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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.

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

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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 → A). The property of *symmetry* is demonstrated when the sample (A) and comparison (B) stimulus become reversible (B → A following A → 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 → C following A → B and B → C training). Given the formation of symmetry and transitivity relations, *equivalence* may be derived (given A → C then C → 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 → B and B → 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 → A; C → B) and transitivity/equivalence (A → C; C → 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; Hessl 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 → A (but not C → 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