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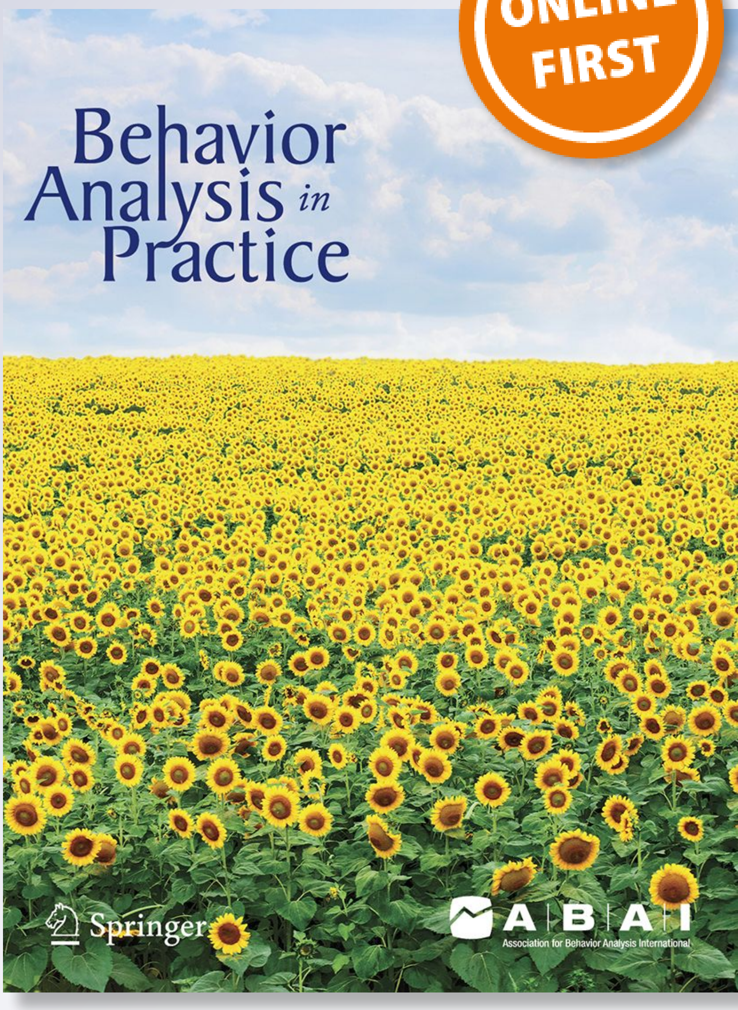

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RESEARCH ARTICLE

Using the Teacher IRAP (T-IRAP) interactive computerized programme to teach complex flexible relational responding with children with diagnosed autism spectrum disorder

Carol Murphy[1] · Keith Lyons[1] · Michelle Kelly[1] · Yvonne Barnes-Holmes[2] · Dermot Barnes-Holmes[2]

Abstract

The research used an alternating-treatments design to compare relational responding for five children with diagnosed autism spectrum disorder (ASD) in two teaching conditions. Both conditions used applied behavior analysis; one was usual tabletop teaching (TT), and one was an interactive computerized teaching program, the Teacher–Implicit Relational Assessment Programme (T-IRAP; Kilroe, Murphy, Barnes-Holmes, & Barnes-Holmes, *Behavioral Development Bulletin, 19*(2), 60–80, 2014). Relational skills targeted were coordination (same/different), with nonarbitrary and arbitrary stimuli. Participants' relational learning outcomes were compared in terms of speed of responding and accuracy (percentage correct) in T-IRAP and TT conditions. Results showed significantly increased speed for all five participants during T-IRAP teaching across all procedures; however, accuracy was only marginally increased during T-IRAP. Pre- and posttraining comparison of participant scores on the Peabody Picture Vocabulary Test, Fourth Edition (Dunn & Dunn, 2007), and the Kaufman Brief Intelligence Test (Kaufman & Kaufman, 1990) was conducted. An improvement in raw scores on both measures was evident for one participant who learned complex arbitrary relations; no changes were shown for participants who learned only basic nonarbitrary relations.

Keywords flexibility · relational responding · relational frame theory · verbal behavior · T-IRAP

A characteristic of autism is social communication deficits, and children with autism spectrum disorder (ASD) frequently show language difficulties, including limited novel utterances of the type that readily emerge in typically developing children as young as 2 years old. Remediation of language deficits has long been a primary target in applied behavior analysis (ABA) teaching programs for children with ASD and related language deficits (Carr, Binkof, & Kologinsky, 1978; LeBlanc, Esch, Sidener, & Firth, 2006; Sundberg & Partington, 2001; Tincani, 2004), and verbal behavior is seen as pivotal (Koegel, Koegel, & Carter, 1998) because it can provide access to a much more expanded range of activities and reinforcers. One cannot, for example, discover that the study of history or mathematics is reinforcing without first accessing these topics via language.

Research has shown that advanced language skills in children with ASD are correlated with improved long-term prognosis (see Carr et al., 1978; Sallows & Graupner, 2005). The success of ABA programs as a treatment method for children with ASD has been well documented in the research literature (see Larsson, 2012, 2013), but modern behavioral researchers have recently sought to incorporate an important dimension that was previously absent from ABA language programs—specifically, derived relational responding (Barnes-Holmes, Barnes-Holmes, & Cullinan, 2000; Murphy, Barnes-Holmes,

Highlights

• An alternating-treatments design compared T-IRAP to TT and found T-IRAP generally produced faster relational responding.
• T-IRAP was found to produce marginally more accurate responding than TT.
• Learning complex relational responding may be related to increased scores on IQ measures (pre- and posttests with one participant with ASD).
• The study was conducted with children with ASD described as "low functioning."

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& Barnes-Holmes, 2005). Behavioral researchers with a relational frame theory (RFT) perspective (Hayes, Barnes-Holmes, & Roche, 2001) propose that derived relational responding may be an important component in advanced and complex language; thus, children with ASD may benefit from language programs that incorporate this type of responding (Murphy et al., 2005; Murphy & Barnes-Holmes, 2010; Rehfeldt & Root, 2005; Rosales & Rehfeldt, 2007). These research methodologies combined commonly used behavioral principles (Skinner, 1938, 1957) and ABA tactics (e.g., positive reinforcement, prompting, fading, shaping) with stimulus equivalence (Sidman, 1971) with derived relational responding. Stimulus equivalence and derived relational responding involve emergent (i.e., novel, untaught) responding. For example, if an individual is taught that a stimulus A is equivalent to B, they may derive (untaught) that B is equivalent to A (symmetry relations; Sidman, 1971); if they are then taught B and C are equivalent (A:B/B:C), they may subsequently derive A:C and C:A equivalence relations with no explicit direction or reinforcement. Thus, a small number of taught relations can result in a proliferation (i.e., exponential) of derived relations among stimuli (see Wulfert & Hayes, 1988). Further, functions learned for one stimulus in such an equivalence relation may emerge untaught with the other stimuli, which has numerous critical implications. For example, consider an individual who has learned an equivalence relation (e.g., same/similar/"goes with") for the words *school*, *college*, and *university*; if the individual likes learning at school such that a positive emotional function is established, he or she may derive a similar positive emotional function associated with college or university, without ever having direct experience of either (transfer of emotional functions via derived relational responding [DRR]; see Dougher, 1998).

