Executive Function and Early Numeracy in Preschoolers: Can Training Help?

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Abstract

Math literacy, or lack thereof, is a major issue in our society. Research on mathematics proficiency has begun to support a more conceptual approach to mathematics understanding. Based on this thinking a growing body of literature supports a relation between executive functions (EF) and mathematics ability in both older and younger children. With the majority of research supporting a relation between mathematics and EF we are lead to the question, can training help improve one or both of these skills? The current study addresses this question in young children by looking at the differential impact of various training programs. Three and 4-year-old typically-developing children (N = 104) were randomly assigned to one of four conditions: EF training, number training, EF + number training or an active control condition and participated in three training sessions as well as pre and post test sessions measuring their EF and math abilities. Results indicated a significant positive effect of training with EF training leading to improvements in EF skills and number training and EF + number training showing improvements in math abilities. Interestingly, the EF training also led to improvements in children's specific counting abilities and number training resulted in improvements in EF skills. These results provide support for a bidirectional relation between EF and math skills, where training in one area can lead to improvements in the other.

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Executive Function and Early Numeracy in Preschoolers: Can Training Help?

Data on poor mathematics ability is prevalent. Research has shown that poor mathematics skills provide an equal or even greater handicap for future success than low literacy skills (Butterworth, Varma & Laurillard, 2011). Individuals with low numeracy abilities tend to earn less, are sick more often, and are more likely to be in trouble with the law than others with higher levels of numerical understanding (Parsons & Bynner, 2005). Many people (22% of US adults) do not have the numeracy skills required for everyday tasks (Geary, Hoard, Nugent & Bailey, 2013). Similarly, United States high school students performed below average on the Programme for International Student Assessment (PISA) and the U.S. was ranked 27th out of 34 countries (OECD, 2012). Over a quarter of U.S. students did not reach PISA baseline Level 2 of mathematics proficiency (OECD, 2012). Even more importantly, this discrepancy in formal mathematics achievement starts in early schooling. Twenty-one percent of 11-year-olds are below their expected mathematics ability level when they leave primary school, and almost 6% of those students are below the proficiency levels expected of a 7-year-old (Gross, 2007). These statistics become even more dramatic when comparing low-income children who perform below their middle-income peers on national and international mathematics assessment starting in preschool and continuing through elementary school and adolescence (Entwisle & Alexander, 1992; Downer & Pianta, 2006). For example, according to the National Assessment of Education Progress (NAEP) in 2015, 28% of 4th graders eligible for free or reduced lunch failed to meet basic level standards and an additional 48% were below proficiency, compared to 8% of children from more socioeconomically privileged backgrounds who were below basic level standards and an additional 35% below proficiency (NAEP, 2015).

Although these statistics are disheartening, it is necessary to understand the factors that influence mathematics success and underachievement. First, the behavioral genetics literature suggests that genetic influences are important for the development of mathematics skills, but that shared or non shared environment still accounts for the majority of variation in mathematics abilities (Petrill & Kovas, 2016). Secondly, this literature has also found that individuals with math disabilities are likely the lowest end of a continuous distribution (as opposed to categorically different from the rest of the distribution (Petrill & Kovas, 2016)). Together, this suggests that mathematics skills and understanding (even at the lowest level) are malleable, but they develop early (National Council of Teachers of Mathematics (NCTM), 2000) and are hierarchical in nature, suggesting that establishing a strong foundation is important. Similarly, early skills are predictive of later mathematics achievement in elementary grades and beyond, with skills at prekindergarten correlating significantly with 5th grade mathematics scores (Duncan et al., 2007). Early mathematics skills are also predictive of achievement in other areas including reading (Duncan et al., 2007). Because of the apparent importance of mathematical skills, it is recommended that foundational mathematics instruction begin in preschool as this will form the basis of children’s mathematical development (NCTM, 2000).

Research to support this position has shown that specific, early numerical knowledge (including addition decomposition, number line accuracy and number set identification) at kindergarten and first grade, predicted adolescent's functional numeracy outcomes (e.g., arithmetical word problems, computational arithmetic, computational fractions and fraction comparisons predictive of employability and wages later in life) (Geary et al., 2013). Importantly, the same study showed that the measures of early numerical knowledge did not predict children's mathematics achievement scores when functional numeracy outcomes were controlled for. This suggests that these early numeracy measures are especially relevant for identifying mathematics competency related to later life outcomes, that may not be captured in standard mathematics achievement tests (Geary et al., 2013).

Traditionally preschool mathematics instruction has been informal, often incorporated into playtime activities (Clarke et al., 2011). However, this emphasis is shifting to more critical mathematics content and effective instructional design (Clarke et al., 2011). Starting in 2000 the NCTM included the pre-kindergarten age-group in its Principles and Standards for School Mathematics recommendations for the first time. The report suggested six overarching principles of mathematics understanding in this age group. These general principles included equity (high expectations and strong support for all students), curriculum (more than a collection of activities and a focus on mathematics within the chosen activities), teaching (understanding of student's current understanding and what they still need to learn), learning (developing an understanding that builds on prior knowledge and experience), assessment (support the learning and provide useful feedback), and technology (NCTM, 2000). As the authors admit, these principles are broad and can apply to all grades, offering little specification for the unique task of teaching mathematics to young children. They argue that effective general teaching techniques should be applied to improving children's mathematical understanding, but that the short- and long-term research on such interventions, necessary to provide more specific recommendations, was lacking (NCTM, 2000).

Since this initial report, the National Association for the Education of Young Children (NAEYC) has identified five domains of mathematics that should be emphasized in preschool: number concepts & quantities, number relationships and operations, geometry and spatial sense, patterns, and measurement and comparison (NAEYC & NCTM, 2002).

Also, a specific list of suggested curriculum structure and components was offered by the National Center on Quality Teaching and Learning (NAEYC & NCTM, 2002). Mathematics teaching should include explicit instruction on those core competencies. Specifically, several recommendations have been offered: children should be exposed to a variety of mathematics concepts, children should play an active role in mathematics learning, curriculum should be research based with clear goals, scope, and sequence, all five domains of mathematics and reasoning and problem-solving abilities should also be strengthened, teaching should be adaptive and vary based on the child's level of understanding and cognitive abilities, mathematics learning should be integrated throughout everyday experiences, various environments and other subjects, so that learning is pervasive and connections can be made should be included throughout children's environment, finally, students progress should be monitored.

In the sixteen years since the National Council on Teaching Mathematics first highlighted the preschool age band and the lack of relevant research, several prominent programs have been studied extensively. Lacking from this list is an awareness or emphasis on domain general skills outside of mathematics. Recent research has begun to emphasize these skills as important precursors and mediators of mathematical development. For instance, a study of 103 preschoolers (40 – 60 months of age) found that different cognitive markers were associated with the various patterns of strengths and weaknesses in mathematics abilities (Gray & Reeve, 2016). Executive Function (EF) is one possible set of skills that may play a role in mathematics ability and better understanding this relation could be beneficial for improving overall mathematics outcomes.

Executive Function

EF refers to a suite of cognitive skills that have been linked to a variety of academic outcomes. A growing body of literature supports a relation between EF and mathematics ability in both older and younger children. Additionally, both skill sets undergo major developmental shifts through early and mid-childhood. We will explore the impact that this developmental pattern might have on the relation between EF to see how training EF, numeracy and a combination of the two might improve overall mathematics ability in young children.

EF is made up of the higher-order processes associated with goal-directed problem solving and planning. Typically, EF is thought to consist of three main skills: updating, inhibition, and flexible thinking (Miyake et al., 2000). In this framework updating refers to monitoring and keeping information in working memory, inhibition means superseding a prepotent or default response for another one, and flexible thinking includes switching between tasks or mental sets. Although these separate skills have been identified, it is important to note that they are largely overlapping and are difficult to separate from one another (Miyake & Friedman, 2012). This lack of separation is especially true for preschool-aged children, where EF is considered to be a more unitary skill (Bull & Lee, 2014; Lee, Bull & Ho, 2013, Wiebe et al., 2011).

Research on EF has found that it is an underlying component of many disorders including learning disabilities, autism, ADHD, and various behavioral problems (e.g., Pickering & Gathercole, 2004, McLean & Hitch, 1999; Ozonoff & Jensen, 1999). By pinpointing the role that a particular skill of EF (either updating, inhibition, or shifting) plays in each of these disorders, researchers have been better able to understand the disorders and their distinguishing behaviors. For example, we now know that children with autism typically have difficulty thinking flexibly but their ability to inhibit remains mostly intact (Ozonoff & Jensen, 1999). Conversely, children with ADHD tend to show the opposite pattern of impairments and abilities (Ozonoff & Jensen, 1999).

This line of thinking, how understanding the underlying cognitive components might elicit a better understanding of complex behaviors, has begun to be applied to academic areas as well. EF is thought to be a crucial contributor to school achievement

(Blair & Razza, 2007; Duckworth, 2011; McClelland et al., 2013). This contribution applies to general academic achievement as well as specific subjects such as science, reading, and writing (Bull, Espy & Wiebe, 2008; Monette, Bigras & Guay, 2011; St Clair-Thompson & Gathercole, 2006). Perhaps the strongest and most direct link has been made between EF and mathematics (for a review see Cragg & Gilmore, 2014).

EF and Mathematical Thinking

Competence in mathematics entails complex skills that require an understanding of both procedures and content. Because of the complexity of this understanding, theoretical conceptualizations about the particular role that EF might play in mathematics have developed. Beginning with a skill like problem-solving, children must hold partial information in mind while simultaneously processing new information, then combine those sets to arrive at a solution. This process has been seen in informal and formal mathematical problem-solving at various ages (Bisanz, Sherman, Rasmussen & Ho, 2005) and perhaps presents the clearest link between mathematics and updating or working memory since it primarily involves holding and manipulating information in mind. This logical link has been supported by substantial research (for a review: Raghubar, Barnes & Hecht, 2010). Additionally, as children learn new skills, content, and strategies for problem-solving, it is necessary that they inhibit competing ways of thinking and understanding. These alternatives change with development. For example, when trying to learn multiplication (e.g., 3 x 3 = 9), a child must suppress the well-established operation of addition (e.g., 3 + 3 = 6). Similarly, they must rework number magnitude information (larger represents greater magnitude) when learning fractions (when in fact larger denominators represent smaller magnitudes), and inhibit irrelevant or misleading information when solving a word problem (Bull & Lee, 2014). Finally, shifting skills may be critical for moving between possible representations, solution strategies, symbols (Arabic numbers, non-symbolic quantities) and switching between tasks on a multi-step problem (for a review: Yeniad, Malda, Mesman, van Ijzendoorn & Pierper, 2013).

One of the first studies to explore the relation between mathematics and EF looked at each of the skills mentioned above (Bull & Scerif, 2001). In this early study, the researchers tested 105 children initially and 93 children at subsequent time points, with an age range of 6 years, 9 months to 8 years, 3 months and a mean age of 7 years, 4 months. Children were tested over three 30-minute sessions. EF was tested using a battery of tasks including the Wisconsin Card Sorting Task (measuring switching/flexible thinking), a dual-task performance test (measuring working memory), a color and number Stroop task (measuring inhibition) and counting span (measuring working memory). Mathematics ability was measured using the Group Mathematics Test where children had to answer questions read by an experimenter using pictures on a test sheet and solve single and multi-digit addition and subtraction problems. The researchers found that mathematics ability was significantly correlated with all the EF tasks except for the dual-task measure. Additionally, each measure of EF was found to predict unique variance in the children's mathematics ability. Bull and Scerif interpreted these findings as suggesting that children with lower mathematics ability have poor working memory skills, and trouble inhibiting their responses, which leads to difficulty switching between and evaluating new strategies. This early study spurred a large body of literature trying to better understand the relations between EF skills and mathematics ability (for a review: Bull & Lee, 2014). Recently, research has begun to focus on what this relationship might look like in even younger children (before formal schooling) and how it changes with age.

Developmental Considerations

Differences in the relation between EF and mathematics may depend on age, but studying the relation between mathematics and EF at various ages is difficult (Bull & Lee, 2014). Both skills are constantly developing starting from a very early age. EF has a very protracted development with certain skills continuing to develop through adolescence and early adulthood (Luciana, Conklin, Hooper & Yarger, 2005; Weintraub et al., 2013). Mathematics ability, and what constitutes a skillful performance, changes dramatically with age as well. Before formal schooling, young children engage, often spontaneously, in skills such as magnitude comparisons, number recognition and basic ordinal relations (Carey, 2009). Over time these skills transition into basic arithmetic and eventually multi-step word problems and algebra. In addition to the complexity created by the varying skills encompassed in mathematical achievement, it is proposed that the various components of EF interact with the skills differently and that those interactions themselves also change over time and through development (Bull & Lee, 2014). Because the majority of studies examining the relation between EF and mathematics have been done with older children, disentangling these developmental issues remains an important task.

Most researchers agree that the theoretical reasoning behind the relation between EF and mathematics could apply for younger children as well (Clark Sheffield, Wiebe & Espy, 2013). For example, early counting requires holding sequential information in mind and continually updating the list with new information. Similarly, young children must maintain multiple meanings of a number. For instance, the number 5 is bigger than 4 but is smaller than 6. Similarly, theories of the development of EF are easily related to mathematics. The Cognitive Complexity and Control theory (CCC) suggests that forming higher order rules enables the expression of executive cognitive abilities. Therefore, the expression of learned information is reliant on not only knowing that information, but on having the EF abilities to demonstrate that knowledge (Zelazo et al., 2003). If children do not possess the higher order rule structure of a mathematical problem, then they will not be able to efficiently dispense the necessary cognitive resources to effectively solve the problem (Blair, Knipe & Gamson, 2008).

The few studies done with young children have supported this theoretical claim (Bull et al., 2008; Bull, Espy, Wiebe, Sheffield & Nelson, 2011; Clark, Pritchard & Woodward, 2010; Clark et al., 2013, Espy et al., 2004). Espy and colleagues (2004) sampled preschool children with an average age of 4 years and found that working memory and inhibition were related to mathematics ability (as assessed by the Woodcock Johnson Applied Problems), but only inhibition remained a unique predictor after controlling for the other EF skills and general intelligence. Interestingly, shifting skills at preschool did not contribute to these mathematics skills. This is in contrast to other studies that have shown an effect of shifting on mathematics abilities in older children

(Andersson, 2008; Bull & Scerif, 2001; Kolkman, Hoijtink, Kroesbergen & Leseman, 2013; Mazzocco & Kover, 2007), suggesting that perhaps the specific relation between the skills changes across development and across domains of mathematical thinking.

Two more recent studies have also focused on this younger age group (Bull et al., 2011; Clark et al., 2013), measuring children's EF and early numeracy starting very early. Bull and colleagues tested children as young as 2-years of age and included a battery of EF tasks meant to target a variety of skills. Mathematics ability was measured using the Applied Problems subtest of the Woodcock Johnson-Revised test. The results showed that EF was strongly related to mathematics abilities, and the correlation remained significant after controlling for IQ (as measured by the Picture Vocabulary subtest of the WJ-R). This is an important finding because some have argued that at this young age EF and IQ are contributing equally to cognitive development and may represent overlapping skills (Bull et al., 2008). Because the inclusion of IQ did not substantially decrease the relation seen between EF and math, it suggests that both EF and IQ and are making unique contributions to the developing mathematical skills. Notably, the age covariate included in the model was highly significant as well, yet the significant relation between EF and mathematics was still seen at all ages tested.

The second recent study looked at early numeracy and EF longitudinally across preschool (Clark et al., 2013). A large sample of children was tested at 3, 3.75, 4.5 and 5.25 years. The preliminary assessment included the Woodcock Johnson Brief Intelligence Assessment, the Test of Early Mathematics Ability (TEMA), and an EF battery. Subsequent testing included repeated administrations of the TEMA and the

Woodcock Johnson - Applied Problems subtest was administered at the final session. The EF battery consisted of three tasks assessing working memory based on maintaining information in mind (Delayed Alternation, Nine Boxes, and Nebraska Barnyard). Three tasks assessed inhibition based on requiring the suppression of a prepotent response (Shape School-Inhibit Condition, Big-Little Stroop, and a Go-No-Go task). The researchers found significant correlations between the Big-Little Stroop, the Shape School Inhibit and the Nebraska Barnyard tasks with mathematics measures at preschool. They also found high correlations within the math measures at the different time points, suggesting stability in mathematics performance. There was also evidence of a significant relation between a latent measure of EF and mathematics performance on the TEMA at 3, 3.75 and 4.5 and finally also for a composite mathematics score (TEMA and Woodcock Johnson Applied Problems) at 5.25 years of age. Clark et al. interpreted these results as suggesting there is a consistently strong relation between EF at age 3 and mathematics abilities over the subsequent two years.

