similarly, if someone entered the room, the tutor would point and announce, ‘(name) is here to say hello.’ Participants were instructed to look at the person, then their tutor, and respond with a greeting. Third, the composite skill practice included more opportunities to respond linked to the performance criteria set.

Mastery Assessment

When the training of the composite skill was completed, participants’ performance was assessed for some of the by-products of fluency. These by-products are considered the golden standard of mastery in PT (Fabrizio & Moors, 2003). Specifically, we assessed *endurance, stability, generalization, and maintenance (ESG-M)*. First, participants’ ability to perform for longer durations (i.e., endurance) was assessed by asking them to engage in a play session that was twice as long (i.e., 30 min) as their usual training session. During the session, the minimum number of joint attention bids initiated by the teachers was also doubled. As a result, performance criteria were set at a minimum of 28 correct responses per session with no more than two incorrect responses to account for the increase in the play session’s duration. Second, the participants’ ability to perform in the face of distraction was assessed. Specifically, we conducted a 15-min session in a busy room where other students and tutors interacted. Third, we assessed their ability to generalize their skills to novel situations by asking them to engage in a 15-min play session with a novel tutor, in a novel room, and with novel toys. Finally, the participants’ ability to maintain their performance improvements on the composite skill was assessed once a week for five consecutive weeks.

Absence Protocol

Instructional sessions happened once a day. If participants missed up to two days of school due to illness or other reasons, they engaged in one or two double sessions (morning and afternoon) to catch up. If participants missed three days of school, the practice was reset for that week, and participants started again the next week. No double sessions were conducted, but participants had to repeat a whole week in some cases due to COVID-19 school closures. Specifically, PT1 had to restart two non-consecutive weeks, while the remaining participants had to restart one week each.

Interobserver Agreement

Interobserver agreement (IOA) was assessed for all participants across each study phase. Specifically, IOA was collected for baseline, component skills instruction (Triad 1 and Triad 2), composite skill instruction, and the mastery and maintenance assessments (ESG-M). Where the number of sessions remained consistent across participants, we conducted IOA for an equivalent number of sessions. As a result, IOA data were collected for 40% of the total sessions in Triad 1, Triad 2, and Maintenance conditions. Furthermore, we ensured IOA data encompassed all assessments conducted during the ESG condition. However, due to variations in the number of baseline and composite skill practice sessions, there was a slight difference in the percentage of sessions where IOA assessments occurred. Specifically, for PT1, we assessed IOA for 40% of baseline sessions and 28.57% of composite skill sessions; PT3 for 37.50% of baseline and 40% of composite skill sessions; PT4 for 44.4% of baseline and 66.67% of composite skill sessions; and lastly, for PT5, 40% of baseline and 50% of composite skill sessions.

A second BCBA independently scored either video recordings of the sessions or in person during a training session. Point-by-point agreement was determined by dividing the number of trials with observer agreement (i.e., where both recorded either a correct or incorrect response to the bid for joint attention) by the total number of trials, and then multiplying the result by 100 to obtain the percentage. Average agreement in baseline was 97% (range 93%–100%) for PT1, 100% for PT3 and PT4, and 98% (range 93%–100) for PT5; in Triad 1 100% for PT1, PT4, and PT5, and 99% (range 93%–100%) for PT3; in Triad 2, 100% for PT1, PT3, and PT4, and 99% (range 93%–100%) for PT5; in the composite, 97% for PT1 (range 93%–100%) and 100% for PT3, PT4, and PT5; in ESG, 99% (range 97%–100%) for PT1, 98% (range 93%–100%) for PT3, and 100% for PT4 and PT5; and finally, in maintenance, 100% for all participants.

Procedural Fidelity

Procedural fidelity was assessed for all participants for the same number of sessions as with IOA and by the same BCBA. Checklists were created on Microsoft Word™ and included items tailored around each skill. All aspects of the baseline, instruction, and mastery assessment procedure were included, such as the way tutors positioned themselves, presented the antecedent stimuli, provided confirmatory or corrective feedback, or the number of response opportunities they provided to participants. Separate checklists were created for the two triads of component skills and the composite skill for each phase of the study (see section titled: Data Repository). The Triad 1 baseline checklist had 14 items, Triad 2 had 16 items, and the composite skills had five items. The Triad 1 instruction checklist had 47 items, Triad 2 had 46 items, and the composite skills had 14 items. The ESG-M assessment checklist of the composite skill had 16 items. The BCBA scored each checklist by tallying either correct or incorrect for each item at each presented opportunity. Average total fidelity in baseline was 99% (range 97%–100%) for PT1, 100% for PT3 and PT5, and 99% for PT4 (range 95%–100%); in Triad 1, 98% (range 90%–100%) for PT1, 99% (range 96%–100%) for PT3, 100% for PT4, and PT5; in Triad 2, 100% for all participants; in the composite, 100% for PT1, PT3, and PT5, and 99% for PT4 (range 98%–100%); in ESG, 99% (range 96%–100%) for PT1 and PT5, 98% (range 95%–100%) for PT3, and 100% for PT4; and finally, in maintenance, 100% across all participants.

Social Validity

At the end of the study, the participants' parents were provided with a questionnaire developed by the authors that included four statements about the training process and their child's progress as a perceived result of this. A 6-point Likert scale was included in each question that ranged from 'strongly disagree' to 'strongly agree.' For example, one question asked them to score the statement, 'My child did not previously display responses to bids for joint attention prior to this intervention,' while another to score the statement, 'My child has gained skills relating to responding to bids for joint attention.' Finally, item five provided the opportunity for parents to add any other comments about the study. All parents chose 'strongly agree' across all items, indicating high satisfaction with the intervention. In addition, one parent commented that *'my son is so much more engaged in everything around him now, (…),'* while a second parent commented, *'I did not know what joint attention was before, but now it is so obvious how important it is for my child to succeed in life.'*

Another questionnaire (see section titled: Data Repository) was provided to participants' lead teachers who were not involved in the study. The questionnaire covered topics similar to the parents,' with the addition of whether the goals, procedures, and outcomes were satisfying for that individual. Five questions were included with the same 6-point Likert scale. For example, one question asked them to score the statement 'X seemed to enjoy taking part in this intervention,' while another asked, 'The intervention was easy to implement effectively by X's tutor.' All teachers chose 'strongly agree' across all items, indicating high satisfaction with the intervention.

Data Analysis

Data were analyzed by using an online version of the Daily per Minute SCC through a software named PrecisionX, available at https://centralreach.com/products/precisionx/, that provided digital copies of the participants' SCC and helped us calculate relevant behavioral metrics. The primary metrics utilized were the level, celeration, bounce, and level change multiplier. The level shows the average performance of the individual across time. The geometric mean was calculated as it is more appropriate for data plotted on the SCC and less affected by extreme variables (Everitt & Howell, 2005). The daily celeration (i.e., count/unit of time)/unit of time) was calculated during the baseline and instructional phases, and the weekly celeration was calculated during maintenance as performance was assessed across weeks, not days. In all cases, the least-squares regression method was used. Kubina and Yurich (2012) offer detailed information on interpreting celeration values. Notably, values close to or above × 2.00 are considered particularly robust. To make it easier to evaluate participants' progress over time, we transformed celeration values into percentages. Bounce produces a ratio quantifying behavioral variability across time and is always reported using a multiplication (*x*) symbol. As with celeration, Kubina and Yurich (2012) offer detailed information on interpreting bounce. It is worth noting that a bounce value up to × 3.00 suggests stable performance. The level change multiplier produces a ratio showing how much average performance changed from one phase to another (e.g., baseline to intervention). The ratio was calculated by dividing the highest number by the lowest number and then assigning the multiplication (x) or division (÷) sign to indicate an increase or decrease in average performance across time (Kubina & Yurich, 2012). In this case, values were also transformed into percentages to improve clarity.