Another important complex feature has been termed *arbitrarily applicable relational responding* (Hayes et al., 2001)—for example, arbitrary word relations that are not based on physical features of related stimuli. To illustrate, learning a nonarbitrary equivalence relation may involve discriminating two identical stimuli as "same"; an arbitrary equivalence relation might be discriminating the word *three* as equivalent to the number 3. Consider also that learning nonarbitrary comparative relations (more/less) may be discriminating a large pile of sweets as having more value than a small pile. An example of learning arbitrary comparative relations would be discriminating that a small coin may be more valuable than a large coin (for a comprehensive account of arbitrarily applicable relational responding and socially designated relations, see Hayes et al., 2001). Theoretically, it seems likely that nonarbitrary relations are more basic and that learning these will facilitate subsequently learning arbitrary relational responding, and there are preliminary supporting studies (Hayes et al., 2001; Kent, Galvin, Barnes-Holmes, Murphy, & Barnes-Holmes, 2017).

Prototype teaching applications combining ABA/DRR have been set down in detailed manuals for practitioners (Rehfeldt & Barnes-Holmes, 2009; see also Promotion of Emergent Advanced Knowledge, PEAK, Dixon, 2014). Earlier studies (Murphy et al., 2005; Murphy & Barnes-Holmes, 2010) set out procedures to establish derived requesting ("mands"; Skinner, 1957) based on trained relations and transformation of functions (e.g., training manding for a token with A, training A:B/B:C relations, testing for derived manding with C). Later a study by Kilroe et al. (2014) combined ABA and DRR in an interactive computerized teaching program (an adapted version of the Implicit Relational Assessment Programme; Barnes-Holmes et al., 2006) termed the Teacher IRAP or T-IRAP, which was adapted to teach complex relational responding with four children with ASD. The T-IRAP combined positive reinforcement and other ABA tactics to teach nonarbitrary relations (e.g., cat and cat: same; cat and flower: different) and then arbitrary symbolic relations (e.g., 1/2 and 0.50: same; 1/2 and 1/4: different). Nonarbitrary comparative relations were taught (e.g., a large bowl of berries is "more than" a small bowl) and then arbitrary comparative relations (e.g., the smaller coin is "more than" the larger coin with lower value; the relationship here is arbitrary in that the value of the coins is assigned by the social community and is unrelated to the physical size of the coins). Kilroe et al. (2014) adapted a multiple-baseline design across four participants; baseline involved relational skills taught in tabletop teaching (TT) conditions, and T-IRAP teaching similar relational skills was introduced to participants at staggered intervals. On each occasion the T-IRAP software program was introduced with a participant, speed and accuracy in relational responding improved and effects were replicated across four participants with all sets of relations. It should be emphasized, however, that the authors did not propose the T-IRAP as a replacement for TT, which would be most certainly deleterious; nonetheless, the T-IRAP could be a useful resource for student practice to increase rate of responding (Skinner, 1953).

Although replication of effects across participants lent support to findings in Kilroe et al. (2014), the experimental design was a multiple-baseline across-participants design in which TT was always taught first. Thus, although the positive effects on responding were frequent and robust, there was a possibility of sequence (practice) effects. To extend the research, the current study used an alternating-treatments design to compare TT and T-IRAP effects when teaching relational responding with five children with ASD. Further, participants in the current research were described in the "low-functioning" range of autism severity, whereas participants in Kilroe et al. (2014) were described as "high functioning."

Previous research and RFT theory suggests that relational responding and intelligent behavior are associated (see correlations between normative IQ measures and relational responding skills; Dixon et al., 2014a; Dixon, Whiting, Rowsey, & Belisle, 2014b), and preliminary research has shown that relational training resulted in a positive impact on IQ scores for disadvantaged students (Cassidy, Roche, & Hayes, 2011). The positive impact was shown only when participants learned complex relational responding; thus, where possible, the current research attempted to combine complex relational responding and contingency reversals (i.e., reinforcement is provided for the wrong answer, and then once again reinforcement is delivered contingent on a correct response). Children with autism sometimes show "rigid" responding, and have difficulty reversing rules (e.g., having learned that telling on their classmates is "bad," they may fail to report negative behavior such as bullying; Grandin, 2008). As stated previously, relational responding abilities have been correlated with skills measured using standardized tests (PEAK-ABA; Dixon, Carman, et al., 2014a; Dixon, Whiting, et al., 2014b). Thus, pre- and post-relational training, measures of IQ and verbal ability were undertaken in the current research to determine if a positive impact resulted on the children's measured scores on the Peabody Picture Vocabulary Test, Fourth Edition (PPVT-IV; Dunn & Dunn, 2007), and the Kaufman Brief Intelligence Test (K-BIT; Kaufman & Kaufman, 1990).

Method

Participants

Participants were four boys and one girl who ranged in age from 7 to 12 years old (pseudonyms: Ann, aged 7; Kevin, aged 8; Stephen, Andrew, and Evan, aged 12) recruited from a local school that specialized in ABA that taught children with intellectual and developmental disabilities. All participants had been previously diagnosed with ASD by an independent clinical psychologist; two participants were classified as severe, two were moderate-severe, and one was moderate. Procedures were conducted during school hours in the participants' usual classroom settings for the most part, although some of the assessments were conducted in the school after hours with the child's parent/carer present throughout.

Ethical Considerations

Appropriate safeguards undertaken included police vetting of researchers, parental or teacher supervision, Board Certified Behavior Analyst supervision, parental informed consent, and participant assent, in accord with current ethical standards applicable in the fields of ABA and psychology.

Materials and Settings

The PPVT-IV (Dunn & Dunn, 2007) and the K-BIT (Kaufman & Kaufman, 1990) were used in pre- and posttraining assessments. The K-BIT is a brief, individually administered test of verbal and nonverbal intelligence suitable for use with populations ranging from 4 to 90 years old. It consists of two subtests, a vocabulary subtest (Part A, expressive vocabulary, and Part B, definitions) and a matrices subtest. The vocabulary subtest assesses word knowledge and verbal concept formation. The matrices subtest assesses the ability to perceive relationships and analogies, with pictorial stimuli. The PPVT-IV is a test of receptive vocabulary that provides a quick index of verbal ability. The test takes approximately 30 min to administer, with pictorial stimuli. The test can be used for anyone from 2 years and 6 months old to over 90 years old and is particularly well suited to those with intellectual disabilities; vocal speech is not necessary, and instead responding involves pointing to pictorial stimuli.

Laminated cards (A4 size, 21.0 cm × 29.7 cm) were used for relational training during TT, and the pictorial images presented on these were sourced via the internet. Identical pictorial stimuli were presented during teaching trials in the T-IRAP (see Fig. 1). Two additional cards (8 in. × 2 in., 20.32 cm × 5.08 cm), one with the printed word "Different" and one with the printed word "Like" in boldface, were also used during TT.

The original IRAP software program (Barnes-Holmes et al., 2006) was written in Visual Basic, Version 6.0. It was readily adapted to present trials, and the T-IRAP was administered using a laptop computer at the participants' desks under normal classroom conditions. The software program controls all aspects of stimulus presentation and automatically records correct and incorrect responses and duration of trial blocks in milliseconds.

Interobserver Agreement

An independent trained observer recorded approximately 20% of all TT trials, and a trial-by-trial analysis showed 100% agreement. It should be noted that the T-IRAP computerized program records data automatically, so collecting IOA data for these trials was considered unnecessary.

