Using the T-IRAP interactive computer program and applied behavior analysis to teach relational responding in children with autism

Helen Kilroe, Carol Murphy, Dermot Barnes-Holmes & Yvonne Barnes-Holmes

National University of Ireland Maynooth

ABSTRACT

The IRAP computer software program was adapted as an interactive teaching tool (T-IRAP) targeting relational frames with four children with diagnosed autism aged 8–10 years. An adaptation of a multiple-baseline design was used to compare participants' relational learning in terms of speed and accuracy during Table-Top (TT) and T-IRAP teaching. The TT procedure was commenced with all participants simultaneously, and the T-IRAP was introduced at stepwise time intervals (after 5, 10, 15, 20 trial blocks) across the four participants. Nonarbitrary then arbitrary coordination, comparative, opposition and derived relations were targeted. Results showed that the T-IRAP was successfully adapted to teach all targeted relations, and in general greater speed and accuracy in relational responding were shown for all four participants during T-IRAP teaching compared with TT teaching. Thus the T-IRAP may be a useful supplementary teaching tool in applied settings.

KEYWORDS: autism, T-IRAP, DRR, computerised interactive teaching, flexibility

PPLIED BEHAVIOR ANALYSIS (ABA) is the application of Skinner's (1938, 1957) basic research on the principles of behavior to address a wide range of human problems. This scientific approach has been found to be efficacious over many decades, and successful behavioral treatment areas include emotional disturbance (Matson & Coe, 1992), AIDS prevention (DeVries, Burnette & Redman, 1991), health and exercise (DeLuca & Holborn, 1992), gerontology (Gallagher & Keenan, 2000) and especially the treatment of individuals with developmental disabilities, most notably autism (Howard, Sparkman, Cohen, Green & Stanislaw, 2005; Sallows, & Graupner, 2005; Cohen, Amerine-Dickens & Smith, 2006; Smith, Eikeseth, Klevstrand, & Lovaas,1997). Children with autism and related language difficulties have benefited greatly from the application of behavior analysis to establish or enhance verbal skills, and the efficacy of ABA with populations with autism has been widely reported even by sources outside and independent of behavior analysis (e.g., American Academy of Pediatrics Council on Children With Disabilities (Myers & Johnson, 2007); New York State Department of Health Early Intervention Program [Satcher,1999]; American Academy of Pediatrics, 2001; National Research Council, 2001; Maine Administrators of Services for Children with Disabilities, 2000). Teaching language skills is traditionally a primary intervention in ABA because it is considered pivotal (Koegel, Koegel & Carter, 1998) in that it can lead to enhanced social and academic skills.

The approach taken is based on Skinner's *Verbal Behavior* (1957), which is a functional account of language comprised of separate verbal operants (e.g., mands, tacts, echoics, intraverbals, autoclitics) that are controlled by antecedents and consequences. Teaching programs in ABA arrange antecedent conditions and contingent positive reinforcement to establish verbal operants with children with delayed speech, and early intervention programs in particular target mands and tacts (Sauter & LeBlanc, 2006) which encompass requesting and labelling objects.

The use of positive reinforcement to teach specific and individual verbal operants is in accord with the principles of behavior derived from basic or experimental science, and might be termed *direct* reinforcement. For example, teaching a directly reinforced mand may involve an antecedent of holding up a preferred item such as "Teddy" before a child and delivering the item when the child requests by saying "I want Teddy". If the child fails to emit the mand, then "Teddy" is withheld. However, it has been suggested that a teaching approach that uses *only* this type of direct reinforcement to establish single verbal operants may be insufficient to promote the generativity that is widely reported as characteristic of language (Hayes, Barnes-Holmes & Roche, 2001; Rehfeldt & Barnes-Holmes, 2009). Thus, ABA programs targeting verbal behavior could be made more comprehensive by synthesising direct reinforcement procedures and complex *derived* responding which may help establish or enhance generative language and untaught novel utterances (see Murphy, Barnes-Holmes & Barnes-Holmes, 2009; Rosales & Rehfeldt, 2007). The point being made is that in addition to responding learned via direct reinforcement, behavioral

Correspondence concerning this article should be addressed to Carol Murphy, JH Building, Department of Psychology, National University of Ireland Maynooth, Maynooth, Co. Kildare, Ireland. Email: Carol.A.Murphy@nuim.ie

research involving stimulus equivalence has shown that humans also respond to more complex contingencies of reinforcement that are less immediately apparent (Sidman, 1971). Stimulus equivalence describes responding to one stimulus in terms of another; for example, imagine a child who likes cookies is taught to relate the name *cookie* to the object *cookie* (equivalent), and subsequently taught that *cookie* and *biscuit* are the same (equivalent) – the child may then smile upon hearing the word *biscuit,* and may ask for a biscuit without having been directly taught to. The child is now responding to the word *biscuit* similarly as to the word *cookie*. The mand function directly taught with *cookie* emerges for *biscuit* based on equivalence relations and a transfer of functions effect (Sidman, 1971). If the child also learns that *cracker* is like *biscuit*, the functions taught for *cookie* may also emerge for *cracker*, and again the child may request a cracker without ever having been directly reinforced for doing so. Briefly, stimulus equivalence means that if humans are taught that stimulus A, B and C are equivalent, functions taught for one of the stimuli will emerge for the other stimuli without direct reinforcement, and this phenomenon has been well-documented in laboratory research (Sidman, 1971, 1994). Derived responding is a complex and important type of responding that has been found to encompass many emergent relations in addition to equivalence or coordination relations (SAME-AS); for example, derived comparative relations (MORE-LESS), derived opposition relations, derived deictic relations (e.g., I-YOU-SHE) and many more. This type of responding is termed arbitrarily applicable relational responding (for a full account see Hayes et al., 2001), and arbitrary relations involve more subtlety. Specifically, nonarbitrary coordination relations involve physical similarity as with identical pictures or objects. Arbitrary coordination relations, however, are socially designated as with language where the word "tree" does not bear a physical resemblance to the object "tree", and the symbolic H$_2$O bears no similarity to water. Learning to respond to relations such as SAME/DIFFERENT based on the physical characteristics of stimuli is obviously advantageous and necessary. However, learning to respond to SAME/DIFFERENT relations that are socially and arbitrarily assigned in a particular context is more complex, and may be essential to advanced language and cognitive skills (Hayes et al., 2001). Thus, an aim in the current research was to build complexity in relational repertoires by teaching arbitrary SAME/DIFFERENT relations. Because the current research is an applied study, the procedure for teaching arbitrary SAME/DIFFERENT relations used stimuli that have practical value; specifically, relations were taught between numerical and percentage symbols that have been previously assigned by the verbal community. These stimuli are arbitrary in that, for example, *50%* bears no physical similarity to ½ and the 'sameness' is designated verbally by the social community.

The precise manner in which derived relational responding (DRR) occurs is not entirely apparent, but it may be that this type of responding is learned primarily via modelling, multiple exemplar training, and positive reinforcement from the social community (Hayes et. al., 2001). Research has shown that even a small number of taught relations among stimuli may generate a great many derived relations (Wulfert & Hayes, 1988). This is an important point because it suggests to behavior analysts that the derived relational

responding paradigm may direct us toward teaching that results in exponential learning of the kind evidenced in human language. Although real world teaching applications with DRR have been quite limited until recently, modern behavioral researchers have scripted many programs that integrate DRR within ABA programs in order to build advanced and complex cognitive repertoires of responding (Rehfeldt & Barnes-Holmes, 2009). Derived manding has been established with children with autism, and with other populations with developmental disorder (Murphy, Barnes-Holmes & Barnes-Holmes, 2005; Murphy & Barnes-Holmes, 2009; Rosales & Rehfeldt, 2005). Derived comparative (more/less) and opposition relational skills have also been demonstrated with young children (Barnes-Holmes, Barnes-Holmes & Smeets, 2004; Barnes-Holmes, Barnes-Holmes, Smeets, Strand & Friman, 2004). Interestingly, a recent study by Cassidy, Roche and Hayes (2011), taught fluent derived relational responding to eight children with a range of educational and behavioral difficulties, and seven out of eight subsequently showed an increase in IQ scores. The full scale intelligence quotient scores for the seven children rose by at least one standard deviation on the *Wechsler Intelligence Scale for Children* (WISC-IVUK; Wechsler, 2004) when compared to measurement at baseline, prior to teaching procedures. At baseline, the children's Full Scale IQ scores ranged from 70 to 92, with half of the children falling below 85. Following the DRR intervention, children's IQ scores ranged from 76 to 111, with only one child showing an IQ score that remained below 85. The importance of these findings lies in the fact that IQ scores tend to remain stable throughout development (Moffitt, Caspi, Harkness, & Silva, 1993), which means that not all teaching procedures are capable of positive influence on important core cognitive skills. It should be noted also that the rise in IQ scores for children in Cassidy et al. were shown to correlate with the increased fluency in DRR subsequent to the teaching procedure. The findings by Cassidy et al. were also predicted by preliminary research with typically-developing adults that demonstrated correlations between high level relational responding skills and higher IQ scores (O'Toole & Barnes-Holmes, 2009; O'Hora, Peláez, Barnes-Holmes, & Amnesty, 2005; O'Hora et al., 2008).

In line with the paradigm that relational skills may be fundamental to advanced cognitive skills, the current study aimed to establish fluent relational responding with children with autism. To facilitate this, an objective was to adapt a computerised procedure known as the Implicit Relational Assessment Procedure (IRAP), more commonly used in behavioral studies of cognition to detect implicit bias in a number of socially sensitive areas (Barnes-Holmes et al., 2006). In the current context the acronym T-IRAP ("T" for "Teaching") is used to distinguish the teaching program from the IRAP. The use of computerised interactive teaching and 'teaching machines' is by no means a new concept in behavior analysis (Skinner, 1958) and the current study aimed to examine if the facility for rapid presentation of trials and automatic data recording afforded by the T-IRAP might have utility for teaching relational responding with participants with diagnosed autism. The IRAP software program is freely available online (http://irapresearch.org/downloads-and-training/), and the current research may encourage behavioral researchers and practitioners to view it as a useful resource for teaching a variety of relational responding

skills. The use of sample stimuli, target words and relational terms in the T-IRAP can be altered depending on the subject matter being tested and on the ability of the individual, and images and or words may be incorporated. The immediacy and consistency of the application of consequences has long been reported as important in learning (Lovaas, 1987; Pierce, Hanford & Zimmerman, 1972), and thus automated procedures may provide an advantage in this regard in addition to that of speeding up trial presentations and trial completions. The T-IRAP could provide consequences in that correct responses result in trials proceeding, whereas incorrect responses present a red "x", and trials cannot proceed until the participant makes a correct response. The T-IRAP also provides onscreen information regarding speed and accuracy of responding subsequent to trial-blocks; therefore students could be taught to establish personal targets based on previous responding, and to graph their results to see their ongoing learning accomplishments. This could facilitate competing with self rather than others, which has been found to encourage learning progress in Precision Teaching (PT). Throughout the T-IRAP procedure the learner can respond at his or her own pace, and the teacher can avoid impeding learning through, for example, poor manipulation of material. As Binder (1996) pointed out, a large proportion of instructional time in trial procedures may be taken up with slow presentation of stimuli, delivery of consequences and recording of results. It should be noted that the T-IRAP is not proposed as an alternative or replacement to Table-Top TT procedures because this would not be ecologically valid, but it may be that the T-IRAP could be a useful and efficient resource in certain circumstances as an additional teaching tool that does not require the presence of a teacher on a one-to-one basis.

Research questions for the present study were as follows: Could the interactive computerised T-IRAP program be adapted to teach relational responding to children with autism? Would participants require pretraining to engage appropriately with the T-IRAP, and was effective pretraining possible? Other aims were to compare participants' fluency (speed and accuracy) in relational responding during TT and T-IRAP teaching, to determine if performance on relational learning tasks were impacted with the introduction of the T-IRAP. The relational 'frames' targeted were coordination (SAME/DIFFERENT), comparison (MORE/LESS), opposition, and derived relational responding. Possible outcomes were as follows: If the T-IRAP could be successfully adapted to teach relational responding this might support use as a supplementary teaching tool to enhance relational learning for students lagging behind peers, particularly if a learning advantage in terms of speed and/ or accuracy was demonstrated. Alternatively, if the T-IRAP had no positive effect but relational learning speed and accuracy data remained stable, this might support the use of the T-IRAP as a convenient utility tool for maintaining responding (that doesn't require one-to-one teaching). Another possible alternative was that the T-IRAP would show a detrimental effect on relational learning; a decrease in either or both of speed and accuracy would undermine potential utility as a teaching tool A series of three research studies was designed to answer the above research questions. The relational repertoires thought to be more basic or fundamental to more complex relations were targeted initially

with four participants; for example, coordination relations and relations with a physical basis were targeted before relations that were arbitrarily designated within the research context (see Hayes et al., 2001). This was in order to gradually build complexity in participants' relational repertoires. An adaptation of a multiple baseline design across participants was used to compare effects of teaching procedures, and this commenced with TT teaching with all participants simultaneously; the T-IRAP was introduced at staggered time intervals to determine any immediate effect on either (or both) of accuracy or speed of participants' relational responding across three studies.