Although these studies have indicated a relation between EF and mathematics ability, another developmental consideration relating to the structure of EF at this young age has arisen. Studies with younger children suggest that EF skills are not differentiated early in development and act more like a unitary system in the preschool period (Bull & Lee, 2014; Lee et al., 2012; Wiebe et al., 2011). Updating appears to separate around the time when children enter formal schooling, but switching and inhibition may not differentiate until even later (Lee et al., 2012). Researchers have suggested that this pattern relates to the development of the frontal lobe (Bull et al., 2008). When the functioning of the frontal lobe is compromised (either due to disability, or in this case, being not fully developed) it functions in a more limited capacity, and the various component skills of EF are less distinguishable. This includes evidence for stronger correlations between EF and intelligence at this age compared to older ages (Bull et al., 2008). This research suggests that to fully understand the relation between mathematics and EF in young children, a more unified framework of EF should be considered.

One recent study used a single broad measure of EF to determine its contribution to mathematics achievement in first grade, controlling for children's number sense in kindergarten (Hassinger-Das, Jordan, Glutting, Irwin & Dyson, 2014). In the study children with lower number sense ability (measured by the Number Sense Brief) in the fall of their kindergarten year were identified. Later in the year, EF was measured using the Minnesota EF Scale (Carlson & Zelazo, 2014), which assessed overall EF. Mathematics achievement was measured in first grade using the Applied Problems and Calculations subtests of the Woodcock Johnson III. Results indicated that EF uniquely predicted 1st grade mathematics scores, controlling for gender, age, English Language Learner status, and number sense in kindergarten. Interestingly, EF was a stronger predictor of success on the Applied Problems subtest than it was for the Calculation subtest. The authors interpret this result as EF impacting conceptual understanding of mathematics more than procedural learning of mental calculation at this age. A second 3-year longitudinal study also measured EF using a single broad measure (also the Minnesota EF scale; Carlson & Zelazo, 2014) and it was predictive of numerical task performance (over and above IQ) at both preschool measurement time points, but that EF abilities become less related to numerical skills across the preschool years (Chu, vanMarle, & Geary, 2016).

Recently researchers have begun using confirmatory factor analysis to better understand the underlying EF skills in younger age groups. Confirmatory factor analysis checks to see if data are better modeled by single or multiple latent factors. Some have argued that previous work has assumed a separation between the EF factors (and therefore measured them separately) rather than testing for the separation (Bull & Lee, 2014). Using this technique, researchers suggested that single factor models are in fact a better fit for data from preschool aged children (Wiebe, Espy & Charak, 2008; Wiebe et al., 2011; but see Miller, Giesbrecht, McInerney, & Kerns, 2012). This single EF factor was found to predict concurrent and subsequent mathematics skills at later ages and the relation remained significant when IQ was controlled for (Bull et al., 2011, Clark et al., 2013).

Developmentally, this pattern of differentiation (or lack thereof) is critical to understanding the relation between EF and mathematics because it is likely that the nature of the relation changes over time as the various EF skills mature. Few studies have looked at this relation experimentally and how variations in each skill set may impact the other.

Recently, the authors attempted to better understand this relation in preschool-aged children (Prager, Sera & Carlson, 2016). Across 142 typically developing 3- and 4-year-olds, a significant positive correlation was found between EF and general mathematics abilities in this age group (r = .53). This relation was found using a unitary measure of EF (the Minnesota Executive Function Scale) making these results among the first to demonstrate the presence of this relation in this age group using a comprehensive measure of EF.

The causal nature of this relation was also explored by varying the EF load on a magnitude comparison task. Results suggested that children at different ages seem to be depending on EF in varying amounts when making magnitude comparisons, and a developmental pattern emerged, wherein 3-year-olds' performance on the magnitude comparison task was worst when EF was taxed the most. Conversely, 4-year-olds performed well on the magnitude task despite varying EF demands, suggesting their EF abilities became less coupled with their magnitude comparison skills. This begins to suggest that EF is necessary for obtaining early mathematics understanding, but as that understanding matures, and specific skills become more practiced, less deployment of EF is needed for their successful expression. This study is consistent with neural imaging data in older children and adolescents showing that on two-operand mental addition and subtraction problems younger children showed increased activation in the prefrontal cortex than older children (despite comparable accuracy across ages) (Rivera, Reiss, Eckert & Menon, 2005). Again suggesting that as mathematics skills become more automatic fewer working memory and attentional resources are needed to solve the same problems.

Training Studies

Given the existing evidence, a crucial next step in understanding EF and early mathematics is exploring how improving one or both skills impacts the other.

Researchers have theorized that by improving EF abilities, children's mathematics performance will improve as well. Currently, only select components of EF and mathematics have been explored in training studies and these training studies have primarily looked at older children.

Holmes, Gathercole, and Dunning (2009) focused on 9 and 10-year-old children who were part of a larger cohort of children identified as having lower working memory capacities (at or below the 15th percentile on listening recall and backward digit recall tests of working memory). These children trained on a computerized working memory task that was either adaptive or non-adaptive. Children participated in the training for five to seven weeks. During that time they spent at least 20 days engaged in the training program for approximately 35 minutes at a time. Each training session consisted of eight tasks chosen from a possible 10 tasks. The tasks remained the same for five days at a time and then every sixth day one of the tasks was replaced with a new one. All of the training tasks required the participants to maintain and manipulate visuospatial and/or verbal information. The results of this study showed that children in the adaptive program group had significant gains in their working memory abilities, and these gains were sustained six months later. Children in this group also showed improvements in mathematics ability at the six-month follow-up test. No control group was included in this study, but similar gains were not seen in the non-adaptive test group.

A second training study looked at slightly younger children, 5-8-year olds (St Clair-Thompson, Stevens, Hunt, & Bolder, 2010). This study also used a computerized working memory training program that teaches memory strategies. Half the children participated in the game over a six- to eight-week period. The other half of children did not engage in training. Again the results showed an increase in working memory abilities after training. Children's mental arithmetic abilities also showed improvement but mathematics ability (as measured by standardized tests) did not increase at post-test or the delayed five-month follow-up session.

Another related study focused on training self-regulation broadly in at-risk pre-school aged children (Schmitt, Mclelland, Tominey & Acock, 2015). The intervention lasted for 8-weeks and consisted of two 20-30-minute classroom sessions where children played games meant to improve self-regulation (e.g., The Freeze Game). Improvements were shown in children's self-regulation skills based on the training. Interestingly, English Language Learners who received the intervention showed significantly improved mathematics abilities (as measured by the Woodcock Johnson Applied Problems) at the Spring time point compared to the control group and English only speakers who also received the intervention (who showed improvements in self-regulation but no transfer effects to mathematics).

A final study focused on working memory in kindergarten aged children (5-year-olds) and was the only study, to our knowledge, to combine working memory training and number information (Kroesbergen, van't Noordende, & Kolkman, 2014). In the study, children were assigned to a numerical or non-numerical working memory training group, or a no-training control group. The training lasted for four weeks and consisted of two 30-minute training sessions per week conducted in small groups. In the non-numerical training, children played games that required the activation and retention of information but explicit memory strategies were not taught. The training was individual and adaptive so that children received feedback and the instructor repeated items or provided extra practice based on children's performance. The numerical training again included the activation and retention of information but that information often included numerical and counting skills. Again, no explicit memory skills were taught, and the instructor adapted the activities to the child's performance. The control condition received no additional training outside of the classroom. The results of the study indicated that visuospatial working memory improved in both training groups compared to the control group. Only the numerical training group showed improvements on counting skills (as measured by the Early Numeracy Test- Revised) compared to the control group. The authors interpret this finding to suggest that training needs to be domain specific to see improvements. Still, this study confirms that both working memory and numeracy can be trained in this age group and that the combination of skills may lead to greater increases in both skills.

The reverse relation has also been found (Wang et al., 2015) where training in mathematics (specifically abacus-based mental calculation) can show improvements in working memory skills. In this traditional training method, children learn to calculate with a physical abacus and then move on to mental calculations, including sums of large of numbers. Research has suggested that this training is effective at improving mental arithmetic abilities and simple working memory (Li et al., 2013; Stigler, 1984). Most recently, improvements were also seen in children's response speed on switching tasks (Wang et al., 2015), suggesting that the abacus arithmetic training has benefits for cognitive flexibility as well. It should be noted that the abacus arithmetic training was intensive, consisting of a 2-hour session every week throughout their schooling. Improvements were seen after one-year and three-years of training.

For the current study, we aim to explore the effect of training further in this young age group. Previous work has focused on training EF skills with the hope of seeing improvements in that specific skill and potential transfer to mathematics ability. No study to our knowledge has investigated whether training EF is more beneficial than mathematics training alone and/or the possible benefit of training the skills concurrently. To do so, it is necessary to survey the established interventions for each skill set.

EF Interventions

Interventions for EF have proven that the skill has considerable plasticity and is malleable to change (see Diamond & Lee, 2011 for a review, but see Jacob & Robinson, 2015 for inconclusive evidence of curriculum based interventions). Interventions have included a variety of both in-school curricula and lab-based measures (e.g., Kloo & Perner, 2003; Lillard & Else-Quest, 2006). The interventions also vary in their design, including full school year curricula or curricular add-ons involving lengthy commitments, (e.g., Blair & Raver, 2014; Diamond, Barnett, Thomas, & Munro, 2007, Bierman et al., 2008; Raver et al., 2009). Other programs are substantially shorter, with among the shortest, requiring only two 15 minute sessions (e.g., Kloo & Perner, 2003; Espinet, Anderson, & Zelazo, 2013). The settings of EF interventions vary dramatically as well with some occurring in community settings such as schools (e.g., Bierman et al., 2008, Tominey & McClelland, 2011) and others in the the foster care system (e.g., Pears, Fisher, & Bronz, 2007; Pears, Kim, & Fisher, 2012)

Some of these training programs have been designed to train EF explicitly (e.g., Espinet et al., 2013; Diamond et al., 2007) whereas others have aimed at social-emotional competence and self-regulation more generally (e.g., Pears et al., 2007 and 2012) and have had additional benefits on EF. Interventions have varied in the specific skills they are targeting, but a common theme recently identified is the role that reflection and reflective processing plays. It has been hypothesized that increasing this reflective processing allows children to reflect on, formulate and maintain higher-order rules thereby allowing them to resolve conflicting information (Zelazo, 2015). As these skills develop (naturally or through training) in the preschool years, children are better able to solve tasks such as the dimensional change card sort (DCCS). This task asks children to first sort cards by one dimension (e.g., color; rule 1) and then to switch and sort by a second dimension (e.g,. shape; rule 2) (Zelazo et al., 2003). Children who can reflect on the different components of the task have been shown to perform better.

One program to highlight these skills trains children in successive sessions to reflect on the rule that they are currently sorting by in the DCCS (Kloo & Perner, 2003). The intervention included increased reflection by drawing attention to the relevant dimensions of the card (e.g., color) and the correct answer associated with that dimension (e.g., the green box). The results showed improvements on the DCCS compared to an active control group, and transfer effects were seen to a more complex EF task as well as a false belief task (Kloo & Perner, 2003). Espinet at al. (2013) replicated the main effect of reflection training on the DCCS in 4- to 5-year-olds (Cohen's $d = 1.43$), as well as extended it to an observed change in the neural correlates of EF using ERP imaging.

Mathematics Interventions

A recent systematic review summarized 16 peer-reviewed studies with controlled designs of preschool mathematics interventions and found effectiveness overall, but also a great deal of variability (Prager & Christ, in prep). There were promising effects of improving mathematics understanding in at-risk populations across all five domains of early mathematics: number concepts & quantities, number relationships & operations, geometry and spatial sense, patterns, measurement and comparison. It seems that the current programming is well aligned with the recommendations initially put forth by the NCTM and NAEYC, with the majority of studies including strong theoretical basis and emphasis on incorporating mathematics into everyday activities. These intervention activities are wide ranging (board games, computer applications, etc.) but are designed to be exciting to young children, allowing them to be actively engaged in their learning. The existing studies are divided in their focus, either on a single skill or broad mathematical abilities, and both approaches seem to be effective.

The hierarchical nature of mathematics learning makes it unsurprising that many studies looking at improving early mathematics understanding and proficiency in young children have focused on number sense (Arnold, Fisher, Doctoroff & Dobbs, 2002; Ramani & Siegler, 2008; Schacter & Jo, 2016). The studies have shown that improving number sense has benefits for many aspects of early mathematics including counting, recognizing and writing numbers, one-to-one correspondence, cardinality, comparison, understanding numbers and quantity, and addition and subtraction computation. It also appears that several of the studies that aimed to improve broad mathematics abilities still included a particular focus (both in activity design and in time allocation) on these earlier skills, most likely because of the age and skill level of the participants.

A recent program using this philosophy focused on foundational skills using numbers 1 through 10 (Sood & Jitendra, 2011). This intervention included four units and was administered in 20-minute sessions over four weeks to at-risk children in a high-poverty school. The units included spatial relationships, one more, one less, two more, and two less, benchmarks of five and ten (digit understanding) and part-part-whole relationships. Post-test measures at the end of the intervention showed a significant increase in all number measures for the intervention group compared to the control group (hedge's $g = .31 - 1.26$), and these effects remained at the 3-week retention test (hedge's $g = .27 - 1.20$).

Current Study

Based on this limited research it is still unknown the exact nature of the relation between EF and mathematics ability in young children, especially when EF is measured as a more unified construct rather than separate components. Additionally, the effect that training may have on this relation is unclear as the current work has been limited to the skill of working memory and has focused primarily on older children. The purpose of this study was to further explore the relation between EF and mathematics (including the specific foundational skill of number sense and counting) in young children through the training of these skills independently and together.

We proposed three hypotheses that were explored in the current study.

1. Number skills and counting training improves early mathematics abilities in preschool-aged children over and above a no training active control condition. The impact of number training on EF is unknown and therefore not hypothesized.

2. Reflective training in EF and training in number skills will improve preschoolers' overall mathematics performance, specific number counting skills and EF skills.

3. Performance on both EF and mathematics outcome measures will be most improved by training that combines number counting skills and EF.

Methods

Participants

Participants were recruited from 10 childcare centers throughout the Twin Cities metro area. The childcare centers were part of a larger network of child care providers, and each center volunteered individually to participate in the research study. Participants were 107 typically developing 3- and 4-year-old children (M = 48.38 months, SD = 6.23; 49% female).

Children were eligible to participate in the study if they were in the specified age range, spoke English and attended the childcare center more than once per week (to allow for minimal time between testing and training sessions). Children were excluded if they had developmental delays (e.g., Down Syndrome), were born prematurely (more than 3 weeks early), were non-English speaking, or had physical disabilities affecting their vision or hearing.

Participants were White, Non-Hispanic (75.0%), Hispanic (2.8%), Asian (5.6%), African American (7.4%), Native American (.9%) and Other (2.8%). The remaining participants (5.6%) did not indicate their ethnicity. The sample was primarily middle class with 12% of the families earning under $50,000 per year, 13% earning between $50,000 and $100,000, 28% earning between $100,000 and $150,000, 20% earning between $150,000 and $200,000 and 13% earning over $200,000; the remaining 14% of families did not report their annual income. Overall the sample was well-educated with 34% of primary caregivers having a graduate or professional degree, 6% with some graduate school, 41% with a Bachelor's Degree, 10% with some college and 1% with a high school diploma and the remaining 8% indicating other or not responding.

Three children (one from the number only training, one from the EF only training and one from the control group) were unable to complete the training because they either stopped attending the center during the training or their attendance changed so as not to be able to complete the training during the specified time frame (e.g., only attending one day per week) and are not included in further analyses.

Recruitment

Parents of eligible children were told about the study via a letter sent home by the childcare centers. Research staff were available during drop-off and pick-up times to meet with parents, answer questions and obtain informed consent for those interested in participating. Following parental consent children were randomly assigned to one of the four training conditions: EF only training (n = 25), number only training (n = 27), EF + number training (n = 27) or no training, a story-book reading control (n = 25). Families were compensated with a $10 Target gift card at the end of the training and children were given stickers after each session and small toys after completing the study.

Power Analyses

The sample size was determined based on the effect size for Espinet, Anderson and Zelazo (2013) and Sood and Jitendra (2011) which used similar protocols. An a priori power analysis using G*Power (v. 3.1; Faul, Erdfelder, Lang, & Buchner, 2007) indicated that a sample of 100 children should provide sufficient power (> .8) to detect a moderate to large main effect of condition assuming $\alpha = .05$.