Experimental Design

A single-subject methodology using an alternating-treatments design was used to compare teaching methods in terms of participant learning outcomes (speed and accuracy in relational responding). The alternating-treatments design was appropriate for the research question (Johnston & Pennypacker, 1993) and did not require a baseline phase to determine if treatment methods were effective; both teaching procedures

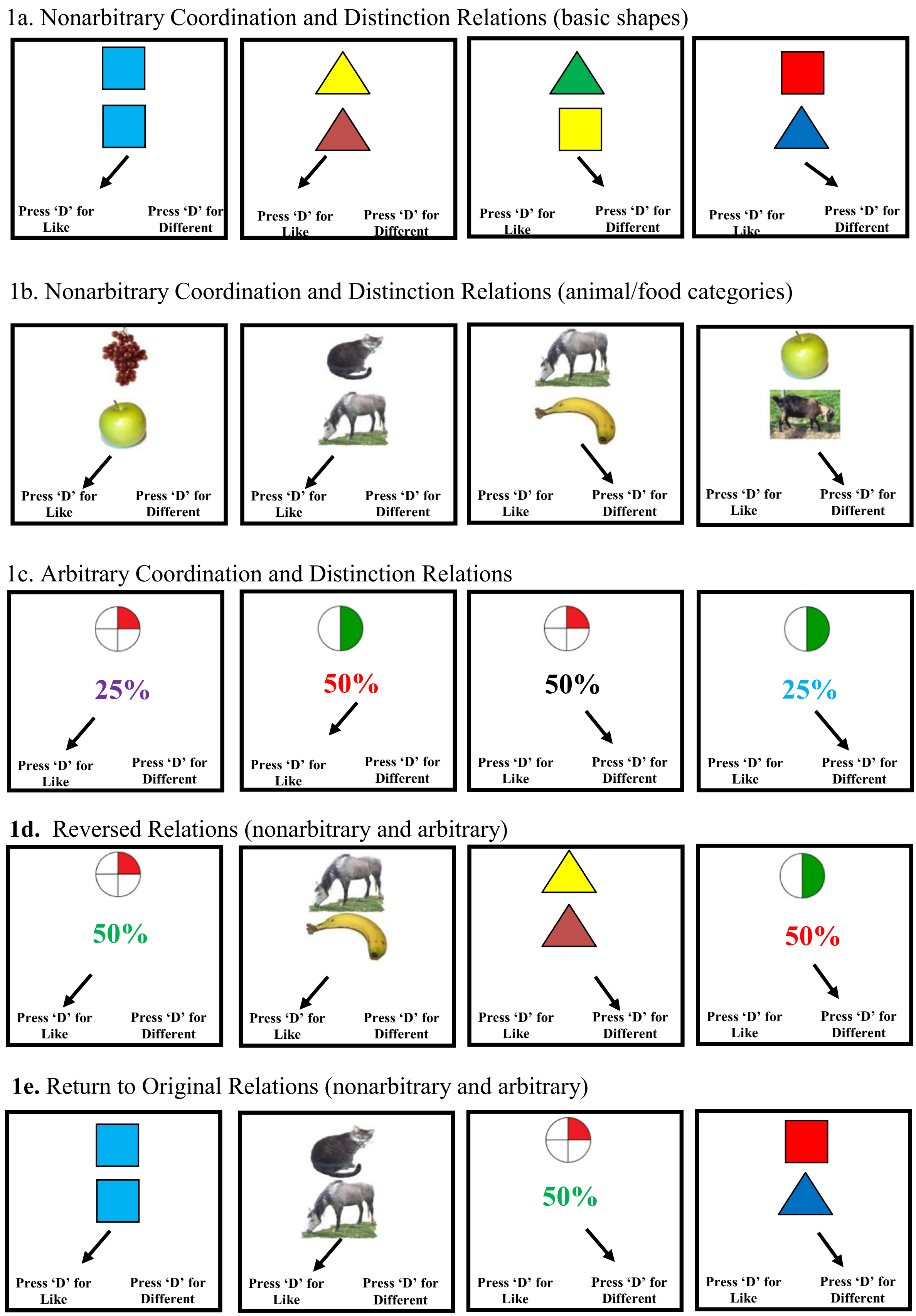

Fig. 1 Examples of stimuli used during trial presentations throughout the study. Arrows were not shown on-screen

use positive reinforcement and other proven behavioral principles, and thus both were considered efficacious. At issue was whether findings that the T-IRAP was *more* efficacious than TT in terms of learning outcomes (Kilroe et al., 2014) would be replicated with five participants with ASD described as low functioning. Pre- and post-relational training, assessments were conducted using the PPVT-IV and the K-BIT with all five participants; a minimum time interval of 6 months between repeat assessments was observed to avoid potential practice effects or related problems.

Standardized Assessments

Each participant was assessed using two test measures, the K-BIT and the PPVT-IV, during normal class hours or immediately after school, with his or her respective class teacher present. Sessions were conducted under standard classroom conditions in each child's respective classroom. Posttest IQ assessments were carried out in the same manner approximately 18 months following the completion of relational training.

Teaching Procedures (T-IRAP and TT)

Following initial assessments using standardized measures, participants received two or three 20-min relational training sessions per week in which teaching methods (T-IRAP and TT) were used alternately; order of teaching regime at commencement was counterbalanced across participants. Teaching procedures were conducted at the participants' desks, and positive reinforcement schedules were individualized for each participant in accord with usual ABA practices.

Nonarbitrary coordination and distinction relations ("Like"/"Different" with basic shapes) See Fig. 1a. Each participant was taught to use the T-IRAP interactive computerized program; trials presented a sample stimulus, a comparison stimulus, and the two response options, "Different" and "Like." Participants responded by pressing a key on the computer keyboard (i.e., D for "Like" and K for "Different"). Before starting the T-IRAP, all children were given the following instructions, which were altered to suit each stimulus set:

> Let's do something new today. Would you like to do some work on the computer? We are going to do some matching. We will see some pictures that are the like each other and some pictures that are different. When the two pictures are "Like" [showing two square stimuli on-screen], press the D button for "Like" [researcher points to the D key]. If the two pictures are "Different" [showing a square and a triangle on-screen], press the K button for "Different" [researcher points to the K key]. If you get it wrong, this will come up [showing a red X on-screen], but that's okay, because we can try again.

Correct responding on the T-IRAP was reinforced in that trials continued uninterrupted, and the researcher delivered positive reinforcement. An incorrect response resulted in a red X being presented on-screen and trials stopped until the correct response was performed; the researcher provided contingent corrective feedback. Teaching procedures during TT used similar stimuli and reinforcement (but corrective feedback did not include a red X). The researcher used a timer during TT that was set at the commencement of a trial block and stopped at completion. Correct and incorrect responses were recorded using pen and paper.

If and when children had difficulty learning the targeted relations, a "blocked-trials" training method was implemented (Smeets & Striefel, 1994) where the same trials are presented repeatedly with stimuli and location kept constant. This intervention procedure was delivered via TT, and participants received six trials where the target relation was "Like" followed by six trials where the target relation was "Different," and this was repeated a second time to give a total of 24 trials per block. When correct responding was at the level of six successive "Like" and "Different" trials, blocked-trial presentation was terminated and trials continued as described previously.

Nonarbitrary coordination and distinction category relations ("Like"/"Different" relations with food or animal categories) See Fig. 1b. Teaching conditions were conducted similarly as before, except that correctly selecting "Like" in this instance meant that the two stimuli presented during trials were similar because they belonged to the same category (e.g., the correct responding when two picture stimuli were presented with cat and dog would be to press D for "Like" because these belong to the category "animals"). Correct responding was to press K for "Different" when trials presented picture stimuli that were not in the same category (e.g., a picture of a dog presented with a picture of an apple).

Arbitrary coordination and distinction relations ("Like"/"Different") These coordination/distinction relations were arbitrary in that the stimuli were symbols that bore no physical similarity to each other but are socially designated within the verbal community to represent amounts (e.g., 0.50 is like 1/2; 0.25 is different from 1/2; see Fig. 1c).