Study 1: Same/different relations

Research commenced with Study 1 which targeted coordination relations (SAME/DIFFERENT) with four participants diagnosed with autism spectrum disorder. Participants were initially exposed to a T-IRAP pretest to determine if they could engage with the computerised program. If they could not, a pretraining procedure was designed to establish the prerequisite skills of pressing keys on the keyboard to correspond with onscreen response options. Subsequent to successful completion of the T-IRAP pretest, a variation of a multiple baseline design across participants was used to compare learning in relational responding during TT and T-IRAP procedures across the four participants. The TT teaching procedures were commenced with all participants simultaneously and the accuracy and trial-block duration data (interpreted as speed of responding) were manually recorded for use as a comparison for similar data automatically recorded during the T-IRAP which was subsequently introduced on a staggered basis across four participants. Nonarbitrary SAME/DIFFERENT were targeted with both procedures prior to more complex arbitrary relational coordination skills. When arbitrary relational skills were targeted with four participants an adapted multiple baseline design was again used and commenced with TT teaching followed by the staggered introduction of the T-IRAP teaching program.

» METHOD

Participants

Four children, three boys and one girl aged 8–10 years, were recruited from an ABA school in Ireland. All participants had been previously diagnosed with autism by a clinical psychologist independent of the current research. Clinical diagnoses were based on criteria in the *Diagnostic and Statistical Manual (Fourth Edition)* (DSM-IV), and the severity was described as within the mild to moderate range for all four participants. All participants had normal or corrected-to-normal vision. All participants had verbal repertoires that included verbal operants (Skinner, 1957) such as manding, tacting, intraverbals, autoclitics and textuals (reading via word recognition).

To avoid a possible photosensitive reaction to the PC screen, parents were advised that children with a history of seizures should be excluded as participants. In addition to formal parental consent, verbal assent was sought from each child before commencing each session. The Investigator worked at the school and was trained in the principles and application of ABA, and was therefore compe-

tent to work with participants, who were provided with frequent short breaks and positive reinforcement throughout procedures. Children were appropriately supervised and monitored throughout the procedures in accordance with usual ABA teaching regimes used at the school, and all procedures were conducted with the consent and supervision of the school Educational Director. The Investigator was known to all participants, and prior to commencing the children were asked if they would like to work with the Investigator on a computer program or if they would prefer to work with another teacher doing other school work. Participants were free to respond by opting to work with the Investigator or continuing with other school work. Participation was conducted on an individual basis, and the Investigator was present with each child throughout all T-IRAP procedures. Procedures were to be terminated if children showed signs of distress. Physical indicators of distress were defined as increased stereotypy or other problem behavior, or verbalised dislike of procedures, or excessive frowning or yawning. None of the children had been previously exposed to a T-IRAP procedure and all were considered naïve in this regard. None of the children showed signs of distress or expressed a wish to end the T-IRAP procedures throughout the study.

Setting

All aspects of the study were conducted in a quiet room in the participants' school with the Investigator present at all times. Sessions were conducted during school hours, usually twice per week. Duration of individual sessions was never more than 20 mins. when teaching children how to use the T-IRAP initially, and never more than 30 mins. when teaching relational skills. The longer duration of teaching sessions was considered justifiable because the educational targets accorded with those in the children's Individualised Educational Program and the teaching schedules for these.

Apparatus and materials

T-IRAP. The IRAP is a computer program written in Visual Basic (Version 6.0.) that controls all aspects of stimulus presentation and the recording of all responses on a Dell computer. The T-IRAP program was adapted from this and designed so that each trial presented a sample stimulus, a comparison stimulus, and two relational terms (e.g., SAME/DIFFERENT response options). Participants responded by pressing a key on the computer keyboard (e.g., 'd' to select SAME, 'k' to select DIFFERENT). All visual pictorial stimuli were sourced via the internet or education software containing catalogues of images (for example *Boardmaker*™). The program recorded correct and incorrect responding, and response latencies (time between trial presentation and participants' response) in milliseconds. Latency data were averaged across trial-blocks to provide trial-block duration data which was interpreted as speed of responding.

Table-top materials. Laminated card 6 cm × 9 cm with words (SAME and DIFFERENT) printed clearly in black font (48 pt.) on a white background were used. Laminated card 6 cm × 9 cm with pictorial stimuli similar to those used in the T-IRAP were also used. A stop-watch was used to time trial-block duration throughout TT teaching, and data were recorded on sheets designed for the purpose.

Interobserver data

All T-IRAP programs throughout the current series of studies recorded duration of trial-blocks (averaged response latency) and accuracy data (percentage correct) automatically. During TT teaching, an independent observer recorded data for accuracy (percentage correct) and speed (duration of trial-blocks) for approximately 20% of all training trials, and these data were compared with data recorded by the Investigator for agreement. Agreement was calculated by dividing the total number of agreements by the number of disagreements plus agreements and converting to a percentage. Agreement for accuracy data was calculated at a mean of 95% (range, 92% to 100%) and mean agreement for trial duration data was 98% (range, 96% to 100%). It should be noted also that a high proportion of the TT trial data throughout the current series of studies were recorded by independent ABA instructors (assistant instructors working in the school) who were 'blind' to the purpose of the research. These IOA details pertain to all three studies in the current series.

Experimental design

The computer program used was the IRAP, which is freely available online (http://irapresearch.org/downloads-and-training/), and the adapted program is referred to in the current text as the T-IRAP (teaching IRAP). It should be emphasised that the training components were conveniently adapted for teaching relational responding, and that the current research involved no aspect of examining responding for implicit bias related to any phenomenon.

A variation of the multiple baseline design across participants was used to compare the T-IRAP with TT teaching in terms of speed and accuracy of relational learning with four children with autism. The experimental design did not involve an initial "no intervention" or "baseline" condition. Instead, the first phase commenced concurrently for each of the four participants with a TT teaching procedure, and both accuracy and speed of relational responding during trials was recorded by the investigator (or other independent instructors) using a stopwatch, paper and pencil. This is customary at the school at which the research was conducted, which routinely implements Precision Teaching practices. Data were collected for four participants across a minimum of 5 trial blocks in order to provide information about participant learning in the TT condition. The T-IRAP was then introduced with one participant while the TT procedure was extended with the other three participants. The interactive computerised T-IRAP was subsequently introduced at staggered time intervals across the three remaining participants (after 10, 15, and 20 trial-blocks, respectively). The TT speed and accuracy data for participants' relational learning were used to compare with similar data recorded automatically during the T-IRAP procedure. The staggered introduction was designed to facilitate an examination of any immediate effect on speed and accuracy in relational responding evident upon the introduction of the T-IRAP. If an immediate effect was demonstrated and replicated across participants it would seem less likely to be a result of extraneous variables.

The aim was to determine if the T-IRAP might be useful as a supplementary teaching tool to increase accuracy or speed in relational responding, or alternatively if T-IRAP teaching had no
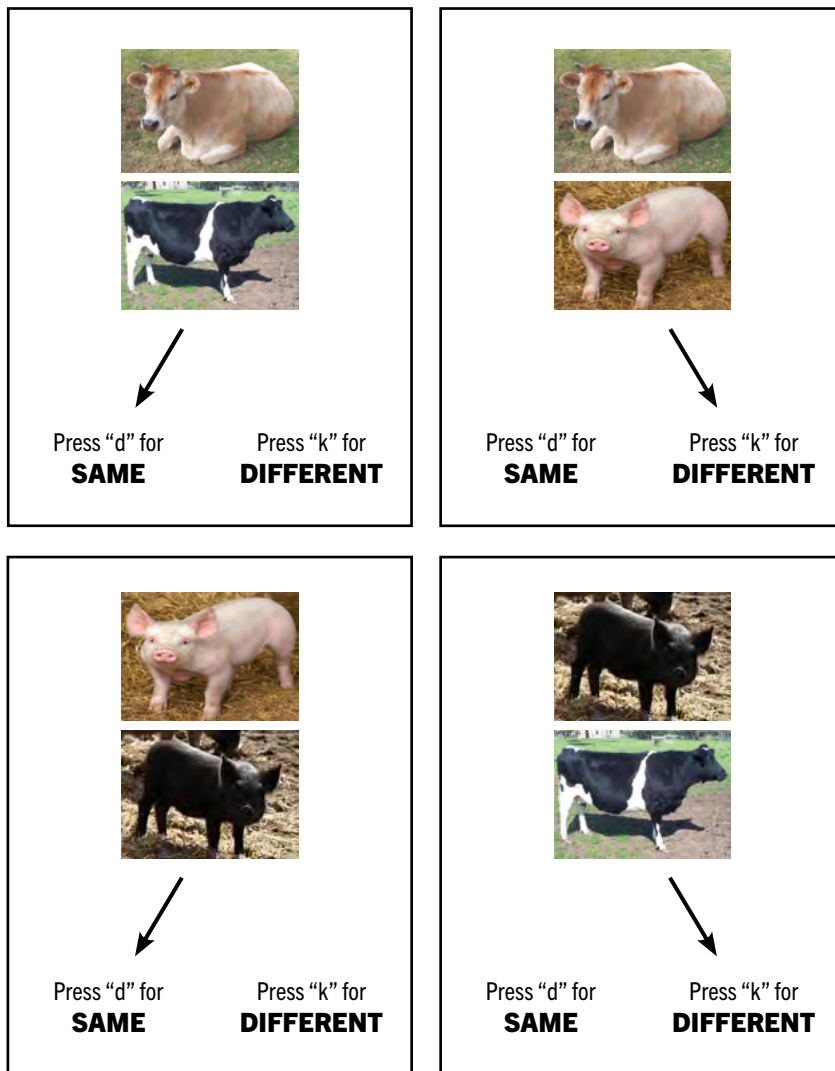
Figure 1. Trial presentation format for SAME/DIFFERENT relational responding with nonarbitrary stimuli.

Same') and you should press the 'd' key (pointing to the letter on the keyboard) because the pictures are the same. If a picture of a tree and of a ball comes up on the screen I will point here 'press k for Different' and you should press 'k' (pointing to the letter on the keyboard) because they are both different. If you get it right more pictures will come up. If you get it wrong a red × will come up, but that's ok, we can try again to get the next one right.

Thus, when the T-IRAP pretest was commenced, each child had to respond by pressing 'd' on the keyboard to select the onscreen response option SAME, and by pressing 'k' to select DIFFERENT. If the child pressed the correct key, for example, 'd' when the two stimuli presented onscreen were identical and the Investigator said "Press the key for 'same', the screen cleared and the next trial was presented, and the Investigator delivered contingent positive reinforcement (token economy on a fixed ratio schedule [FRI]; social praise on a variable ratio schedule [VR 3]). If the child pressed no key on the keyboard or pressed the wrong key, the researcher pressed the correct key and provided corrective feedback (e.g., "Press this one, because they're the same", while pressing the correct key). The pretest had a success criterion of a minimum of 8/10 correct trials. The aim was simply to determine if children could engage appropriately with the T-IRAP program. If a child was unable to meet the T-IRAP pretest criterion, TT pre-training was commenced to teach correspondence between the response options SAME/DIFFERENT and the letters 'd' and 'k', respectively. When all participants successfully completed the pretest, the experiment proper commenced.

positive effect on relational responding, but that the data remained stable (which might suggest T-IRAP as a convenient utility tool for maintaining responding), or if T-IRAP had a detrimental effect on relational responding in terms of either accuracy or speed, or both.

Procedure

T-IRAP pretesting. Pretesting was conducted in order to determine if the participants could engage with the T-IRAP interactive computerised teaching program; for example, if they could understand that the response options SAME/DIFFERENT on the computer screen corresponded with designated keys on the keyboard ('d' and 'k', respectively). Children were given instructions to the following effect:

We're going to do some work on the computer. We will see things that are the same and things that are different. If the two pictures are the same, press the 'd' key for Same. If the two pictures are different, press the 'k' key for Different. So, for example, if a picture of a tree comes up here (pointing to top picture) and a picture of a tree comes up here (pointing to bottom picture) I will point here (pointing to the onscreen prompt 'press d for

Pretraining

Pretraining involved a TT procedure to teach correspondence between the response options SAME and DIFFERENT, and the letters 'd' and 'k', respectively. Two laminated cards with the printed words SAME and DIFFERENT were placed on the table in front of the child, and laminated cards with the printed letters 'd' and 'k' were used also. The Investigator handed the child either the letter 'd' or 'k' and instructed the child to match with either SAME or DIFFERENT as appropriate. The Investigator provided a verbal and gestural prompt by pointing to the correct option and saying, for example, " 'd' goes with SAME" when handing the letter 'd' to the child to match with the response option SAME. The verbal and gestural prompts were provided for the first two trials only, and subsequent trials required the participant to independently and correctly match the letter with the word assigned. Positive reinforcement was delivered contingent upon participants matching 'd' to SAME and 'k' to DIFFERENT (token economy on a fixed ratio schedule [FRI]; social praise on a variable ratio schedule [VR 3]). For incorrect responses, the Investigator provided verbal feedback and a gestural prompt

indicating the designated correct response option. Social positive reinforcement for attempting a correct response was also provided (e.g., "Good trying, let's try again"). If a participant showed 100% correct across 3 trial-blocks for correspondence pretraining they were subsequently re-exposed to the pretest for the T-IRAP to determine if they could now select 'd' or 'k' on the keyboard to correspond with the correct onscreen response option. If the child again failed the pretest, he or she would return to the TT pretraining procedure for an additional block of 10 pretraining trials before returning to the T-IRAP pretest (this was not found to be necessary for any participant). SAME/DIFFERENT picture stimuli presented during T-IRAP pretesting were not used in subsequent relational training procedures.