Procedure

All testing was done in individual sessions at private locations within the childcare center (e.g., empty room, staff lounge, the hallway, away from other students) with trained research staff. Each child participated in five total sessions including one pre-test session, three training sessions, and one post-test session. A visual representation of the study design is shown in Figure 1. The pre- and post-test sessions lasted approximately 40 minutes, and the training sessions lasted for 15 minutes. The number of days between children's pre-test and post-test varied across participants (M = 12.34, SD = 4.05). This variability was due to differences in children's schedules and overall availability. Attempts were made to keep the distance as short as possible, but the timing was dependent on the child's schedule including how many days per week they attended the childcare center, if they attended for full days or half days, and absences due to sickness or vacation.

Pre-test session. Children's preliminary EF, math, and verbal abilities were tested at an initial session using the following measures: Minnesota EF Scale (MEFS), the Number Knowledge Test, Test of Early Mathematics Ability (TEMA), Head, Toes, Knees Shoulders (HTKS), and the Stanford Binet Verbal Knowledge Subtest. The same order of tasks was given across the conditions. Each of the measures will be described in greater detail below.

Training sessions. Training was conducted over three 15-minute sessions. Training sessions occurred during students' regular school day, typically not during academic time, meals or naps. Training sessions varied as follows based on condition.

EF Training. EF training was based on the procedure described by Espinet, Anderson, and Zelazo (2013). The training focused on the Minnesota Executive Function Scale (Carlson & Zelazo, 2014), a scaled version of the Dimensional Change Card Sort task (DCCS; Zelazo, 2006). In the task, children were asked to sort bivalent cards according to a certain dimension (e.g., color – blue and red) into boxes that are labeled with target cards (e.g., a red truck and a blue star). After sorting five cards by one dimension, the children are then asked to switch and sort by another dimension (e.g., shape – stars and trucks). Typically, young children will sort incorrectly after the switch, continuing to sort the cards by the previous rule. The EF scale includes several levels of sorting and switching increasing in complexity, first sorting by only a single dimension or separate dimensions, and then moving onto levels that include bivariate stimuli and switching the sorting rule on each trial. Because of the additional levels, the EF scale captures the full spectrum of skill and developmental levels. At each level, no matter the complexity, a rule switch occurs and children must change the way they are sorting the cards. The levels of the EF scale levels used in the training also closely match the levels of the MEFS administered at pre-test.

Using children's pre-test performance on the MEFS, reflection training started at the level that children had failed to pass initially. For example, if children passed levels 2 and 3 on the MEFS but failed to pass level 4, then the reflection training would begin on level 4. In the reflection training feedback (both positive and negative) was given. When children sorted the cards correctly, the experimenter would say, "Good Job" or "That's right!" If children sorted the card incorrectly the experimenter would indicate that that was not the correct box ("Oops, that's not right"). The experimenter would then draw attention to the features that the child sorted by that were not correct and then highlight the correct sorting dimension and the correct features on it. For example, if the child had continued to sort the card by color rather than switching and sorting the card by shape, the experimenter would say: "When you saw the blue one you put it in the box with the blue one on it. That means you are looking at the color. But we're not playing the *color* game right now, the game with *red* and *blue*, anymore. Now, we are playing the *shape* game, the game with *cars* and *trucks* (pointing at the appropriate pictures). Children were then asked to remember and say which game they were playing (e.g., the shape game), and they reviewed the shapes of the target boxes. Finally, they were given another card to sort correctly. A schematic representation of the levels in the EF training can be seen in

Figure 2. The full script for all levels of the reflection training is available in Appendix A. Feedback, and additional instruction occurred for every trial.

After children correctly sorted four out of five cards on both dimensions of the level the experimenter advanced to the next level. For example, if the child correctly sorted four out of five cards by color and then switched and correctly sorted four out of five cards by shape then the experimenter would move on to the next level. However, if the child only sorted two out of the five cards correctly by shape, then the experimenter would remain there, repeating the trials until a correct performance of 80% was reached, or the training session ended. If the training session ended and the child had not correctly sorted 80% of the cards on the current dimension, then the training would begin at the same level on the next day of training. The particular stimuli (i.e., target card pictures) differed for each day of training to keep the children interested and to promote generalizability. Equivalency of levels and pictures was maintained.

Number Training. Number training was based on the procedure described by Sood and Jitendra (2011). The goal of the number training was to use an established procedure to train a basic number skill that involved little to no executive function. Therefore, basic counting training was chosen using dot cards of varying quantities from 1 to 20.

The training began by introducing patterns of dots in groupings ranging from 1 to 20. All children started at the first level, and each saw the same dot cards (i.e., the same quantities). The first level of training was Experimenter Identification. At this level, the child was shown a dot card with a standardized array of dots and the experimenter labeled the number of dots (e.g., “This card has four dots.”). The card was then turned over, and the child was asked, “How many dots were there?” If the child responded correctly, the experimenter moved on to the next card. If the child responded incorrectly, then the experimenter said, “Oops that’s not quite right, let's check.” Then the experimenter turned the card over, and the experimenter and the child counted the dots together (touching each dot as they counted). Next, the experimenter asked again, “How many dots were there?” If the child still incorrectly labeled the number of dots the experimenter moved on and returned to the dot card later. Next, the experimenter showed the child two dot cards (in the same order they were initially presented) and said, “Here are some dots and here are some dots, which card has more dots?” If the child correctly pointed to the card with more dots, the experimenter said, “That’s right! This card had (ex. 8) dots, and this had (ex. 5) dots. Eight is bigger than 5, so we say 8 is *more than* 5.” If the child incorrectly pointed to the card with fewer dots, the experimenter said, “Oops! That’s not quite right, let’s count!” and the experimenter and child counted the dot cards together. After children correctly answered 80% of the trials, the experimenter moved on to the next level. This 80% criterion applied to all the levels and was chosen to best match the passing criterion used in the EF training.

For the second level, the child was asked to identify the number of dots themselves. Again, if the child could not identify the dots on their own then the experimenter and the child would count the dots together (touching each dot). Children were also asked to identify which was more between pairs of the dot cards. The third and fourth levels had children counting the number of dots, first in a new (but still standardized) arrangement (level 3), and then in a randomized array (level 4). If children were able to pass all four levels and time remained in the training sessions, then addition and subtraction trials were added. For these trials, the child was shown a card and the experimenter labeled the number of dots and asked the child how many dots there would be if one more was added. If the child responded correctly, the experimenter said, “That’s right!” and moved on. If the child responded incorrectly, then the experimenter would then put a card with one extra dot next to the original dot card and ask again, “If I added one more dot how many dots would there be?” Subsequent trials included adding two dots and subtracting (taking away) one or two dots. A new card with two dots or a blank card (used to cover up dots) was used if children were unable to respond correctly on their own. A schematic representation of the levels for the number training can be seen in Figure 3. The full script for each level of the Number training is available in Appendix B. As mentioned, children remained at each level until they were able to respond correctly to 80% of the trials. If the training time ended in the middle of a level, then the experimenter began training at the same level on the next day. To maintain similarities across the training conditions and to increase children’s level of interest, the color of the dots changed for each day of training.

EF + Number Training. The EF + Number training was a combination of the Number and EF training procedures described above. Again, children were shown cards of varying quantities ranging from 1 to 20. However, instead of cards with arrangements of dots, children saw cards with arrangements of pictures. The pictures matched the stimuli presented in levels 4 – 7 of the EF training. For example, if in the number training children saw a dot card with 5 dots on it, and the EF target cards were red trucks and blue stars, then the equivalent card in the EF + Number training would be 5 smaller pictures of stars and trucks (examples of the EF + Number cards and their equivalences can be seen in Figure 5).

Using these picture cards, children progressed through various levels of EF + Number training. All the children began at the first level and were shown the same quantities on the cards. Similar to the other training procedures, children moved on to the next level after they correctly answered 80% of the prompts on a particular level.

All children started at the first level, described as the Number Game. For this level, the children were shown a sample card and told that in this game they counted all the pictures. This level was included to ensure that children had exposure to higher numeral quantities to match better the quantities used in the Number training condition. Once children were able to correctly count 8 of 10 cards presented they moved on to the second level, the Color Game. In the Color Game children were again shown a sample card and told that in the Color game they would count the red ones and then the blue ones (with the experimenter pointing to the correctly colored pictures). The children were then asked, “How many red ones are there?” If they answered correctly, then they were asked, “How many blues ones are there?” If children counted incorrectly at either point, then they were given reflective feedback, reminding them of the rules of the game, and then assistance counting the pictures again. After correctly counting the pictures by color the experimenter then asked, “Are there more red ones or more blue ones?” Again, children were given feedback based on their answer and assistance counting if they answered incorrectly.

After completing the Color game children moved on to the Shape game. They were shown a sample card and told that now they would be playing the Shape game, where they counted trucks and stars (with the experimenter pointing to example pictures). Children were asked how many trucks there were and then how many stars there were. If the children counted incorrectly or continued to count according to color rather than shape, then they were given reflective feedback, reminding them that they were now playing the shape game (not the color game) and reiterating the rules. This reflective feedback was modeled off the feedback given to the children in the EF training condition. Once children had correctly counted the pictures by shape, they were asked if there were more trucks or more stars and feedback based on their answer was given. After answering correctly on 80% of the trials, the children moved on to the Combination Game where they had to switch between the Color Game and the Shape Game at each trial. The experimenter would show they child a card and say, “Play the Shape Game” or, “Play the Color Game.” If children counted the pictures incorrectly they were given the same reflective feedback described above. The final level of the EF + Number training was Addition/Subtraction. Children were shown a card and asked how many there would be if one more as added. These prompts varied between the shape and color game as well as addition of 1 or 2 objects and subtraction of 1 or 2 objects. An example prompt would be “There are five red ones. What if I added *one more red one*, how many red ones would there be?” The next trial might then be, “There are three trucks. What if I *took away two* *trucks*, how many trucks would there be?" Similar to the Number training, if the child could not answer correctly on their own then an additional card with the extra pictures or covering the pictures would be placed next to the original card to assist them. A schematic representation of the levels in the EF + number training can be seen in Figure 4. The full script for each level of the EF + Number training is available in Appendix C.

Similar to the other training procedures children progressed through the levels during the 15-minute training sessions. If the time ran out in the middle of the level than the experimenter would start at that same level during the next training session. Additionally, the stimuli (i.e., pictures on the cards) varied for each day of training, matching the target card pictures used in the EF training. Examples of the cards used for each day of training and the equivalency across training conditions can be seen in Figure 5.

Story-Book Control. The control condition consisted of story-book reading with the child. The child was given a choice of 5 stories to read during the session based on a pre-selected group of options. Books were screened to ensure that they didn't contain any number or EF content in the story. Children read with the experimenter for 15 minutes (typically finishing one or two stories).

Post-test session. The post-test session closely mirrored the pre-test session. The MEFS, Number Knowledge Test, TEMA, HTKS, and Stanford Binet Verbal Subtest were re-administered to all children using a different form than was used at pre-test.

Measures

Minnesota EF Scale (Carlson & Zelazo, 2014). EF was measured using the MEFS for iPad. The MEFS is a virtual card sorting task that is an age-appropriate, brief, reliable and valid measure of EF abilities from 2-7 years of age, having national U.S. norms. Children were given Form A at pre-test and Form B at post-test. A small subgroup of the sample was given Form A at both pre-test and post-test because Form B had not been developed yet. Testing began automatically at age appropriate starting points according to task instructions. Testing progressed in a forward manner if a criterion (4 out of 5) score was met for each level. If the criterion score was not met the examiner moved backward according to the instructions given, until a lower level was passed (basal). Testing continued until the child failed a level after their basal had been established. Individual items closely mirrored the items on the EF scale in the EF training condition and consisted of the child correctly or incorrectly sorting cards based on the rules of the particular level. The MEFS used different stimuli across all levels than those used for the EF training. The final score was computed by the MEFS software using an algorithm that combined information about the child's errors, highest level passed, highest level attempted and the child's reaction times during the test trials.

Number Knowledge Test (Griffin & Case, 1997). The Number Knowledge Test was administered to measure basic number sense and counting skills. Children were asked a series of questions looking at their understanding of counting, number sequencing, and other related skills. Children were given a score of one (correct) or zero (incorrect) for each item. All children started at the beginning level of the test, asking them to count from 1 – 10. Children progressed through the levels of the test (up to level

4), with each level having its own continuation criterion and discontinue rule. A final score was calculated by summing the score for each item administered. Children were administered Form A of the Number Knowledge Test at pre-test and an equivalent Form B at post-test.

Test of Early Mathematics Ability 3 (Ginsburg & Baroody, 2003). General mathematics abilities were tested using a modified version of the Test of Early Mathematical Abilities (TEMA). The TEMA covers a wide range of early mathematics topics and to increase the ease and efficiency of testing, the individual items were rearranged to group similar problem types together. For each problem, children were given applicable visual and/or auditory prompts. The majority of questions were administered using the provided picture book, but some questions also required a worksheet, visuals, or manipulatives. The administrator read the directions to the child, following the picture book's specific examples. The child answered based on the directions. Most answers were verbal or pointing, but some required writing or manipulating objects. All children began at the beginning of the test. Each item was given a score of one (correct) or zero (incorrect). Several items included multiple parts and were therefore only counted correct if children answered the required number of parts correctly. Despite the rearrangement of questions, the end of the test followed the standardized procedure. The test ended when the children answered five consecutive problems incorrectly (ceiling). Total scores were calculated as a sum of all the items administered up to the ceiling. Children were administered Form A at pre-test and Form B at post-test.

Head Toes Knees and Shoulders (Ponitz, McClelland, Matthews, & Morrison, 2009). To look at generalization, EF abilities were also measured using the Head Toes Knees and Shoulders (HTKS). This task begins with the experimenter asking the child to touch his/her head and touch his toes. The experimenter then explains that the child should do the opposite of what they say (e.g., touch their head when they say touch your toes, etc.). Scoring is based on a 0, 1, 2 scale with partial credit awarded for self-correction. A second level (shoulders and knees) and third level (combination of both pairings) were administered if children correctly answered more the 50% of the test trials at level 1. A final score was calculated as a sum of all 20 test trials. Children were administered Form A at pre-test and equivalent Form B at post-test.

Stanford Binet Early 5 Verbal Abilities (Roid, 2005). General verbal abilities were measured using the verbal abilities subtest following the standardized procedures. Children were asked to identify objects and describe common words. Children received as score of 0, 1 or 2 based on the quality of their response according to the testing manual. Testing continued until 4 consecutive scores of 0 were obtained. Final scores based on the number of correct responses were calculated.

Parent Questionnaire. Parents were asked to complete a brief demographic questionnaire. This measure included questions about developmental delays, hospitalizations, primary language (spoken by the child and at home), ethnicity of the child, primary caregivers, household income and parental education levels.

Results

Preliminary Analyses

Descriptive statistics for all measures showed that mean scores at pre-test and post-test were within the typical range for 3 and 4-year-olds (Table 1). However, this analysis revealed that there was a floor effect on the Head, Toes, Knees, Shoulders task (Table 1; at pre-test: skewness of 1.41 (SD = .24), kurtosis of .76 (SE = .47) and post-test: skewness of .70 (SD = .24), kurtosis of -.86 (SE = .47)). Based on the task scores it could not be confirmed that the children understood the task and therefore it was not deemed to be an accurate measure of their abilities. Therefore, this task was not included in further analyses.

Preliminary analyses also included looking at the correlations between all measures used (Table 2). Based on these correlations a composite SES score was created created. Caregiver Education level and Family Income were highly correlated, $r(81) = .60$, $p < .001$ and so a composite SES score was created by standardizing both scores and taking the average for each participant. Scores on the Number Knowledge Test and TEMA were highly correlated at pre-test, $r(104) = .74$, $p < .001$ and at post-test, $r(104) = .63$, $p < .001$ but the measures were analyzed individually (as opposed to creating a composite) because of their unique relations to children's math skills with the Number Knowledge test measuring children's specific number skills and the TEMA measuring more general mathematics abilities.

A series of one-way Analyses of Variance (ANOVAs) confirmed that there were no systematic differences between conditions on any outcome measure of interest, age, or gender at pre-test.

