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Effects of computerized match-to-sample training on emergent fraction–decimal relations in individuals with fragile X syndrome

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Abstract

Individuals diagnosed with fragile X syndrome (FXS), the most common known form of inherited intellectual disability, are reported to exhibit considerable deficits in mathematical skills that are often attributed to brain-based abnormalities associated with the syndrome. We examined whether participants with FXS would display emergent fraction–decimal relations following brief, intensive match-to-sample training on baseline relations. The performance profiles on tests of symmetry and transitivity/equivalence of 11 participants with FXS, aged 10–23 years, following baseline match-to-sample training were compared to those of 11 age- and IQ-matched controls with idiopathic developmental disability. The results showed that both groups of participants showed significant improvements in the baseline (trained) relations, as expected. However, participants with FXS failed to show significant improvements in the (untrained) symmetry and transitivity/equivalence relations compared to those in the control group. A categorical analysis of the data indicated that five participants with FXS and eight controls showed at least “intermediate” emergence of symmetry relations, whereas one individual with FXS and three controls showed at least intermediate emergence of transitivity/equivalence relations. A correlation analysis of the data indicated that improvements in the symmetry relations were significantly associated with improvements in the transitivity/equivalence relations in the control group ($r = .69, p = .018$), but this was not the case in the FXS group ($r = .34, p > .05$). Participant IQ was significantly associated with improvements in the symmetry relations in individuals with FXS ($r = .60, p = .049$), but not in controls ($r = .21, p > .05$). Taken together, these results suggest that brief, computerized match-to-sample training may produce emergent mathematical relations for a subset of children with FXS and developmental disabilities. However, the ability of individuals with FXS to form transitivity/equivalence relations may be impaired relative to those with idiopathic developmental disabilities, which may be attributed to neurodevelopmental variables associated with the syndrome.

Keywords

Fragile X syndrome; Match-to-sample; Stimulus equivalence; Emergent relations; Math skills

1. Introduction

The identification of instructional procedures that not only efficiently teach a targeted skill, but also facilitate the emergence of previously untaught stimulus relations, is of utmost importance when designing curricula for learners with developmental disabilities (Sidman, 1994). Given that individuals with developmental disabilities often lag several years behind in their educational progress, relative to their typically developing age-related peers, closing the proverbial learning gap is critical (cf. Hall, Burns, Lightbody, & Reiss, 2008; Purdie & Ellis, 2005). Match-to-sample (MTS) training is one such procedure that has been shown to be extremely effective at teaching a range of skills to learners of various functioning levels (Saunders & Green, 1999). This form of instruction involves the repeated presentation of a sample stimulus – to which a comparison stimulus (presented in an array of two or more comparison stimuli) is to be matched – based on shared yet physically non-identical properties. Contingent reinforcement delivered immediately following selection of the correct comparison stimulus can result in the development of conditional discriminations, which eventually may produce derived equivalence relations (cf. Sidman, 2000).

In his seminal study, Sidman (1971) used the mathematical properties of reflexivity, symmetry, and transitivity to describe the manner in which equivalence relations are formed following MTS training (cf. Saunders & Green, 1992; Sidman & Tailby, 1982). The property of *reflexivity*, or generalized identify matching, is demonstrated when the sample stimulus (A) is matched to itself ($A \rightarrow A$). The property of *symmetry* is demonstrated when the sample (A) and comparison (B) stimulus become reversible ($B \rightarrow A$ following $A \rightarrow B$ training). The property of *transitivity* is demonstrated when a third (previously untrained) stimulus relation is derived from two or more trained conditional discriminations ($A \rightarrow C$ following $A \rightarrow B$ and $B \rightarrow C$ training). Given the formation of symmetry and transitivity relations, *equivalence* may be derived (given $A \rightarrow C$ then $C \rightarrow A$). As such, all members may be said to form an *equivalence* class following MTS training.