Reversed nonarbitrary relations The previously learned coordination and distinction relations were taught in reverse. The participant was instructed that this time when trials presented two similar stimuli, he or she should press K for "Different." When trials presented two different stimuli, pressing D for "Like" was correct. Contingencies of

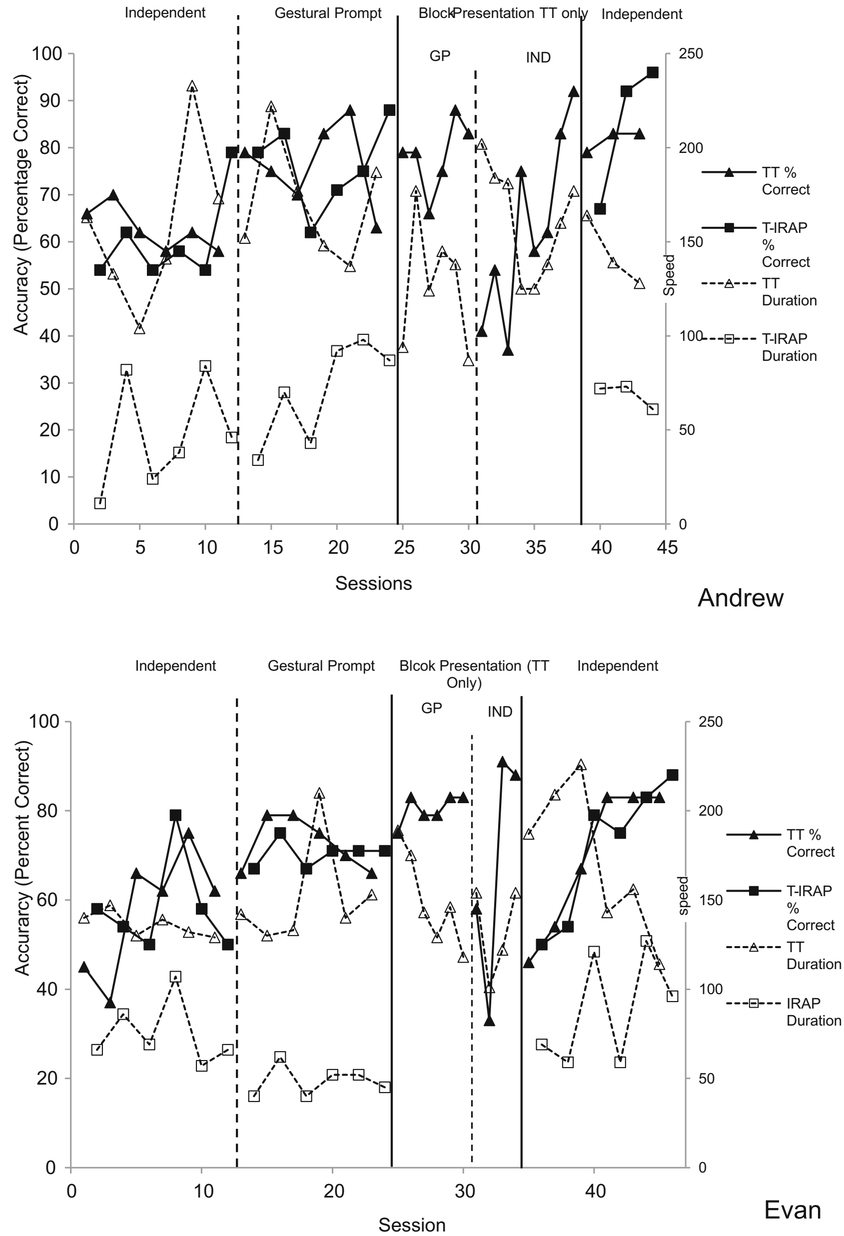

Fig. 2 Nonarbitrary coordination relations (basic shapes). Duration and accuracy data for Andrew (top) and Evan (bottom) during T-IRAP teaching and TT

reinforcement and corrective feedback were reversed to support learning reversed relations. Subsequently, the original, correct relations were taught again and reinforcement and corrective feedback were delivered as before (double reversal; Fig. 1d and e).

Reversed arbitrary relations Contingencies were changed to support reversed arbitrary coordination and distinction relations (e.g., reinforcement for a correct response was delivered when pressing D for "Like" when the two stimuli presented were of different values such as 50% and 1/4) and then changed back to support the original relations (reinforcement was delivered for pressing D for "Like" when the two stimuli presented had similar values, such as 50% and 1/2; Fig. 1e and d).

Results

All five participants with low-functioning ASD successfully learned to use the T-IRAP for relational training. An alternating-treatments methodology was used to graph representations of each participant's data (accuracy and duration) in two teaching conditions, which are presented in Figs. 2, 3, 4, 5, 6, 7, and 8. Accuracy data (percentage correct) are represented using an unbroken line between data points and are scaled on the primary *y*-axis (left side of the graph); trial-block duration data are represented using a broken line and are scaled in milliseconds on a secondary *y*-axis (right side of the graph).

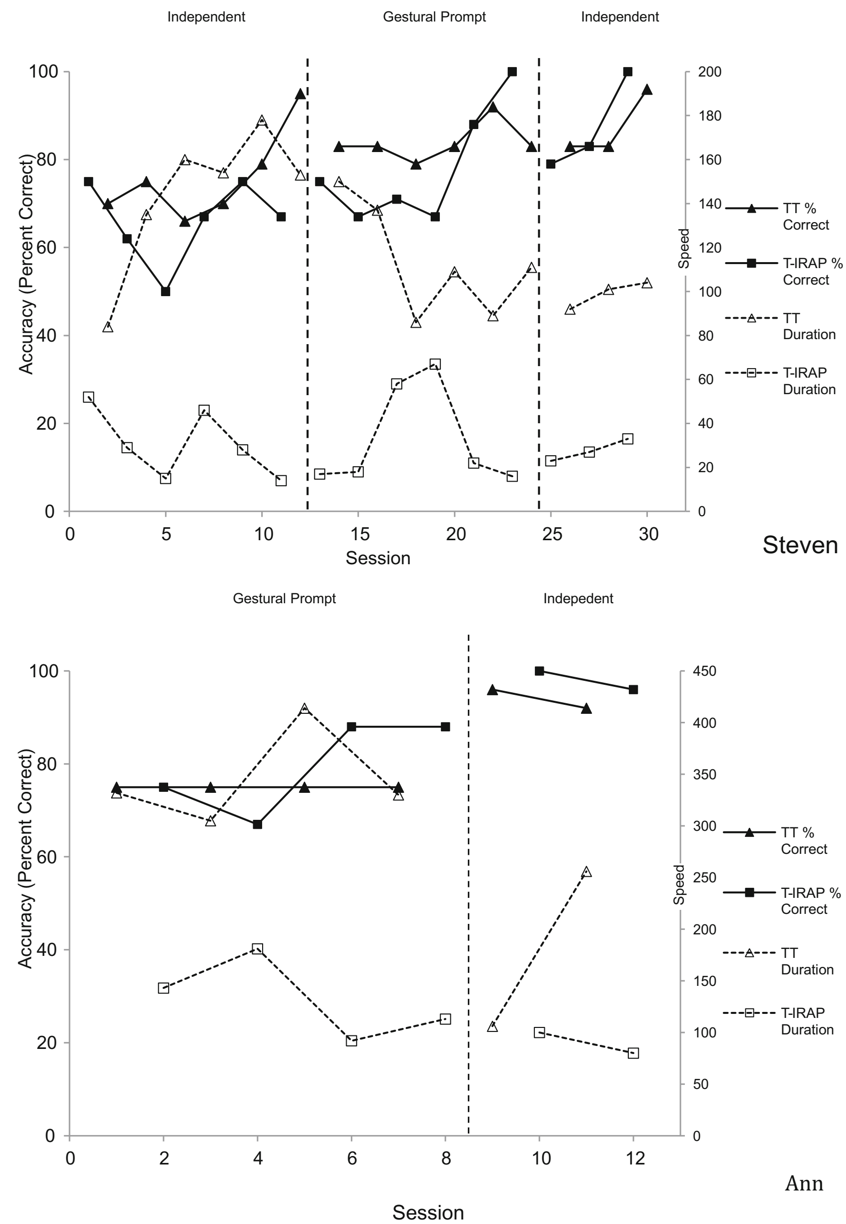

Fig. 3 Nonarbitrary coordination/distinction relations (basic shapes). Duration and accuracy data for Stephen (top) and Ann (bottom) during T-IRAP teaching and TT