Training Condition Differences

We further tested our hypotheses in four parallel, mixed-design 4x2 ANOVAs with condition (EF only training, number only training, EF + number training and control) as a first, between-subjects factor and testing time (pre-test vs. post-test) as a second, within-subjects factor. The first ANOVA looked at EF ability (MEFS score) as an outcome measure, the second looked at specific counting abilities with the Number Knowledge test as the outcome measure, and the third look at generalization to other mathematics skills, using the TEMA. The final ANOVA looked at verbal ability based on scores from the Stanford Binet verbal subtest. This final ANOVA was meant as a control since no improvement based on training was expected for this measure.

The initial ANOVA on EF abilities showed a significant main effect of time, $F(1, 100) = 13.23$, $p = .001$, $\eta^2 = .12$. These analyses also revealed a significant interaction of time x condition on the MEFS measure, $F(3, 100) = 2.51$, $p =.06$, $\eta^2 = .07$ (Figure 6). Post hoc tests revealed the greatest improvements from pre-test ($M = 37.00$, $SD = 12.24$) to post-test ($M = 47.76$, $SD = 13.79$) were in the EF training condition, $t(24) = -3.75$, $p = .001$, however, significant improvements were also seen in the number training condition, $t(26) = -2.26$, $p =.03$). Significant improvements were not seen in the EF + number training condition or in the story book control condition (ps = .56 and.46, respectively).

The second ANOVA on counting skills showed a significant main effect of time, $F(1, 100) = 24.47$, $p < .001$, $\eta^2 = .20$. The interaction of time x condition on the Number Knowledge measure was not significant ($p = .19$). However, planned post hoc tests revealed significant improvements from pre-test to post-test in the number training condition, $t(26) = -3.51$, $p = .002$ and the EF + Number training, $t(26) = -3.84$, $p = .001$, as well as marginally significant improvements in the EF training condition, $t(24) = -1.94$, $p = .06$. Significant improvements were not seen in the story book control condition, $p = .43$ (Figure 7).

The third ANOVA looking at generalization of training onto other mathematics skills showed a significant main effect of time, $F(1, 100) = 24.47$, $p < .001$, $\eta^2 = .20$. The interaction of time x condition on the TEMA measure was not significant, $p = .19$. However, planned post hoc tests revealed significant improvements from pre-test to post-test in the number training condition, $t(26) = -2.58$, $p = .02$ and the EF + Number training, $t(26) = -2.14$, $p = .04$. Significant improvements were not seen in the EF training or the story book control conditions, *p*s = .56 and .49, respectively (Figure 8).

The fourth ANOVA with the Stanford Binet verbal subtest showed no main effect of time, $p = .15$ or interaction with condition, $p = .43$. The planned post hoc tests also revealed no significant improvements from pre-test to post-test in any group, *p*s = .14 - .93.

After these primary analyses, a rank variable (using a median split) was created for participant's pre-test score on the MEFS. A similar variable was attempted pre-test score on the Number Knowledge test but the distribution among the conditions of high and low initial scores made this unfeasible. The initial EF variable was entered as a covariate in the ANOVA described above to see if participant's initial EF abilities impacted the effect of training on EF.

The ANCOVA on initial EF levels showed that the significant main effect of time, $F(1, 96) = 20.35$, $p < .001$, $\eta^2 = .18$ and the time x condition interaction, $F(1, 96) = 4.68$, $p < .004$, $\eta^2 = .13$ were maintained after controlling for initial EF levels. Additionally there was a significant interaction between time and initial EF level, $F(1, 96) = 32.22$, $p < .001$, $\eta^2 = .25$. Post-hoc tests reveled that across all training conditions the significant time x initial EF level interaction was led by the group who had lower EF scores at pre-test (*p*s = .02 - .001).

The participant's SES level (composite with parental education level and family income) and training progress (how many levels children completed during their three training sessions) were both looked at potential moderators. Neither variable significantly impacted the relations described above.

Discussion

The primary objective of the current study was to explore the relation between EF and mathematics in young children through the training of these skills independently and together. Specifically, preschool aged children participated in one of three training conditions: training EF skills independently, training number skills independently, training EF and number skills combined, or an active control comparison condition (story book reading). Our results showed that both mathematics (generally, and specific number counting skills) and EF skills improved as a result of training and training the skills independently showed improvements on the other skill sets as well. Across all analyses of interest, a significant main effect of time was found, suggesting an improvement from pre-test to post-test across all measures, with the exception of the measure of verbal ability where no improvements were expected.

First let's consider training outcomes on EF. Not surprisingly given the shared methods, the EF training showed the greatest improvement on the MEFS outcome measure. Interestingly, though, the Number training condition, which had no surface similarity to the MEFS, also resulted in improved MEFS scores, suggesting some degree of transfer from mathematics training to EF. Given this pattern, it is unclear why EF + Number training did not show significant improvements on the MEFS. Additional analyses also found that, across conditions, the participants who had lower levels of EF initially benefitted more from the training. For these participants all three types of training (EF only, Number only and EF + Number) led to improvements in EF at post-test. This finding is in line with other research on EF interventions that suggests those who start lower benefit most from training (e.g., Bierman et al., 2008; Flook et al., 2010; Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005; Tominey & McClelland, 2011).

When considering outcomes on mathematics, number training showed significant improvements on specific counting skills using the Number Knowledge Test and on more general mathematics abilities using the TEMA. EF+ number training also resulted in significant improvements in both mathematics outcome measures (Number Knowledge

Test and TEMA), and these improvements were comparable to the gains seen in the number only training condition. Finally, there was evidence of transfer from EF training to math, but this was limited to the Number Knowledge Test and did not extend to general mathematics abilities as measured by the TEMA.

Our results differ slightly from those found by Kroesbergen and colleagues (2014), in the only previous study to combine working memory and number information in trainings. As previously reviewed, this study (with slightly older children) found that both the non-numerical working memory training and the numerical working memory training led to improvements in working memory, but only the numerical working memory led to improvements in counting skills compared to the control condition. The authors suggested that this means training should be domain specific to be effective. While we too found that EF training and number training led to improvements in EF skills, we also found that EF training had marginal effects on young children's counting skills. Additionally, unlike the findings of Kroesbergen and colleagues, we did not find that training the skills in combination had a positive effect on EF skills.

Two factors may be contributing to these divergent findings. First, while Kroesbergen and colleagues (2014) focused on working memory training, we attempted to train EF more broadly. It is possible in doing so we were able to improve EF skills more generally, that then positively impacted participants number skills. Additionally, the children involved in our study were younger (3 and 4-year-olds as opposed to 5-year-olds). Given that the counting skills of 3 and 4-year-olds are likely different than those of 5-year-olds, it is possible that the EF skills that were improved during our training were more influential because of the differing level of counting abilities. Research has suggested that as skills become more automatic they may require less EF resources (Prager et al., 2016; Rivera et al., 2005). Perhaps then, the counting skills being measured by Kroesbergen and colleagues (2014) were less challenging for the older children and were thereby less impacted by improvements in working memory, whereas the younger children in our study were more likely to still be recruiting additional EF. As the training improved these skills, their number counting skills improved in tandem. The lack of effect of training the skills in combination that we found was still surprising given the results of Kroesbergen (2014) and this will be discussed further below.

Overall our results relate to an open question in regard to the association between EF and mathematics abilities, that of directionality. Theoretically, it is believed that EF affects children's ability to succeed in school because of the connection to the underlying cognitive processes of learning (Anghel, 2010), and thereby acts as a prerequisite skill or support for understanding mathematical concepts or literacy (Clements, Sarama & Germeroth, 2016). As mentioned previously, this may be represented as inhibiting previous understandings of numerical relations to learn new ones, such as learning multiplication after learning addition. Similarly, when solving a problem, students must use working memory and switching skills to keep the ultimate goal of the problem in mind while subsequently solving individual steps (Geary, Hoard & Nugent, 2012). Although longitudinal studies have supported this theoretical relation of EF as a predictive skill for mathematics achievement (Chu et al., 2016; Clark et al., 2010; Grimm, Steele, Mashburn, Burchinal & Pianta, 2010), it is also possible that the reverse relation exists as well. Previous studies using EF skills to predict later mathematics achievement have often not measured early mathematics abilities, making it difficult to know the influence of early mathematics skills (Bull et al., 2008). One recent longitudinal study did include an early measure of mathematics skills and found EF (working memory specifically) and mathematics achievement predicted each other (van de Ven, Kroesbergen, Boom, & Leseman, 2012).

The current study further supports these findings and presents evidence for a bidirectional relationship between the skills. Notably, the number training significantly increased children's performance on the EF measure and the reverse was true as well. Although only marginally significant, EF training also resulted in improvements in children's number knowledge and counting abilities. Again, this suggests that perhaps the skills are mutually benefitting each other, and when one skill set increases, there are improvements to the other as well.

These results are especially noteworthy given the evidence suggesting that EF is difficult to train (Diamond & Lee, 2011) and that EF training often does not generalize (Mackey, Hill, Stone & Bunge, 2011; Rueda et al., 2005; Thorell et al., 2009). Instead, in this study neither of these claims were supported. EF skills improved through direct training as well as from indirect training (specifically through improving counting skills and mathematics abilities). Additionally, EF training was related to improvements in counting abilities and number knowledge, suggesting some transfer of training across domains.

Interestingly, the improvements from the EF training were only seen on the specific measure of counting and number sense (Number Knowledge Test), and no improvement was seen on the more general measure of mathematics ability (TEMA). Typically, the relation between EF and mathematics skills has been based on general measures of mathematics ability and the type of mathematical skill being measured is not discussed (Cragg & Gilmore, 2014). Even when a certain skill is measured, the conclusions are often regarding broad mathematics abilities. One major reason for this discrepancy is the prevalence of standardized tests of mathematics in this literature (e.g., Woodcock Johnson Calculation and/or Problem Solving, etc.). Often these tests include multiple skills including factual understanding, conceptual knowledge, and procedural abilities. All of these components may be contributing to a successful performance but may not all be equally related to EF. In fact, our data suggest that the EF training – at least at this preschool age – was most effective for the specific skill set of counting and less beneficial for general mathematics abilities. Still, conclusions about the larger relation of mathematics and EF based on these results should be taken with caution. As mentioned, the improvement on the Number Knowledge Test by the EF training group was only marginally significant, and it is possible that significant improvements could also be seen on the TEMA (generalized mathematics abilities) if the training lasted longer or if the study included additional post-test measurement points.

Looking at the pattern of results in the number training condition it is also difficult to piece apart the specific reasons for the improvement. Because the number training resulted in significant improvements on both specific counting skills (Number

Knowledge Test) and generalized mathematics abilities (TEMA), it is unknown which of these skill areas (if either, or both) was influential in promoting the improvements seen in EF skills. Relatedly, improvements were seen on both areas of mathematics skills for the EF + Mathematics training condition as well but, unlike with the number training, those improvements did not translate to benefits in EF skills. Therefore, it seems that something specific to the number training condition was influential in improving EF skills.

The lack of improvement on EF in the the EF + Number condition was surprising and contrary to our original hypotheses. While the combination training did result in improvements in mathematics abilities, those improvements were similar to (and not greater than) the improvements seen in the number only training. Conversely, the improvements seen on EF skills from the EF training were much larger than the improvements seen from the combination training and, in fact, the EF + number condition did not result in significant improvements on EF skills. The possible explanations for these results are varied. Perhaps, while the EF + number training was created to be a combination of skills training, in practice, it was primarily a number sense/counting training. It seems possible that when presented with so much additional information including counting, shape, color and reflection all within the same brief intervention students may have been overwhelmed and confused. Due to possible confusion or simply attentional preferences, perhaps children chose to attend to number and counting rather than the attributes (e.g., color and shape) of the pictures they were counting. This would begin to explain the results which showed improvements in counting skills but not in EF skills. Curiously, as already discussed, in the number training condition, this focus on counting skills did, in fact, lead to improvements in EF skills making it unclear why one type of training led to improvements and the other did not.

This again leads to the question, what component or components of the number training were beneficial to EF skill building? One possibility is that the number training inadvertently included EF training. While attempts were made to remove as much of the EF as possible from the number training to keep it pure, this proved both difficult and fairly artificial to do. As mentioned, mathematics understanding is highly correlated with EF skills and it is likely that the two skills sets are mutually beneficial (Bull & Lee, 2014; Clements et al., 2016; Cragg & Gilmore, 2014). Therefore, it is possible that EF was still being trained in the number training condition. For instance, in the later stages of training, when the dots were randomly arranged, children may have used working memory to remember which dots they had already counted. Similarly, for those students who found the number training especially challenging, it is possible that other secondary skills in the form of EF were being utilized. While typically counting is not thought to involve EF skills, for a child who is just learning this pattern, it is possible that they are utilizing skills like inhibition (e.g., not calling out a different number that is not in order), shifting or overall attention skills. Therefore, while not explicitly designed to do so, perhaps the number training condition was, in fact, an EF training condition as well, and trained EF skills more effectively than the EF + Number combination condition did.

The proposal that the simple process of learning mathematics may be beneficial to EF skills has been discussed recently (Clements et al., 2016). According to this framework, mathematical activities may inherently strengthen EF processes through the scaffolding of these skills in the problem sets. For example, the narrative structure of a story problem may assist children in translating the information into a systematic and logical problem framework that has identifiable steps and solutions. While this sequence certainly relates to mathematical skills it may also be building EF proficiencies.

Similarly, it has been suggested that EF skills benefit the most when students are engaged in the process of learning (as opposed to demonstrating skills that they already have). Research in the realm of EF intervention has supported this possibility, demonstrating that the most effective interventions are those that target the most difficult EF skill sets and that provide continued challenges throughout training (Diamond & Lee, 2011). Therefore, it seems logical that when children are learning new and challenging mathematics concepts, their EF abilities would be most engaged as well.

This hypothesis has been further supported by neuroimaging literature. Neural measures with older children and adults have suggested a developmental pattern of activation. This pattern shows diffuse activation in younger ages that becomes more focal with age for both mathematics skills and EF (Ansari, Garcia, Lucas, Hamon, Dhital, 2005). Specifically, when asked to compare magnitudes, children showed increased activity in the frontal areas such as the medial and inferior frontal gyri while adult activity was greatest in the posterior parietal areas. The parietal regions are more associated with numerical cognition and less with memory and attention, suggesting that

EF is utilized less for mathematics problems in later development, as the skills become more rote and less new learning is occurring.

Two studies comparing neural patterns in 7- and 9-year-olds showed increased activation in the frontal regions (including the dorsolateral and ventrolateral prefrontal cortex) for the children who used more sophisticated problem solving strategies (Cho, Ryali, Geary, Menon, 2011; Rosenberg-Lee, Barth & Menon, 2011). These findings suggest that those children who were more advanced actually had increased activation in the areas more related to EF. Researchers have interpreted these findings as demonstrating a greater recruitment of attention and EF followed by a decrease (Cragg & Gilmore, 2014) although the differences in activation could also be related to the task type (arithmetic versus magnitude). Importantly, neither of these studies measured activation for EF skills specifically so all the conclusions are based on the presumed areas related to these skills. Future work should correlate the activity seen for both mathematics and EF tasks and look at how the activation changes in relation to learning.

Future Directions

Future studies should examine the possibility that the number training in this study in fact trained EF by further varying the amount of EF that is included in the mathematics programming. This should be done with caution as our data also suggest that a full integration of the two skills is overall less effective at improving EF, although it was equally effective at improving math. It is also possible that the integration used in this study tried to cover too much information in too short of a time period, overwhelming the children and ultimately producing less benefit. This possibility could also be tested by using varying levels of integration to see if there is a tipping point where the training becomes more or less effective.

Another interesting future direction is to see if the effect of training varies by type or level of mathematics that is targeted. As mentioned, the distinction between different types of mathematics skills is rarely made (Cragg & Gilmore, 2014). EF training led to benefits on the specific counting measure (Number Knowledge Test) and the number training led to improvements in EF skills (MEFS), but a similar pattern was not seen on the measure of general mathematics abilities (TEMA). EF training did not lead to improvements on this measure. Is there something specific about EF and number sense skills, or would another mathematics measure that was similarly targeted also show benefits from the EF training? Future studies should explore other specific mathematics skills to see if EF training can help them, and whether training those specific skills can have a positive effect on EF abilities. Furthermore, as Chu and colleagues (2016) and others have suggested, it is possible that the role EF plays in mathematics understanding changes with time. Perhaps the role of EF is largest as new skills are acquired and becomes less important as these skills develop. Or perhaps, EF is generally more important when children are younger, and have fewer foundational skills, and becomes less important as mathematics learning becomes more specific. It would be interesting to target different, specific skills at different ages to determine if EF is most influential when a skill is being newly learned and/or when the targeted skill is appropriate to the child's developmental and mathematical ability level.