The manner in which MTS training is conducted may vary according to the number of comparison stimuli employed (e.g., two, three, or four), class size (the number of stimuli included in each class), the number of nodes (stimuli that are linked to two or more stimuli during training), the distribution of single stimuli around nodes (the number of training clusters increases as the number of stimuli increases; cf. O'Mara, 1991), as well as the training structure (i.e., linear-series training, sample-as-node training, and comparison-as-node training) (Arntzen & Vaidya, 2008; Fields & Verhave, 1987). Over the past 40 years, using a variety of methods listed above, MTS training has been shown to produce desirable outcomes across a wide range of skill sets in various populations (cf. O'Donnell & Saunders, 2003). For example, equivalence relations have been shown to emerge when teaching reading and spelling to socio-economically disadvantaged children (de Rose, de Souza, & Hanna, 1996); in the identification of two-dimensional forms to intellectually disabled children (Dube, Iennaco, & McIlvane, 1993); name–face matching (Cowley, Green, & Braunling-McMorrow, 1992), as well as emotion recognition (Guercio, Podolska-Schroeder, & Rehfeldt, 2004) to adults with acquired brain injury; naming to preschool children with autism (Eikeseth & Smith, 1992); geography skills to learners with autism (LeBlanc, Miguel, Cummings, Goldsmith, & Carr, 2003) and fragile X syndrome (Hall, DeBernardis, & Reiss, 2006); money skills (McDonagh, McIlvane, & Stoddard, 1984; Stoddard, Brown, Hurlburt, Manoli, & McIlvane, 1989) and numerical sequence production to adults with intellectual disabilities (Maydak, Stromer, Mackay, & Stoddard, 1995); as well as more complex mathematical comprehension, such as fraction– decimal conversion (Hall et al., 2006; Lynch & Cuvo, 1995).

Although many variations of MTS training and testing formats have been reported in the literature (O'Donnell & Saunders, 2003), the most frequently used procedure (adopted by Sidman and others) involves training three classes of stimuli using the linear-series training structure (i.e., $A \rightarrow B$ and $B \rightarrow C$ training) (cf. Saunders & McEntee, 2004). Once baseline relations are trained to criterion performance (typically 90% correct or above) under feedback and reinforcement conditions, symmetry ($B \rightarrow A$; $C \rightarrow B$) and transitivity/equivalence ($A \rightarrow C$; $C \rightarrow A$) relations subsequently are tested on trials in the absence of reinforcement and/or feedback (cf. Saunders & Green, 1992). As described by O'Donnell and Saunders (2003), if participants demonstrate >90% correct on these extinction test trials, then it can be inferred that symmetry and transitivity/equivalence have “fully” emerged. If participants demonstrate 66.7% correct or above, then it can be inferred that “intermediate” emergence of symmetry and transitivity/equivalence has occurred.

Not all individuals with developmental disabilities acquire emergent symmetry and transitivity/equivalence relations following MTS training with the baseline stimuli, however. In their review of the literature, O'Donnell and Saunders (2003) found that nine of 55 subjects with developmental disabilities failed to obtain at least “intermediate” emergence on at least one of the equivalence tests. The authors suggested that several participant and procedural variables might have affected the number of positive outcomes obtained in their evaluation. Such factors included the participants' IQs, diagnoses, and/or histories with the stimuli. For example, individuals with higher IQs and/or those who obtain higher pre-test scores on the baseline relations may acquire equivalence more readily than those who have lower IQs and/or those who are required to learn the stimulus relations “from scratch” (O'Donnell & Saunders, 2003; Saunders, Wachter, & Spradlin, 1988).