Table-top: SAME/DIFFERENT nonarbitrary relations

When all participants had successfully completed the pretest, they proceeded to the experiment proper, which commenced with TT teaching for SAME/DIFFERENT relations. Learning SAME/DIFFERENT relations is important in itself, and it may provide a foundational basis for learning more complex relational responding (Hayes et al., 2001). The SAME/DIFFERENT relations taught first were nonarbitrary and based on physical similarity or difference. The TT procedure was commenced with the four participants simultaneously on the same day and data in this phase were collected using an adaptation of a multiple baseline design across participants. During the TT procedure laminated cards (6 cm × 9 cm) with pictures and printed words were placed on the desk in front of the child, in a format similar to that to be used during the T-IRAP program (see Figure 1). The Investigator placed a sample stimulus (e.g., picture of a cow) above a single comparison (e.g., an identical picture of a cow, or else a picture of something different such as a ball), with the printed words SAME and DIFFERENT placed below the pictures. The Investigator instructed each child to select the correct response, SAME or DIFFERENT when presented with the first trial. Positive reinforcement was delivered contingent upon correct responding and corrective feedback was provided for incorrect responding. Positive reinforcement involved token economy systems with tokens delivered contingent upon accurate and speedy responding (e.g., token economy with VR 3 schedule for accurate responding, FR1 for increased speed indicated by trial-block duration data). Reinforcement schedules were arranged on an individual basis for each participant and delivery of contingent reinforcement was kept constant for each participant across both TT and T-IRAP conditions. A criterion level for accuracy in relational responding was preset at 3 trial-blocks × 100% correct. This criterion was used throughout teaching procedures because it is commonly used in the school in which the research was conducted and thus was familiar to Instructors.

T-IRAP: SAME/DIFFERENT nonarbitrary relations

The initial TT phase for SAME/DIFFERENT nonarbitrary relations was continued across 5 trial blocks (10 trials in each trial-block) with all four participants, at which point the T-IRAP was introduced with one participant. The TT phase was extended for three other participants, and the T-IRAP was introduced at staggered time intervals (e.g., after 10, 15, and 20 trial-blocks, respectively) to discover any immediate effect on the accuracy and/or duration data for relational learning across participants. The T-IRAP trial-blocks consisted of 10 trials teaching SAME/DIFFERENT relations and these operated similarly as described for the T-IRAP pretest, except that the stimuli used were novel and the Investigator did not point to the correct onscreen prompt as in pretest trials. The Investigator delivered similar instructions as per the pretest and added: "Go fast, but try to get it right".

General T-IRAP format

Stimuli presented onscreen during programs consisted of pictorial images as sample and comparison stimuli (e.g., dog and dog; dog and cow), and printed words presented as relational response options (e.g., SAME/DIFFERENT). During all trials in all T-IRAP teaching programs, a correct response (selecting the key that corresponded with the correct onscreen response option) was immediately followed by the screen clearing and presentation of the next trial. An incorrect response (selecting the key corresponding to the incorrect onscreen response option) was followed by a red 'x' presented onscreen, and participants then had to select the correct response option before the screen would clear the screen and present the next trial. Because the children were not familiar with the red x to indicate an incorrect response, the Investigator initially provided additional verbal feedback also (e.g., "nice try but you should select this one" while pointing to the correct stimulus). Throughout all T-IRAP and TT teaching the Investigator delivered positive reinforcement contingent upon accurate and speedy responding (e.g., token economy with VR 3 schedule for accurate responding, FR1 for increased speed indicated by trial-block duration data). Corrective feedback was delivered for incorrect responding. The schedules of reinforcement were always arranged in accordance with the individual child's current level of responding.

All the T-IRAP programs measured and recorded response latency data and percentage of correct responses for each participant across each session. Response latency data were averaged for each trial-block and this provided a measure of duration which was taken to indicate speed of participant responding; the T-IRAP presents onscreen speed and accuracy data at the end of each session. Right and left positions of response option stimuli were not counterbalanced across trials during any of the procedures during Study 1. This was because other studies have shown that including such counterbalancing of stimuli in initial learning can impede learning progress for children with autism (Smeets & Striefel, 1994). Although the aim was ultimately to include counterbalancing of stimuli to enhance fluent relational learning, the added complexity of counterbalancing of position of response options was only introduced in the T-IRAP subsequent to Study 1 after participants had learned SAME/DIFFERENT relational frames. Counterbalancing of response options was not used with any TT teaching procedures throughout the current research because the Instructor would have to physically manipulate position in addition to presenting stimuli and recording data manually and this would likely have impacted quite negatively on speed of responding.
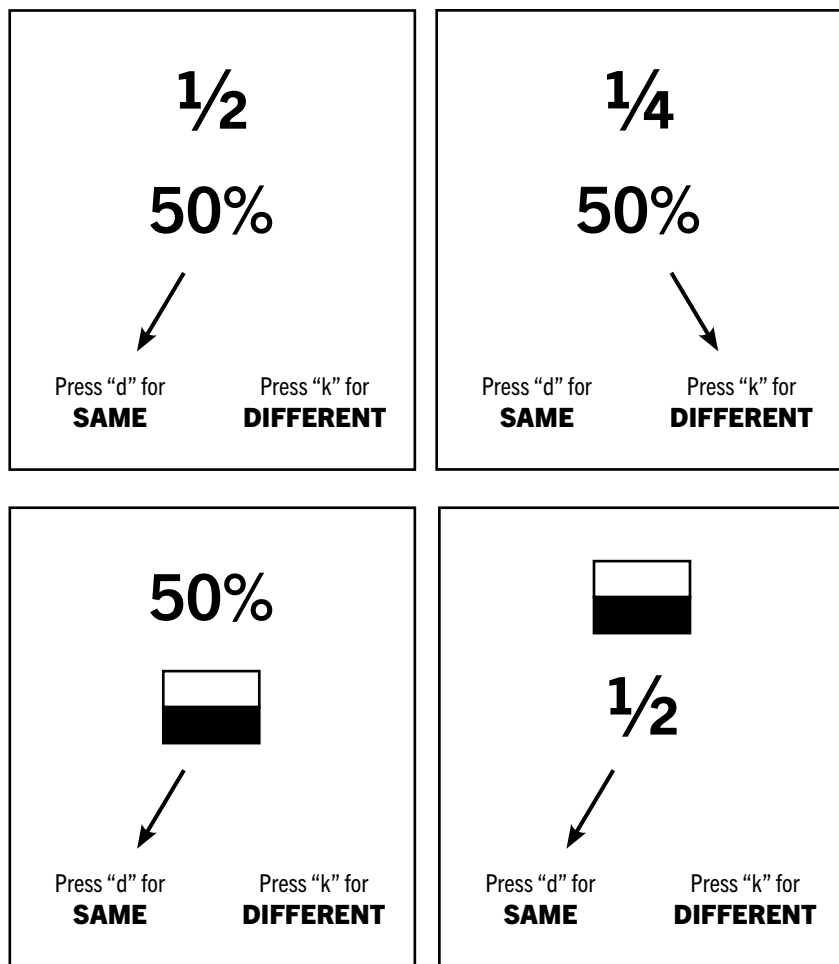
½

50%

Press "d" for
SAME
Press "k" for
DIFFERENT

¼

50%

Press "d" for
SAME
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50%

Press "d" for
SAME
Press "k" for
DIFFERENT

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Press "d" for
SAME
Press "k" for
DIFFERENT

Figure 2. Trial presentation format for SAME/DIFFERENT relational responding with arbitrary stimuli.

Table-top: SAME/DIFFERENT arbitrary relations

Study 1 aimed to show that arbitrary stimulus relations frequently used in educational and real-world settings could be taught with four participants using the T-IRAP format to facilitate accurate and speedy responding. Thus, arbitrary SAME/DIFFERENT relational responding involved teaching children to relate as 'SAME', the numerical symbol for half (½) with the percentage symbol (50%), and then to relate the percentage symbol to a visual graphic representation of half (see Figure 2). When a symbol such as that for a quarter was presented with a symbol for half, the children were taught to select the response option 'DIFFERENT'.

To compare learning data (speed and accuracy) for TT with those for T-IRAP, a variation of the multiple baseline design across four participants was again used. The procedure commenced with TT teaching, and stimuli were presented on the table in front of each participant in a similar format as before (e.g., sample stimulus on top [e.g., ½], comparison below this [e.g., 50% for a SAME trial, 25% for a DIFFERENT trial], and two printed response options SAME/DIFFERENT below the sample stimuli. The presentation format and positioning of stimuli for TT and for the T-IRAP program was similar. When commencing TT teaching for arbitrary SAME/DIFFERENT relational responding with four participants, the Investigator prompted each child to select the

correct response during the first few (3 or 4) trials. Specifically, when trials presented two symbols for half the Investigator said "Point to same" using a gestural prompt to indicate the SAME response option, and when trials presented a symbol for half and a symbol for quarter the Investigator said "Point to different" and used a gestural prompt to indicate the DIFFERENT response option. The prompts were faded after initial trials. Positive reinforcement and corrective feedback procedures were conducted similarly as described previously. The T-IRAP for arbitrary relational responding was gradually introduced across the four participants in a stepwise fashion when participants had completed sufficient TT trial-blocks to provide data for comparison (after 5, 10, 15, 20 trial-blocks).

T-IRAP: SAME/DIFFERENT arbitrary relations

Procedures operated similarly as for the nonarbitrary SAME/DIFFERENT relations, except that the nonarbitrary pictorial stimuli used previously were replaced with arbitrary stimuli.

» RESULTS AND DISCUSSION
Pretest and pre-training procedure

Three of the four participants (Conor, Niamh and Nicholas) failed to achieve a minimum of 8/10 correct responses during the T-IRAP pretest, and therefore these participants completed pretraining in order to teach correspondence between response options onscreen and keys on the computer keyboard. One participant, Robert, successfully completed the pretest on the first occasion. The data for pretraining for three participants to establish pre-requisite T-IRAP skills indicate that they succeeded in learning the necessary correspondence (see Figure 3). Subsequently the three participants successfully completed a repeated pretest.

SAME/DIFFERENT nonarbitrary relations

The data for four participants learning SAME/DIFFERENT relational responding during TT and T-IRAP are presented using a multiple baseline graph (Figure 4). Accuracy data are depicted using a solid line, and data for duration of trial-blocks (speed of responding) are shown with a broken line. Accuracy data points indicate the percent of correct trials and relate to the *y* value axis labelled Percentage Correct. Duration data points represent the time taken in seconds to complete a trial-block, and relate to an additional value axis on the right side of the graph, time-scaled in seconds. Criterion levels for accuracy (percentage correct) throughout teaching procedures was pre-set at 100% × 3 trial-blocks, and no criterion was pre-set for duration data (speed of responding).

Robert's data across 5 trial-blocks (Figure 4, top panel) indicate that he readily acquired SAME/DIFFERENT nonarbitrary relational skills during TT teaching and achieved a criterion performance (100% × 3 trial-blocks). Trial-block duration data for Robert across TT teaching show a steady decreasing trend, indicating that speed
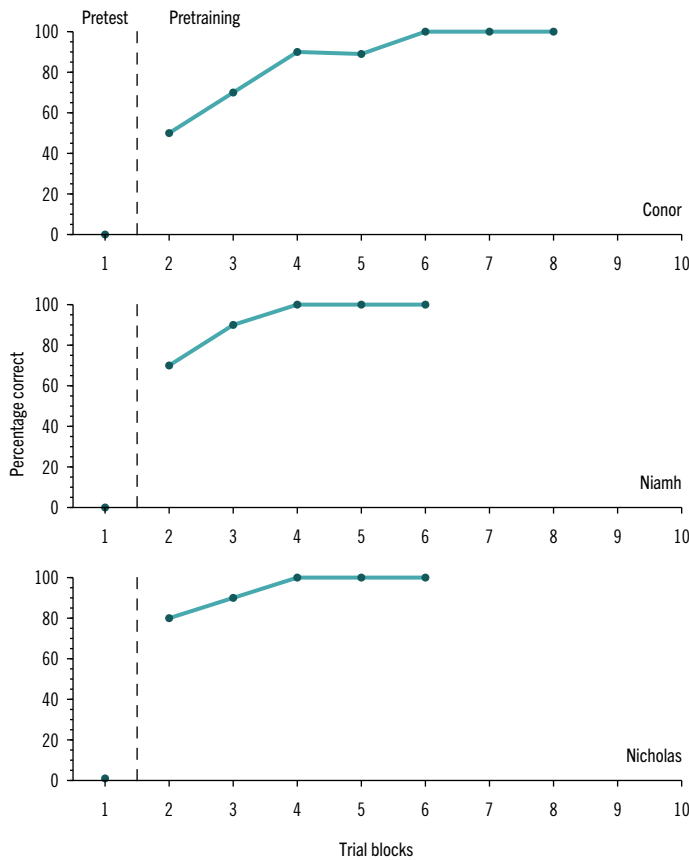
Figure 3. Pretraining data for three participants

but recovered again fairly rapidly and ascended to the criterion levels. Data representing speed of responding during T-IRAP trial-blocks showed an immediate drop in level (time taken to complete trial-blocks), and the descending trend in duration data continued throughout the 6 T-IRAP trial-blocks at which point the learning criterion was achieved.

For the fourth participant, Nicholas (Figure 4, bottom panel), the TT teaching procedure was continued across 20 trial-blocks. Accuracy data were somewhat variable with an ascending trend evident. Duration data for Nicholas during the 20 TT trial-blocks showed some variability and a weak descending trend. When the T-IRAP was introduced with Nicholas the variability in accuracy data was eliminated and the ascending trend was continued to criterion levels across 8 trial-blocks. Duration data during T-IRAP teaching also became more stable and showed a steadily decreasing trend. Thus, responding became increasingly more accurate and rapid in the T-IRAP teaching procedure compared with TT teaching for Nicholas.