In addition to these metrics, the baseline corrected TAU was calculated through an online calculator available at https://ktarlow.com/stats/tau/ (Tarlow, 2016, 2017). The baseline corrected TAU is a nonparametric effect size that makes possible the evaluation of the presence of a monotonic trend in the baseline and its correction if necessary (Tarlow, 2017). This effect size was calculated using participants' correct responses and by comparing baseline to instruction data for the component skills and baseline to maintenance data for the composite skill. Small effects were between 0 and 0.65, medium effects were between 0.66 and 0.92, and large effects were between 0.93 and 1.00 (Fig. 1).

Results

Triads of Component Skills

All participants benefitted from the intervention across both triads of component skills (see Table 3). PT1 demonstrated an average increase in correct responses by 317% (range 266%–383%) across the three skills in Triad 1 with small effect sizes (see Fig. 2, first panel). In Triad 2, they improved by 267% (range 187%–327%) with small to moderate effect sizes across the three skills (see Fig. 3, first panel). PT3 improved by 277% (range 218%–354%), with moderate effect sizes in Triad 1 (see Fig. 2, second panel). In Triad 2, they improved by 182% (range 47%–331%) with small to moderate effect sizes (see Fig. 3, second panel). PT4 improved by 461% (range 357%–568%) with moderate effect sizes in Triad 1 (see Fig. 2, third panel). In Triad 2, they improved by 508% (range 139%–707%) with moderate effect sizes (see Fig. 3, third panel). PT5 improved by 298% (range 268%–352%) with moderate effect sizes in Triad 1 (see Fig. 2, fourth panel). In Triad 2, they improved by 514% (range 202%–767%) with moderate effect sizes (see Fig. 3, fourth panel).

Table 3 Behavioral Metrics for the Two Triads of Component Skills

	Component 1			
	Celeration		Bounce	
	Average Correct (Min–Max)	Average Incorrect (Min–Max)	Average Correct (Min–Max)	Average Incorrect (Min–Max)
PT1	×2.40 (×1.50–×4.66)	÷2.90 (÷2.64–÷3.51)	×2.01 (×1.40–×3.60)	×2.00 (×1.90–×2.10)
PT3	×4.98 (×1.76–×20.00)	÷2.49 (÷1.76–÷4.41)	×1.79 (×1.70–×2.00)	×1.71 (×1.30–×2.40)
PT4	×1.57 (×1.33–×1.75)	÷2.90 (÷1.33–÷4.29)	×1.56 (×1.40–×1.70)	×2.28 (×1.70–2.90)
PT5	×4.41 (×2.64–×7.56)	÷3.65 (÷1.50–÷10.00)	×1.64 (×1.40–×2.10)	×1.43 (×1.30–×1.60)
	Component 2			
PT1	×1.42 (÷1.08–×1.76)	÷2.10 (÷1.76–×1.99)	×1.83 (×1.50–×2.40)	×2.10 (×2.40–×4.30)
PT3	×2.98 (×1.76–×4.29)	÷1.86 (÷1.76–÷1.99)	×1.76 (×1.60–×2.00)	×1.66 (×1.20–×2.40)
PT4	×1.36 (×1.00–×2.16)	÷1.67 (×1.00–÷2.87)	×1.56 (×1.40–×3.40)	×2.62 (×2.20–×3.40)
PT5	×4.05 (×1.00–×15.50)	÷4.05 (×1.00–÷39.70)	×1.78 (×1.30–×2.40)	×1.78 (×1.50–×2.10)
	Component 3			
PT1	×5.75 (×4.41–×6.96)	÷5.23 (÷2.04–÷20.00)	×1.75 (×1.40–×2.40)	×1.40 (×1.30–×1.50)
PT3	×4.17 (×1.5–×11.30)	÷4.04 (÷2.50–÷10.00)	×1.46 (×1.40–×1.60)	×1.59 (×1.20–×2.10)
PT4	×3.42 (×1.37–×15.00)	÷5.92 (÷2.64–÷11.30)	×1.39 (×1.20–×1.50)	×1.91 (×1.70–×2.40)
PT5	×2.56 (1.00–×4.41)	÷3.86 (÷1.00–÷20.00)	×1.63 (×1.30–×2.40)	×1.75 (×1.50–×2.10)
	Component 4			
PT1	×3.35 (×1.75–×12.30)	÷5.04 (÷4.29–÷6.96)	×1.58 (×1.40–×2.00)	×2.43 (×2.40–×2.50)
PT3	×3.01 (×1.37–×6.18)	÷4.12 (÷2.64–÷7.56)	×1.68 (×1.30–×2.30)	×2.22 (×1.50–×2.70)
PT4	×1.21 (×1.00–×1.75)	÷1.62 (×1.00–÷4.29)	×1.43 (×1.30–×1.60)	×2.44 (×2.10–×2.90)
PT5	×1.98 (×1.17–×3.23)	÷4.40 (÷1.62–÷7.56)	×1.37 (×1.30–×1.40)	×2.05 (×1.50–×2.40)
	Component 5			
PT1	×3.75 (×3.51–×4.29)	÷1.88 (÷1.67–÷1.99)	×2.33 (×2.30–×2.40)	×1.76 (×1.50–×1.90)
PT3	×2.61 (÷1.33–×6.18)	÷2.38 (÷1.33–×1.33)	×1.87 (×1.60–×2.40)	×1.85 (×1.70–×2.20)
PT4	×1.49 (×1.17–×2.43)	÷2.46 (÷1.62–÷5.69)	×1.52 (×1.40–×1.80)	×2.33 (×2.20–×2.40)

Table 3 (continued)

	Component 1			
	Celeration		Bounce	
	Average Correct (Min–Max)	Average Incorrect (Min–Max)	Average Correct (Min–Max)	Average Incorrect (Min–Max)
PT5	×1.98 (×1.17–×3.23)	÷4.40 (÷1.62–÷7.56)	×1.37 (×1.30–×1.40)	×2.05 (×1.50–×2.40)
	Component 6			
PT1	×3.44 (×1.67–×9.25)	÷3.79 (÷1.37–÷9.25)	×1.90 (×1.60–×2.70)	×1.91 (×1.50–×2.90)
PT3	×2.79 (×1.17–×9.52)	÷5.92 (÷1.62–÷18.40)	×1.69 (×1.40–×2.30)	×2.50 (×2.40–×2.70)
PT4	×2.51 (×1.00–×11.60)	÷4.29 (×1.00–÷29.90)	×1.54 (×1.30–×2.00)	×2.01 (×1.60–×2.40)
PT5	×1.48 (×1.17–×2.04)	÷3.09 (÷1.62–÷6.96)	×1.77 (×1.20–×2.70)	×3.03 (×1.70–×4.80)

Celeration and Bounce were calculated separately for the correct and incorrect responses. Celeration is presented with the multiplication sign (*x*) to indicate an acceleration of performance across time and the division sign (÷) to indicate a deceleration. Bounce is always reported using a multiplication symbol (*x*). The daily Celeration and Bounce were calculated for each week of the three weeks of instruction and then averaged using the geometric mean. Component skills 1–3 were taught interchangeably during 15-min sessions. Component skills 4–6 were introduced after skills 1–3 and taught interchangeably during 15-min sessions

Composite Skill

All participants improved considerably in the composite skill that produced moderate effect sizes and were maintained across five weeks (see Fig. 4). They also maintained their performance near the performance criteria set, during the ESG mastery assessment, except for the stability assessment, which demonstrated a slight drop for PT1 and PT4. However, a clear functional relation was not demonstrated due to performance improvements in the final baseline session across all participants.