Nonarbitrary coordination and distinction relations ("Like"/"Different" With Basic Shapes)

The data for Andrew and Evan are presented in Fig. 2, which demonstrates speed and accuracy in learning with TT and T-IRAP teaching. Visual inspection of graphic data representations for Andrew (top) showed levels of duration data during T-IRAP much lower than in TT conditions, indicating speedier responding. Accuracy data showed high levels of correct responding with some variability in both teaching methods. Evan's duration data (bottom) overall showed markedly lower levels during T-IRAP teaching compared to TT, again indicating speedier responding, though in the final phase the duration data for TT showed a downward trend. The accuracy data are similar for both teaching procedures for Andrew and Evan: slightly variable initially, then rising to the criterion level.

The data for Stephen and Ann for nonarbitrary relational responding ("Like"/"Different" with basic shapes) are represented in Fig. 3. Again, duration data were shown at markedly lower levels and speedier responding occurred during T-IRAP teaching compared to TT for Stephen (top), and overall there was no substantial difference discernible in the accuracy data in either condition. Ann's duration data during T-IRAP teaching were lower overall, indicating faster responding,

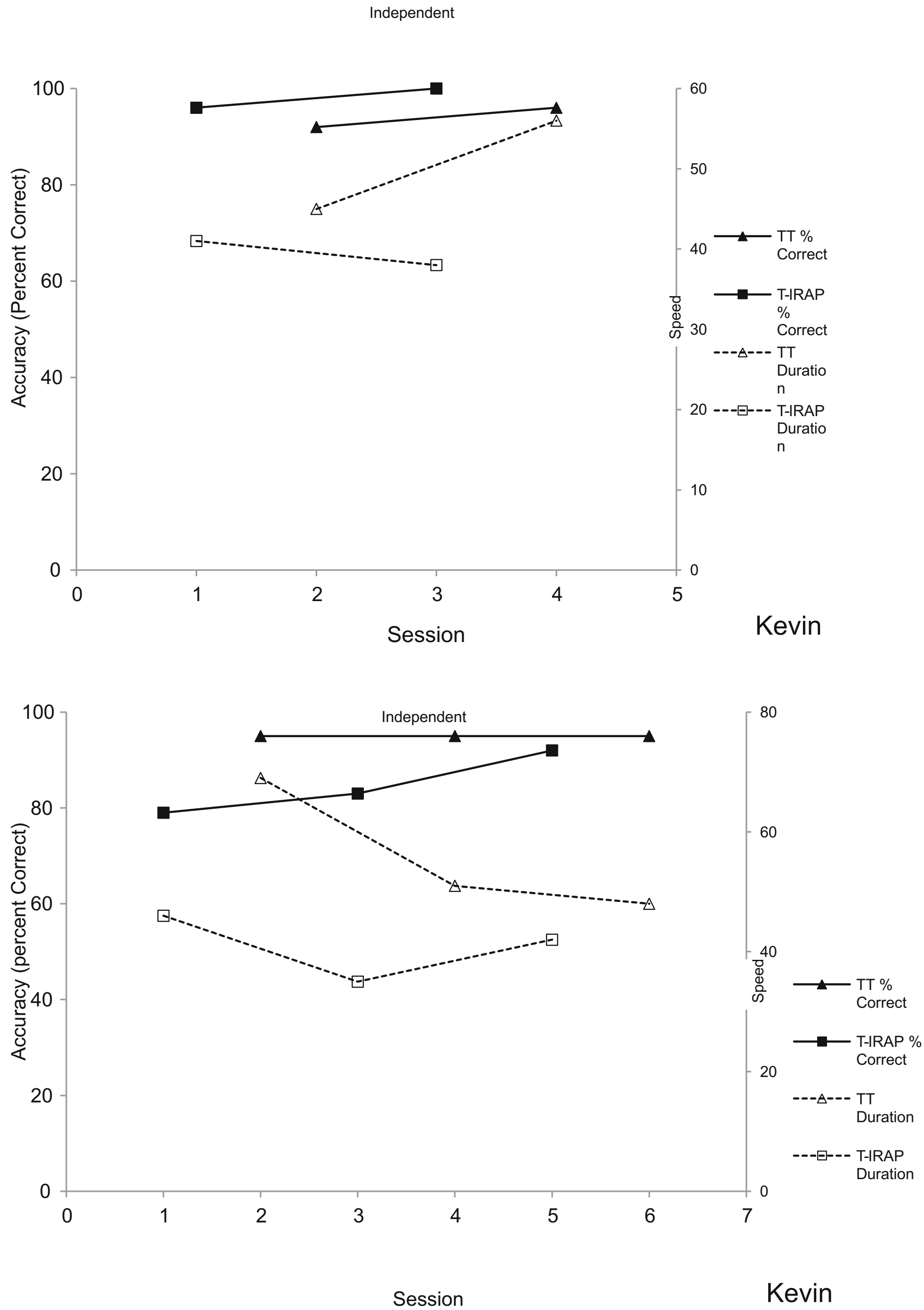

Fig. 4 Nonarbitrary coordination/distinction relations (basic shapes; top), and nonarbitrary category coordination relations (bottom). Duration and accuracy data for Kevin during T-IRAP teaching and TT

compared to TT, and her accuracy data showed slightly higher levels of correct responding during T-IRAP teaching compared to TT. Nonarbitrary coordination and distinction relational responding for Kevin is represented in Fig. 4 (basic shapes; top). Duration data showed slightly lower levels during T-IRAP teaching compared to TT, so responding was only marginally faster in T-IRAP for “Like”/“Different” with basic shapes, and correct responding was slightly higher during T-IRAP.

Nonarbitrary Category Coordination Relations

Three participants (Kevin, Stephen, and Ann) learned nonarbitrary coordination category relations (“Like”/“Different” food or animal categories). Kevin’s duration data showed lower levels during T-IRAP teaching compared to TT when learning category relations (Fig. 4, bottom), again indicating slightly faster responding. Both teaching regimes produced immediate high levels of accurate correct responding; however, TT accuracy