Figure 4. Nonarbitrary SAME/DIFFERENT relational data for four participants in TT and T-IRAP teaching conditions
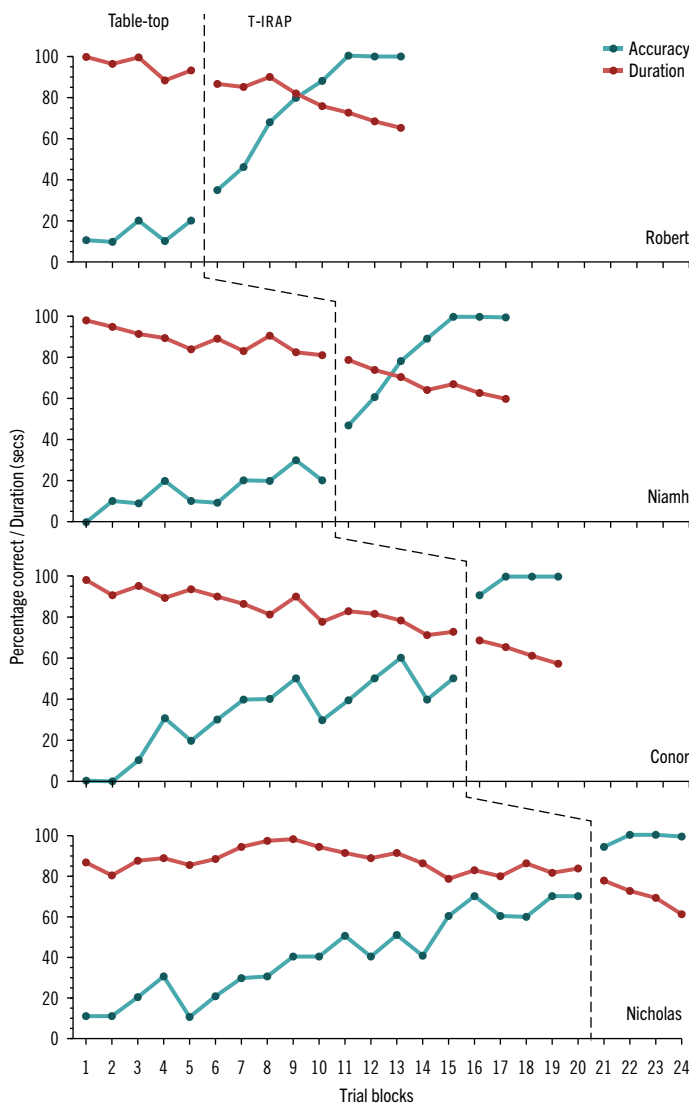

of responding increased. When the T-IRAP teaching program was introduced subsequent to 5 trial-blocks, accuracy data initially dipped marginally and then rapidly returned to criterion levels. Duration data showed that the trend toward faster responding continued throughout 5 T-IRAP trial-blocks.

The SAME/DIFFERENT nonarbitrary relational data for Niamh (Figure 4, second panel) during TT teaching were extended across a total of 10 trial-blocks. Accuracy data were very variable during TT teaching, but the tenth trial-block showed a rise in accuracy. The duration data for SAME/DIFFERENT relational responding for Niamh during TT teaching were also variable and showed no trend. Initially, when the T-IRAP program was commenced with Niamh, the accuracy data dipped slightly but returned rapidly to high levels and remained stable at high levels; there was an immediate and substantial decrease in the level of duration data evident when T-IRAP teaching commenced, indicating speedier responding. Duration data throughout T-IRAP teaching for Niamh continued to descend across a total of 9 T-IRAP trial-blocks (when Niamh's responding met the accuracy criterion level).

The data for SAME/DIFFERENT nonarbitrary relational responding for Conor (Figure 4, third panel) were extended across 15 trial-blocks during TT teaching, and accuracy data throughout showed a steady ascending trend and almost reached criterion levels. Duration data showed a descending trend toward speedier responding during TT teaching. Accurate responding initially decreased slightly when the T-IRAP was introduced with Conor,

Figure 5. Arbitrary SAME/DIFFERENT relational data for four participants in TT and T-IRAP teaching conditions

SAME/DIFFERENT arbitrary relations

The relational data for Robert (Figure 5, top panel) show that across five trial-blocks during the Table-Top procedure Robert began to acquire the SAME/DIFFERENT arbitrary relational responding, and accuracy levels were slowly ascending when the T-IRAP was commenced. Duration data during the TT procedure showed no discernable trend across TT teaching. During T-IRAP trials, accuracy immediately increased and ascended to the criterion level across 6 trial-blocks. Duration data showed a steadily descending trend indicating that speed of responding increased during T-IRAP teaching.

The accuracy data for Niamh (Figure 5, second panel) showed a steadily accelerating trend of accurate responding during the 10 trial-blocks in which the TT procedure was conducted. Duration data were a little variable but with a slightly downward trend during TT teaching. When the T-IRAP program was commenced with Niamh, the ascending trend in accuracy became immediately steeper and data rose to criterion levels across 6 T-IRAP trial-blocks. Duration data throughout T-IRAP teaching showed a steady gradual decrease indicating more rapid responding.

Accuracy data for Conor (Figure 5, third panel) during TT teaching show a steady but somewhat slowly ascending trend across a total of 15 trial-blocks. Duration data during TT teaching are slowly descending indicating Conor is gradually gaining speed in relational responding. When the T-IRAP was introduced with Conor the accuracy data indicated an immediate jump to higher levels and these data remained stable at the criterion level across 4 trial-blocks. There was also quite a pronounced immediate decrease in levels of duration data, and these proceeded in a steady downward trend, indicating speedier responding during T-IRAP teaching.

The accuracy data for Nicholas (Figure 5, bottom panel) showed a very gradual ascent across 20 trial-blocks, and almost rose to criterion level. Duration data showed some little variability across the 20 trial-blocks but overall the trend was flat indicating that speed of responding was not increasing for Nicholas during TT teaching for SAME/DIFFERENT arbitrary relations. During T-IRAP trials Nicholas' accuracy data remained stable at high levels and met the accuracy criterion after 4 trial-blocks. There was an immediate drop evident in the levels of duration data when the T-IRAP was introduced, and these data continued in a steady descending trend indicating that speed of relational responding was increasing.

In summary, results in Study 1 showed that it was possible to adapt the interactive T-IRAP computerised program to teach SAME/DIFFERENT relational frames, both nonarbitrary (physically-based) and arbitrary, with four participants diagnosed with autism. Three children required brief pretraining to establish correspondence between relevant keys on the computer keyboard and onscreen response options. The staggered introduction of the T-IRAP after participants had completed several TT trial-blocks was used to compare relational learning data for four participants in terms of speed and accuracy levels attained during both teaching procedures. The TT method was successful in increasing speed and accuracy, however, results showed more rapid gains in accuracy during T-IRAP teaching for all four participants during SAME/DIFFERENT relational responding, and the effect was apparent with both nonarbitrary and arbitrary coordination relations. The downward trend evident in the TT duration data (indicating increasing speed of responding) continued during T-IRAP teaching for three participants; for the fourth participant (Nicholas) the duration data had remained relatively flat across numerous TT trial-blocks, but began to show a downward trend when T-IRAP teaching was introduced.

Study 2: Comparative more/less relational responding

Study 1 targeted the relational frame of coordination (SAME/DIFFERENT) relations, because these are likely the earliest type of relation learned by children and may be foundational to more complex relational responding such as comparative, OPPOSITIONAL, hierarchical, or analogy relations (Hayes et al., 2001). The aim in Study 2 was to extend the findings that the T-IRAP could be used to teach relational responding, this time targeting comparative (MORE/LESS) relations, first nonarbitrary and then arbitrary, with the four participants diagnosed with autism who participated in Study 1. Study 2 also compared relational learning outcomes

for the four participants across TT teaching and interactive computerised T-IRAP teaching. As in Study 1, an adapted multiple baseline design across participants was used and four participants simultaneously commenced learning MORE/LESS nonarbitrary relations in TT teaching conditions. The T-IRAP program was subsequently introduced stepwise at time intervals across participants, when considerable accuracy and duration data had been collected for TT teaching (after 5, 10, 15, 20 trial blocks). Nonarbitrary comparative relations in Study 2 meant that participants were taught MORE/LESS relations based on the physical size of stimuli; for example, pictorial stimuli were used depicting greater and smaller piles of items. Arbitrary MORE/LESS relations were subsequently taught with four participants, and this involved pictorial stimuli of coins that have been assigned greater/lesser value by the wider social community (see Figure 6). The MORE/LESS relations in this case are arbitrary in that the comparative relation does not correspond to physical dimensions of the stimuli; for example, the 1Euro coin is a smaller coin than the coin which is half the value, the 50 cent coin. As in Study 1, it was not considered necessary to use novel or laboratory type stimuli for teaching arbitrary relations because the current research is applied. It was considered more practically useful for participants to learn arbitrary relations between coins used as local currency.

As before, teaching procedures were compared with regard to participants' relational learning outcomes in terms of recorded accuracy and trial-block duration data for each participant learning comparative nonarbitrary and arbitrary relational responding. If an effect on accuracy or speed of relational responding was found with one participant when the T-IRAP was introduced, replication of effects across participants when the T-IRAP was introduced would provide strong support for the latter as an effective and useful teaching tool that could complement TT teaching procedures, particularly for children who might benefit from extended practice.

An additional aim in Study 2 was to counterbalance position of response option stimuli during the T-IRAP teaching procedures, as this might facilitate participants' in acquiring flexibility in relational skills. (The left/right positions were kept constant in Study 1 to facilitate students in learning initial relational responding skills.) Position of response options was held constant throughout TT teaching during Study 2, however, because it was felt that manual manipulation of position of stimuli, in addition to manual presentation and data recording, might result in an impediment to the speed of participant responding, making a comparison of teaching procedures somewhat futile. The learning criterion for accuracy levels in Study 2 was similar to that in Study 1 and required 100% across three trial-blocks.
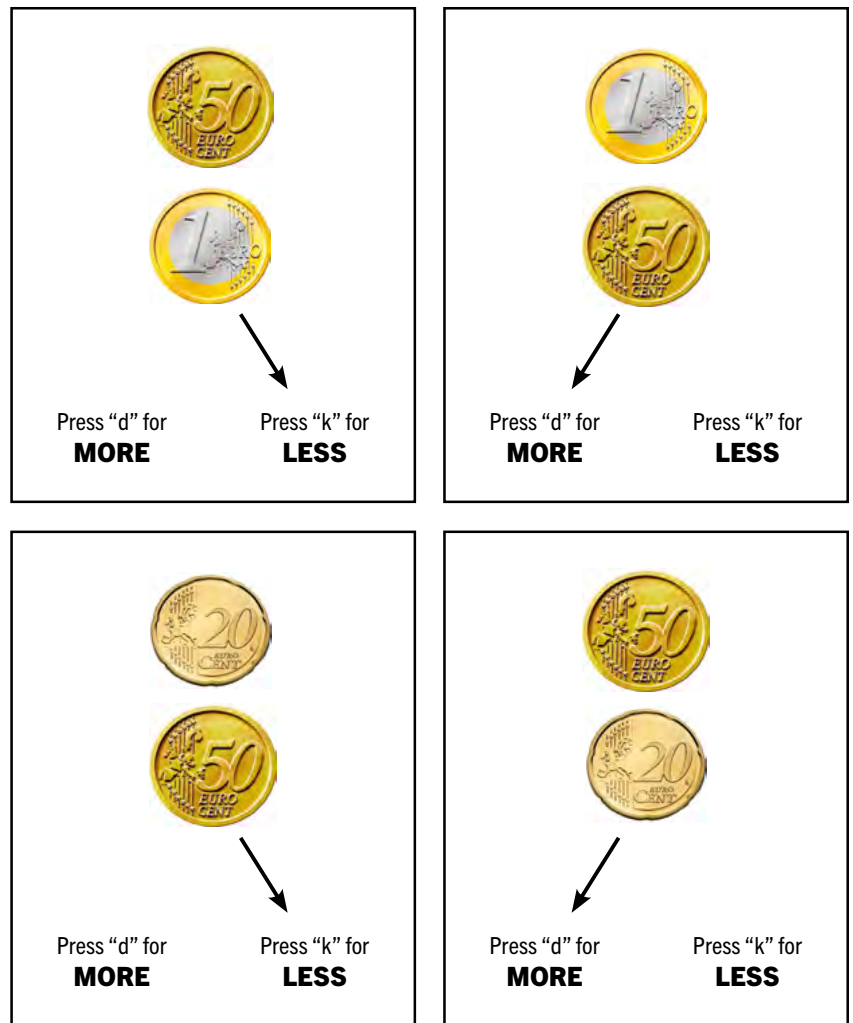

Figure 6. Trial presentation format for MORE/LESS relational responding with arbitrary stimuli

» METHOD

Participants

Participants were the same as in Study 1. The setting was the children's school classroom, also as per Study 1, and there were no additional ethical issues relevant to Study 2.