For PT1, baseline lasted five days, including a final baseline probe after completing component skills training (see Fig. 4, first panel). PT1's baseline performance was stable at × 2.80 bounce, and incorrect responses were consistently higher than correct ones. In the final baseline probe, PT1 increased their correct responses, indicating the emergent application of component skills. However, incorrect responses remained higher, suggesting the need for explicit training. During the instructional phase, performance improved considerably by the third day, suggesting an immediate effect. PT1's correct responses accelerated by × 2.09 (109%) with × 2.00 bounce, while incorrect responses decelerated by ÷ 10.90 (91%) with a × 3.90 bounce. Overall, during instruction, PT1 averaged 0.73 correct responses per minute, an average increase of 1350% from baseline, with no data overlap between the baseline and instructional phases. Incorrect responses averaged 0.12 per minute, an 86% average decrease from baseline, with no overlap between phases. During maintenance, PT1 averaged 0.97 correct responses and 0.04 incorrect responses.

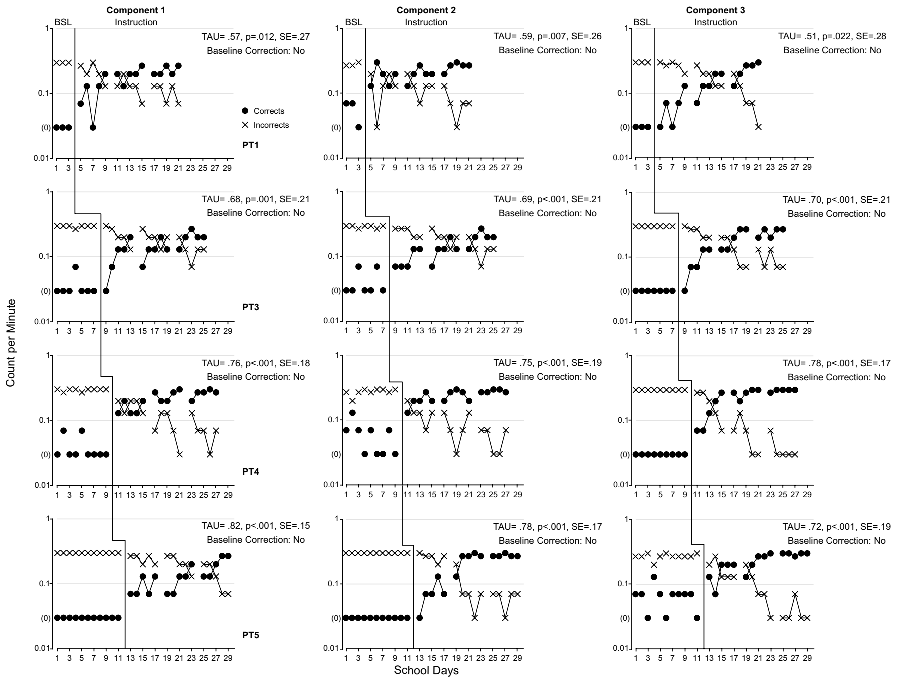


Fig. 2 First Triad of Component Skills. As the ratio axis has no actual zero value, we followed Precision Teaching conventions related to plotting zero values on the family of Standard Celeration Charts. We added zero in brackets to improve clarity. The baseline corrected TAU was calculated by comparing baseline to instruction data

For PT3, baseline lasted eight days, including the final baseline probe (see Fig. 4, second panel). PT3's baseline performance was stable at × 2.40 bounce, and incorrect responses were consistently higher than correct ones. In the final baseline probe, PT3 also increased their correct responses, indicating the emergent application of components. However, incorrect responses remained higher. During the instructional phase, performance improved considerably by the third day, suggesting an immediate effect. PT3's correct responses accelerated by × 5.98 (498%) with × 1.80 bounce, while incorrect responses decelerated by ÷ 138.90 (99%) with × 3.80 bounce. Overall, during instruction, PT3 averaged 0.70 correct responses per minute, an average increase of 1160% from baseline, with no data overlap. Incorrect responses averaged 0.13 per minute, an 86% average decrease from baseline, with only one datum point overlapping (7.69%). During maintenance, PT3 averaged 0.98 correct responses and 0.03 incorrect responses.

For PT4, baseline lasted nine days (see Fig. 4, third panel). PT4's baseline performance was moderately variable at × 3.10 bounce, and incorrect responses were consistently higher than correct ones. PT4 increased their correct responses in the final baseline, though incorrect responses remained higher as with the other participants. During the instructional phase, performance improved immediately.

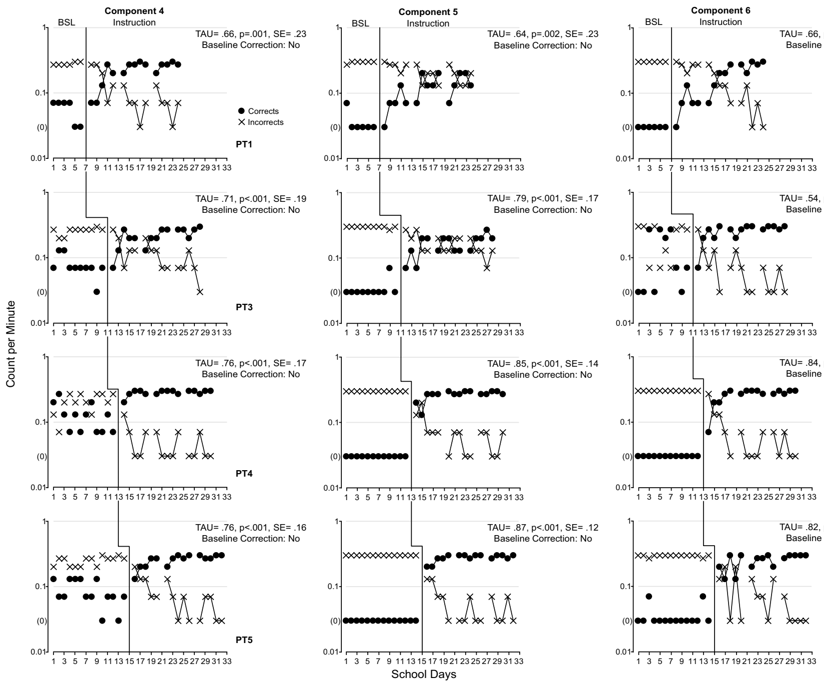


Fig. 3 Second Triad of Component Skills. As the ratio axis has no actual zero value, we followed Precision Teaching conventions related to plotting zero values on the family of Standard Celeration Charts. We added zero in brackets to improve clarity. The baseline corrected TAU was calculated by comparing baseline to instruction data

PT4's correct responses accelerated by × 1.27 (27%) with × 1.10 bounce, while incorrect responses decelerated by ÷ 11.30 (91%) with × 1.60 bounce. Overall, during instruction, PT4 averaged 0.97 correct responses per minute, an average increase of 1530% from baseline, with no data overlap. Incorrect responses averaged 0.04 per minute, a 96% average decrease from baseline, with no overlap. During maintenance, PT4 averaged 0.98 correct responses and 0.03 incorrect responses.

For PT5, baseline lasted ten days (see Fig. 4, fourth panel). PT5's baseline performance was moderately variable at × 3.10 bounce, and incorrect responses were consistently higher than correct ones. PT5 also increased their correct responses in the final baseline, though incorrect responses remained higher. During the instructional phase, performance improved immediately. PT5's correct responses accelerated by × 1.29 (29%) with × 1.10 bounce, while incorrect responses decelerated by ÷ 11.30 (91%) with × 2.90 bounce. Overall, during instruction, PT5 averaged 0.94 correct responses per minute, an average increase of 1320% from baseline, with no data overlap. Incorrect responses averaged 0.05 per minute, a 94% average decrease from baseline, with no overlap. During maintenance, PT5 averaged 0.95 correct responses and 0.05 incorrect responses.

Overall, PT1 required seven days of instruction to meet the performance criteria and increased their response accuracy from 4.00% in baseline to 97.33% in maintenance. PT3 required five days of instruction to meet the performance criteria and increased from 5.83% in baseline to 98.67% in maintenance. PT4 required three days of instruction and increased from 5.93% to 98.67%, and PT5 required four days and increased from 8.67% to 96%.