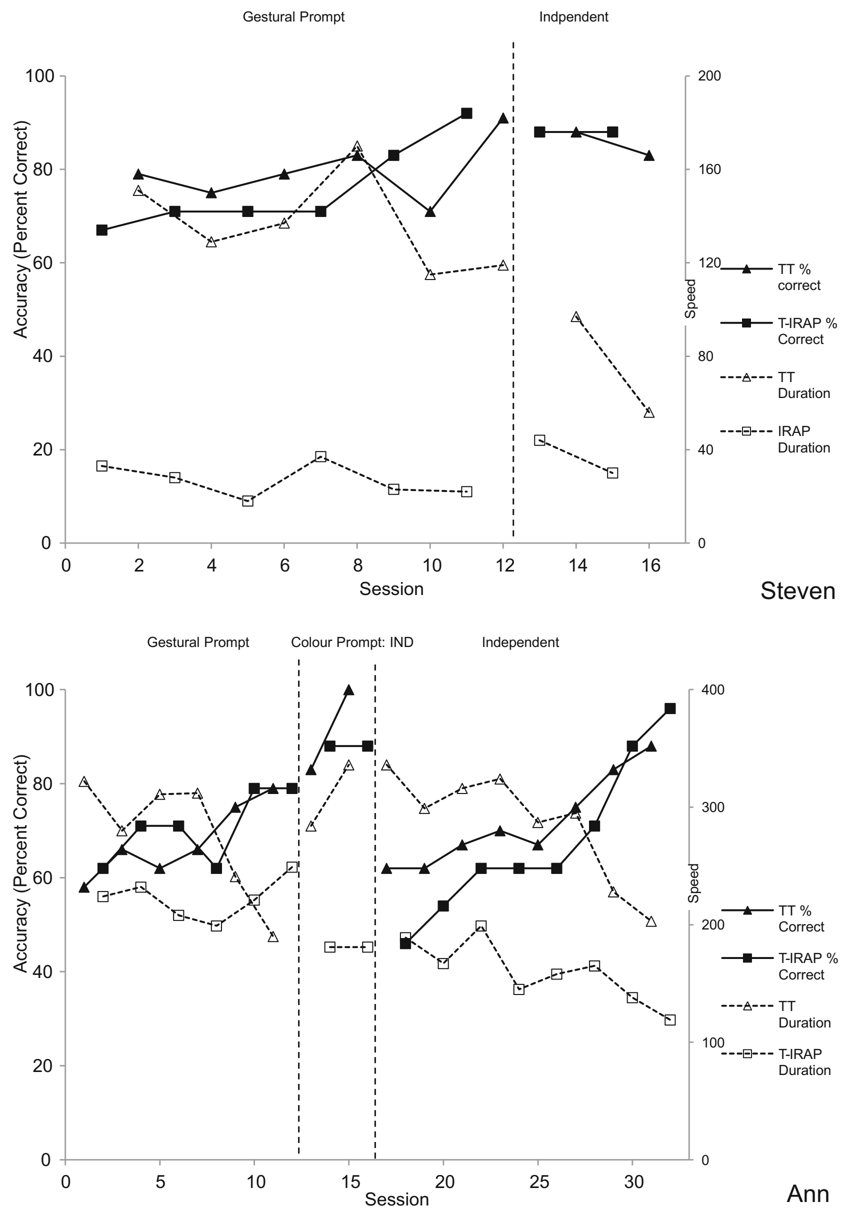

Fig. 5 Nonarbitrary coordination relations (categories). Duration and accuracy data for Stephen (top) and Ann (bottom) during T-IRAP teaching and TT

levels were slightly higher. Results for Stephen and Ann are presented in Fig. 5. Stephen's data (top) showed significantly lower duration levels, indicating faster responding during T-IRAP teaching compared to TT. Accuracy data for Stephen were slightly higher for TT initially; however, overall there was little or no accuracy difference for either regime. Ann's duration data (bottom) showed variability for both teaching regimes in the initial prompted phase, but in the final learning phase, duration data showed much lower levels during T-IRAP, indicating speedier responding. Accuracy data for Ann overall showed no important differences between teaching regimes.

In summary, relational responding (nonarbitrary coordination) was generally faster in T-IRAP across participants and procedures. Accuracy was not significantly different between conditions.

Reversed Relations (Nonarbitrary)

Two participants, Andrew and Evan, underwent training to reverse the learned nonarbitrary relations (Fig. 6), but before completion, these participants became unavailable to participate in the research due to changes in schedules (the researcher ensured that retraining the original correct relations was conducted subsequently at school). Two more participants, Stephen and Ann, successfully completed reversal of nonarbitrary relations (Fig. 7). Subsequently, the original relations were retrained. Speed and accuracy data were compared across T-IRAP and TT during all nonarbitrary reversal training, and results again showed more rapid responding during T-IRAP and no meaningful difference for accuracy for either teaching regime.

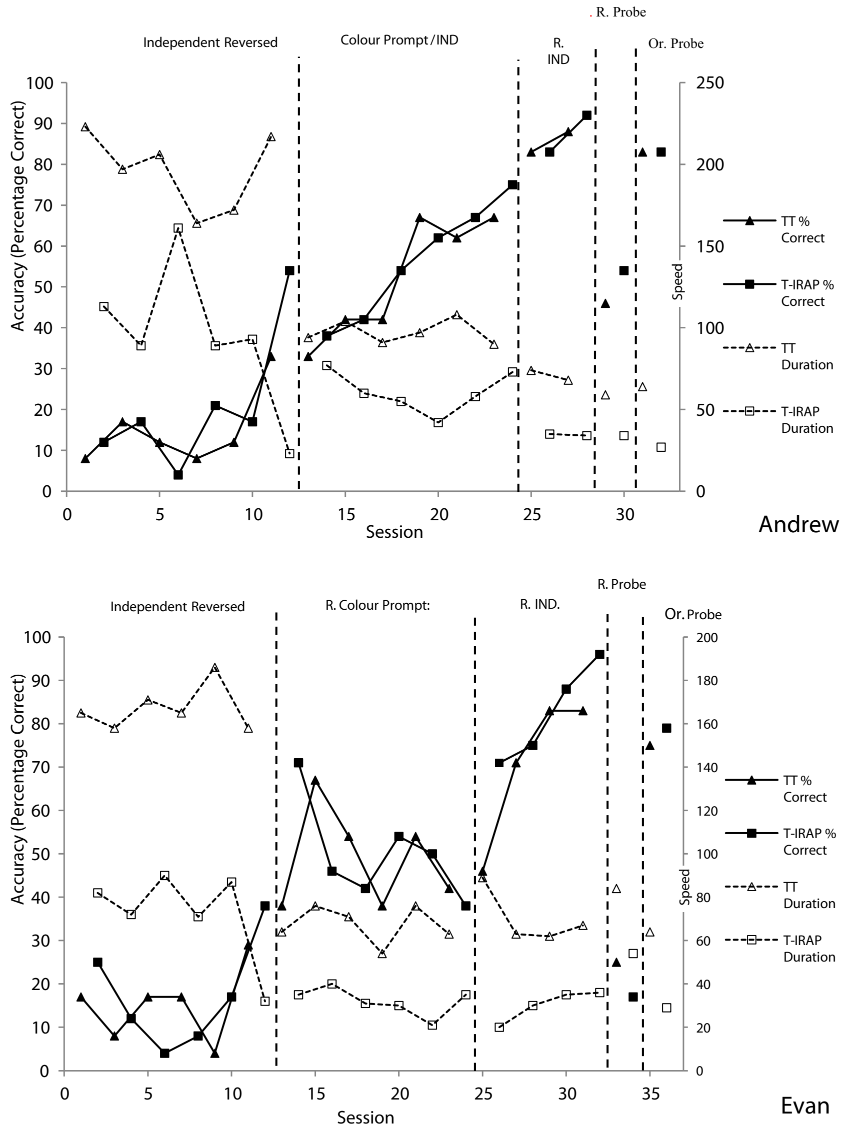

Fig. 6 Reversed nonarbitrary coordination relations. Duration and accuracy data for Andrew (top) and Evan (bottom) during T-IRAP teaching and TT

Arbitrary Relational responding

One participant, Kevin, successfully learned complex arbitrary relations ("Like"/"Different" with math symbols) using TT and T-IRAP (Fig. 8, top). As before, responding was markedly more speedy during T-IRAP compared to TT, and accuracy was marginally increased during T-IRAP compared to TT procedures.

Reversed Relations (Arbitrary)

Kevin completed reversed arbitrary relational responding with math symbols with double contingency reversals (i.e., reversed relations trained to criterion, then original learned relations retrained). Kevin's speed and accuracy data for reversed arbitrary relational responding are shown in Fig. 8 (bottom). Kevin's relational responding throughout was speedier during T-IRAP, and accuracy was similar in T-IRAP and TT.