The issue of changes across development is also of interest because of the changes seen in EF. As mentioned, in the preschool years EF exists mostly as unitary system that begins to differentiate into the component parts as children enter kindergarten (Bull & Lee, 2014; Lee et al., 2012; Wiebe et al., 2011). Relatedly, a recent factor analysis showed two distinct components of EF at kindergarten, a working memory-flexibility factor and an inhibition factor (Viterbori, Usai, Traverso, & De Franchis, 2015). Longitudinal data suggested that the working memory-flexibility factor was a significant predictor of composite math scores as well as written calculation (at first grade) and problem solving and arithmetic fact performance (at third grade) (Viterbori et al., 2015). It would be interesting to then see if as EF becomes more differentiated, if training it skills individually might have differential impacts on mathematics outcomes.

Limitations

Despite the promising results described above, this study has several limitations which should be acknowledged.

A limitation of the current study was the lack of opportunity to study generalization of EF skills. While the Head, Toes, Knees, Shoulders (HTKS) task was included in our testing battery to provide this analysis, the measure proved too difficult for the study sample and floor effects were seen at pre-test and post-test across conditions. The HTKS task was hence not included in additional analyses. Therefore, it is unknown whether the EF training could have generalized to other measures of EF outside of the specific measure that was being trained. Still, the effect of EF training on counting skills does suggest that perhaps transfer of EF to other domains did occur.

Another limitation of the current study was the lack of a delayed post-test session. Because of the study design, the length of time between pre and post-test was fairly short and it is unknown if the improvements seen would remain – or even increase – at a later post-test after the training had ended. Furthermore, given that significant improvements were seen after a brief period of training, it is likely that longer periods of training may lead to increased durability of the benefits.

Finally, the conclusions that can be drawn from our data are somewhat limited because of our sample. Although efforts were made to include a diverse sample, our participants were largely Caucasian and of upper-middle socio-economic status based on both family income and levels of parental education. Therefore, it is unknown how our results would differ for children from less privileged backgrounds. Research suggests that children from disadvantaged backgrounds tend to have lower academic achievements as well as lower EF skills (e.g., Hackman & Farah, 2009). It is unknown how children from this population might respond to training as research on the subject is mixed. Some research suggests that children from extremely low SES backgrounds do not benefit as greatly from EF training (Raver et al., 2008), whereas other research has shown that these children show an increased benefit (Schubert, in prep). This final study is particularly applicable because the training administered closely mirrored the EF training condition in the current study.

Conclusions and Implications

Ultimately this study suggests that brief interventions targeting EF and number skills can be effective for improving those skill sets. We were also able to show that training EF skills could have a benefit on specific mathematics abilities and that training number knowledge also benefitted students' EF skills. Contrary to our original hypothesis, training EF and mathematics skills in combination did not lead to increased improvements in both skill sets. The training did lead to significant improvements in both children's specific and general mathematics abilities, but there was no benefit to children's EF skills. Future work should continue to look at the possibility of training the skills in combination, both by simplifying the overall training to see if benefits can increase and by lengthening the training to see if the skills can be better improved when given more time. This work could also benefit from incorporating activities into classrooms and daily mathematics learning activities (rather than engaging children in separate, individual training sessions).

Importantly, this work also strengthened the argument that the relation between EF and mathematics skills is bidirectional. The majority of theoretical and empirical work in the past has focused on EF skills as a prerequisite or boost to mathematics abilities. Our study supported this with evidence that training EF led to marginal improvements in mathematics skills. However, the current study also suggests that improving mathematics skills, and possibly the process of learning in and of itself, may benefit EF skills as well. Ultimately, this study has shown that mathematics and EF are distinct skills that benefit most when trained directly but, even through this direct instruction, improving one skill set can have positive effects on the other.

Table 1

Descriptive Statistics for All Measures at Pre-Test and Post-Test

Measure	Pre-Test Range	Pre-Test Mean (SD)	Post-Test Range	Post-Test Mean (SD)
Minnesota EF Scale	3-73	35.66 (13.58)	3-90	40.48 (14.18)
Number Knowledge Test	0-11	4.07 (2.56)	0-14	5.22 (3.10)
Test of Early Mathematics Ability	0-27	10.56 (5.98)	0-33	11.43(6.11)
Head, Toes, Knees, Shoulders	0-43	7.16 (11.08)	0-39	10.30 (11.60)
Stanford Binet – Verbal Subtest	8-27	17.95 (3.55)	9-26	18.39 (3.48)

Table 2

Bivariate Correlations Between All Measures

Measure	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
1. Age (months)	--													
2. Gender	.16	--												
3. Caregiver Education	-.11	-.04	--											
4. Income Level	-.12	-.05	.60***	--										
5. Pre-MEFS Score	.43***	.02	.16	.18	--									
6. Post-MEFS Score	.43***	.05	.11	.07	.54***	--								
7. Pre-Number Knowledge Test	.54***	.03	.11	-.02	.56***	.49***	--							
8. Post-Number Knowledge Test	.54***	.15	.06	.05	.50***	.58***	.64***	--						
9. Pre-TEMA	.61***	.13	.08	.07	.62***	.60***	.74***	.75***	--					
10. Post-TEMA	.46***	.06	.10	.05	.50***	.50***	.50***	.63***	.68***	--				
11. Pre-HTKS	.40**	.01	.14	.11	.40***	.30**	.50***	.54***	.55***	.47***	--			
12. Post-HTKS	.54***	.04	.02	.07	.47***	.48***	.60***	.55***	.68***	.51***	.68***	--		
13. Pre-Stanford Binet	.18	.06	.15	.11	.30**	.35***	.28**	.36***	.34***	.25**	.37***	.39***	--	
14. Post-Stanford Binet	.34***	-.03	.11	.18	.37***	.37***	.39***	.30**	.40***	.30**	.35***	.55***	.63***	--

Note. *$p < .05$ **$p < .01$ ***$p < .001$

Figure 1

Study Design

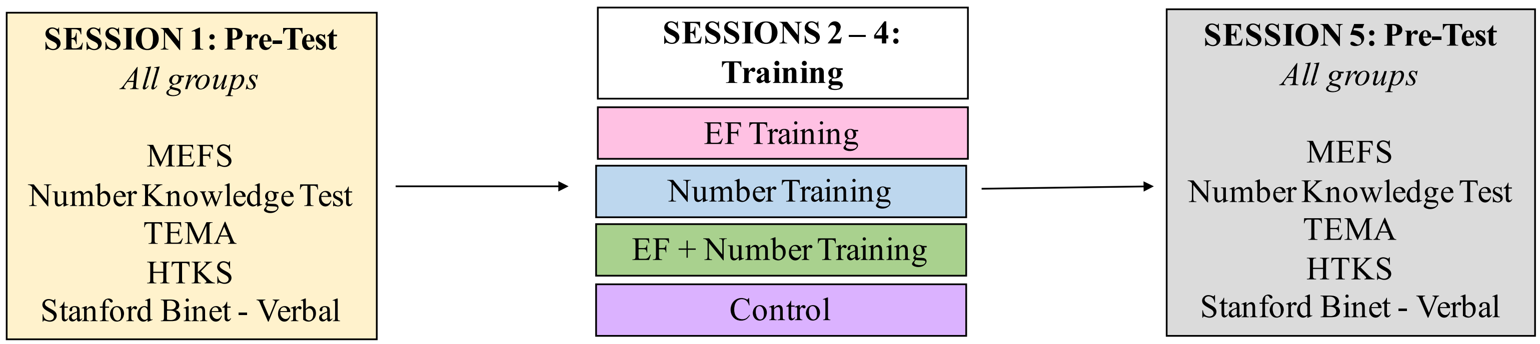


Figure 2

EF Training Levels

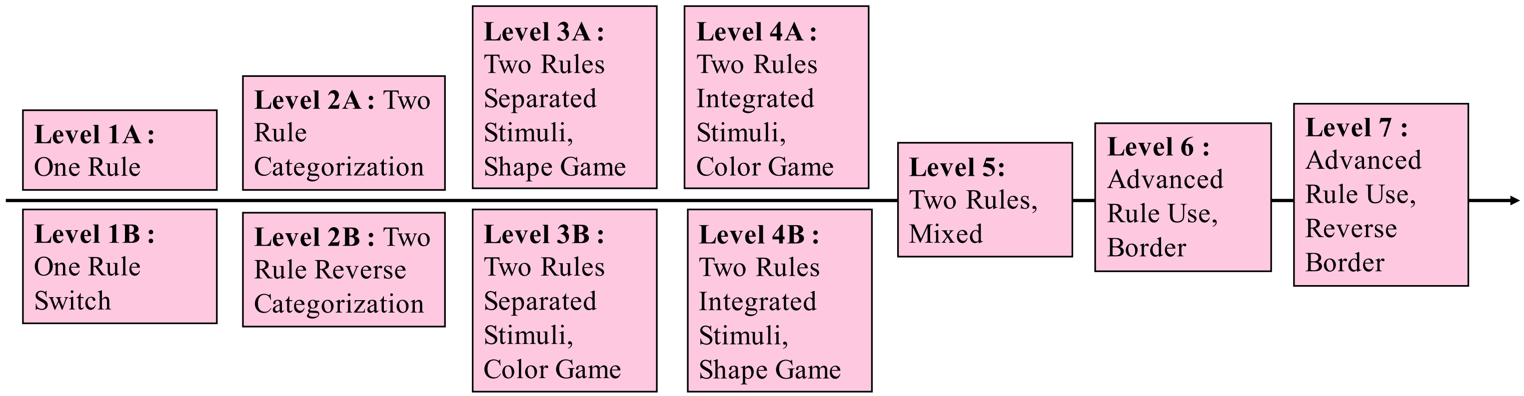


Figure 3

Number Training Levels

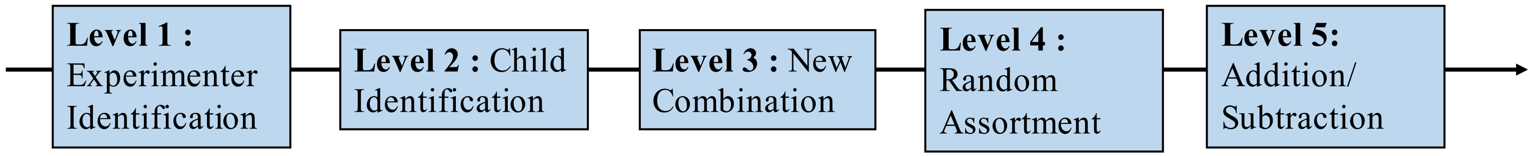


Figure 4

EF + Number Training Levels

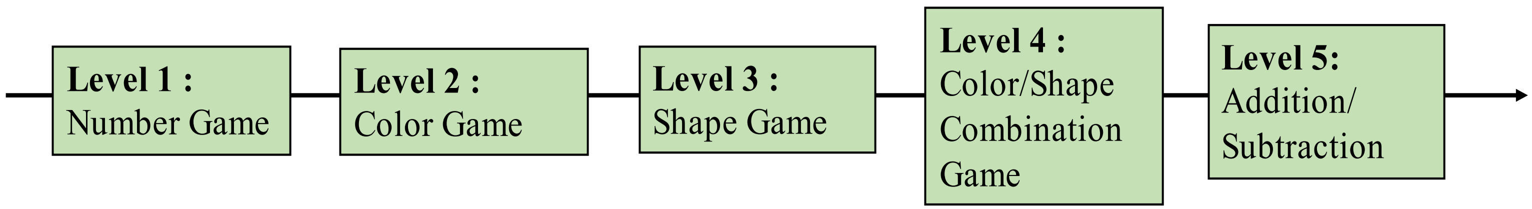


Figure 5

Sample Stimuli Cards

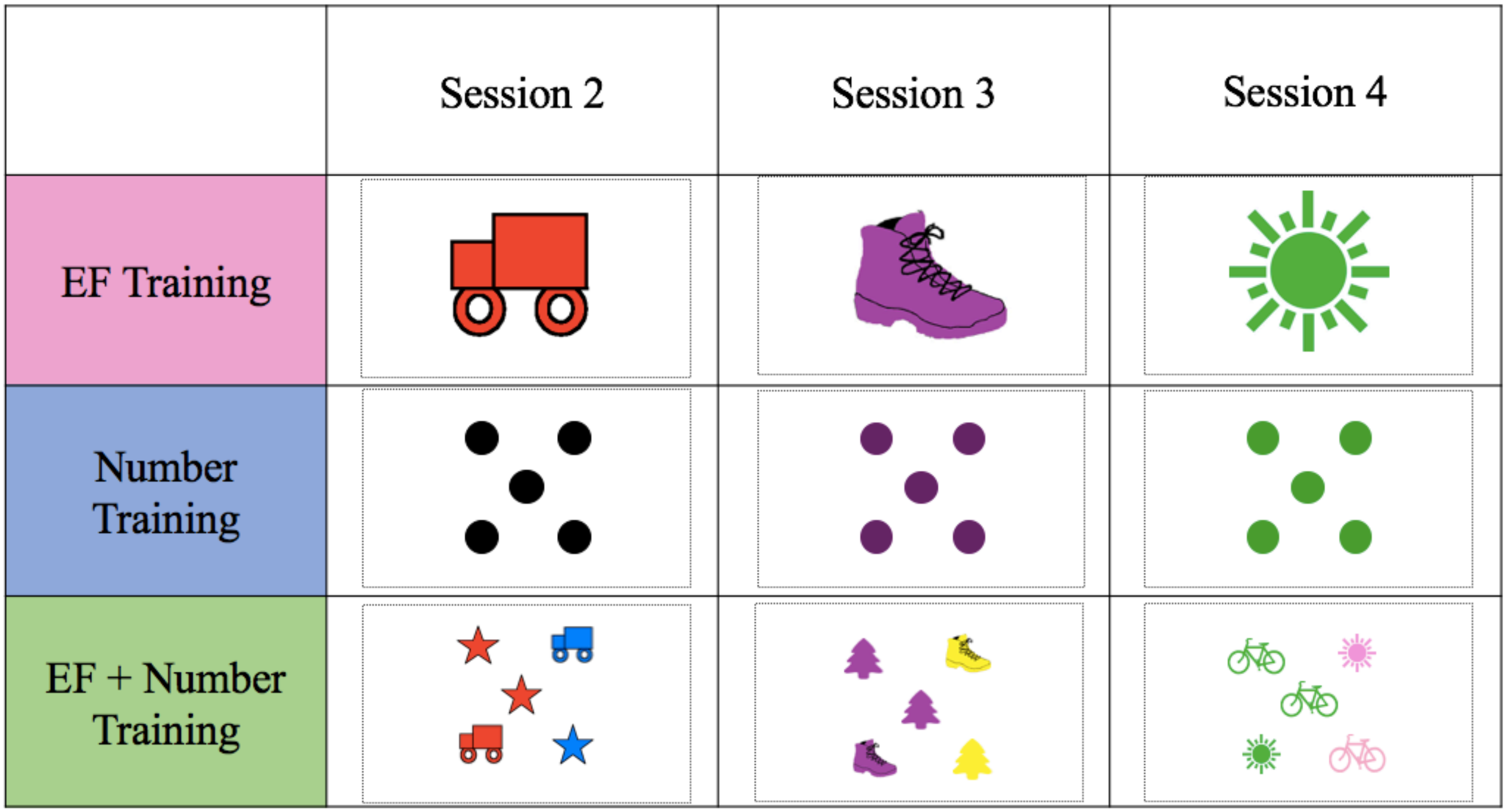
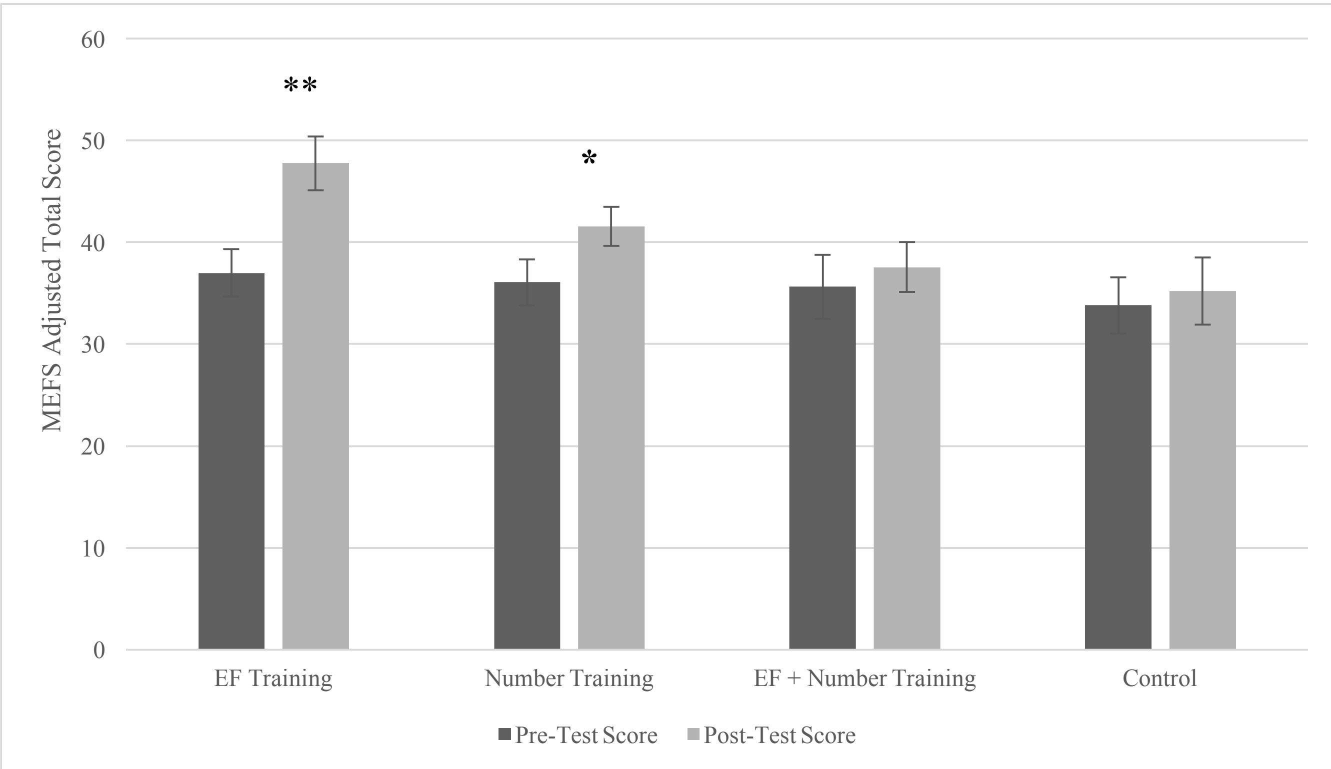