Discussion

This study sought to evaluate whether a PT framework combined with play-based, natural environment teaching could effectively teach autistic children to respond to bids for joint attention by offering instruction in underlying skills to fluency before targeting the primary skill of concern. The intervention included elements of best practice as highlighted in the existing literature, such as the focus on multiple topographies, the use of a play context, the application of evidence-based interventions such as natural environment teaching, and a focus on generalization (White et al., 2011). The results were encouraging as all participants made considerable improvements that were maintained. This study demonstrates an original application of PT and adds more evidence about its effectiveness in improving performance and accelerating learning across different skills (Gist & Bulla, 2022; McTiernan et al., 2022; Ramey et al., 2016).

We believe this study to be an essential addition to the existing PT literature. Precision teaching has historically been used across different behaviors, such as imitation (Lin & Kubina, 2015), ballet movements (Lokke et al., 2008), Tap dancing (Pallares et al., 2021), steps walked (Junaid et al., 2021), thoughts and feelings (Patterson & McDowell, 2009), and speech and language conditions (Aravamudhan & Awasthi, 2021). However, the field's greatest impact has been in the area of academic skills (Gist & Bulla, 2022; Johnson et al., 2021; McTiernan et al., 2022; Sawyer et al., 2021).

Despite this, PT has much to offer to practitioners focused on other areas of development, such as joint attention. We hope this study is a valuable resource for practitioners who wish to integrate PT into existing evidence-based intervention frameworks. We propose that PT could enhance and fine-tune practitioners' outcomes by focusing on frequency as a measure of performance, assessing the by-products of fluency as a measure of true mastery, and using behavioral metrics to achieve an advanced understanding of students' overall progress. Furthermore, it is crucial to underscore that PT is not meant to function in isolation. On the contrary, it has been designed to be embedded within other intervention frameworks to help practitioners gather precise data about the effectiveness of their efforts. Therefore, the potential for integrating PT within early childhood education is considerable.

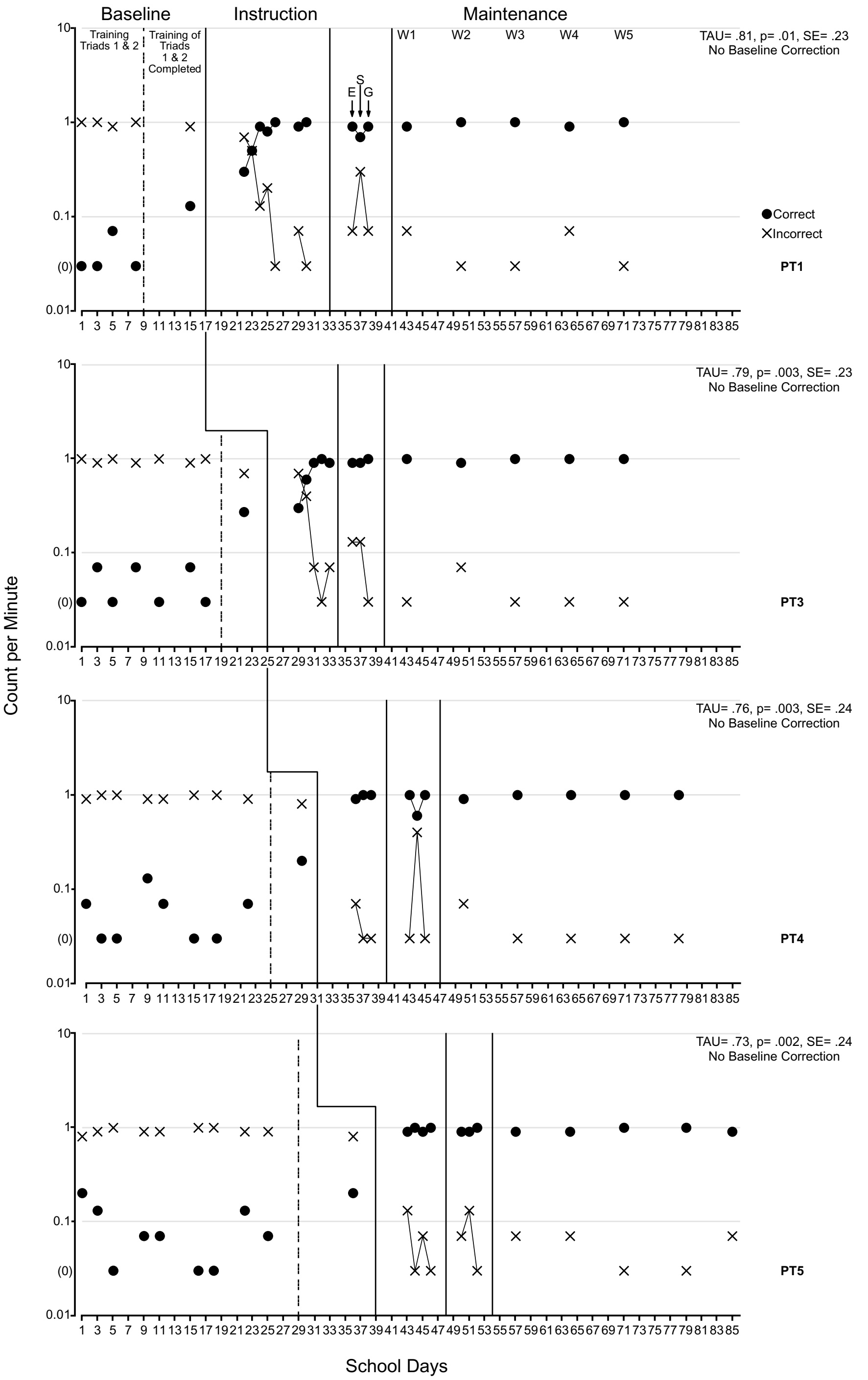
This study demonstrates the significance of incorporating frequency as the primary measure of students' joint attention skills. Unlike the conventional reliance on dimensionless performance measures based on percent correct, PTers have advocated for an emphasis on functional mastery (Berens, 2020; Johnson & Layng, 1992; Lindsley, 1990). Frequency measures focus practitioners' efforts on arranging

Fig. 4 Composite Skill. As the ratio axis has no actual zero value, we followed Precision Teaching conventions related to plotting zero values on the family of Standard Celeration Charts. We added zero in brackets to improve clarity. The annotation line in the baseline highlights the impact on the composite skill produced by training the two triads of component skills. ESG = endurance, stability, and generalization. This assessment was delivered in one day. However, the data were graphed as separate days to support visual analysis. Each datum point presented represents each assessment. The baseline corrected TAU was also calculated by comparing baseline to maintenance data and presented within each tier. Maintenance assessments were conducted once a week for five consecutive weeks; W = Week ▶

instruction in ways that promote natural responding that leads to proficient performance. In this study, participants were not expected to engage in free-operant practice (e.g., short timings using worksheets) typically used within PT when engaging in academic skills practice (Datchuk & Kubina, 2014; Johnson & Street, 2012). Still, instruction was arranged in ways to promote a natural pace of responding, and frequency was used as the primary measure of evaluating performance in each session. As a result, participants were able to develop fluency in the primary skill as demonstrated by their ability to respond to bids for joint attention for longer periods (endurance), in the presence of distracting stimuli (stability), across different situations (generalization), and in the absence of practice (maintenance). Therefore, this study adds to the existing literature demonstrating ways to focus on fluency when not developing academic skills (Aravamudhan & Awasthi, 2021; Lin & Kubina, 2015; Vascelli et al., 2020).

Second, this study showcases how behavioral metrics can offer an advanced understanding of an intervention's impact not only on participants' performance, as measured by frequency, but also learning, as measured by celeration. Celeration is a behavioral phenomenon that has not been adequately investigated within the field of PT and broader behavior analysis. Celeration offers a unique measure of behavior change across time that can be particularly useful when developing repertoires. In simple terms, celeration allows practitioners to quantify the student's pace of transitioning from slow and hesitant to quick and effortless performance. In other words, celeration is a measure of students' learning rate (Binder, 1996). Celeration calculations are missing from mainstream behavior-analytic literature on joint attention skills. We posit that celeration can lead to additional discoveries and a more nuanced understanding of how these skills develop. It can also offer information on behavioral agility (Meyer et al., 2021).