Apparatus and materials

(See also general details described in Study 1). The T-IRAP program trials for comparative relational responding presented a sample stimulus, a comparison stimulus, and two relational terms (e.g., MORE/LESS). Pictorial stimuli such as images with small and large piles of objects were used for nonarbitrary comparative relational responding trials. Pictorial stimuli for arbitrary relational responding involved images of European coins of differing value, such as a 1 Euro coin, 50cent coin, 20cent coin (Figure 6). All visual stimuli used in the T-IRAP program were sourced via the internet or education software containing catalogues of images (for example *Boardmaker*™). As before, participants were required to select a response option by pressing a key on the computer keyboard (either 'd' or 'k'). The facility to use counterbalancing available in the T-IRAP program was utilised in Study 2, and left/

right positioning of the response options was counterbalanced throughout all T-IRAP trial-blocks. The computerised program automatically recorded correct and incorrect responding in addition to overall duration of trial-blocks in milliseconds (averaged response latencies for each trial-block).

Table-top materials. Two laminated cards 6 cm × 9 cm with response options 'MORE' or 'LESS' printed in black (48 pt. font) on white background. Laminated card 6 cm × 9 cm with pictorial stimuli similar to those used in the T-IRAP (e.g., depicting greater and lesser piles of objects [nonarbitrary relations]; depicting euro coins of differing value [arbitrary relations]).

Procedure

Table-top: MORE/LESS nonarbitrary relations. MORE/LESS nonarbitrary relational teaching was commenced simultaneously with four participants with diagnosed autism, and a multiple baseline design was adapted to compare TT teaching with a T-IRAP interactive computerised program to determine which teaching method produced best relational learning outcomes (in terms of accuracy and speed of responding) across four participants. As in Study 1, the teaching was commenced in TT conditions with all participants, and the T-IRAP was gradually introduced first with Robert after 5 trial-blocks. The T-IRAP was then introduced at staggered time intervals across the other three participants who meanwhile continued extended trial-blocks in TT conditions (completing 10, 15, 20 trial-blocks, respectively) to provide sufficient data to facilitate a comparison of TT and T-IRAP procedures.

Nonarbitrary comparative (MORE/LESS) relations were targeted prior to arbitrary MORE/LESS relations, because the latter are thought to be more complex than the former (Hayes et al., 2001), which are based on the physical size dimensions of stimuli. During the TT procedure for nonarbitrary relations the Investigator presented laminated card stimuli (6cm x 9cm) with images of greater and smaller piles of objects. The pictorial stimuli were presented on the Table-Top in front of each participant in the following format: Sample stimulus on top, comparison below this and two printed response options 'MORE' and 'LESS' below the other stimuli. The comparative response always corresponded to the sample stimulus. For example, if the sample stimulus depicted a greater amount than the comparison, the correct response was to select 'MORE', and if the sample stimulus depicted a lesser amount than the comparison, the correct response was to select 'LESS'. The left/right position of response options remained constant throughout the Table-Top procedure. The Investigator prompted the child to select the correct response during the first few trials (3 or 4) in order to teach the child the correct relations; for example, if the sample stimulus presented a greater amount the Investigator said "Point to More", and gestured toward the card with the printed word MORE, and when the sample stimulus presented a lesser amount the Investigator said "Point to Less", and provided a gestural prompt. The verbal and gestural prompts were faded after initial trials. Positive reinforcement procedures throughout Study 2 were used similarly as described in Study 1. Corrective feedback was delivered for incorrect responding. The Investigator manually recorded speed and accuracy during the TT procedure using paper and pencil, prepared data sheets, and a stopwatch.

T-IRAP: MORE/LESS nonarbitrary relations. Trials in the T-IRAP teaching program for nonarbitrary MORE/LESS relational responding presented pictorial stimuli that were visual images of greater/lesser amounts of objects (similar to those used during TT teaching). The sample stimulus was presented onscreen above a comparison stimulus and the response options, printed words "MORE" and "LESS" were presented underneath the comparison stimulus. Right/left position of response options were counter-balanced across trials during T-IRAP trials and participants selected a response option by pressing either 'd' or 'k' on the keyboard as appropriate. As in the Table-top procedure, correct selection of the response option was related to the sample stimulus, so that if the sample stimulus presented depicted a greater amount of objects than the comparison stimulus presented, the correct response was to select 'MORE' by pressing the appropriate key (either 'd' or 'k'). Conversely if the sample stimulus presented a lesser amount of objects than the comparison stimulus the correct response was to select 'LESS' by pressing the correct key (either 'd' or 'k'). As in Study 1, the T-IRAP provided corrective feedback in the form of a red '×' for selecting an incorrect response option and trials did not proceed until the participant selected the correct response option.

Table-top: MORE/LESS arbitrary relations. When participants had completed the T-IRAP program for nonarbitrary MORE/LESS relational responding, they proceeded to learn arbitrary MORE/LESS relational responding. A multiple baseline design was again implemented across four children during arbitrary relational training procedures, to compare learning outcomes in TT and T-IRAP teaching conditions. The TT teaching commenced first with four participants, and during trials the Investigator presented laminated cards, 6cm by 9cm, with pictorial and printed stimuli (Figure 6). If a 1 Euro coin was presented as a sample stimulus with a 50 cent coin as comparison stimulus, the correct response was to select 'MORE' because the 1 Euro coin has greater value than the 50 cent coin, although the 50 cent coin is a physically larger coin. Conversely if a 50 cent coin was presented as sample stimulus with a 1 Euro coin presented as comparison, the correct response was to select 'LESS'. Students were thus learning to select the options 'MORE' or 'LESS' based on the value arbitrarily assigned to the stimuli by the social community, and not based on physical size.

During TT trials, stimuli were presented in a similar format to that in the nonarbitrary procedure with the sample stimulus on top, comparison below this, and two response options which were printed words "MORE" and "LESS" below the comparison stimulus. Left/right position of the response options were not counterbalanced across TT trials. Initially, the Investigator prompted the child to select the correct response option, and after three or four trials the prompts were faded so that participant responding became independent. Reinforcement contingencies for correct responding were delivered similarly as before. Throughout the TT teaching procedure the Investigator manually recorded speed and accuracy of relational responding using paper and pencil and a stopwatch. When data were collected across 5 trial-blocks for all four participants, a T-IRAP teaching program was introduced with one participant. The three other participants continued in

TT teaching conditions and the T-IRAP was introduced across these participants in a staggered fashion as before (e.g., after 10, 15, and 20 trial blocks) when sufficient data were collected to provide a graphic impression of relational learning (speed and accuracy) in TT conditions.

T-IRAP: MORE/LESS arbitrary relations. The T-IRAP interactive program for teaching arbitrary MORE/LESS relations operated similarly to the T-IRAP for nonarbitrary MORE/LESS relations, except that the pictorial stimuli presented were different and the physical size of the stimuli was not relevant. Reinforcement procedures were arranged for individual participants as described previously.

» RESULTS AND DISCUSSION
MORE/LESS nonarbitrary relations

The data for nonarbitrary comparative relational responding during TT and T-IRAP procedures with four participants are represented in Figure 7. Accuracy data are represented using an unbroken line between data points, and duration data are represented using a broken line between data points. Accuracy data points represent percentage correct scores for each trial-block (*y* axis). Duration data are depicted by using a second value axis (right of graph), and duration data points represent the time taken in seconds to complete each trial-block.

The accuracy data for Robert (Figure 7, top panel) during the TT procedure for MORE/LESS nonarbitrary relational responding initially showed a relatively low level (40% correct) and showed an ascending trend with some variability across 5 trial-blocks. The duration data also showed a slightly ascending trend across five trial-blocks for Robert during the TT teaching, which was not a positive trend and indicated that speed of responding actually decreased somewhat as teaching progressed. When the T-IRAP was introduced with Robert after 5 TT trial-blocks, the accuracy data ascended in a more stable slope than previously up to criterion levels after 11 T-IRAP trial-blocks. The T-IRAP trial-block duration data (based on recorded response latencies averaged across each trial-block) showed an immediate drop in level, and proceeded in a gradually descending trend across T-IRAP trial blocks, indicating increased speed of responding during T-IRAP teaching.

The accuracy data for Niamh (Figure 7, second panel) during TT teaching for nonarbitrary comparative relational responding were initially quite low (20% correct) and then showed an ascending trend, but with quite some variability. The duration data for Niamh during TT teaching showed no discernable trend, therefore speed of responding failed to increase across 10 trial-blocks. When the T-IRAP teaching procedure for nonarbitrary comparative relational responding was introduced for Niamh, the data showed a steady increase of accurate responding with very little variability and the trend proceeded to high stable levels of accurate responding. Niamh met the accuracy learning criterion after 16 T-IRAP trial-blocks.

The accuracy data for Conor (Figure 7, third panel) during comparative nonarbitrary relational responding in TT teaching conditions commenced at low levels (10% correct) and showed a fairly steady ascent across 15 trial-blocks. The data representing speed of responding (duration data) for Conor during TT teaching remained relatively flat indicating that speed of responding
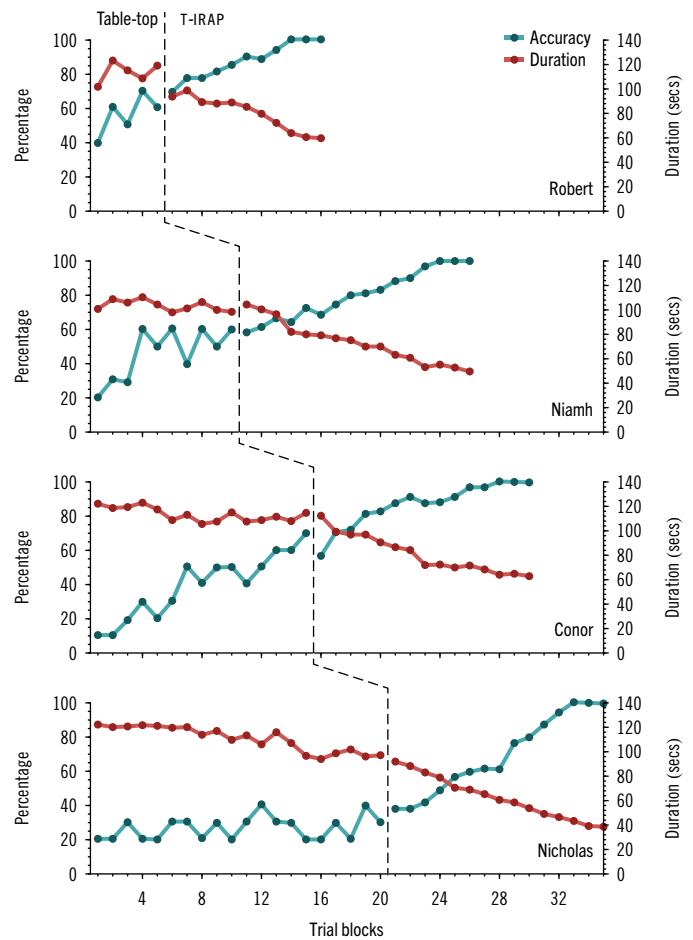

Figure 7. Nonarbitrary MORE/LESS relational data for four participants in TT and T-IRAP teaching conditions

failed to increase across 15 trial-blocks. From the point of T-IRAP introduction, Conor's accuracy data for MORE/LESS responding showed a steady ascent with little variability up to high stable levels of accurate responding, and met criterion after 15 T-IRAP trial-blocks. The duration data for T-IRAP teaching steadily decreased to lower levels indicating faster relational responding during T-IRAP teaching compared to TT teaching.

The accuracy data for MORE/LESS nonarbitrary relational responding during TT teaching for Nicholas (Figure 7, bottom panel) showed low somewhat variable levels (approximately 20–40% correct) with little or no trend evident throughout a total of 20 TT trial-blocks. Duration data for Nicholas during TT teaching were initially flat across trial-blocks and then showed a gradually descending trend, indicating some gains in speed of relational responding. After the extended amount of TT trial-blocks (20), the T-IRAP for teaching comparative nonarbitrary relational responding was introduced with Nicholas. The accuracy data during T-IRAP teaching showed a steady ascent to high stable (criterion) levels after 15 trial-blocks. The duration data for Nicholas during T-IRAP teaching showed a more steady and steeper descent across 15 T-IRAP trial-blocks compared to duration data across 20 trial-blocks in the TT teaching condition, thus indicating Nicholas' MORE/LESS relational responding was gaining speed during the T-IRAP program.
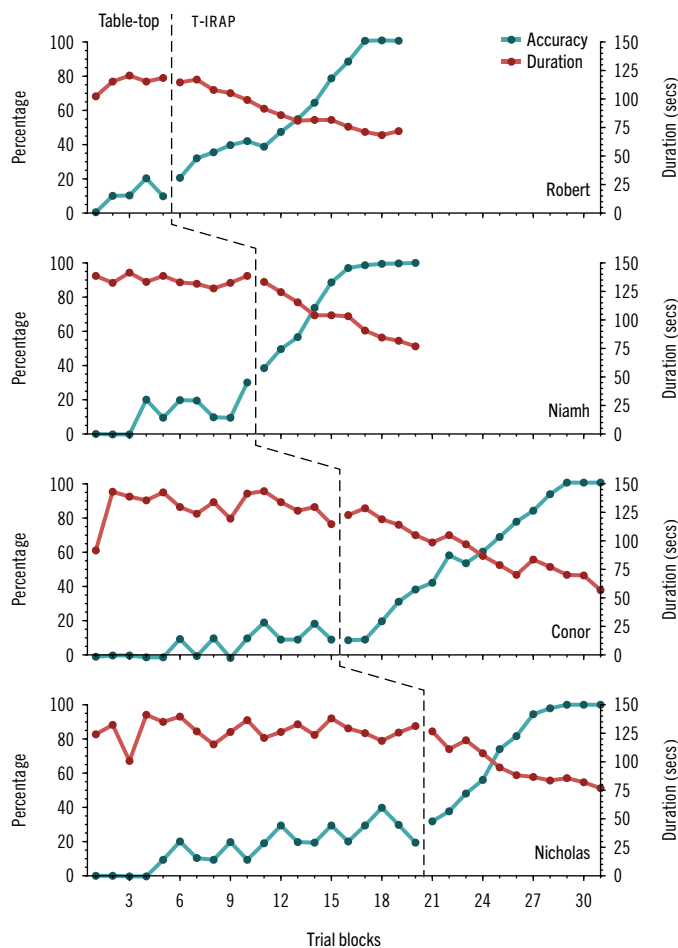
Figure 8. Arbitrary MORE/LESS relational data for four participants in TT and T-IRAP teaching conditions

Briefly, the data for four participants indicated that speed of MORE/LESS nonarbitrary relational responding increased more rapidly and steadily during T-IRAP teaching compared to Table-Top teaching. Interestingly, the accuracy levels of data for comparative relational responding for all participants were nevertheless maintained, and even showed a steeper slope (increased accuracy) during T-IRAP teaching compared to TT, indicating that accuracy of participants' relational responding was by no means compromised by the speedier responding evident in the T-IRAP procedure.