In a previous study, Hall et al. (2006) evaluated the extent to which MTS training would prove effective at teaching fraction–decimal (as well as US state–capital) relations to children diagnosed with fragile X syndrome (FXS), a genetic disorder in which visual–spatial, executive functioning, and mathematical deficits are commonly noted (Bennetto, Taylor, Pennington, Porter, & Hagerman, 2001; Cornish et al., 2004; Hessler et al., 2009; Mazzocco, 2001; Mazzocco, Singh Bhatia, & Lesniak-Karpiak, 2006; Murphy & Mazzocco, 2008). These deficits are suspected to arise from brain-based abnormalities associated with mutations of the FMR1 gene, the mutations that cause FXS (cf. Reiss & Hall, 2007). Results showed that four of the five participants with FXS mastered the baseline relations following an average of 357 computerized-training trials (range, 64–847) that were conducted over 2 days; improvements in the symmetry relations were moderate at best, however, as most gains exhibited were on the $B \rightarrow A$ (but not $C \rightarrow B$) relations only. Furthermore, only one of the five participants demonstrated transitivity and equivalence at post-test. Although the results of this study support previous research showing that children with FXS manifest considerable deficits in visual–spatial and mathematical skills, given the absence of a comparative control group, the extent to which such poor performance outcomes can be attributed to impairments in the learning profiles specific to FXS cannot be determined. In addition, given the small sample size, the authors were unable to determine whether the emergence of symmetry and transitivity relations may be associated with particular participant characteristics such as age, IQ, and stimulus familiarity.

The purpose of the present study, therefore, was to evaluate the effects of an intensive computerized MTS training format on emergent mathematical relations of children with FXS, and to compare the resultant performance profiles to those of similarly aged- and IQ-matched control participants. Should FXS participants exhibit poorer performance outcomes than those of similarly matched children with idiopathic developmental disability, further support would be garnered regarding the mathematical skill deficits that are characteristic of FXS, and would point to the need for additional research to evaluate both interventions for

such specific learning profiles in this population, as well as potential biomarkers for such cognitive deficits. A secondary purpose of the study was to determine whether the emergence of equivalence relations would be associated with specific participant characteristics such as age, IQ, and/or the extent to which participants were familiar with the stimuli at pre-test.

2. Method

2.1. Participants and setting

Participants were 11 children diagnosed with FXS (five female, six male) and 11 children diagnosed with idiopathic developmental disability (three female, eight male). All participants were taking part in a concurrent investigation examining the effects of discrete trial training on the acquisition of math skills in individuals with FXS (Hall, Hammond, Hirt, & Reiss, under revision). (In that study, 15 children were included in each group; however, four children per group were unable to master the $A \rightarrow B$ and $B \rightarrow C$ relations within 1500 trials. Consequently, those children were not included in this study.) Participants were aged between 10 and 23 years, had an IQ between 50 and 90, communicated vocally, were able to use a computer mouse, and could match sample stimuli to identical comparison stimuli (demonstrating reflexivity/generalized identify matching) with at least 90% accuracy. All participants with FXS had a confirmed genetic diagnosis (i.e., >200 CGG repeats on the *FMRI* gene and evidence of aberrant methylation), and participants in the control group tested negative for a neurogenetic disorder. Participants in the control group were matched to participants in the FXS group on age, IQ, and prior familiarity with the stimuli. In the FXS group, two participants were prescribed an antidepressant medication (sertraline), three participants were prescribed a stimulant medication (atomoxetine, methylphenidate, dextroamphetamine), and one participant was prescribed an antipsychotic medication (risperidone). In the control group, three participants were prescribed a stimulant medication (methylphenidate), one participant was prescribed an antidepressant (imipramine), and one participant was prescribed an antipsychotic medication (aripiprazole). Participant group characteristics are listed in Table 1.

Sessions were conducted in one of two rooms located within the Department of Psychiatry and Behavioral Sciences at Stanford University. Session rooms contained a table or desk, chairs, a laptop computer, a computer mouse, and a button box (see below). All procedures were approved by the local IRB at Stanford University; parental consent and participant assent were obtained in all cases.

2.2. Procedures

The stimulus sets employed in the study (labeled A, B and C) are shown in Fig. 1. Each participant received the testing and training procedures in the following order conducted over a 3-day period: (a) pre-test, (b) training of baseline relations, (c) post-test, and (d) brief reinstitution of baseline relations training.