Behavioral agility is defined as one's ability to learn more efficiently and is evaluated through advanced metrics with a primary focus on celeration values and how they change across time. Specifically, PTers evaluate, among other things, whether celeration values increase (or celeration lines become steeper on the Standard Celeration Chart) as instruction progresses. That way, they are able to determine whether their students are developing the ability to learn related content faster and, therefore, progress across their curriculum at an optimal rate (for a more detailed discussion of agility, see Meyer et al., 2021). This measure could be useful to practitioners training joint attention skills across different sets of stimuli. Measuring celeration with each set could show whether participants increase their learning rate as novel sets are introduced.


Baseline
Instruction
Maintenance
Training Triads 1 & 2
Training of Triads 1 & 2 Completed
E S G
W1
W2
W3
W4
W5
TAU= .81, p= .01, SE= .23
No Baseline Correction
Correct
Incorrect
PT1
TAU= .79, p= .003, SE= .23
No Baseline Correction
PT3
TAU= .76, p= .003, SE= .24
No Baseline Correction
PT4
TAU= .73, p= .002, SE= .24
No Baseline Correction
PT5
Count per Minute
School Days

Finally, celeration values offer more objectivity during visual analysis. By using celeration to quantify the trend lines depicted on SCCs, practitioners can more uniformly agree on whether progress is adequate or not. This can lead to more consistent decision-making across practitioners or researchers investigating joint attention or related skills (Kubina et al., 2023). To our knowledge, this is the first study to collect celeration data on joint attention skills. A closer look at the celeration values produced by this study's participants seems to suggest a very encouraging impact. Typically, PTers consider a × 2.00 (i.e., 100%) weekly acceleration as an optimal outcome as it leads to a doubling of performance each week (Johnson & Street, 2013; Johnson et al., 2021). To that end, they strive to arrange instructional conditions that minimize performance barriers and allow students to accelerate their learning rapidly. In this study, participants' celeration values were at times considerably higher than × 2.00 (see Table 3). Specifically, a calculation of the average weekly acceleration across the three weeks of component skills practice showed that participants exceeded a × 2.00 value in 79.16% of cases across all six component skills. Moreover, there were cases where celeration exceeded × 10.00 (i.e., 900% improvement). Therefore, our data confirm similar findings in the PT literature (Vostanis et al., 2021, 2022) and suggest that autistic students' potential to accelerate their learning is considerable. By incorporating this measure in naturalistic developmental behavioral interventions, we could be better equipped to evaluate whether certain components of instructional packages have a greater or lesser effect on students' improvements.

Moreover, this study extends the existing literature by providing a comprehensive framework for developing RJA with students within the upper end of the age range of individuals typically included in similar studies who have minimally developed verbal repertoires. Basso et al. (2021) highlighted a need for more research with this population, as it is never too late to develop joint attention skills. Specifically, joint attention studies have historically included participants aged between 0 and 7 years old (Hansen et al., 2018). In this study, students were aged between 5:6 and 6:6 years old and would be considered early learners based on their scores on the various assessment tools used in this study. Consequently, our findings augment the existing body of evidence and highlight that even students nearing the upper age range and exhibiting more complex needs have the potential to develop one of the two types of joint attention, which could yield numerous beneficial outcomes in the areas of communication, social, and play skills, to name a few (Murza et al., 2016).

This study also had a series of additional noteworthy findings. First, all participants improved their component skills, albeit to a varying degree. As a result, we noticed some minimal spillover effects to the composite skill. Specifically, although incorrect responses in the composite skill remained considerably high, an increase in correct responses was noted in each participant's last baseline session, suggesting that participants were becoming more able to recruit their component skills when expected to engage in the more complex composite skill. This would suggest that participants were supported to engage in what PTers call application, which is combining prerequisite skills to perform a more complex skill (Stocker et al., 2018). This fact was further confirmed by the number of days participants needed to meet their performance criterion. Participants needed seven, five, three, and four days, respectively, to master the skill. This quick transition to mastery suggests that training the component skills optimized participants' ability to master the composite skill.

Second, the results of this study add more evidence about the beneficial outcomes of breaking down joint attention into its component skills (Kourassanis-Velasquez & Jones, 2019). Meindl and Cannella-Malone (2011) discussed that IJA and RJA are separate skills that could be targeted separately, while Monlux et al. (2019) discussed that joint attention is not always uniform, as it can happen across senses (e.g., visual, auditory, or tactile), and can include bids that involve pointing, showing an object, or activating an object, to name a few. So far, there is a mixture of approaches in the literature, with some studies treating RJA as one skill (Chohan & Jones, 2019; Krstovska-Guerrero & Jones, 2016; Kryzak et al., 2013), while others offering more explicit instruction across different types of joint attention or stimuli (Ferraioli & Harris, 2011; Fredericks et al., 2023; Isaksen & Holth, 2009). Rudy et al. (2014) discussed in detail that RJA and IJA could be broken down even further and suggested that teaching their underlying component skills separately could lead to better outcomes, an argument supported by the results of this study. Specifically, this study focused on developing participants' ability to engage in a single response or dyadic response sequence, such as directing their gaze first at a stimulus and then at the instructor during the practice of component skills. Nevertheless, when practicing the composite skill, participants quickly mastered a triadic sequence, involving directing their eye gaze at a stimulus, then at the instructor, and finally back to the stimulus.

Finally, it is worth noting that the training focused on eye gaze and not eye contact. Specifically, participants were expected to orient their eye gaze toward the broader area of the instructor's face and not specifically their eyes. Autistic individuals have reported that eye contact can be particularly aversive to them (Trevisan et al., 2017) while emerging neural evidence further supports those reports (Stuart et al., 2023). Therefore, it was considered essential that instruction be provided in a way that respects participants' neurodiversity.

Limitations and Strengths

This study had a series of limitations. As previously noted, participants exhibited emergent application of component skills during the final baseline session of the composite skill. While this finding is promising and suggests benefits from practicing component skills, it also poses challenges for demonstrating experimental control. Specifically, all participants demonstrated improvements in their final baseline session, making it difficult to conclusively attribute further improvements demonstrated solely to the intervention. Moreover, the intervention provided was multi-component, making it hard to determine whether certain elements had a greater or lesser impact. Although this applies to the inclusion of PT, as already discussed, readers should note that PT was never meant to be a system used in isolation (Kubina & Yurich, 2012). Furthermore, we did not measure ancillary behaviors that the training could have affected, such as spontaneous speech or social–communicative behaviors. What is more, although we attempted to cover all essential component skills, there could be additional skills we could have targeted, such as responding vocally to a bid for joint attention. In addition, we only targeted RJA and not IJA. To offer comprehensive training in joint attention, both repertoires should be trained. Finally, we assessed the participants' ability to engage in RJA in the presence of distracting stimuli. This assessment is considered essential in PT as it links to the by-products of fluency (Fabrizio & Moors, 2003). In hindsight, this assessment could have been delivered differently as RJA involves the presentation of stimuli that would attract one's attention, making it hard for participants to discriminate which ones they should respond to and which ones they should ignore.

Despite the limitations, the study also had various strengths, such as the use of a concurrent multiple baseline for all skills, the random allocation of participants to each tier of intervention, the inclusion of typically developing peers to guide performance criteria, the monitoring of procedural fidelity and inter-observer agreement, along with the encouraging and positive improvements for all participants.