Figure 6

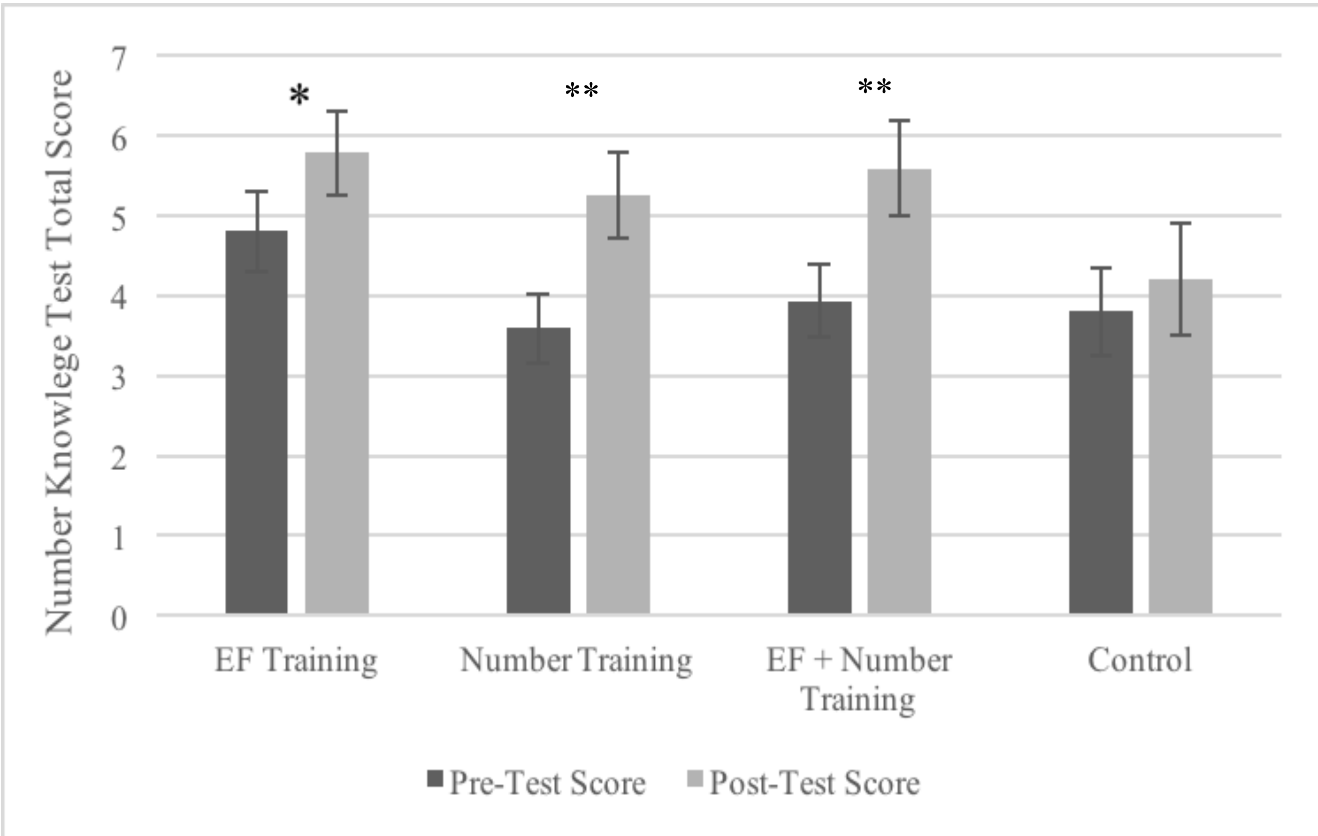
Pre and Post-Test Performance by Condition on the Minnesota Executive Function Scale (MEFS)



Note. Bars indicate 95% confidence interval. *** $p < .01$, ** $p < .05$, * $p < .10$

Figure 7

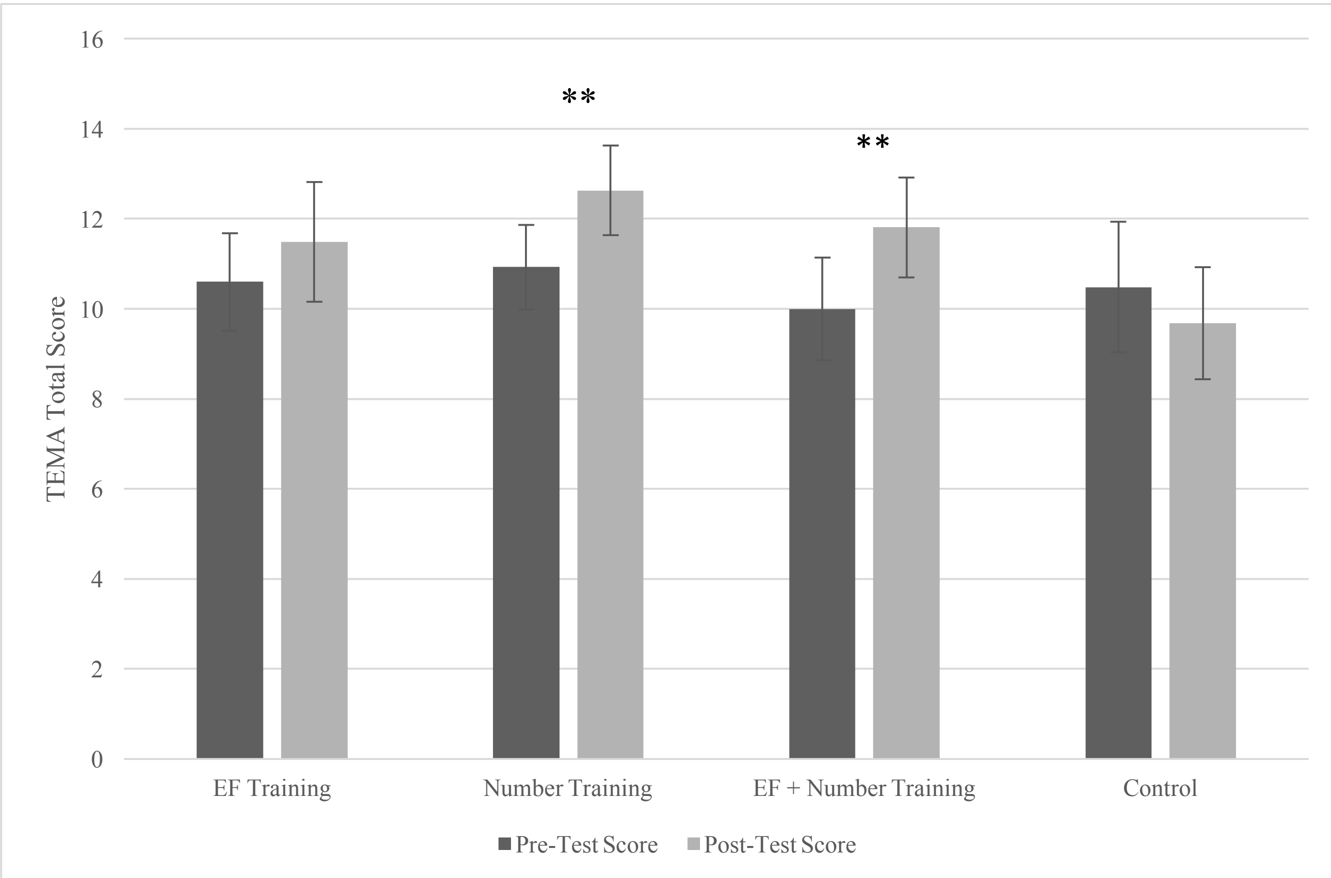
Pre and Post-Test Performance by Condition on the Number Knowledge Test



Note. Bars indicate 95% confidence interval. *** $p < .01$, ** $p < .05$, * $p < .10$

Figure 8

Pre and Post-Test Performance by Condition on the Test of Early Mathematics Ability (TEMA)



Note. Bars indicate 95% confidence interval. *** $p < .01$, ** $p < .05$, * $p < .10$

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Appendix A

EF Training Script – Training Day 1

<u>Level 1/Fish</u>

"No, that's wrong. When you saw the [Fish], you put it in the box with the [Elephant] on it. That means you were looking at the WRONG BOX. We're not playing the elephant game right now. Now we're playing the fish game.

"What game are we playing?" *Wait for response* **"Right/No. We're playing the fish game now. So you have to look at what PICTURE is here** *(point to card)* **and what PICTURE is on the box** *(point).* **Is it a elephant or fish?**

Bring up same stimulus that they just got wrong. **"Look, what picture is this? Right/No. It is a fish."**

(Pg. 1/2)

Then, ask child to label the corresponding target box. **"Look, what picture is on this box? Right/No. It is a fish.**

Repeat the relevant rules **"In the fish game, when you see a fish right here** *point* **you have to put it in the box with the fish on it** *point* **like this** *Put card in box.*

"So, which box would you put a fish in during the fish game? Can you point to it for me? *Ensure child points correctly* **Right. When I show you a fish, you put it in the box with the fish one it.**

Show another fish stimulus **"Look here is a fish. Which box do you put it in during the fish game?"** *Gesture, point, or direct hand to ensure correct answer.* **"Great job! Now you know how to play. Let's try some more."**

(Pg. 2/2)

Level 1/Elephant

"No, that's wrong. When you saw the [Elephant], you put it in the box with the [Fish] on it. That means you were looking at the WRONG BOX. We're not playing the fish game right now. Now we're playing the elephant game.

"What game are we playing?" *Wait for response* **"Right/No. We're playing the elephant game now. So you have to look at what PICTURE is here** *(point to card)* **and what PICTURE is on the box** *(point).* **Is it a elephant or fish?**

Bring up same stimulus that they just got wrong. **"Look, what picture is this? Right/No. It is a elephant."**

(Pg. 1/2)

Then, ask child to label the corresponding target box. **"Look, what picture is on this box? Right/No. It is a elephant.**

Repeat the relevant rules **"In the elephant game, when you see a elephant right here** *point* **you have to put it in the box with the elephant on it** *point* **like this** *Put card in box.*

"So, which box would you put a elephant in during the elephant game? Can you point to it for me? *Ensure child points correctly* **Right. When I show you a elephant, you put it in the box with the elephant one it.**

Show another elephant stimulus **"Look here is a elephant. Which box do you put it in during the elephant game?"** *Gesture, point, or direct hand to ensure correct answer.* **"Great job! Now you know how to play. Let's try some more."**

(Pg. 2/2)

<u>Level 2/Matching Cat Game</u>

"No, that's wrong. When you saw the [____ Cat], you put it in the box with the [____ Cat] on it. We're playing the Matching Cat Game. In the Matching Cat Game, the [___ Cat] belongs with all of his friends here *point* **and the [____ Cat] belongs with all of his friends here** *point***.**

"What game are we playing?" *Wait for response* **"Right/No. We're playing the Matching Cat game now. So you have to look at what KIND OF CAT is here** *(point to card)* **and what KIND OF CAT is on the box** *(point).* **Is it big or little?**

Bring up same stimulus that they just got wrong. **"Look, what kind of cat is this? Right/No. It is a [_____ Cat]."**

(Pg. 1/2)

Then, ask child to label the corresponding target box. **"Look, what kind of cat is on this box? Right/No. It is a [_____ Cat].**

Repeat the relevant rules **"In the matching cat game, when you see a [____ Cat] right here** *point* **you have to put it in the box with the [_____ Cat] on it** *point* **like this** *Put card in box.*

"So, which box would you put a [_____ Cat] in during the matching cat game? Can you point to it for me? *Ensure child points correctly* **Right. When I show you a [____ Cat], you put it in the box with the [_____ Cat] on it.**

Show another [_____ Cat] stimulus **"Look here is a [_____ Cat]. Which box do you put it in during the matching cat game?"** *Gesture, point, or direct hand to ensure correct answer.*
"Great job! Now you know how to play. Let's try some more."

(Pg. 2/2)

<u>Level 2/Silly Cat Game</u>

"No, that's wrong. When you saw the [____ Cat], you put it in the box with the [_____ Cat] on it. But we're playing the Silly Cat Game. In the Silly Cat Game, the Little Cat belongs with his mommy here *point* **and the [____ Cat] belongs with her baby here** *point*.