MORE/LESS arbitrary relations

The data for four participants learning arbitrary comparative relational responding using TT and T-IRAP procedures are represented in Figure 8. The accuracy data (unbroken line) for Robert (top panel) during TT trial-blocks showed low levels of accurate responding, with some variability. Robert's duration data for TT teaching ascended slightly, indicating that relational responding was becoming slower across 5 trial-blocks. During the T-IRAP procedure, the accuracy data for Robert showed a steadily trend that reached criterion levels. T-IRAP duration data for Robert showed a gradually descending trend indicating that relational responding had increased in speed.

The accuracy data for Niamh (Figure 8, second panel) during MORE/LESS arbitrary relational responding showed very low levels with some variability across a total of 10 trial-blocks of the TT procedure. Duration data remained flat at high levels, indicating that speed of responding failed to increase across TT teaching procedures. When the T-IRAP procedure was introduced with Niamh after 10 TT trial-blocks, there was a rapid increase in accurate responding that rose to criterion levels. Duration data for Niamh showed a steadily decreasing trend during T-IRAP for arbitrary comparative relations, indicating that speed of responding was increased across trial-blocks.

The accuracy data for Conor (Figure 8, third panel) during TT teaching remained at zero levels across the first five trial-blocks of arbitrary MORE/LESS relational responding, and remained at very low levels throughout some 15 trial-blocks. Duration data for Conor indicate that speed of responding failed to increase across TT procedures. When the T-IRAP procedure was introduced accurate responding initially remained low across trial-blocks 16 and 17, and then there was a steady increase in accuracy up to the criterion performance level. Duration data for Conor during T-IRAP teaching overall showed a steadily decreasing trend, indicating that speed of relational responding was increasing across trial-blocks.

Nicholas' data (Figure 8, bottom panel) for arbitrary MORE/LESS relational responding during TT teaching showed the first four trial-blocks with zero correct and although some correct responding was shown across the next TT trial-blocks, the data remained at low levels with some variable responding across 20 trial-blocks. Duration data for Nicholas were high and variable with no discernible trend during TT teaching, indicating there were no gains in speed of responding throughout these numerous trial-blocks. When the T-IRAP for arbitrary comparative relational responding was introduced with Nicholas subsequent to 20 TT trial-blocks, the accuracy data ascended steadily to criterion levels. Duration data for Nicholas during the MORE/LESS arbitrary relational trials showed a descending trend, indicating that speed of responding was increased across these eleven T-IRAP trial blocks.

In summary, results in Study 2 showed that the T-IRAP could be used to teach comparative relational responding with four children diagnosed with autism. Findings showed that participants responded with greater accuracy and speed during T-IRAP teaching compared to TT teaching, and this effect was more pronounced during the more complex arbitrary comparative relational responding compared to relational responding with nonarbitrary stimuli (based on physical size).

The results in Study 2 supported and extended the findings in Study 1 that the T-IRAP was a useful teaching tool for establishing rapid and accurate relational responding with four children with diagnosed autism.

Study 3: Oppositional relational skills

The aim in Study 3 was to adapt the T-IRAP to teach Oppositional relational responding and to test for derived relational responding, which would further expand the complexity of relational responding skills for four children with diagnosed autism who had previously learned coordination relational responding

(SAME/DIFFERENT; Study 1), and comparative relational responding (MORE/LESS; Study 2). As in the previous studies in the current series, the T-IRAP and TT teaching procedures were compared regarding speed and accuracy in relational learning outcomes for the four participants; however, in Study 3 the comparison was made regarding nonarbitrary relations only. Oppositional relations may be more complex than, for example, SAME/DIFFERENT relations (Hayes et al., 2001), however, it is not currently clear that OPPOSITIONAL relations are typically learned by children subsequent to comparative relations; OPPOSITIONAL relations may be more complex and difficult to learn than comparative relations, or may be similarly difficult as comparative relations, but further research is needed to clarify these matters.

An adapted multiple-baseline design across participants was employed, and all participants were exposed firstly and simultaneously to TT teaching for nonarbitrary OPPOSITIONAL relational responding with the T-IRAP introduced at staggered time intervals (after 5 trial-blocks, 10 trial-blocks, 15 trial-blocks, and 20 trial-blocks) across the four participants. As in previous studies, teaching commenced with nonarbitrary relational responding because it seems likely that relations based on physical dimensions of stimuli are more readily learned than relations between stimuli that are assigned by the context and arbitrary in the sense that they are not physically-based. It may be that nonarbitrary Oppositional relations are foundational to learning arbitrary Oppositional relations skills, although this is not currently clear. Nonarbitrary SAME/OPPOSITE relations in the current teaching context involved, for example, night as opposite to day (Figure 9); full container

Figure 9. Trial presentation format for oppositional relational responding with nonarbitrary stimuli

as opposite to empty container; and so on. Arbitrary Oppositional relations were taught subsequent to nonarbitrary Oppositional relations, with the T-IRAP only. Due to time constraints, the teaching for arbitrary OPPOSITIONAL relations did not involve any TT teaching or any comparison between TT and T-IRAP teaching procedures. Subsequent to the T-IRAP for arbitrary Oppositional relations, four participants were exposed to two tests for derived opposition relations using the T-IRAP.

The test for derived relational responding was an additional aspect of Study 3 that extended the prior two studies in relational responding with four participants with autism. As outlined in the general introductory section, derived relational responding (DRR) is an advanced type of relational responding that emerges untaught for typically-developing and language-able humans when a number of relations have been learned. For example, if humans learn that A is opposite to B, and B is opposite to C, they will typically derive A is same as C without being explicitly taught. This type of advanced arbitrary relational responding is
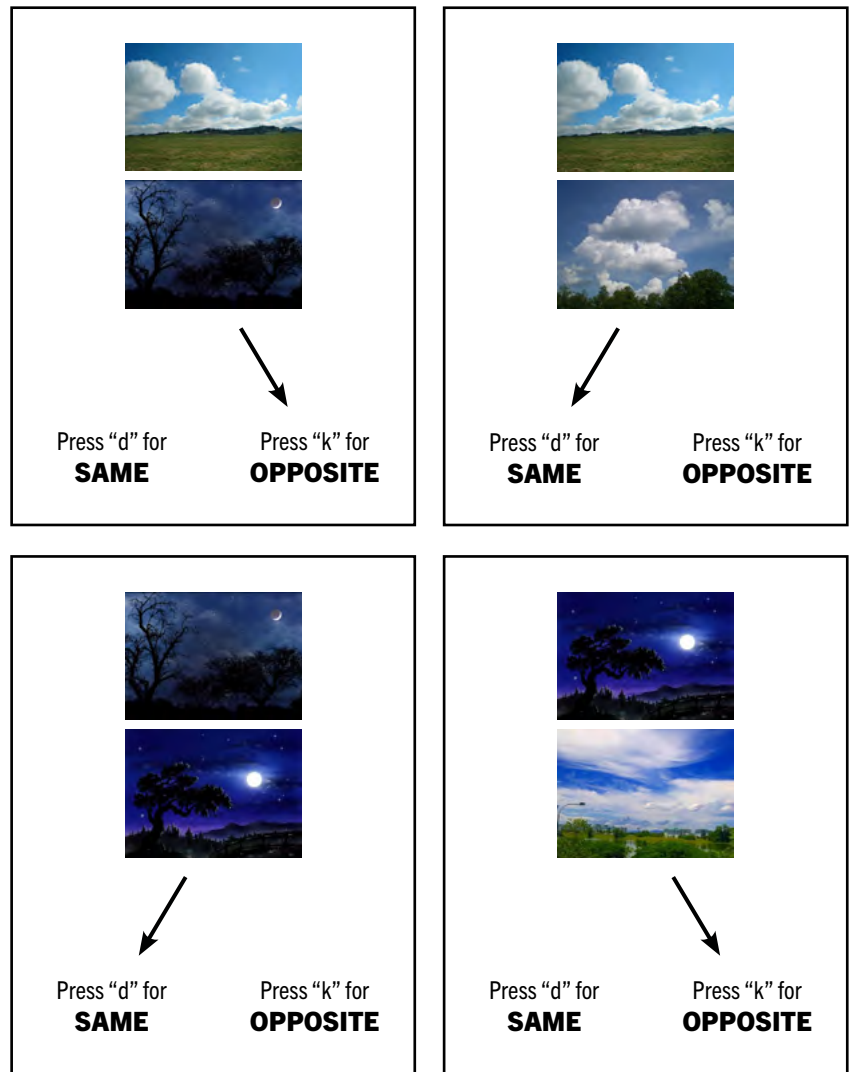
thought to be fundamental to development of complex cognitive repertoires and it may be important therefore to establish DRR skills in children with autism. Thus, in Study 3, arbitrary SAME/OPPOSITION relational responding was taught as follows based on a published protocol (Rehfeldt & Barnes-Holmes, 2009): X is small and is the opposite of Z, and Z is the same as P. Is Z big or small, and is P big or small? The T-IRAP was adapted to answer this question using four phases (see Figure 10). Phase A taught the relations X/SMALL/SAME; X/BIG/OPPOSITE. Phase B taught Z/P/SAME; Z/X/OPPOSITE. Phase C probed for derived relational responding Z/BIG/SAME? Phase D probed for derived opposition relations P/SMALL/SAME?

» METHOD

Participants

Participants were the same as in Studies 1 and 2. The setting was the children's school classroom, also as per Studies 1 and 2, and there were no additional ethical issues relevant to Study 3.
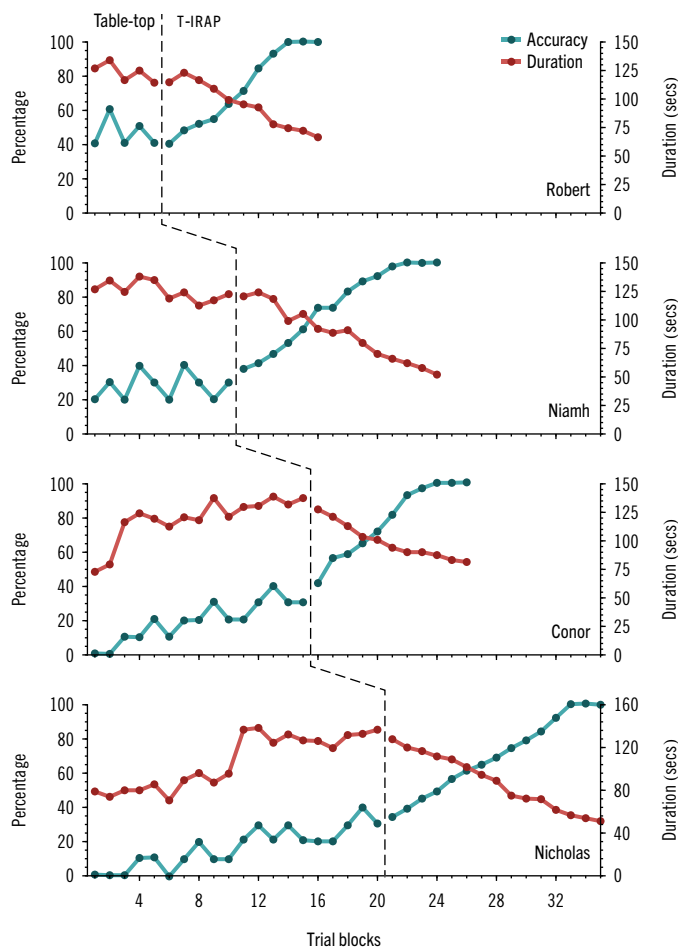
Figure 10. Nonarbitrary oppositional relational data for four participants in TT and T-IRAP teaching conditions

Apparatus and materials

T-IRAP. See also general details provided in Study 1 regarding T-IRAP procedure. The T-IRAP program was readily adapted to present trials with pictorial stimuli with SAME/OPPOSITE physical dimensions (e.g., Day and Night scenes; empty and full containers; Figure 9) when teaching nonarbitrary oppositional relations. Arbitrary stimuli (printed letters and words) were used subsequently in teaching arbitrary oppositional relations and during the test for derived oppositional relations. These stimuli were presented with the onscreen response options which were the printed words SAME and OPPOSITE.