Future Directions

Despite the encouraging results, more research is required on how PT could help provide a more nuanced understanding of RJA and related skills. For example, additional data on celeration could uncover an optimal learning rate when training RJA. That way, it would be possible to more precisely evaluate whether the interventions offered produce adequate improvements for participants across time. We also suggest future research addresses some of the limitations highlighted in this paper. For example, we recommend conducting additional baseline sessions once the component skills practice has been concluded to allow for a more robust demonstration of experimental control. Similarly, we recommend that future replications include continuous measures of IJA as it would be interesting to examine whether RJA training would lead to improvements to IJA without direct training. Also, it would be valuable to replicate these results with students of different ages and overall abilities. Finally, it would be worth exploring PT's application more in other skill areas, such as verbal behavior, self-management, and school readiness skills, to name a few.

Acknowledgements We would like to thank Suzie Eaton, Katie Sparkes, Louisa Lazarus, Danielle Lee, Anna Colgate, and Hope Edmonds for supporting us with this project.

Data Availability Additional materials for this study including the SCCs, procedural fidelity checklists, and social validity questionnaires are available through the Figshare data repository, DOI: https://doi.org/https://doi.org/10.6084/m9.figshare.c.7452415.v1.

Declarations

Conflict of interest The second author was a staff member at the school where the research occurred. However, steps were taken to mitigate biases, ensuring data integrity and objective analysis. The authors declare no other conflicts of interest.

References

Aravamudhan, S., & Awasthi, S. (2021). The use of prompts and precision teaching to address speech sound disorders in a 17-year-old girl with autism. *Behavior Analysis in Practice, 14*(3), 644–659. https://doi.org/10.1007/s40617-020-00470-7

Basso, T., Charlop, M. H., & Gumaer, C. B. (2021). Using a functional play intervention to increase joint attention of school-aged, non-verbal children with autism spectrum disorder (ASD). *International Electronic Journal of Elementary Education, 13*(3), 323.

Berens, K. N. (2020). *Blind Spots: Why students fail and the science that can save them.* The collective book studio.

Beverley, M., Hughes, J. C., & Hastings, R. P. (2016). Using SAFMEDS to assist language learners to acquire second-language vocabulary. *European Journal of Behavior Analysis, 17*(2), 131–141. https://doi.org/10.1080/15021149.2016.1247577

Binder, C. (1996). Behavioral fluency: Evolution of a new paradigm. *The Behavior Analyst, 19*(2), 163–197. https://doi.org/10.1007/BF03393163

Bottema-Beutel, K., Kapp, S. K., Lester, J. N., Sasson, N. J., & Hand, B. N. (2021). Avoiding ableist language: Suggestions for autism researchers. *Autism in Adulthood, 3*(1), 18–29. https://doi.org/10.1089/aut.2020.0014

Bruinsma, Y., Koegel, R. L., & Koegel, L. K. (2004). Joint attention and children with autism: A review of the literature. *Mental Retardation and Developmental Disabilities Research Reviews, 10*(3), 169–175. https://doi.org/10.1002/mrdd.20036

Calkin, A. B. (2005). Precision teaching: The standard celeration charts. *The Behavior Analyst Today, 6*(4), 207–215. https://doi.org/10.1037/h0100073

Carr, J. E. (2005). Recommendations for reporting multiple-baseline designs across participants. *Behavioral Interventions, 20*(3), 219–224. https://doi.org/10.1002/bin.191

Chohan, M., & Jones, E. A. (2019). Initiating joint attention with a smile: Intervention for children with autism. *Behavioral Development, 24*(1), 29–41. https://doi.org/10.1037/bdb0000087

Datchuk, S. M., & Kubina, R. M., Jr. (2014). Effects of sentence-combining instruction and frequency building to a performance criterion on adolescents with difficulty constructing sentences. *Journal of Evidence-Based Practices for Schools, 14*(2), 160–185.

Dawson, G., Toth, K., Abbott, R., Osterling, J., Munson, J., Estes, A., & Liaw, J. (2004). Early social attention impairments in autism: Social orienting, joint attention, and attention to distress. *Developmental Psychology, 40*(2), 271–283. https://doi.org/10.1037/0012-1649.40.2.271

DeLeon, I. G., & Iwata, B. A. (1996). Evaluation of a multiple-stimulus presentation format for assessing reinforcer preferences. *Journal of Applied Behavior Analysis, 29*(4), 519–533. https://doi.org/10.1901/jaba.1996.29-519

Evans, A. L., Bulla, A. J., & Kieta, A. R. (2021). The precision teaching system: A synthesized definition, concept analysis, and process. *Behavior Analysis in Practice, 14*(3), 559–576. https://doi.org/10.1007/s40617-020-00502-2

Everitt, B., & Howell, D. C. (Eds.). (2005). *Encyclopedia of statistics in behavioral science*. John Wiley & Sons.

Fabrizio, M. A., & Moors, A. L. (2003). Evaluating mastery: Measuring instructional outcomes for children with autism. *European Journal of Behavior Analysis, 4*(1–2), 23–36. https://doi.org/10.1080/15021149.2003.11434213

Ferraioli, S. J., & Harris, S. L. (2011). Teaching joint attention to children with autism through a sibling-mediated behavioral intervention. *Behavioral Interventions, 26*(4), 261–281. https://doi.org/10.1002/bin.336

Fonger, A. M., & Malott, R. W. (2019). Using shaping to teach eye contact to children with autism spectrum disorder. *Behavior Analysis in Practice, 12*(1), 216–221. https://doi.org/10.1007/s40617-018-0245-9

Fredericks, B. M., Sng, S. S. Y., Parry-Cruwys, D., & MacDonald, R. P. F. (2023). Teaching joint attention: Assessing generalization and maintenance of effects using multiple exemplar training. *Journal of Autism and Developmental Disorders, 53*(3), 1117–1129. https://doi.org/10.1007/s10803-022-05615-x

Gabouer, A., & Bortfeld, H. (2021). Revisiting how we operationalize joint attention. *Infant Behavior and Development, 63*, 101566. https://doi.org/10.1016/j.infbeh.2021.101566

Gilliam, J. E. (2006). *Gilliam autism rating scale* (2nd ed.). Pro-Ed.

Gist, C., & Bulla, A. J. (2022). A systematic review of frequency building and precision teaching with school-aged children. *Journal of Behavioral Education, 31*(1), 43–68. https://doi.org/10.1007/s10864-020-09404-3

Graf, S., & Lindsley, O. R. (2002). *Standard celeration charting 2002*. Graf Implements.

Hamlet, C. C., Axelrod, S., & Kuerschner, S. (1984). Eye contact as an antecedent to compliant behavior. *Journal of Applied Behavior Analysis, 17*(4), 553–557. https://doi.org/10.1901/jaba.1984.17-553

Hansen, S. G., Carnett, A., & Tullis, C. A. (2018). Defining early social communication skills: A systematic review and analysis. *Advances in Neurodevelopmental Disorders, 2*(1), 116–128. https://doi.org/10.1007/s41252-018-0057-5

Heinicke, M. R., Carr, J. E., LeBlanc, L. A., & Severtson, J. M. (2010). On the use of fluency training in the behavioral treatment of autism: A commentary. *The Behavior Analyst, 33*(2), 223–229. https://doi.org/10.1007/BF03392221

Hughes, C. J., Beverley, M., & Whitehead, J. (2007). Using precision teaching to increase the fluency of word reading with problem readers. *European Journal of Behavior Analysis, 8*(2), 221–238. https://doi.org/10.1080/15021149.2007.11434284

Isaksen, J., & Holth, P. (2009). An operant approach to teaching joint attention skills to children with autism. *Behavioral Interventions, 24*(4), 215–236. https://doi.org/10.1002/bin.292

Jaswal, V. K., & Akhtar, N. (2019). Being versus appearing socially uninterested: Challenging assumptions about social motivation in autism. *Behavioral and Brain Sciences, 42*, e82. https://doi.org/10.1017/S0140525X18001826

Jeffries, T., Crosland, K., & Miltenberger, R. (2016). Evaluating a tablet application and differential reinforcement to increase eye contact in children with autism. *Journal of Applied Behavior Analysis, 49*(1), 182–187. https://doi.org/10.1002/jaba.262

Jimenez, B., Root, J., Shurr, J., & Bouck, E. C. (2021). Using the four stages of learning to assess, set goals, and instruct. *Teaching Exceptional Children*. https://doi.org/10.1177/00400599211054873

Johnson, K. R., & Layng, T. J. (1992). Breaking the structuralist barrier: Literacy and numeracy with fluency. *American Psychologist, 47*(11), 1475–1490. https://doi.org/10.1037/0003-066X.47.11.1475

Johnson, K. R., & Layng, T. V. J. (1996). On terms and procedures: Fluency. *The Behavior Analyst, 19*(2), 281–288. https://doi.org/10.1007/BF03393170

Johnson, K., & Street, E. M. (2012). From the laboratory to the field and back again: Morningside Academy's 32 years of improving students' academic performance. *The Behavior Analyst Today, 13*(1), 20–40. https://doi.org/10.1037/h0100715

Johnson, K., & Street, E. M. (2013). *Response to intervention and precision teaching: Creating synergy in the classroom*. Guilford Press.