"What game are we playing?" *Wait for response* **"Right/No. We're playing the Silly Cat game now. So you have to look at what KIND OF CAT is here** *(point to card)* **and what KIND OF CAT is on the box** *(point).* **Is it big or little?**

Bring up same stimulus that they just got wrong. **"Look, what kind of cat is this? Right/No. It is a [_____ Cat]."**

(Pg. 1/2)

Then, ask child to label the corresponding target box. **"Look, what kind of cat is on this box? Right/No. It is a [_____ Cat].**

Repeat the relevant rules **"In the silly cat game, when you see a [____ Cat] right here** *point* **you have to put it in the box with the [_____ Cat] on it** *point* **like this** *Put card in box.*

"So, which box would you put a [_____ Cat] in during the silly cat game? Can you point to it for me? *Ensure child points correctly* **Right. When I show you a [______ Cat], you put it in the box with the [_____ Cat] on it.**

Show another [_____ Cat] stimulus **"Look here is a [_____ Cat]. Which box do you put it in during the silly cat game?"** *Gesture, point, or direct hand to ensure correct answer.* **"Great job! Now you know how to play. Let's try some more."**

(Pg. 2/2)

<u>Level 3A / Shape</u>

"No, that's wrong. When you saw the [COLOR] one, you put it in the box with the [COLOR] one on it. That means you were looking at the COLOR. But we're not playing the color game right now, the game with yellow and blue. Now we're playing the shape game – the game with *point* **flowers and hearts.**

"What game are we playing?" *Wait for response* **"Right/No. We're playing the shape game now. So you have to look at what SHAPE is here** *(point to card)* **and what SHAPE is on the box** *(point).* **Is it a butterfly or an heart?**

Bring up same stimulus that they just got wrong. **"Look, what shape is this? Right/No. It is a [SHAPE]."**

(Pg. 1/2)

Then, ask child to label the corresponding target box. **"Look, what shape is on this box? Right/No. It is a [SHAPE].**

Repeat the relevant rules **"In the shape game, when you see a [SHAPE] right here** *point* **you have to put it in the box with the [SHAPE] on it** *point* **like this** *Put card in box.*

"So, which box would you put a [SHAPE] in during the shape game? Can you point to it for me? *Ensure child points correctly* **Right. When I show you a [SHAPE], you put it in the box with the [SHAPE] on it.**

Show another butterfly stimulus **"Look here is a [SHAPE]. Which box do you put it in during the shape game?"** *Gesture, point, or direct hand to ensure correct answer.* **"Great job! Now you know how to play. Let's try some more."**

(Pg. 2/2)

<u>Level 3B / Color</u>

"No, that's wrong. When you saw the [SHAPE], you put it in the box with the [SHAPE] on it. That means you were looking at the SHAPE. But we're not playing the shape game right now, the game with flowers and hearts. Now we're playing the color game – the game with *point* **yellow and blue.**

"What game are we playing?" *Wait for response* **"Right/No. We're playing the color game now. So you have to look at what COLOR is here** *(point to card)* **and what COLOR is on the box** *(point).* **Is it yellow or blue?**

Bring up same stimulus that they just got wrong. **"Look, what color is this? Right/No. It is [COLOR]."**

(Pg. 1/2)

Then, ask child to label the corresponding target box. **"Look, what color is on this box? Right/No. It is [COLOR].**

Repeat the relevant rules **"In the color game, when you see a [COLOR] one right here** *point* **you have to put it in the box with the [COLOR] one on it** *point* **like this** *Put card in box.*

"So, which box would you put a [COLOR] one in during the color game? Can you point to it for me? *Ensure child points correctly* **Right. When I show you a [COLOR] one, you put it in the box with the [COLOR] one on it.**

Show another yellow stimulus **"Look here, it's [COLOR]. Which box do you put it in during the color game?"** *Gesture, point, or direct hand to ensure correct answer.* **"Great job! Now you know how to play. Let's try some more."**

(Pg. 2/2)

Level 4 & 5 / Shape

"No, that's wrong. When you saw the [COLOR] one, you put it in the box with the [COLOR] one on it. That means you were looking at the COLOR. But we're not playing the color game right now, the game with blue and red. Now we're playing the shape game – the game with *point* **stars and trucks.**

"What game are we playing?" *Wait for response* **"Right/No. We're playing the shape game now. So you have to look at what SHAPE is here** *(point to card)* **and what SHAPE is on the box** *(point).* **Is it a star or a truck?**

Bring up same stimulus that they just got wrong. **"Look, what shape is this? Right/No. It is a [SHAPE]."**

(Pg. 1/2)

Then, ask child to label the corresponding target box. **"Look, what shape is on this box? Right/No. It is a [SHAPE].**

Repeat the relevant rules **"In the shape game, when you see a [SHAPE] right here** *point* **you have to put it in the box with the [SHAPE] on it** *point* **like this** *Put card in box.*

"So, which box would you put a [SHAPE] in during the shape game? Can you point to it for me? *Ensure child points correctly* **Right. When I show you a [SHAPE], you put it in the box with the [SHAPE] on it.**

Show another star stimulus **"Look here is a [SHAPE]. Which box do you put it in during the shape game?"** *Gesture, point, or direct hand to ensure correct answer.* **"Great job! Now you know how to play. Let's try some more."**

(Pg. 2/2)

Level 4 & 5/Color

"No, that's wrong. When you saw the [SHAPE], you put it in the box with the [SHAPE] on it. That means you were looking at the SHAPE. But we're not playing the shape game right now, the game with stars and trucks. Now we're playing the color game – the game with *point* **blue and red.**

"What game are we playing?" *Wait for response* **"Right/No. We're playing the color game now. So you have to look at what COLOR is here** *(point to card)* **and what COLOR is on the box** *(point).* **Is it blue or red?**

Bring up same stimulus that they just got wrong. **"Look, what color is this? Right/No. It is [COLOR]."**

(Pg. 1/2)

Then, ask child to label the corresponding target box. **"Look, what color is on this box? Right/No. It is [COLOR].**

Repeat the relevant rules **"In the color game, when you see a [COLOR] one right here** *point* **you have to put it in the box with the [COLOR] one on it** *point* **like this** *Put card in box.*

"So, which box would you put a [COLOR] one in during the color game? Can you point to it for me? *Ensure child points correctly* **Right. When I show you a [COLOR] one, you put it in the box with the [COLOR] one on it.**

Show another blue stimulus **"Look here, it's [COLOR] one. Which box do you put it in during the color game?"** *Gesture, point, or direct hand to ensure correct answer.* **"Great job! Now you know how to play. Let's try some more."**

(Pg. 2/2)

Level 6 / Boarder = Color

"No, that's wrong. When you saw the [SHAPE], you put it in the box with the [SHAPE] on it. That means you were looking at the SHAPE. But this card has a BOARDER, so we're not playing the shape game. We're playing the color game – the game with *point* **blue and red**

"What game do we play when we see a BOARDER?" *Wait for response* **"Right/No. We're play the color game. So you have to look at what COLOR is here** *(point to card)* **and what COLOR is on the box** *(point).* **Is it blue or red?**

Bring up same stimulus that they just got wrong. **"Look, does this picture have a boarder? Right/No. It has a BOARDER, so we will play the color game."**

(Pg. 1/2)

Then, ask child to label the corresponding target box. **"Look, what color is on this box? Right/No. It is [COLOR].**

Repeat the relevant rules **"In the boarder game, when you see a boarder right here** *point* **you play the color game like this** *Put card in box.*

"So, which game do you play when you see a card with a boarder *Ensure child answers correctly* **Right. When you see a boarder** *point* **you play the color game.**

Show another boarder stimulus **"Look here is one with a boarder. Which box do you put it in when you see a boarder?** *Gesture, point, or direct hand to ensure correct answer.* **"Great job! Now you know how to play. Let's try some more."**

(Pg. 2/2)

<u>Level 6 / No Boarder = Shape</u>

"No, that's wrong. When you saw the [COLOR] one, you put it in the box with the [COLOR] one on it. That means you were looking at the COLOR. But this card does not have a boarder, so we're not playing the color game. We're playing the shape game – the game with *point* **stars and trucks.**

"What game do we play when we do not see a BOARDER?" *Wait for response* **"Right/No. We play the shape game. So you have to look at what SHAPE is here** *(point to card)* **and what SHAPE is on the box** *(point).* **Is it a star or a truck?**

Bring up same stimulus that they just got wrong. **"Look, does this picture have a boarder? Right/No. It does not have a boarder, so we will play the shape game."**

(Pg. 1/2)

Then, ask child to label the corresponding target box. **"Look, what shape is on this box? Right/No. It is a [SHAPE].**

Repeat the relevant rules **"In the boarder game, when you do not see a boarder right here** *point* **you play the shape game like this** *Put card in box.*

"So, which game do you play when you see a card with NO boarder *Ensure child answers correctly* **Right. When you see NO boarder** *point* **you play the shape game.**

Show another boarder stimulus **"Look here is one that does not have a boarder. Which box do you put it in when you don't see a boarder?** *Gesture, point, or direct hand to ensure correct answer.* **"Great job! Now you know how to play. Let's try some more."**

(Pg. 2/2)

Level 7 / Boarder = Shape

"No, that's wrong. When you saw the [COLOR] one, you put it in the box with the [COLOR] one on it. That means you were looking at the COLOR. But this card has a boarder, so we're not playing the color game. We're playing the shape game – the game with *point* **stars and trucks.**

"What game do we play when we see a BOARDER?" *Wait for response* **"Right/No. We play the shape game. So you have to look at what SHAPE is here** *(point to card)* **and what SHAPE is on the box** *(point).* **Is it a star or a truck?**

Bring up same stimulus that they just got wrong. **"Look, does this picture have a boarder? Right/No. It has a boarder, so we will play the shape game."**

(Pg. 1/2)

Then, ask child to label the corresponding target box. **"Look, what shape is on this box? Right/No. It is a [star].**

Repeat the relevant rules **"In the boarder game, when you see a boarder right here** *point* **you play the shape game like this** *Put card in box.*

"So, which game do you play when you see a card with a boarder *Ensure child answers correctly* **Right. When you see a boarder** *point* **you play the shape game.**

Show another boarder stimulus **"Look here is one with a boarder. Which box do you put it in when you see a boarder?** *Gesture, point, or direct hand to ensure correct answer.* **"Great job! Now you know how to play. Let's try some more."**

(Pg. 2/2)

<u>Level 7/No Boarder = Color</u>

"No, that's wrong. When you saw the [SHAPE], you put it in the box with the [star] on it. That means you were looking at the SHAPE. But this card does not have a BOARDER, so we're not playing the shape game. We're playing the color game – the game with *point* **blue and red**

"What game do we play when we do not see a BOARDER?" *Wait for response* **"Right/No. We're play the color game. So you have to look at what COLOR is here** *(point to card)* **and what COLOR is on the box** *(point).* **Is it blue or red?**

Bring up same stimulus that they just got wrong. **"Look, does this picture have a boarder? Right/No. It does not have a BOARDER, so we will play the color game."**

(Pg. 1/2)

Then, ask child to label the corresponding target box. **"Look, what color is on this box? Right/No. It is [COLOR].**

Repeat the relevant rules **"In the boarder game, when you do not see a boarder right here** *point* **you play the color game like this** *Put card in box.*

"So, which game do you play when you see a card with NO boarder *Ensure child answers correctly* **Right. When you see NO boarder** *point* **you play the color game.**

Show another boarder stimulus **"Look here is a card that does not have a boarder. Which box do you put it in when you don't see a boarder?** *Gesture, point, or direct hand to ensure correct answer.* **"Great job! Now you know how to play. Let's try some more."**

(Pg. 2/2)

Appendix B

Number Training Script – All Training Days

Day 2: Black Dots

"Today we're going to play with black dots."

Day 3: Purple dots

"Today we're going to play with purple dots."

Day 4: Green dots

"Today we're going to play with green dots."

Identification (Experimenter)

TRIAL 1

I'm going to show you a dot card.
Flip card over, **There are ______ dots.**
After 3 seconds turn card over
How many dots are there?

(Correct) **That's right.**

(Incorrect) **That's not quite right**.

If child responds incorrectly: TRIAL 1a

Flip card over, **See there are _____ dots.**

Let's count to see how many there are.
Count the number of dots – POINT to each dot and count with child.
How many dots are there?
Only count as correct if child is able to correctly identify the total number of dots

(Put EVERY OTHER CORRECT CARD back in pile)
(Put incorrect cards back in pile)

Repeat until child gets 8/10 correct

Day 2: Black Dots

"Today we're going to play with black dots."

Day 3: Purple dots

"Today we're going to play with purple dots."

Day 4: Green dots

"Today we're going to play with green dots."

Identification (Child)

TRIAL 1

I'm going to show you a dot card. Tell me how many you see. See if you know how many quickly without counting.
Flip card over, **how many do you think there are?**

After 3 seconds turn card over

(Correct) **That's right. There are** ____(number of dots).
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect) **That's not quite right**.

If child responds incorrectly: TRIAL 1a

Let's look again.
Hold card up. Leave card up.
Let's count to see how many there are.
DO NOT point to dots, allow child to count on their own and point to the dots themself if necessary
How many dots are there?
Only count as correct if child is able to correctly identify the total number of dots

(Correct) **That's right. There are** ____(number of dots).
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect) **Oops. That's not quite right. There are** ____ (number of dots). *Count, POINT to each dot and have child count along. Do not count as correct.*
(Put incorrect cards back in pile)

Repeat until child gets 8/10 correct

<u>TRIAL 2</u>

Place two cards in front of child.
Which has more dots? This one *(point to first card)* **Or this one** *(point to second card).*
See if you know how many quickly without counting.

If C tries to count, cover cards and say: **See if you can know without counting.**

(Correct) **That's right. There are ____***(number of dots)* **dots here** *(point to lesser card)*
and _____*(number of dots)* **dots here. ______ is more than ________**.
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect) **Oops. That's not quite right.**

<u>If child responds incorrectly: Trial 2a</u>

Let's count. *(DO NOT point to dots, allow child to count on their own and point to the dots themself if necessary).* **Which has more dots?**

(Correct) **That's right. There are ____***(number of dots)* **dots here** *(point to lesser card)*
and _____*(number of dots)* **dots here. ______ is more than ________**.
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect) **Oops. That's not quite right.** *Count, POINT to each dot and have child count along.* **There are ____***(number of dots)* **dots here** *(point to lesser card)* **and _____***(number of dots)* **dots here. ______ is more than ________**.
Do not count as correct.

(Put incorrect cards back in pile)

Repeat until child gets 4/5 correct

Day 2: Black Dots
"Today we're going to play with black dots."
Day 3: Purple dots
"Today we're going to play with purple dots."
Day 4: Green dots
"Today we're going to play with green dots."

New Combination

<u>TRIAL 1</u>

I'm going to show you a dot card. Tell me how many you see. See if you know how many quickly without counting.
Flip card over, **how many do you think there are?**

After 3 seconds turn card over

(Correct) **That's right. There are** ____(number of dots).
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect) **That's not quite right**.

<u>If child responds incorrectly: TRIAL 1a</u>

Let's look again.
Hold card up. Leave card up.
Let's count to see how many there are.
DO NOT point to dots, allow child to count on their own and point to the dots themself if necessary
How many dots are there?
Only count as correct if child is able to correctly identify the total number of dots

(Correct) **That's right. There are** ____(number of dots).
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect) **Oops. That's not quite right. There are** ____ (number of dots). *Count, POINT to each dot and have child count along. Do not count as correct.*
(Put incorrect cards back in pile)

Repeat until child gets 8/10 correct

TRIAL 2

Place two cards in front of child.
Which has more dots? This one *(point to first card)* **Or this one** *(point to second card).*
See if you know how many quickly without counting.

If C tries to count, cover cards and say: **See if you can know without counting.**

(Correct) **That's right. There are ____***(number of dots)* **dots here** *(point to lesser card)*
and _____*(number of dots)* **dots here. ______ is more than ________.**
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect) **Oops. That's not quite right.**

If child responds incorrectly: Trial 2a

Let's count. *(DO NOT point to dots, allow child to count on their own and point to the dots themself if necessary).* **Which has more dots?**

(Correct) **That's right. There are ____***(number of dots)* **dots here** *(point to lesser card)*
and _____*(number of dots)* **dots here. ______ is more than ________.**
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect) **Oops. That's not quite right.** *Count, POINT to each dot and have child count along.* **There are ____***(number of dots)* **dots here** *(point to lesser card)* **and _____***(number of dots)* **dots here. ______ is more than ________.**
Do not count as correct.

(Put incorrect cards back in pile)

Repeat until child gets 4/5 correct

Day 2: Black Dots

"Today we're going to play with black dots."

Day 3: Purple dots

"Today we're going to play with purple dots."

Day 4: Green dots

"Today we're going to play with green dots."

Random

TRIAL 1

I'm going to show you a dot card. Tell me how many you see. See if you know how many quickly without counting.
Flip card over, **how many do you think there are?**

After 3 seconds turn card over

(Correct) **That's right. There are ____**(number of dots).
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect) **That's not quite right**.

If child responds incorrectly: TRIAL 1a

Let's look again.
Hold card up. Leave card up.
Let's count to see how many there are.
DO NOT point to dots, allow child to count on their own and point to the dots themself if necessary
How many dots are there?
Only count as correct if child is able to correctly identify the total number of dots

(Correct) **That's right. There are ____**(number of dots).
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect) **Oops. That's not quite right. There are ____** (number of dots). *Count, POINT to each dot and have child count along. Do not count as correct.*
(Put incorrect cards back in pile)

Repeat until child gets 8/10 correct

<u>TRIAL 2</u>

Refer to score sheet for instructions per trial

<u>Addition</u>

There are ________ dots. *Identify number of dots on card.*
What if I added one (two) more dot(s)? How many dots would there be?

(Correct) **That's right. If there are _____ dots and I add one (two) more, there would be _____ dots.**

(Incorrect) **That's not quite right.** *Place card with one (two) dot(s) next to original card.*
If I added one (two) more dot(s) how many dots would there be?
If child still responds incorrectly count dots: **Let's count together**. *POINT to each dot and have child count along. Do not count as correct.*

No matter response say: **If there are _____ dots and I add one (two) more, there would be _____ dots.**

OR

<u>Subtraction</u>

There are ________ dots. *Identify number of dots on card.*
What if I took away one (two) dot(s)? How many dots would there be?