2.2.1. Pre-test—Baseline tests were conducted to evaluate participants' performance levels prior to MTS training on the targeted math skills. All tests were conducted on a PC computer, and stimuli were presented using E-Prime© 2.0 software (Psychology Software Tools, 2010). A three-button response pad (Mag Design and Engineering, Sunnyvale, CA; www.magconcept.com) was used to record responses. Participants first were shown how to use the response pad by placing their index, middle, and ring fingers on each of the respective buttons; the experimenter prompted the participants to press each of the buttons in a varied format several times to ensure proper utilization of the response pad. Participants also received practice on a computerized training game in which the numbers "1", "2", and

“3” were presented on the screen in random order and the participants were required to match the numbers by pressing the respective buttons on the response pad. Once participants demonstrated at least 90% accuracy within a practice session (demonstrating the ability to identity match), the experimenter delivered the following vocal instructions: “Today you are going to work on some math tasks on the computer. First, you will see a fraction or a pie chart appearing at the top of the computer screen. You will also hear a question spoken in a female voice. Three boxes then will appear below the top box, one of which will be the correct answer to the question. Your job will be to pick one of the boxes from the bottom row that best matches the top box using the button box (response pad). Another math problem then will appear, and so on. You will have about 7 seconds to answer, so you should have plenty of time. And it doesn’t matter how fast you answer – the program is still going to take the same amount of time to finish, no matter what. Please try to do the best you can. And if you’re not sure of an answer, it’s okay to guess.” On the first couple of trials, participants were prompted vocally and/or physically if they did not appear to understand the procedure.

Stimulus relations were tested in the following order: baseline tests ($A \rightarrow B$ and $B \rightarrow C$ relations), transitivity tests ($A \rightarrow C$ relations), equivalence tests ($C \rightarrow A$ relations), and symmetry tests ($B \rightarrow A$ and $C \rightarrow B$ relations); therefore, six separate test sessions were conducted. Each test session contained 36, 7-s trials, with each sample stimulus being presented six times. On each trial, the sample stimulus was displayed centrally at the top of the screen, and three comparison stimuli were displayed in a row at the bottom of the screen. Sample stimuli were randomly presented throughout each session, as were the comparison stimuli and their position in the row at the bottom of the screen. Stimulus presentation order was held constant across all participants. At the beginning of each trial, the sample and comparison stimuli were displayed on the computer screen, accompanied by a computerized vocal prompt (e.g., “show me the correct fraction”). Following a response, the stimuli were removed for the remainder of the 7-s trial, a 3-s inter-trial interval (ITI) was instituted, and the next trial began. If the participant did not press a button on the response pad within 7 s, a 3-s ITI was instituted and the next trial began. A correct response was recorded if the comparison stimulus selected by the participant corresponded to the sample stimulus. At the end of each test session, the words “Good job!”, the percentage of correct responses, and the average response time across trials were displayed in the center of the screen.

2.2.2. Computer-based training—Training of $A \rightarrow B$ and $B \rightarrow C$ baseline relations was conducted using the *Discrete Trial Trainer*® v2.3.2 (Accelerations Educational Software, 2007; www.dtrainer.com), a commercially available software program designed for use with individuals with developmental disabilities. The stimuli shown in Fig. 1 were incorporated into two programs within the *Discrete Trial Trainer*®: “fractions to pie charts” ($A \rightarrow B$) and “pie charts to decimals” ($B \rightarrow C$). Training sessions (with feedback and reinforcement for correct responses) were conducted in 15-min blocks, with small breaks allowed between sessions, depending on each participant’s particular needs. All participants received MTS training on the baseline relations over 2 days until they had (a) achieved the mastery criteria for both relations at least twice or (b) completed at least 1500 training trials. The computer indicated that a participant had mastered an item after the correct comparison stimulus had been selected across five consecutive trials. For participants who mastered the baseline relations within the training time allotted, additional sessions were conducted (i.e., over-training) until the computer indicated that the mastery criteria had been met at least twice. (A detailed description of the training procedures can be provided upon request.)

2.2.3. Post-test—Procedures were the same as those used in the pre-test. Stimulus relations were tested in the following order: baseline ($A \rightarrow B$; $B \rightarrow C$), transitivity/equivalence ($A \rightarrow C$; $C \rightarrow A$), and symmetry ($B \rightarrow A$; $C \rightarrow B$).