Johnson, K., Street, E. M., Kieta, A. R., & Robbins, J. K. (2021). *The Morningside model of generative instruction: Building a bridge between skills and inquiry teaching*. Sloan Publishing.

Jones, E. A., Carr, E. G., & Feeley, K. M. (2006). Multiple effects of joint attention intervention for children with autism. *Behavior Modification, 30*(6), 782–834. https://doi.org/10.1177/0145445506289392

Junaid, H., Bulla, A. J., Benjamin, M., Wind, T., & Nazaruk, D. (2021). Using self-management and social media to increase steps in sedentary college students. *Behavior Analysis in Practice, 14*(3), 734–744. https://doi.org/10.1007/s40617-020-00445-8

Kapoor, G., Vostanis, A., Mejía-Buenaño, S., & Langdon, P. E. (2023). Using precision teaching to improve typically developing student's mathematical skills via teleconferencing. *Journal of Behavioral Education*. https://doi.org/10.1007/s10864-023-09520-w

Kostewicz, D. E., Kubina, R. M., & Brennan, K. M. (2020). Improving spelling for at-risk kindergartners through element skill frequency building. *Behavioral Interventions, 35*(1), 131–144. https://doi.org/10.1002/bin.1701

Kourassanis-Velasquez, J., & Jones, E. A. (2019). Increasing joint attention in children with autism and their peers. *Behavior Analysis in Practice, 12*(1), 78–94. https://doi.org/10.1007/s40617-018-0228-x

Krstovska-Guerrero, I., & Jones, E. A. (2016). Social-communication intervention for toddlers with autism spectrum disorder: Eye gaze in the context of requesting and joint attention. *Journal of Developmental and Physical Disabilities, 28*(2), 289–316. https://doi.org/10.1007/s10882-015-9466-9

Kryzak, L. A., Bauer, S., Jones, E. A., & Sturmey, P. (2013). Increasing responding to others' joint attention directives using circumscribed interests. *Journal of Applied Behavior Analysis, 46*(3), 674–679. https://doi.org/10.1002/jaba.73

Kubina, R. M., & Cooper, J. O. (2000). Changing learning channels: An efficient strategy to facilitate instruction and learning. *Intervention in School and Clinic, 35*(3), 161–166. https://doi.org/10.1177/105345120003500306

Kubina, R. M., Halkowski, M., Yurich, K. K. L., Ghorm, K., & Healy, N. M. (2022). Comparing the detection accuracy of operational definitions and pinpoints. *Journal of Behavioral Education*. https://doi.org/10.1007/s10864-022-09485-2

Kubina, R. M. Jr., & Yurich, K. K. L. (2012). *The precision teaching book*. Greatness Achieved.

Kubina, R. M., King, S. A., Halkowski, M., Quigley, S., & Kettering, T. (2023). Slope identification and decision making: A comparison of linear and ratio graphs. *Behavior Modification, 47*(3), 615–643. https://doi.org/10.1177/01454455221130002

Lin, F.-Y., & Kubina, R. M. (2015). Imitation fluency in a student with autism spectrum disorder: An experimental case study. *European Journal of Behavior Analysis, 16*(1), 2–20. https://doi.org/10.1080/15021149.2015.1065637

Lindsley, O. R. (1990). Precision teaching: By teachers for children. *Teaching Exceptional Children, 22*(3), 10–15. https://doi.org/10.1177/004005999002200302

Lokke, G. E., Lokke, J. A., & Arntzen, E. (2008). Precision teaching, frequency-building, and ballet dancing. *Journal of Precision Teaching and Celeration, 24*, 21–27.

MacDuff, J. L., Ledo, R., McClannahan, L. E., & Krantz, P. J. (2007). Using scripts and script-fading procedures to promote bids for joint attention by young children with autism. *Research in Autism Spectrum Disorders, 1*(4), 281–290. https://doi.org/10.1016/j.rasd.2006.11.003

Malabello, G. (1998). IMAGINE-The first six months. *Journal of Precision Teaching and Celeration, 15*(2), 43–51.

Martinho, M. T., Booth, N., Attard, N., & Dillenburger, K. (2022). A systematic review of the impact of precision teaching and fluency-building on teaching children diagnosed with autism. *International Journal of Educational Research, 116*, 102076. https://doi.org/10.1016/j.ijer.2022.102076

McTiernan, A., Holloway, J., Leonard, C., & Healy, O. (2018). Employing precision teaching, frequency-building, and the morningside math facts curriculum to increase fluency with addition and subtraction computation: A randomised-controlled trial. *European Journal of Behavior Analysis, 19*(1), 90–104. https://doi.org/10.1080/15021149.2018.1438338

McTiernan, A., McCoy, A., Mendonca, J., Lydon, H., & Diffley, S. (2022). The implementation of precision teaching for the improvement of academic skills: A systematic review of the literature over thirty years. *Behavioral Interventions, 37*(2), 505–528. https://doi.org/10.1002/bin.1852

Meindl, J. N., & Cannella-Malone, H. I. (2011). Initiating and responding to joint attention bids in children with autism: A review of the literature. *Research in Developmental Disabilities, 32*(5), 1441–1454. https://doi.org/10.1016/j.ridd.2011.02.013

Meyer, S., Newsome, D., Fuller, T., Newsome, K., & Ghezzi, P. M. (2021). Agility: what it is, how to measure it, and how to use it. *Behavior Analysis in Practice, 14*(3), 598–607. https://doi.org/10.1007/s40617-020-00465-4

Monlux, K., Pelaez, M., & Holth, P. (2019). Joint attention and social referencing in children with autism: A behavior-analytic approach. *European Journal of Behavior Analysis, 20*(2), 186–203. https://doi.org/10.1080/15021149.2019.1644831

Mundy, P., Block, J., Delgado, C., Pomares, Y., Van Hecke, A. V., & Parlade, M. V. (2007). Individual differences and the development of joint attention in infancy. *Child Development, 78*(3), 938–954. https://doi.org/10.1111/j.1467-8624.2007.01042.x

Murray, D. S., Creaghead, N. A., Manning-Courtney, P., Shear, P. K., Bean, J., & Prendeville, J.-A. (2008). The relationship between joint attention and language in children with autism spectrum disorders. *Focus on Autism and Other Developmental Disabilities, 23*(1), 5–14. https://doi.org/10.1177/1088357607311443

Murza, K. A., Schwartz, J. B., Hahs-Vaughn, D. L., & Nye, C. (2016). Joint attention interventions for children with autism spectrum disorder: A systematic review and meta-analysis. *International Journal of Language & Communication Disorders, 51*(3), 236–251. https://doi.org/10.1111/1460-6984.12212

Pallares, M., Newsome, K. B., & Ghezzi, P. M. (2021). Precision teaching and tap dance instruction. *Behavior Analysis in Practice, 14*(3), 745–762. https://doi.org/10.1007/s40617-020-00458-3