Table-top. Laminated card were used with pictorial stimuli (6 cm × 9 cm) similar to that presented during T-IRAP trials for nonarbitrary OPPOSITIONAL relations, and with the printed words SAME and OPPOSITE. (Arbitrary opposition relations were not taught using TT procedures.)

Procedure

Table-top: OPPOSITIONAL nonarbitrary relations. An adaptation of the multiple baseline design across four participants was used to compare a TT teaching procedure with a T-IRAP teaching procedure to determine if the introduction of the T-IRAP program impacted relational learning in terms of changes in accuracy

(percentage correct) and or speed of responding (measuring trial-block duration). Trials during TT teaching involved the Investigator presenting nonarbitrary pictorial stimuli positioned as follows: Sample stimulus positioned above comparison stimulus, and two response options (printed words SAME and OPPOSITE) below both of the pictorial stimuli (Figure 9). Response options were not counterbalanced during the TT procedure as it was felt that this might unduly impede speedy presentation as the Investigator would have to manually manipulate and keep track of the stimuli during each trial. During the first 3 or 4 trials the Investigator instructed or prompted (gestured) the child to select the correct response (e.g., select OPPOSITE if the pictorial stimuli presented were scenes of Day and Night, select SAME if both stimuli presented were non-identical Day scenes). In the former case, the verbal prompt was "Point to opposite", and in the latter case the Investigator said "Point to same". Prompts were rapidly faded and participants responded independently.

Positive reinforcement procedures were conducted similar as in previous studies in the current series, and corrective feedback was delivered contingent on incorrect responding. During TT teaching, the Investigator manually recorded speed and accuracy using paper and pencil, prepared data sheets, and a stopwatch.

The TT procedure for nonarbitrary OPPOSITIONAL relations was commenced simultaneously with all four participants. Subsequent to all four participants having completed 5 trial-blocks (10 trials in each block) of TT teaching, a T-IRAP teaching procedure for teaching nonarbitrary OPPOSITIONAL relations was introduced with one participant. The three other participants continued across extended TT teaching conditions, and the T-IRAP was introduced with the remaining participants at staggered time intervals after 10, 15, and 20 trial-blocks.

T-IRAP: OPPOSITIONAL nonarbitrary relations. The T-IRAP program for nonarbitrary SAME/OPPOSITE relational responding presented pictorial stimuli with images with similar or opposite dimensions (e.g., two different scenes of Night, or one scene of Day and one of Night, respectively). The onscreen stimulus presentation format was similar to that used in TT teaching: Sample stimulus presented above a comparison stimulus and the response options, printed words SAME and DIFFERENT presented underneath the comparison stimulus. Participants selected a response option by pressing either 'd' or 'k' on the keyboard as appropriate, and the T-IRAP option was selected to counterbalance automatically the right/left position of response options across trials. The T-IRAP trials for OPPOSITIONAL relations again provided corrective feedback for incorrect responses in the form of a red '×' and failed to proceed until the participant made the correct response. The next trial presentation proceeded immediately when the participant made a correct response. When participants had successfully completed the T-IRAP program to teach nonarbitrary OPPOSITIONAL relations, they were then exposed to a T-IRAP program to teach arbitrary OPPOSITIONAL relations, followed by two brief tests probing for derived oppositional relations.

T-IRAP: OPPOSITIONAL arbitrary relations and derived relational responding. The procedure was based on a protocol outlined in the recently published text-book for DRR applications for learners with autism and other developmental disabilities

(Rehfeldt & Barnes-Holmes, 2009). Teaching and testing OPPOSITIONAL relational responding with arbitrary stimuli was conducted as follows in brief outline: Participants were taught that X is small and is the opposite of Z, and Z is the same as P. The tests that followed probed, is Z big or small, and is P big or small? The T-IRAP was adapted accordingly to present four Phases as follows (Figure 10).

Phase A (taught relations). Phase A: Trials presented, for example, the letter X as a sample stimulus above a printed word, either 'small' or 'big', with response options SAME and OPPOSITE below. The program provided reinforcement (trials proceed) and corrective feedback (red × and trials cannot proceed until the participant selects the designated correct response) for selecting SAME when trials presented X and 'small', and for selecting OPPOSITE when trials presented X and 'big'. The Investigator provided additional positive reinforcement contingent on participants' correct responding (e.g., token economy on a schedule tailored to the learning needs of the individual participant). Trial presentations and counterbalancing of response options across phases A and B were operated similarly as for T-IRAP for nonarbitrary SAME/OPPOSITE relations, and when relational responding met a preset accuracy criterion (100% × 3 trial-blocks) during the T-IRAP training trials, the next phase was commenced with that participant.

Phase B (taught relations). Procedures were operated similarly as in Phase A, except that on this occasion trials presented Z above either X or P with the response options SAME/OPPOSITE below; reinforcement was delivered for selecting SAME when trials presented Z and P, and for selecting OPPOSITE when trials presented Z and X.

Phase C (test 1). Test trials presented Z and either the word 'big' or 'small' above response options SAME/OPPOSITE. No programmed contingencies were arranged and test trials proceeded unimpeded regardless whether participant responding was correct or incorrect. Children were told at the beginning of the test: "This is a test so I'm not going to say if you picked the right word, but you will get tokens when it is finished for working nicely. Do your best to pick the right word nice and quickly". If participants selected the SAME response option during trials presenting Z and 'big', and selected the DIFFERENT response option when trials presented Z with 'small', trials were recorded as correct. Trial-blocks during testing had 10 trials, and the criterion for demonstrating derived relational responding was preset at 100% × 3 trial-blocks.

Phase D (test 2). Test procedures were similar to Phase C except that on this occasion trials presented P above either 'big' or 'small' with the response options SAME/OPPOSITE. If participants selected the SAME response option during trials presenting P and 'big', and selected the DIFFERENT response option when trials presented P with 'small', trials were deemed correct.
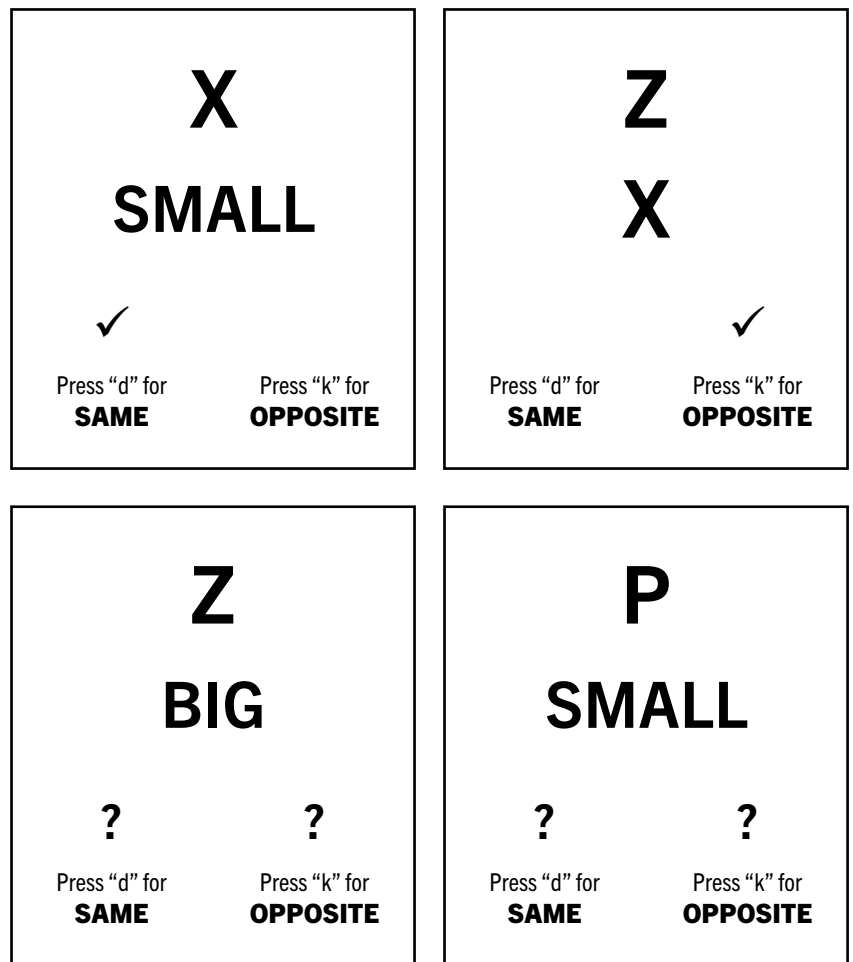

Figure 11. Trial presentation format for SAME/DIFFERENT relational responding with arbitrary stimuli.

» RESULTS

Oppositional relations (nonarbitrary)

The data for four participants with diagnosed autism who were taught OPPOSITIONAL relational responding in TT and T-IRAP procedures are represented in Figure 11. Accuracy data are represented using an unbroken line between data points, and duration data are represented using a broken line between data points. Accuracy data points represent percentage correct scores for each trial-block (y axis). Duration data are depicted by using a second value axis (right of graph), and duration data points represent the time taken in seconds to complete each trial-block.

The accuracy data for Robert (Figure 11, top panel) throughout TT teaching showed some variability and no trend was evident, while the duration data were also a little variable but appeared overall to be descending across 5 trial-blocks. When the T-IRAP teaching program for nonarbitrary Oppositional relations was introduced at this point Robert's accuracy data for relational responding showed a very steady upward trend to criterion levels (100% across 3 trial-blocks). Duration data during T-IRAP teaching showed a descending trend indicating that responding was speedier than in TT teaching, even though accuracy increased and was maintained at high levels.
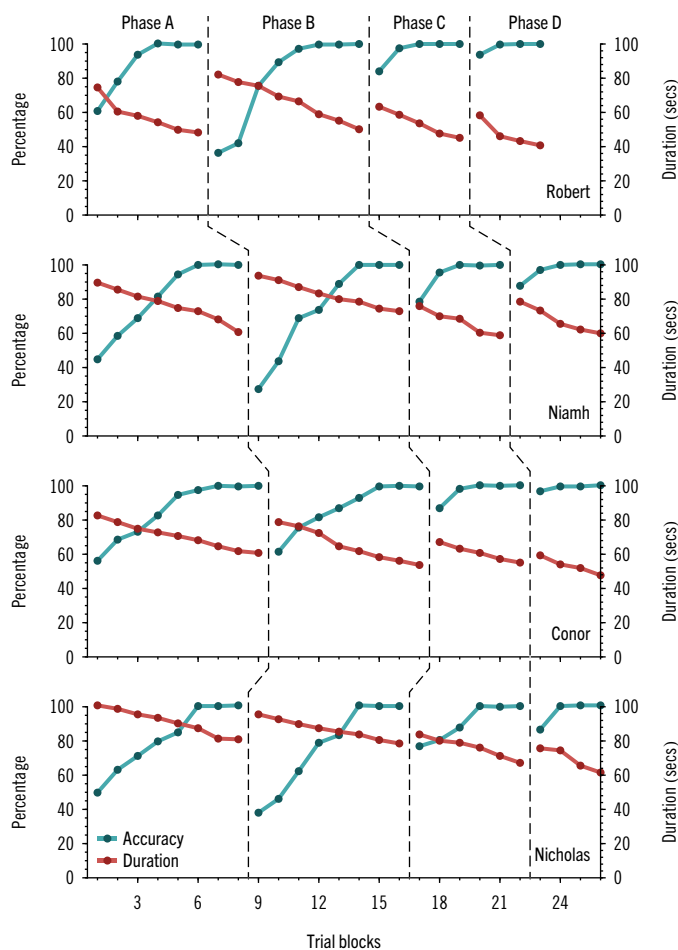
Figure 12. Arbitrary oppositional relational data for four participants (phases A and B). Test data for derived opposition relations (phases C and D)

The data for Niamh (Figure 11, second panel) for nonarbitrary OPPOSITIONAL relations were extended across 10 trial-blocks in the TT teaching condition, and indicated low and variable levels of accurate responding. Duration data for Niamh remained at high slightly variable levels with no trend overall, indicating that speed of responding did not increase across 10 trial-blocks of TT teaching. Accuracy levels for oppositional relational responding steadily increased when the T-IRAP teaching program was introduced for Niamh after 10 TT trial-blocks, and the accuracy criterion was achieved across 14 T-IRAP trial-blocks. Duration data showed a decreasing trend across T-IRAP teaching, indicating that speed or responding increased.

Conor's data (Figure 11, third panel) for nonarbitrary OPPOSITIONAL relational responding remained at zero levels during 2 initial TT trial-blocks and remained somewhat low and variable levels across a total of 15 TT trial-blocks. Duration data during TT showed a surprising ascending trend, indicating that speed was decreasing across these extended TT trial-blocks. When the T-IRAP teaching program for nonarbitrary oppositional relations was commenced with Conor, accuracy levels of relational responding steadily ascended to the criterion levels after a total of 11 T-IRAP trial-blocks. Interestingly, the duration data showed a descending trend throughout the T-IRAP teaching procedure indicating that speed of relational responding increased during this phase even while accuracy also increased.