2.2.4. Reinstitution of baseline relations—Following post-test, computer-based MTS training was conducted within a 15-min session to assess the participants' performance levels on the baseline relations when reinforcement and feedback were reinstituted, and to determine whether mastery levels of performance were maintained.

2.3. Data analysis

To determine whether performance had improved from pre-test to post-test on the baseline and untrained test relations for each group, we conducted a series of paired t-tests using SPSS Version 18 (SPSS Inc, 2010). To examine the extent to which the symmetry and transitivity/equivalence relations had emerged following training on the baseline relations, both categorical and correlation analyses were conducted. In the categorical analysis, we adopted the criteria used by O'Donnell and Saunders (2003) to determine whether "intermediate" emergence (>66.7% correct) or "full" emergence (>90% correct) had occurred for each of the stimulus relations tested. Participants were regarded as having failed a particular relation if they obtained less than 66.7% on that measure at post-test (cf. O'Donnell & Saunders). In the correlation analysis, we examined whether improvements in baseline relations were associated with improvements in symmetry relations, as would be predicted by stimulus equivalence theory. Similarly, we examined whether improvements in symmetry relations were associated with improvements in transitivity/equivalence relations. Finally, we examined whether background characteristics of the participants were associated with subsequent improvements in the baseline and untrained relations. The level for statistical significance was set at $\alpha = .05$.

3. Results

3.1. Baseline relations

Fig. 2 (top panel) shows the percentage of correct responses that each participant pair obtained at pre-test and at post-test on the baseline ($A \rightarrow B$ and $B \rightarrow C$) relations. For the FXS group, the mean percentage correct was 47.3% ($SD = 10.7$; range, 31.9–63.9%) at pre-test and 65.9% ($SD = 21.1$; range, 33.3–95.8%) at post-test – a statistically significant improvement [$t(10) = 3.67$, $p = .004$]. For the control group, the mean percentage correct was 51.0% ($SD = 13.0$; range, 27.8–65.3%) at pre-test and 79.4% ($SD = 20.4$; range, 31.9–100%) at post-test – a statistically significant improvement [$t(10) = 5.92$, $p < .001$].

3.2. Symmetry relations

Fig. 2 (middle panel) shows the percentage of correct responses that each participant pair obtained at pre-test and at post-test on the symmetry ($B \rightarrow A$ and $C \rightarrow B$) relations. For the FXS group, the mean percentage correct was 52.0% ($SD = 10.1$; range, 34.7–65.3%) at pre-test and 62.5% ($SD = 23.3$; range, 31.9–94.4%) at post-test – an improvement that just failed to reach statistical significance [$t(10) = 1.94$, $p = .081$]. For the control group, the mean percentage correct was 53.9% ($SD = 13.5$; range, 33.3–72.2%) at pre-test and 73.5% ($SD = 24.9$; range, 25.0–97.2%) at post-test – a statistically significant improvement [$t(10) = 3.63$, $p = .005$].

3.3. Transitivity/equivalence relations

Fig. 2 (bottom panel) shows the percentage of correct responses that each participant pair obtained at pre-test and at post-test on the transitivity/equivalence ($A \rightarrow C$ and $C \rightarrow A$) relations. For the FXS group, the mean percentage correct was 35.1% ($SD = 8.9$; range, 18.1–47.2%) at pre-test and 44.8% ($SD = 18.2$; range, 26.4–88.9%) at post-test – a slight improvement that did not reach statistical significance [$t(10) = 1.64$, $p = .13$]. For the control group, the mean percentage correct was 34.2% ($SD = 5.0$; range, 26.4–44.4%) at pre-test

and 54.5% ($SD = 23.8$; range, 29.2–100%) at post-test – a statistically significant improvement [$t(10) = 3.00, p = .013$].

3.4. Categorical analysis of untrained relations

Two criterion lines depicting intermediate emergence (>66.7% correct) and full emergence (>90% correct) are indicated on the middle and bottom panels of Fig. 2. Five participants with FXS and eight control participants achieved the intermediate emergence criterion on the symmetry relations – a non-significant difference between the groups ($p = .39$, Fisher's Exact Test). One participant with FXS and three control participants achieved the full emergence criterion on the symmetry relations – a non-significant difference between the groups ($p = .59$, Fisher's Exact Test). For the transitivity/ equivalence relations, one participant with FXS and three control participants achieved the intermediate emergence criterion on the transitivity/equivalence relations – a non-significant difference between the groups ($p = .59$, Fisher's Exact Test). Only one participant achieved the full emergence criterion on the transitivity/equivalence relations; this participant was a control.