In summary, arbitrary relational training and reversed relational training was generally faster during T-IRAP across participants and procedures. There was no meaningful difference evident in accuracy; however, accuracy was in general only marginally higher for T-IRAP (see Table 1; total mean accuracy percentage: M = 984.56%, M = 975.58%, respectively; total mean duration: M = 969 s, M = 2,057.2 s, respectively).

Standardized test measures

Pre- and post-relational training participant scores on standardized measures for five children with ASD are shown in Table 2. Participants' measured scores on the K-BIT at pretest ranged from 40 to 62, and at posttest participant scores ranged from 40 to 74. It should be noted that a score of 40 on the K-BIT represents the lowest possible score, and a standard score of 20 on the PPVT-IV represents the lowest possible score.

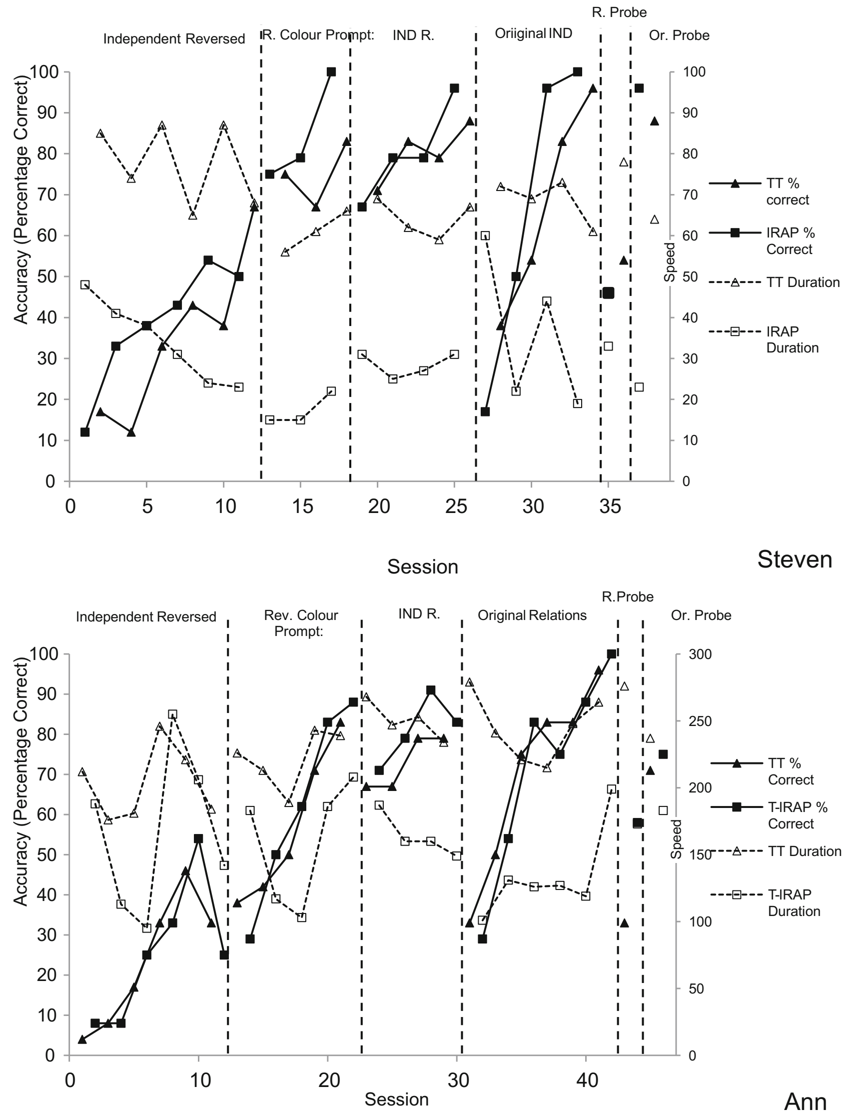

Fig. 7 Reversed nonarbitrary coordination relations and original nonarbitrary relations. Duration and accuracy data for Stephen (top) and Ann (bottom) during T-IRAP teaching and TT

Table 2 shows the standard and raw scores for each participant on the K-BIT and the PPVT-IV at pre- and posttest.

There was a significant change evident in Kevin's posttest measured scores on the K-BIT and the PPVT-IV, which showed improved test scores. There was no meaningful change in pre- and posttest measures on standardized tests for the other four participants who completed nonarbitrary relational training and reversals only.

Discussion

All five participants with diagnosed ASD (four boys and one girl: Ann, aged 7; Kevin, aged 8; Stephen, Andrew, and Evan, aged 12) described as low functioning successfully engaged with the T-IRAP interactive computerized teaching program. All participants learned nonarbitrary coordination relations and completed some reversal training, and one participant (Kevin) successfully completed arbitrary relational training with double contingency reversals. An alternating-treatments design showed much faster relational responding in general during T-IRAP compared to TT across participants and procedures. Accuracy in responding was not shown to be significantly improved in either T-IRAP or TT, although overall, the mean accuracy percentage was only marginally higher throughout T-IRAP training across participants and procedures. There was a significant change shown in scores on standardized measures (K-BIT, PPVT-IV) post-relational training for one participant only, Kevin, the only participant to complete the more complex arbitrary relational training and contingency reversals with arbitrary relations.

It seems likely that the greater overall speed of responding produced by the T-IRAP was related to the rapid speed at which the computerized program can present stimuli as compared to TT methods. As such, the T-IRAP by its very nature may be an efficient tool for teaching fluent relational

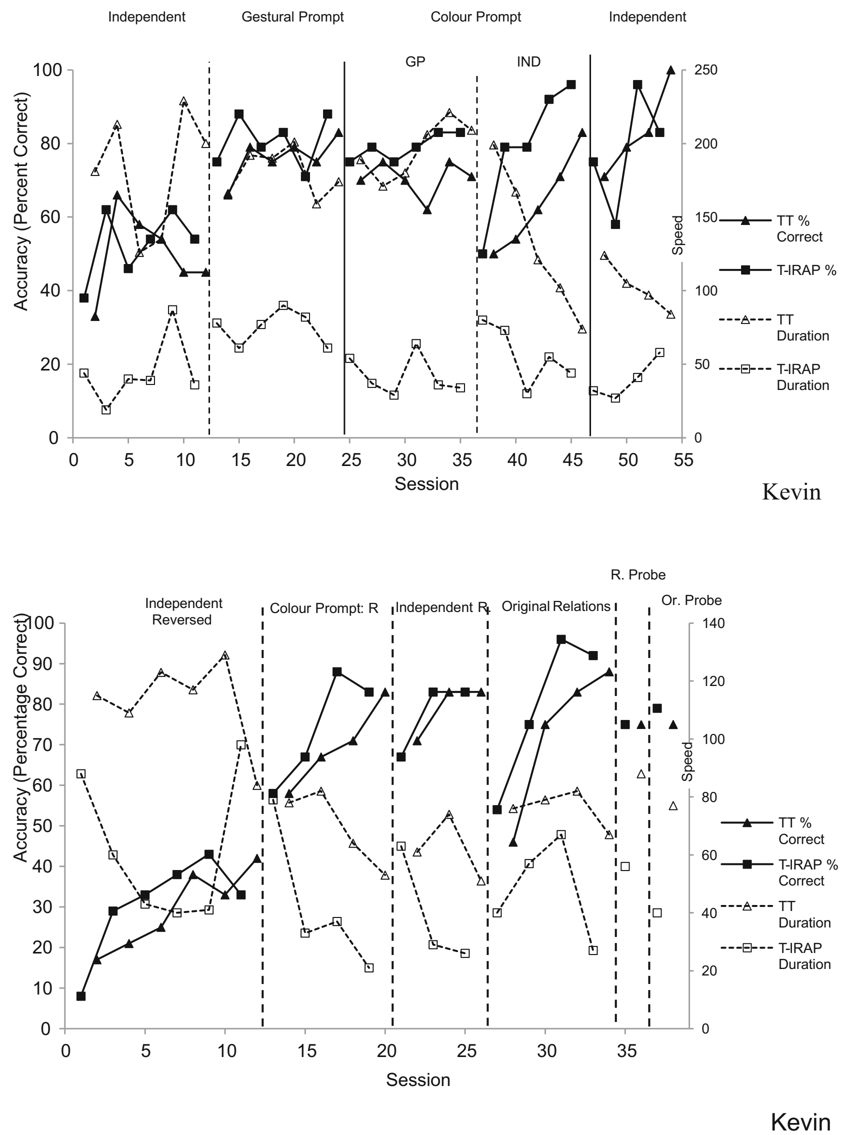

Fig. 8 Arbitrary coordination relations for Kevin (top), and Kevin's reversed arbitrary coordination relations and original arbitrary relations (bottom). Duration and accuracy data in TT and T-IRAP teaching