The accuracy data for nonarbitrary OPPOSITIONAL relational responding for the fourth participant, Nicholas (Figure 11, bottom panel) during TT teaching showed zero correct across 3 initial trial-blocks, and data remained at low levels throughout a total of 20 TT trial-blocks, while the duration data showed an ascending trend, indicating speed of relational responding was actually decreasing across 20 trial-blocks. The T-IRAP procedure for nonarbitrary relational responding was introduced for Nicholas at this point, and accuracy data immediately stabilised and gradually but steadily ascended to the criterion levels across 15 T-IRAP trial-blocks. Duration data in the T-IRAP teaching condition showed a steadily descending trend indicating that speed of relational responding increased.

T-IRAP: oppositional relations (arbitrary)

Phase A. The data for four participants are presented in Figure 12. Accuracy levels for arbitrary oppositional relational responding for Robert (top panel) ascended steadily to the criterion levels across 6 trial-blocks, while duration data descended simultaneously, indicating that speed of responding increased. Accuracy data for Niamh (second panel) showed a fairly steady ascent to criterion levels across 8 trial-blocks and Niamh's duration data showed a descending trend indicating that speed of responding increased. The data for Conor (third panel) during Phase A showed a steady ascending trend to the criterion performance level, while simultaneously the duration data showed a descending trend indicating increased speed across 9 trial-blocks. The data for Nicholas (bottom panel) in this phase showed that accuracy steadily increased and the criterion performance was achieved across 8 trial-blocks. Duration data for Nicholas showed a slowly decreasing trend toward speedier responding.

Phase B. Robert's accuracy data (Figure 12, top panel) began at a relatively low level but showed a steep slope toward the criterion levels across 8 trial-blocks. Speed of responding increased across these trial-blocks as indicated by a descending trend in the duration data. Niamh's accuracy data (second panel) during Phase B showed a rapidly ascending trend to criterion levels across 8 trial-blocks, and duration data showed a descending trend. A similar pattern showed in Conor's data (third panel) during this phase, in that accuracy increased across 8 trial-blocks while a descending trend in duration data indicated increased speed in relational responding. Nicholas' accuracy data (bottom panel) showed a steady ascending trend to criterion, and the duration data showed a gradual descent as speed of responding increased.

Phases C and D (tests for derived oppositional relations). The test data for four participants during Phases C and D are presented in Figure 12. All four participants commenced with high levels of accurate responding and achieved a criterion performance during phases C and D. Four participants were thus deemed to have demonstrated derived opposition relations across both tests.

» GENERAL DISCUSSION

A series of three studies showed that it was possible to adapt the existing freely available IRAP so that it could be used as an interactive computerised teaching tool, renamed T-IRAP, to teach fluent relational responding skills with four children diagnosed with au-

tism. The relational frames targeted were SAME/DIFFERENT (Study 1), MORE/LESS (Study 2), SAME/OPPOSITE and derived relational responding (Study 3). All relational frames were taught with nonarbitrary stimuli before targeting the same relational frames with more abstract arbitrary stimuli to build complexity in relational responding repertoires, and all four participants succeeded in learning all targeted relational frames with nonarbitrary and arbitrary stimuli. Levels of accuracy and speed of responding (interpreted via trial-block duration data) for all participants were compared in TT and T-IRAP teaching conditions, and results showed that levels of accuracy and speed of responding were increased for all participants during all T-IRAP teaching in comparison to TT teaching. These effects were found with four participants across all three studies for both nonarbitrary and arbitrary SAME/DIFFERENT, MORE/LESS and OPPOSITIONAL relations. The T-IRAP was also used to probe for derived relational responding (Study 3) and four participants demonstrated derived opposition relations. Specifically, during tests with no programmed reinforcement the four participants demonstrated opposition relations that emerged without having been taught or directly reinforced; they derived SAME/OPPOSITE functions for the test stimuli in accord with previously taught opposition relations (Hayes et al., 2001).

As stated in the general introductory section, to suggest that the T-IRAP should replace TT teaching for relational responding would not be desirable or ecologically valid, however, the current findings suggest that the T-IRAP may be a useful additional teaching tool that a child could use for practice without the necessity of one-on-one teaching. Initially there were minor difficulties for three out of four participants with autism using the T-IRAP (Study 1), but relatively minimal training was sufficient to teach the prerequisite correspondence between response options onscreen and the relevant keys on the keyboard, and participants could then successfully engage with the T-IRAP program. A fourth participant with autism readily engaged with the T-IRAP and needed no pretraining. Future research may be necessary to determine if other children with lower levels of adaptive functioning need more extensive pretraining to learn to use the T-IRAP program. For some children, it may be more efficient to teach correspondence between the response options and the relevant keys on the keyboard via a material prompt stretching from the onscreen response options to the relevant keys on the keyboard (pilot data indicated that this may be effective). In any event, time spent in pretraining need not be seen as a great disadvantage, because currently the use of computer technology is so widespread in education that the acquisition of computer literacy skills may be seen as useful. In addition, developing proficiency in learning via computer can facilitate more independence for students in need of practice either for learning or maintaining relational responding skills. Study 1 thus successfully adapted the T-IRAP to target nonarbitrary and arbitrary coordination relations (SAME/DIFFERENT) with four children with autism, and a comparison of learning outcomes with TT and T-IRAP teaching showed that participants' relational responding was more accurate and rapid with T-IRAP. The effects were demonstrated by the use of staggered introduction of the T-IRAP across participants after extended time intervals and numerous TT trial-blocks (an adaptation of a multiple baseline design

across participants). Visual analyses of the resulting graphs show that accuracy increased and duration data decreased indicating greater speed of responding on each occasion that the T-IRAP was introduced, and this was replicated across participants.

Study 2 extended the research conducted in Study 1, and adapted the T-IRAP to successfully establish nonarbitrary and arbitrary comparative relational skills (MORE/LESS), which are thought to be more complex than coordination relations (Hayes et al., 2001), with four participants with autism. In addition, Study 2 counter-balanced the left/right position of the response options during T-IRAP trials to facilitate teaching more fluent relational responding, whereas left/right position of response options was held constant during all procedures in Study 1 to help students learn basic relational responding skills. Counter-balancing of left/right position was not conducted during TT procedures in any of the studies in the current series because it was felt that this would be quite an impediment to speedy responding due to time spent by the Instructor in manually arranging the stimuli during each trial, as well as keeping track and manually recording correct and incorrect responding. It seems likely therefore that had the TT procedures in studies 2 and 3 incorporated counterbalancing of left/right position of response options, the difference in speed of responding between TT and T-IRAP may have been even greater than that observed. A further point of interest regarding the comparison data for teaching procedures in Study 2 was that in general there appeared to be greater differential effects between resulting learning outcomes from the two programs compared to that found in Study 1. Specifically, visual analyses of graphs suggested that the positive differential effects on speed and accuracy for T-IRAP versus TT appeared more pronounced for all participants in Study 2. The reason for this remains unclear at this point in time, but it might be speculated that the children were becoming more generally proficient at using the T-IRAP as they continued to engage with the program, whereas proficiency levels of responding in TT teaching had perhaps already reached optimal levels prior to the current research due to participants' extensive experience with the latter teaching format at school. Findings in Study 2 were consistent with those in Study 1, in that across teaching procedures for both nonarbitrary and arbitrary relational responding across participants, the data at no point showed deterioration in either speed or accuracy in relational responding when T-IRAP was introduced. Furthermore, increased accuracy in relational responding was maintained across T-IRAP trial-blocks even as the speed of responding was increased for all four participants. In contrast, speed of responding failed to increase during TT teaching even while accuracy levels remained low across extensive numbers of trial-blocks with three participants.

Results in Study 3 replicated findings in studies 1 and 2 in that the T-IRAP was readily adapted to teach oppositional relations with four participants diagnosed with autism, and a comparison of relational learning data for four participants in TT versus T-IRAP teaching conditions showed that speed and accuracy of relational responding were increased during T-IRAP teaching for nonarbitrary oppositional relational responding. Study 3 extended the previous studies in targeting the relational frames of opposition (nonarbitrary and arbitrary) with four participants with autism, and an

additional extension was that subsequent to a T-IRAP teaching procedure for teaching arbitrary opposition relations, participants demonstrated derived opposition relations using the T-IRAP. Due to time constraints, TT and the T-IRAP were compared only when teaching nonarbitrary opposition relations (no comparison was made when teaching arbitrary oppositional relations). Graphs for all four participants showed quite some disparity between levels of speed and accuracy of relational responding recorded during TT and T-IRAP teaching. Specifically, the T-IRAP data for nonarbitrary opposition relations showed markedly greater speed and accuracy levels for four participants when compared to the TT data.

Four participants with autism learned arbitrary opposition relations via the T-IRAP, and speed and accuracy data were roughly comparable with participant data during the T-IRAP for nonarbitrary opposition relations. Importantly, Study 3 showed that four participants demonstrated derived opposition relations with arbitrary stimuli when tested via a T-IRAP procedure. As stated in the general introductory section, derived relational responding is thought to underlie generativity of the kind typically shown in human language; research has shown that even a small number of taught relations among stimuli may promote learning an exponential number of derived relations (Wulfert & Hayes, 1988). This type of emergent generative responding appears to be similar to the processes that underlie generative speech and novel utterances, and thus may be very useful for children with autism who frequently do not show generative language and indeed may fail to show generative learning of any kind from an initial context to a novel context (Lovecky, 2004). The success in teaching complex arbitrary relations in the current research is quite significant as arbitrary relational responding has been shown to be important regarding intelligent behavior (Cassidy et al., 2011; O'Hora et al., 2008). The research conducted by Cassidy et al. with educationally disadvantaged children showed that learning complex arbitrary relational responding resulted in positive impacts in children's IQ scores. These findings accord with theoretical predictions and preliminary investigations in derived relational responding and intelligent responding (see Relational Frame Theory; Hayes et al., 2001; O'Toole & Barnes-Holmes, 2009; O'Hora et al., 2005; O'Hora et al., 2008).

The current series of studies highlight how the principles of derived relational responding can be incorporated into a contemporary applied behavioral approach to teaching and combined with positive reinforcement and other well-known principles to teach flexible relational responding (O'Toole, Barnes-Holmes, Murphy & O'Connor 2009). Four children with diagnosed autism successfully learned various and complex relational responding skills (coordination, comparison, opposition, with nonarbitrary and arbitrary stimuli; derived opposition relations) across three experimental studies, and resulting data demonstrated that the T-IRAP produced more favourable learning outcomes compared to TT teaching for all participants across all procedures compared in three studies. Specifically, relational responding skills for all four participants were shown to be more fluent during T-IRAP, insofar as there was greater speed and accuracy shown during T-IRAP teaching. This was the case even when complexity was advanced to arbitrary relational responding with four participants.

The experimental design used in the current research used staggered introduction of T-IRAP with four participants who had been exposed to extended TT trial-blocks (up to 20). The design allowed a demonstration of positive effects on speed and accuracy data for relational responding subsequent to the introduction of the T-IRAP, and effects were replicated across four participants for all relations targeted (nonarbitrary and arbitrary) across three studies. These findings provide support for the T-IRAP as an efficient teaching tool, however, because the T-IRAP was always introduced subsequent to the Table-Top teaching procedure, results may be viewed as vulnerable to sequence effects. Notwithstanding this, in many cases the TT procedures were extended across numerous trial-blocks with participants prior to introducing T-IRAP, and the positive impact on trends and levels of speed and accuracy was frequently immediate or very soon after the T-IRAP was introduced. The replications across participants and across the three studies also make it less likely that the data were spurious; however future similar research using, for example, an alternating treatments design to compare relational learning in TT and T-IRAP may provide additional support.

It seems likely that the possibility of speedy responding is facilitated by T-IRAP program due to the fact that procedures are rapid and automatic. That is, all trial presentations are automatically presented intact on-screen during T-IRAP programs, whereas with TT procedures the teacher must manipulate the stimuli manually in order to present the trial, and the physical act of doing so may place a ceiling on the possibility of speedier responding for the child. Another advantage is that the speed and accuracy data are recorded automatically on the T-IRAP, because this also facilitates greater speed. Automated trial presentation and data recording may mean greater consistency in trial presentation and more accurate data than might be possible with manual procedures. Other features are that the time required to omit a response can be pre-determined (shortened or lengthened) in the set-up of the T-IRAP program as required, so that if child does not respond within the pre-determined time the trial is counted as incorrect. The time allowed to respond can be gradually shortened as the child's responding becomes faster until it reaches an acceptable fluency level. Programmed contingencies (red x contingent on incorrect response, proceed to next trial contingent on correct response) which provide immediate and consistent feedback are also advantageous, and can be supplemented with teacher delivered reinforcement. The speed and accuracy data presented onscreen may be useful feedback for learners setting goals and learning to self-monitor. Teaching programs in ABA frequently involve goal-setting for levels of accuracy and rate of responding, especially for example in Precision Teaching, such that learners aim for a higher target than their current level of competence and strive to beat their own record. This can provide a means of learning to compete with self, which avoids some of the potential problems related to competing with others, for example when there are substantial disparities in students' learning, competition with others may not be an optimal strategy for the slow learner. Students could be taught to graph their T-IRAP results and learn to self-manage goals and achievements, which may be important in and of itself as well as facilitating greater academic learning

(Wilkinson, 2008). From the perspective of the instructor, the T-IRAP is quite a simple program and can be readily adapted using an extensive variety of picture/word/numerical stimuli to teach numerous complex relations and categories. Other researchers are also refining computerised teaching methods for assessing and teaching relational responding (e.g., Moran, Stewart, McElwee & Ming, 2010; Cassidy et al., 2011), however it is hoped that the current research may provide an additional method that is flexible in terms of meeting teaching needs and is freely available to practitioners via the internet. ■

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