3.5. Correlation analyses of emergent relations

Correlation analyses were conducted to determine whether improvements in the baseline relations were associated with improvements in the symmetry relations, as Sidman's (1971) theory of stimulus equivalence would predict (cf. Sidman, 1994). Fig. 3 (top panel) shows the percent improvement scores on the symmetry relations plotted as a function of the percent improvement scores on the baseline relations for each group.

For the vast majority of participants – irrespective of diagnostic group – improvements in scores on the baseline relations were significantly associated with improvements in scores on the symmetry relations (FXS group: $r(11) = .80, p = .003$; control group: $r(11) = .79, p = .004$). These data therefore indicate that – so long as gains observed on the baseline relations during MTS training were *maintained* under extinction conditions at post-test – similar improvements emerged in the symmetry relations at post-test.

We also examined whether improvements in the symmetry relations were associated with improvements in the transitivity/equivalence relations (Fig. 3, bottom panel). Although a significant association between improvements in these relations from pre-test to post-test was exhibited by the control group ($r(11) = .69, p = .018$), no such association was evident in the FXS group ($r(11) = .34, p > .05$). These data therefore suggest that when FXS participants exhibited improvements in their symmetry scores following MTS training, their transitivity/equivalence scores generally did not increase in a concomitant fashion.

3.6. Association between participant characteristics and improvement scores

Correlation analyses were conducted to evaluate whether improvement scores in the baseline, symmetry, and transitivity/equivalence relations were associated with participant characteristics (e.g., age, IQ, and/or scores obtained at pre-test on the baseline relations). Results showed that, for the FXS group, IQ was significantly associated with improvements in the baseline relations ($r(11) = .70, p = .016$) as well as the symmetry relations ($r(11) = .60, p = .049$), but not the transitivity/equivalence relations ($r(11) = .32, p > .05$). For the control group, IQ was not associated with improvement scores on any of the relations. There were no significant associations between other participant characteristics and improvement scores in either group.

3.7. Reinstitution of baseline relations

All participants obtained >90% correct on the baseline relations during reinstitution of the computer-based training following post-test. These data indicate that the baseline relations were maintained at mastery levels when feedback and reinforcement were forthcoming.

4. Discussion

Previously researchers have suggested that children diagnosed with FXS demonstrate characteristic deficits in mathematical performance, presumably as a consequence of brain-based abnormalities associated with the syndrome (Hall et al., 2006; Mazzocco, 2001; Reiss & Hall, 2007). This study utilized a computer-based training procedure to examine whether participants with FXS would display emergent fraction–decimal relations following brief, intensive MTS training on baseline $A \rightarrow B$ and $B \rightarrow C$ relations – and whether their performance profiles would differ in any way from those of age- and IQ-matched controls. Statistically significant improvements in the baseline relations were identified for both groups following MTS training. Conversely, statistically significant improvements in the symmetry and transitivity/equivalence relations were found for the control group only. Based on categorical analyses of the data, using standard cut-off criteria, we found that five participants with FXS and eight control participants showed at least intermediate emergence (>66.7% correct) of symmetry relations at post-test; only one participant with FXS and three control participants achieved the full emergence (>90% correct) criterion on symmetry relations at post-test. With respect to transitivity/equivalence, we found that one participant with FXS and three controls showed at least intermediate emergence of these relations at post-test. Finally, only one participant achieved the full emergence criterion on the transitivity/equivalence relations; this participant was a control.