responding; however, faster stimulus presentation may not be entirely responsible. Ann took an average 155 s to complete a T-IRAP trial block and 276 s to complete a TT trial block (see Table 1); however, it may be that this was related to greater attentiveness due to an expressed preference for the computerized presentation format, and such matters will need clarification via further research. In either case, the T-IRAP could be used independently by students to practice to build fluent relational repertoires. Where appropriate, this could reduce the need for one-to-one instruction (e.g., during maintenance training regarding previously learned material).

Preintervention assessment showed that measures for all five participants scored within the 1st percentile (lowest 1% of the population in terms of verbal ability). Post-relational training, Kevin's standard score on the K-BIT increased by a remarkable 12 points, which moved his placement to the 4th percentile. Similarly, his standard score of 50 on the PPVT-IV placed him in the lowest 0.1% of the general population, and his increased score of 60 post-relational training placed him among the lowest 2.2% of the population. There was no significant change in scores for the remaining participants. Findings of gains in IQ scores related to the complexity of relational training were shown in previous applied research (Cassidy et al., 2011); relational training that involved nonarbitrary coordination (stimulus equivalence relations) did not result in increased IQ scores for participants (disadvantaged children), and gains on IQ tests were shown only for participants who learned complex arbitrary relational responding.

With the exception of Kevin, all participants in the current study required a large number of teaching trials to reach mastery of even the most basic relations with nonarbitrary stimuli (e.g., "Like"/"Different"). Prior to commencement, school records indicated that all participants had met the learning criteria for coordination relations; however, when this was more closely investigated, participants frequently had "same" coordination relations but not "different" relations. It may be

Table 1 Mean Accuracy and Duration (Speed) for Participants Using T-IRAP and TT

	T-IRAP Mean Duration (Seconds)	TT Mean Duration (Seconds)	T-IRAP Mean Accuracy (Percentage)	TT Mean Accuracy (Percentage)
Nonarbitrary coordination relations				
Andrew	48	166.8	71.6	70.72
Evan	67.8	138.1	66.67	69.64
Stephen	30.7	148.5	75.07	81.33
Kevin	39.5	50.5	98	94
Ann	124.7	312.6	85.67	81.33
Nonarbitrary coordination relations (category)				
Stephen	29.4	121.8	78.88	81.13
Kevin	41	56	84.6	95
Ann	185.9	285.3	71.31	72.69
Arbitrary coordination relations (symbols)				
Kevin	52.1	163.5	73.41	67.93
Reversed relations nonarbitrary (and arbitrary*)				
Andrew	66.4	126.8	48.44	43.94
Evan	46.1	102	46.17	42.67
Stephen	30.7	69.6	63.68	61.52
Ann	157	231	58.74	54
Kevin*	49.7	84.7	62.32	59.68
Totals	969	2,057.2	984.56	975.58

that educators expect that students who successfully learn same relations will derive different relations without being explicitly taught. Unlike typically developing children, children with ASD may not readily derive such verbal relations, but it may be important to ensure that the early basic nonarbitrary coordination and distinction relations are firmly established with children with ASD before moving on to the more complex arbitrary relations, as research on sequencing in relational training suggests that learning basic same/different relations with stimuli that are physically similar or different is foundational to establishing a repertoire of more complex arbitrary relational responding with abstract stimuli (Kent et al., 2017). The PEAK-ABA relational assessment and training curricula may be useful in this regard, as it sets out procedures to assess and teach fundamental relations, such as coordination, in clear, easy-to-follow detail.

Table 2 Standard (S) and Raw (R) Scores for Each Participant on the K-BIT and PPVT-IV Pre- and Post-Relational Training

	K-BIT (S) Pre|Post	K-BIT (R) Pre|Post	PPVT-IV (S) Pre|Post	PPVT-IV (R) Pre|Post
Andrew	40|42	18|23	23|21	46|46
Ann	40|40	10|12	34|30	34|31
Evan	40|40	5|5	20|20	22|26
Kevin	62|74	31|45	50|60	48|79
Stephen	40|40	21|20	20|20	43|47

A limitation in the current study is that for IQ test measures, it was not possible to use an assessor who was "blind" to the purpose of the study. Nonetheless, the tests provide clear instructions that were carefully adhered to. It should be noted also that IQ tests may not be sufficiently sensitive toward ability and motivation to respond in children with learning disorders.

The current findings of speedier relational responding during T-IRAP with children with low-functioning ASD are consistent with previous research findings with children with high-functioning ASD (Kilroe et al., 2014); however, current findings differed from those in Kilroe et al. (2014), in that accuracy in relational responding with children with low-functioning ASD was marginal to no improvement during T-IRAP, whereas accuracy was shown to be substantially increased during T-IRAP for children with high-functioning ASD. It is not clear why this should be the case, and further research is needed for clarification of circumstances in which accuracy might be significantly increased during T-IRAP. Additionally, the current study extended previous research by using an alternating-treatments design to eliminate potential practice confounds involved when using a multiple-baseline design to compare two teaching conditions. An alternating-treatments design may assist in avoiding practice effects when comparing treatments; however, it may not be possible to state conclusively that they were eliminated. Specifically, despite rapid alternation of treatments, the stimulus control established during one session of one condition may carry over to the next session of the other condition. Therefore, although highly unlikely, it is possible that one of the conditions could be less effective than it appears to be and that the effectiveness of one condition is actually evidence for generalization or maintenance from the other condition. In conclusion, interested practitioners should note that the computerized interactive teaching program used in the current research is freely available at the following website: https://contextualscience.org/goirap_software_and_manual. Furthermore, development is ongoing, so that the current version (GO-IRAP) is already far more sophisticated and adaptable than the precursor (T-IRAP) and could be used for teaching a wide array of relations, from basic to complex, including derived arbitrary relational responding.

Compliance with Ethical Standards

Conflict of Interest Carol Murphy declares that she has no conflict of interest. Keith Lyons declares that he has no conflict of interest. Michelle Kelly declares that she has no conflict of interest. Yvonne Barnes-Holmes declares that she has no conflict of interest. Dermot Barnes-Holmes declares that he has no conflict of interest.

Ethical Approval All procedures performed involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from individual parents/guardians before their child's participation in the study. Children cannot provide informed consent, but methods were carefully documented to ensure that each child participated on a voluntary basis (i.e., gave verbal or tacit assent at each session). Tacit assent was interpreted by the absence of any signs of distress, negative facial expression, or other behavioral indicators, which were monitored throughout. If indicators were that a child did not assent, the session was terminated; if a child did not assent for three consecutive sessions, participation was suspended and not recommenced without a review with child and parent at a later date. Safeguards were applied in accordance with current ethical standards when conducting research with vulnerable populations.

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