Patterson, K., & McDowell, C. (2009). Using precision teaching strategies to promote self-management of inner behaviours and measuring effects on the symptoms of depression. *European Journal of Behavior Analysis, 10*(2), 283–295. https://doi.org/10.1080/15021149.2009.11434326

Pelaez, M., & Monlux, K. (2018). Development of communication in Infants: Implications for stimulus relations research. *Perspectives on Behavior Science, 41*(1), 175–188. https://doi.org/10.1007/s40614-018-0151-z

Pérez-Fuster, P., Herrera, G., Kossyvaki, L., & Ferrer, A. (2022). Enhancing joint attention skills in children on the autism spectrum through an augmented reality technology-mediated intervention. *Children, 9*(2), 258. https://doi.org/10.3390/children9020258

Pollard, J. S., Betz, A. M., & Higbee, T. S. (2012). Script fading to promote unscripted bids for joint attention in children with autism. *Journal of Applied Behavior Analysis, 45*(2), 387–393. https://doi.org/10.1901/jaba.2012.45-387

Ragnarsdóttir, A. G. (2007). Teaching an Icelandic student with autism to read by combining direct instruction and precision teaching. *European Journal of Behavior Analysis, 8*(2), 289–304. https://doi.org/10.1080/15021149.2007.11434290

Ramey, D., Lydon, S., Healy, O., McCoy, A., Holloway, J., & Mulhern, T. (2016). A systematic review of the effectiveness of precision teaching for individuals with developmental disabilities. *Review Journal of Autism and Developmental Disorders, 3*(3), 179–195. https://doi.org/10.1007/s40489-016-0075-z

Rocha, M. L., Schreibman, L., & Stahmer, A. C. (2007). Effectiveness of training parents to teach joint attention in children with autism. *Journal of Early Intervention, 29*(2), 154–172. https://doi.org/10.1177/105381510702900207

Roos, E. M., McDuffie, A. S., Weismer, S. E., & Gernsbacher, M. A. (2008). A comparison of contexts for assessing joint attention in toddlers on the autism spectrum. *Autism, 12*(3), 275–291. https://doi.org/10.1177/1362361307089521

Rudy, N. A., Betz, A. M., Malone, E., Henry, J. E., & Chong, I. M. (2014). Effects of video modeling on teaching bids for joint attention to children with autism. *Behavioral Interventions, 29*(4), 269–285. https://doi.org/10.1002/bin.1398

Sawyer, M. R., Newsome, K. B., & Newsome, D. (2021). From private practice to public service: A preliminary investigation of the Fit LiteTM model with at-risk students. *Behavior Analysis in Practice, 14*(3), 623–630. https://doi.org/10.1007/s40617-020-00460-9

Schertz, H. H., & Odom, S. L. (2007). Promoting joint attention in toddlers with autism: A parent-mediated developmental model. *Journal of Autism and Developmental Disorders, 37*(8), 1562–1575. https://doi.org/10.1007/s10803-006-0290-z

Smith, L., & Ulvund, S. E. (2003). The role of joint attention in later development among preterm children: Linkages between early and middle childhood. *Social Development, 12*(2), 222–234. https://doi.org/10.1111/1467-9507.00230

Smith, T. (2001). Discrete trial training in the treatment of autism. *Focus on Autism and Other Developmental Disabilities, 16*(2), 86–92. https://doi.org/10.1177/108835760101600204

Sparrow, S. S., Cicchetti, D. V., & Balla, D. A. (2005). *Vineland adaptive behavior scales* (2nd ed.). AGS Publishing.

Stocker, J. D., Schwartz, R., Kubina, R. M., Kostewicz, D., & Kozloff, M. (2018). Behavioral fluency and mathematics intervention research: A review of the last 20 years. *Behavioral Interventions, 34*, 102–117. https://doi.org/10.1002/bin.1649

Stuart, N., Whitehouse, A., Palermo, R., Bothe, E., & Badcock, N. (2023). Eye gaze in autism spectrum disorder: A review of neural evidence for the eye avoidance hypothesis. *Journal of Autism and Developmental Disorders, 53*(5), 1884–1905. https://doi.org/10.1007/s10803-022-05443-z

Sundberg, M. L. (2008). *VB-MAPP: Verbal behavior milestones assessment and placement program*. AVB Press.

Sundberg, M. L., & Partington, J. W. (1998). *Teaching language to children with autism or other developmental disabilities*. Behavior Analysts, Inc.

Tarlow, K. R. (2016). *Baseline Corrected Tau calculator*. http://ktarlow.com/stats/tau/

Tarlow, K. R. (2017). An improved rank correlation effect size statistic for single-case designs: Baseline corrected tau. *Behavior Modification, 41*(4), 427–467. https://doi.org/10.1177/0145445516676750

Tiede, G., & Walton, K. M. (2019). Meta-analysis of naturalistic developmental behavioral interventions for young children with autism spectrum disorder. *Autism, 23*(8), 2080–2095. https://doi.org/10.1177/1362361319836371

Trevisan, D. A., Roberts, N., Lin, C., & Birmingham, E. (2017). How do adults and teens with self-declared autism spectrum disorder experience eye contact? A qualitative analysis of first-hand accounts. *PLoS ONE, 12*(11), e0188446. https://doi.org/10.1371/journal.pone.0188446

Twarek, M., Cihon, T., & Eshleman, J. (2010). The effects of fluent levels of Big 6 + 6 skill elements on functional motor skills with children with autism. *Behavioral Interventions, 25*(4), 275–293. https://doi.org/10.1002/bin.317

Vascelli, L., Iacomini, S., Gueli, G., Cavallini, C., Pelizzoni, I., Cavallini, F., & Berardo, F. (2020). The effects of the Big 6+6 skills training on daily living skills for an adolescent with intellectual disability. *Behavior Analysis in Practice, 13*(4), 955–960. https://doi.org/10.1007/s40617-020-00471-6

Vostanis, A., Padden, C., & Langdon, P. E. (2022). Investigating the relationship between learning channel sets during the mathematical practice of autistic students. *British Journal of Special Education*. https://doi.org/10.1111/1467-8578.12408

Vostanis, A., Padden, C., McTiernan, A., & Langdon, P. E. (2021). Comparing the minimum celeration line and the beat your personal best goal-setting approaches during the mathematical practice of students diagnosed with autism. *Journal of Behavioral Education*. https://doi.org/10.1007/s10864-021-09432-7

Weiss, M. J. (2001). Expanding aba intervention in intensive programs for children with autism: The inclusion of natural environment training and fluency based instruction. *The Behavior Analyst Today, 2*(3), 182–186. https://doi.org/10.1037/h0099946

Whalen, C., & Schreibman, L. (2003). Joint attention training for children with autism using behavior modification procedures: Joint attention training for children with autism. *Journal of Child Psychology and Psychiatry, 44*(3), 456–468. https://doi.org/10.1111/1469-7610.00135

White, O. R. (1985). Aim*Star Wars (Setting Aims that Compete). Episode I: The Deathstar. *Journal of Precision Teaching, 5*, 55–63.

White, P. J., O'Reilly, M., Streusand, W., Levine, A., Sigafoos, J., Lancioni, G., Fragale, C., Pierce, N., & Aguilar, J. (2011). Best practices for teaching joint attention: A systematic review of the intervention literature. *Research in Autism Spectrum Disorders, 5*(4), 1283–1295. https://doi.org/10.1016/j.rasd.2011.02.003

Authors and Affiliations

Athanasios Vostanis[1] · Rianna Ritchie[2] · Peter E. Langdon[3,4]

✉ Athanasios Vostanis
a.vostanis@kent.ac.uk

1 Tizard Centre, University of Kent, Cornwallis Northeast, Canterbury, Kent CT2 7NF, UK

2 ABA Pathways, Chelmsford CM2 9DA, UK

3 School of Social Policy and Society, University of Birmingham, Birmingham B15 2TT, UK

4 Herefordshire and Worcestershire Health and Care NHS Trust, Worcester WR5 1JR, UK