We also conducted correlation analyses to examine whether improvements in one relation would be associated with improvements in another relation, as Sidman's (1971) theory of stimulus equivalence would predict (cf. Sidman, 1994). Specifically, we made two predictions: first, we predicted that improvements in the baseline relations would be associated with improvements in the symmetry relations; second, we predicted that improvements in the symmetry relations would be associated with improvements in the transitivity/equivalence relations. The first prediction was confirmed in both groups. In the FXS group, however, the second was not. That is, for participants with FXS, improvements in the symmetry relations did not yield corresponding improvements in the transitivity/equivalence relations. One reason for the difference between the groups may be due to the specific neurodevelopmental and/or other neurological factors involved in FXS – such as reduced or absent FMRP resulting from mutations to the FMR1 gene. Given that FMRP is involved in synaptic pruning and dendritic maturation in the brain, it is possible that specific brain abnormalities associated with FXS may hamper stimulus equivalence (or “concept”) formation. We aim to examine this possibility in future neuroimaging studies.

Additionally, we found that IQ was significantly associated with improvements in the baseline and symmetry relations for participants with FXS, but not for control participants. Again, it is possible that the variability in outcomes between the groups may be accounted for by considering the particular neurodevelopmental factors involved in FXS. Indeed, Sidman (2000) has highlighted the potential role that neurological variables may contribute to the formation of equivalence relations:

“Variability [in outcomes] may also exist within a species, including the human, when factors like developmental retardation, acquired brain damage, sensory deficiencies, or genetic abnormalities may be found to bear on the production of equivalence relations by reinforcement contingencies ... As formulated, however,

the present theory is neutral with respect to the relevance of neurological structure and function, genetic factors, or developmental processes.” (p. 144)

We hope that genetic, developmental, and/or neurological factors will continue to be explored in future studies of stimulus equivalence.

Although all participants demonstrated 100% correct across five successive trials for each item of the baseline relations following MTS training (and obtained >90% correct following brief reinstitution of training following post-test) when reinforcement and feedback for correct responding were provided, only six of 22 participants (27.3%) achieved >90% correct on the baseline ($A \rightarrow B$ and $B \rightarrow C$) relations at post-test when extinction was in effect. Because outcome test data on the baseline (trained) relations typically are not presented in stimulus equivalence research, the extent to which these post-test results correspond with previous studies is unknown. Regardless, our test results on the baseline relations suggest that – once extinction conditions were imposed – performance deteriorated rather rapidly.

Several other facets of the training and testing arrangements used in this study may have contributed to our failure to obtain equivalence for the majority of subjects at post-test. First, we conducted MTS training of baseline relations over a relatively brief period of time (i.e., 2 days using a computerized training procedure; see Hall et al., under revision). This training arrangement might be considered relatively intensive and short lived, as compared to previous studies on stimulus equivalence, wherein MTS training typically occurred several times per week, over the course of several weeks (Adams, Fields, & Verhave, 1993; Lynch & Cuvo, 1995) to months (Cowley et al., 1992; Sidman & Cresson, 1973) (see Hall et al., 2006, p. 649, for a discussion). However, it should be pointed out that the number of training trials the participants received in this study (~1500) did not exceed those generally reported in the discrete trial training literature (cf. Smith, 2001, p. 87).

It is also possible that the training structure used in this study – linear-series training – may have influenced the participants’ demonstration of emergent mathematical relations. For example, several investigators have suggested that the comparison-as-node training structure may be a more effective form of training in stimulus equivalence research (cf. Fields & Verhave, 1987; Saunders & Green, 1999). Given these considerations, it is possible that, had comparison-as-node training been implemented in this study, equivalence class relations would have emerged for a greater proportion of participants at post-test. Additional research perhaps is warranted to evaluate the effectiveness of the different training structures.

Another factor that may have influenced the likelihood that participants would demonstrate emergent mathematical relations pertains to the manner in which reinforcement and feedback were implemented during training and testing. During MTS training, reinforcement and feedback were provided on a fixed-ratio 1 (FR1) schedule – contingent on each selection of the correct comparison stimulus (during unprompted trials). Similarly, following each incorrect response, both verbal feedback and visual feedback were provided (i.e., the correct comparison stimulus was presented on the screen for 2 s, accompanied by a verbal statement of the correct response). Conversely, during testing, reinforcement and feedback no longer were forthcoming – which necessarily amounted to extinction (EXT). Although EXT typically is in effect during evaluations of emergent relations (cf. Saunders & Green, 1999), it is possible that the removal of reinforcement and/or feedback during testing at least somewhat contributed to the poorer performance levels displayed by most participants during the post-test evaluations. It is possible that, had we thinned the schedules of reinforcement and feedback used during training, performance outcomes would have been enhanced (cf. Adams et al., 1993). Future research might evaluate this possibility.

Similarly, perhaps improved outcomes would have been observed had reinforcement (either contingent or noncontingent) been delivered on test trials. Equivalence relations might be more likely to emerge under such conditions because participants' "motivation" to respond correctly feasibly would be enhanced. LeBlanc et al. (2003) evaluated this possibility with two children diagnosed with autism. During the EXT–EXT condition, no feedback or reinforcement was presented during pre-test or post-test evaluations. During the FR1–FR1 condition, preferred edible items were delivered to the participants following each response during testing – regardless of accuracy (thus, more precisely comprising a noncontingent [as opposed to FR1] schedule of reinforcement). During the EXT–INT (interspersal of training trials) condition, reinforcement was not provided at pre-test. During the post-test, however, after every third test trial, a training trial was presented (incorporating relations previously trained); and reinforcement in the form of preferred edibles was provided contingent on correct responding during these (trained) trials. Although results showed that all three testing procedures produced similar effects – additional research perhaps is warranted to further evaluate the potential influence of such motivational variables on emergent relational responding following MTS training.

Taken together, these results suggest that – although children with FXS and developmental disabilities may learn the targeted mathematical relations at the same rate (i.e., acquisition rates were similar across the two groups during MTS training; see Hall et al., under revision) – improved outcomes, particularly of those with FXS (observed during training) do not necessarily maintain under test conditions when reinforcement and/or feedback no longer are forthcoming. Correlation analyses showed that improvements in the transitivity/equivalence relations were more likely to occur if corresponding improvements had been obtained on the symmetry relations in control participants, but not in participants with FXS. Furthermore, participants in the FXS group – but not those in the control group – were more likely to show improvements in the symmetry relations following MTS training if their cognitive test scores yielded a higher IQ. These data perhaps suggest that subtle yet important neurodevelopmental factors in children diagnosed with a specific genetic disorder – such as FXS – may hamper the ability of those individuals to form equivalence relations. Our hope is that this study will facilitate additional research in this area to broaden our understanding of the interplay between genetic and/or neurodevelopmental factors in the development of equivalence relations in individuals with developmental disabilities (cf. Sidman, 2000).

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Fig. 1.
Stimuli presented during testing and training.

Fig. 2.

Percentage of correct responses exhibited by pairs of FXS and control participants on the baseline relations (top panel), symmetry relations (middle panel), and transitivity/equivalence relations (bottom panel). Pre-test data points are denoted by circles and squares for FXS and control groups, respectively; post-test data points are represented by directional arrows with horizontal lines. On the middle and bottom panels only, the intermediate emergence criterion (>66.7% correct) is denoted with a solid line, and the full emergence criterion (>90% correct) is denoted with a dotted line.

Fig. 3.

Top panel: Percent improvement scores on symmetry relations plotted as a function of percent improvement scores on baseline relations for FXS and control participants. Bottom panel: Percent improvement scores on transitivity/equivalence relations plotted as a function of percent improvement scores on symmetry relations for FXS and control participants. Open circles denote percent improvement scores for FXS participants, and closed squares denote improvement scores for control participants. Regression lines are fitted to the data for each group.

Table 1

Chronological age and IQ of the FXS and control groups. Means, standard deviations (*SD*) and ranges are shown for each measure.

Measures	FXS group (N = 11)	Control group (N = 11)
Chronological age (years)		
Mean	17.7	16.8
<i>SD</i>	4.0	4.4
Range	(11.2–23.9)	(10.0–23.0)
IQ ^a		
Mean	67.0	66.3
<i>SD</i>	10.8	12.5
Range	(54–86)	(55–90)

^a Assessed using the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999).