(Correct) **That's right. If there are _____ dots and I took away one (two) dot(s), there would be _____ dots.**

(Incorrect) **That's not quite right.** *Cover up one (two) dots on original card.* **If I took away one (two) dot(s) how many dots would there be?**
If child still responds incorrectly count dots: **Let's count together**. *POINT to each dot and have child count along. Do not count as correct.*

No matter response say: **If there are _____ dots and I take away one (two) dot(s), there would be _____ dots.**

Appendix C

Number Game

Let's play the *number* game. In the *number* game I have cards like this. *Flip over sample card.* **In the *number* game we count all the pictures.**

TRIAL 1 (number)

See if you know how many quickly without counting.
Flip card over, **how many do you think there are?**

After 3 seconds turn card over

(Correct) **That's right. There are** ____(number of pictures). *(Move on to next card)*
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect) **That's not quite right**. *(Move on to Trial 1a)*

If child responds incorrectly: TRIAL 1a

Let's look again.
Hold card up. Leave card up.
Let's count to see how many there are.
DO NOT point to pictures, allow child to count on their own and point to the pictures themself if necessary
How many pictures are there?
Only count as correct if child is able to correctly identify the total number of dots

Correct) **That's right. There are** ____(number of pictures).
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect) **Oops. That's not quite right. There are** ____ (number of pictures). *Count, POINT to each picture and have child count along. Do not count as correct.*
(Put incorrect cards back in pile)

Repeat number game until child gets 8/10 correct
Move on to color game and repeat.

<u>Color Game</u>

Now we are going to play a different game. Let's play the *color* game. In the *color* game I have cards like this. *Flip over first card.* **In the *color* game we count the red ones and then the blue ones.** *(Point to red and point to blue).*

<u>TRIAL 1 (color A)</u>

How many red ones are there? *DO NOT point to pictures, allow child to count on their own and point to the pictures themself if necessary*

(Correct) **That's right. There are _______ red ones.** *(Move on to Trial 2).*

OR

(Incorrect) **Not quite.** *(Move on to Trial 1a)*

<u>TRIAL 1a (color A)</u>

(Incorrect – Reflective feedback) **What game are we playing?"** *Wait for response* **"Right/No. We're playing the *color* game now. So you have to look at the *color* of the pictures. What color is this?** *Point to red picture* **Right/No. It is a red one." In the color game you have to look at the *color* of the pictures and count all the *red* ones first and then all the *blue* ones. How many *red* ones are there?**

(Correct) **That's right. There are _______ red ones. Now you know how to play the *color* game. Let's try some more.** *(Move on to Trial 2).*

(Incorrect) *(If student is still incorrect count, POINT to each picture and have child count along).* **There are _______ red ones. How many red ones are there?** *Do not count as correct.*
(Put incorrect cards back in pile)

Move onto Trial 2 (same card)

TRIAL 2 (color B)

How many blue ones are there? *DO NOT point to pictures, allow child to count on their own and point to the pictures themself if necessary*

(Correct) **That's right**. **There are _______ blue ones.** *(Move on to Trial 3).*

OR

(Incorrect) **Not quite.** *(Move on to Trial 2a)*

TRIAL 2a (color B)

(Incorrect – Reflective feedback) **What game are we playing?"** *Wait for response* **"Right/No. We're playing the *color* game now. So you have to look at the *color* of the pictures. What color is this?** *Point to blue picture* **Right/No. It is a blue one." In the color game you have to look at the *color* of the pictures and count all the *red* ones first and then all the *blue* ones. How many *blue* ones are there?**

(Correct) **That's right. There are _______ blue ones. Now you know how to play the *color* game. Let's try some more.** *(Move on to Trial 3a).*

(Incorrect) *(If student is still incorrect count, POINT to each picture and have child count along).* **There are _______ blue ones. How many blue ones are there?** *Do not count as correct.*

Move on to More/Less Trial 3 (same card)

Repeat until child gets 16/20 correct (on counting) and 8/10 correct on More/Less

<u>TRIAL 3 (More/Less)</u>

Place card in front of child.
Are there more red ones or blue ones? See if you know quickly without counting.

If C tries to count, cover cards and say: **See if you can know without counting**

(Correct) **That's right. There are** ____*(number of red ones)* **and** _____*(number blue ones)*. ______ **is more than** ________.
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect) **Oops. That's not quite right.**

<u>If child responds incorrectly: Trial 3a</u>

Let's count. *(DO NOT point to pictures, allow child to count on their own and point to the pictures themself if necessary).* **Are there more red ones or blue ones?**

(Correct) **That's right. There are** ____*(number of red ones)* **and** _____*(number blue ones)*. ______ **is more than** ________.
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect) **Oops. That's not quite right.** *Count, POINT to each picture and have child count along.* **There are** ____*(number of red ones)* **red ones here and** _____*(number of blue ones)* **blue ones.** ______ **is more than** ________.
Do not count as correct.

(Put incorrect cards back in pile)

Move on to new card, repeat Trials 1-3

Repeat until child gets 16/20 correct (on counting) and 8/10 correct on More/Less

Move on to shape game.

Shape Game

Now we are going to play a different game. Let's play the *shape* game. In the *shape* game I have cards like this. *Flip over first card.* **In the *shape* game we count the *trucks* and then the *stars*.** *(Point to trucks and point to stars).*

TRIAL 1 (shape A)

How many trucks are there? *DO NOT point to pictures, allow child to count on their own and point to the pictures themself if necessary*

(Correct) **That's right. There are _______ trucks.** *(move on to Trial 2).*

OR

(Incorrect) **Not quite.** *(move on to Trial 1a)*

TRIAL 1a (shape A)

(Incorrect – Reflective feedback) **What game are we playing?"** *Wait for response* **"Right/No. We're playing the *shape* game now. So you have to look at the *shape* of the pictures. What shape is this?** *Point to truck picture* **Right/No. It is a truck." In the shape game you have to look at the *shape* of the pictures and count all the *trucks* first and then all the *stars*. How many *trucks* are there?**

(Correct) **That's right.** *(move on to Trial 2).* **There are _______ trucks. Now you know how to play the *shape* game. Let's try some more.**

(Incorrect) *(If student is still incorrect count, POINT to each picture and have child count along).* **There are _______ tucks. How many trucks are there?** *Do not count as correct.*

Move onto Trial 2 (same card)

<u>TRIAL 2 (shape B)</u>

How many stars are there? *DO NOT point to pictures, allow child to count on their own and point to the pictures themself if necessary*

(Correct) **That's right. There are _______ stars.** *(Move on to Trial 3).*

OR

(Incorrect) **Not quite.** *(Move on to Trial 2a)*

<u>TRIAL 2a (shape B)</u>

(Incorrect – Reflective feedback) **What game are we playing?"** *Wait for response* **"Right/No. We're playing the *shape* game now. So you have to look at the *shape* of the pictures. What shape is this?** *Point to star picture* **Right/No. It is a star." In the shape game you have to look at the *shape* of the pictures and count all the *trucks* first and then all the *stars*. How many *stars* are there?**

(Correct) **That's right. There are _______ stars. Now you know how to play the *shape* game. Let's try some more.** *(Move on to Trial 3).*

(Incorrect) *(If student is still incorrect count, POINT to each picture and have child count along).* **There are _______ stars. How many stars are there?** *Do not count as correct.*

Move on to More/Less Trial 3 (same card)

Repeat until child gets 16/20 correct (on counting) and 8/10 correct on More/Less

<u>TRIAL 3 (More/Less)</u>

Place card in front of child.
Are there more trucks or stars? See if you know quickly without counting.

If C tries to count, cover cards and say: **See if you can know without counting**

(Correct) **That's right. There are** ____*(number of trucks)* **and** _____*(number stars)*.
______ **is more than** ________.
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect) **Oops. That's not quite right.**

<u>If child responds incorrectly: Trial 3a</u>

Let's count. *(DO NOT point to pictures, allow child to count on their own and point to the pictures themself if necessary).* **Are there more trucks or stars?**

(Correct) **That's right. There are** ____*(number of trucks)* **and** _____*(number stars)*.
______ **is more than** ________.
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect) **Oops. That's not quite right.** *Count, POINT to each picture and have child count along.* **There are** ____*(number of trucks)* **trucks here and** _____*(number of stars)* **stars.** ______ **is more than** ________.
Do not count as correct.

(Put incorrect cards back in pile)

Move on to new card, repeat Trials 1-3

Repeat until child gets 16/20 correct (on counting) and 8/10 correct on More/Less

Move on to combo game.

Combo Game

Now we are going to play a different game. In this game *sometimes* we play the *shape* game and sometimes we play the *color* game. I'll show you a card and say, "Play the *shape* game" or, I'll say, "Play the *color* game". If I say play the *shape* game then you play the *shape* the game. In the *shape* game we count the *trucks* and then the *stars*. But, if I say play the *color* game then we play the *color* game. In the *color* game we count the *red* ones and then the *blue* ones.

Refer to score sheet for instructions per trial (color/shape and addition/subtraction)

<u>COLOR - Combo</u>

Play the color game.
Hold card up, Leave card up. Child should count the number of red pictures and then the number of blue pictures. If this is done correctly, give credit for Trial 1 on score sheet and correct feedback (below).

(Correct) **That's right. There are _______ red ones and _______ blue ones.**

<u>Trial 2a</u>
If child doesn't respond:
How many red ones are there?

(Correct) **That's right. There are ____**(number of reds). *Administer Trial 2b*

(Incorrect – Reflective feedback) **Not quite. What game are we playing?"** *Wait for response* **"Right/No. We're playing the *color* game now. So you have to look at the *color* of the pictures. What color is this?** *Point to red picture* **Right/No. It is a red one." In the color game you have to look at the *color* of the pictures and count all the *red* ones first and then all the *blue* ones. How many *red* ones are there?**

<u>Trial 3a</u>
(Correct) **That's right. There are _______ red ones. Now you know how to play the *colo*r game. Let's try some more.** *Administer Trial 2b*

(Incorrect) *(If student is still incorrect count, POINT to each picture and have child count along).* **There are _______ red ones. How many red ones are there?** *Do not count as correct. Administer Trial 2b*

<u>Trial 2b</u>
How many blue ones are there?

(Correct) **That's right. There are** ____(number of blue).
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect – Reflective feedback) **Not quite. What game are we playing?"** *Wait for response* **"Right/No. We're playing the *color* game now. So you have to look at the *color* of the pictures. What color is this?** *Point to blue picture* **Right/No. It is a blue one." In the color game you have to look at the *color* of the pictures and count all the *red* ones first and then all the *blue* ones. How many *blue* ones are there?**

<u>Trial 3b</u>
(Correct) **That's right. There are _______ blue ones. Now you know how to play the *colo*r game. Let's try some more.** *(Move on to new card, administer Trial 1)*

(Incorrect) *(If student is still incorrect count, POINT to each picture and have child count along).* **There are _______ blue ones. How many blue ones are there?** *Do not count as correct. (Put incorrect cards back in pile)*

Move on to next combo trial. Repeat until child gets 8/10 correct.

Move onto addition/subtraction

SHAPE - Combo

Play the shape game.
Hold card up, Leave card up. Child should count the number of trucks and then the number of stars. If this is done correctly, give credit for Trial 1 on score sheet and correct feedback (below).

(Correct) **That's right. There are _______ trucks and _______ stars.**

Trial 2a
If child doesn't respond:
How many trucks are there?

(Correct) **That's right. There are ____**(number of trucks). *Administer Trial 2b*

(Incorrect – Reflective feedback) **Not quite. What game are we playing?"** *Wait for response* **"Right/No. We're playing the *shape* game now. So you have to look at the *shape* of the pictures. What shape is this?** *Point to truck picture* **Right/No. It is a truck." In the shape game you have to look at the *shape* of the pictures and count all the trucks first and then all the *stars*. How many *trucks* are there?**

Trial 3a
(Correct) **That's right. There are _______ trucks. Now you know how to play the *shape* game. Let's try some more.** *Administer Trial 2b*

(Incorrect) *(If student is still incorrect count, POINT to each picture and have child count along).* **There are _______ trucks. How many trucks are there?** *Do not count as correct. Administer Trial 2b*

<u>Trial 2b</u>
How many stars are there?

(Correct) **That's right. There are** ____(number of stars).
(Put EVERY OTHER CORRECT CARD back in pile)

(Incorrect – Reflective feedback) **Not quite. What game are we playing?"** *Wait for response* **"Right/No. We're playing the *shape* game now. So you have to look at the *shape* of the pictures. What shape is this?** *Point to star picture* **Right/No. It is a star." In the shape game you have to look at the *shape* of the pictures and count all the *trucks* first and then all the *stars*. How many *stars* are there?**

<u>Trial 3b</u>
(Correct) **That's right. There are _______ stars. Now you know how to play the *shape* game. Let's try some more.** *(Move on to new card, administer Trial 1)*

(Incorrect) *(If student is still incorrect count, POINT to each picture and have child count along).* **There are _______ stars. How many stars are there?** *Do not count as correct. (Put incorrect cards back in pile)*

Move on to next combo trial. Repeat until child gets 8/10 correct.

Move onto addition/subtraction

Combo Game + Addition/Subtraction

Let's keep going.

Refer to score sheet for instructions per trial (color/shape and addition/subtraction)

COLOR A – Add/Subtract

Addition

There are _________ red ones. *Identify number of red pictures on card*
What if I added one (two) more red one(s)? How many red ones would there be?

(Correct) **That's right. If there are _____ reds ones and I add one (two) more, there would be _____ red ones.**

(Incorrect) **That's not quite right.** *Place card with one (two) red one(s) next to original card.* **If I added one (two) more red one(s) how many red ones would there be?**
If child still responds incorrectly count red pictures: **Let's count together**. *POINT to each red picture and have child count along. Do not count as correct.*

No matter response say: **If there are _____ red ones and I add one (two) more, there would be _____ red ones.**

OR

Subtraction

There are _________ red ones. *Identify number of red pictures on card*
What if I took away one (two) red one(s)? How many red ones would there be?

(Correct) **That's right. If there are _____ red ones and I took away one (two) red one(s), there would be _____ red ones.**

(Incorrect) **That's not quite right.** *Cover up one (two) red ones on original card.* **If I took away one (two) red one(s) how many red ones would there be?**
If child still responds incorrectly count red ones: **Let's count together**. *POINT to each red one and have child count along. Do not count as correct.*

No matter response say: **If there are _____ red ones and I take away one (two), there would be _____ red ones.**

COLOR B – Add/Subtract

Addition

There are _________ blue ones. *Identify number of blue pictures on card*
What if I added one (two) more blue one(s)? How many blue ones would there be?

(Correct) **That's right. If there are _____ blue ones and I add one (two) more, there would be _____ blue ones.**

(Incorrect) **That's not quite right.** *Place card with one (two) blue one(s) next to original card.* **If I added one (two) more blue one(s) how many blue ones would there be?**
If child still responds incorrectly count blue pictures: **Let's count together**. *POINT to each blue picture and have child count along. Do not count as correct.*

No matter response say: **If there are _____ blue ones and I add one (two) more, there would be _____ blue ones.**

OR

Subtraction

There are _________ blue ones. *Identify number of blue pictures on card*
What if I took away one (two) blue one(s)? How many blue ones would there be?

(Correct) **That's right. If there are _____ blue ones and I took away one (two) blue one(s), there would be _____ blue ones.**

(Incorrect) **That's not quite right.** *Cover up one (two) blue ones on original card.* **If I took away one (two) blue one(s) how many blue ones would there be?**
If child still responds incorrectly count blue ones: **Let's count together**. *POINT to each blue one and have child count along. Do not count as correct.*

No matter response say: **If there are _____ blue ones and I take away one (two), there would be _____ blue ones.**

SHAPE A – Add/Subtract

Addition

There are _________ trucks. *Identify number of trucks on card*
What if I added one (two) more truck(s)? How many trucks would there be?

(Correct) **That's right. If there are _____ trucks and I add one (two) more, there would be _____ trucks.**

(Incorrect) **That's not quite right.** *Place card with one (two) truck(s) next to original card.* **If I added one (two) more truck(s) how many trucks would there be?**
If child still responds incorrectly count trucks: **Let's count together**. *POINT to each truck and have child count along. Do not count as correct.*

No matter response say: **If there are _____ trucks and I add one (two) more, there would be _____trucks.**

OR

Subtraction

There are _________ trucks. *Identify number of trucks on card*
What if I took away one (two) truck(s)? How many trucks would there be?

(Correct) **That's right. If there are _____ trucks and I took away one (two) trucks, there would be _____ trucks.**

(Incorrect) **That's not quite right.** *Cover up one (two) trucks on original card.* **If I took away one (two) trucks(s) how many trucks would there be?**
If child still responds incorrectly count trucks: **Let's count together**. *POINT to each truck and have child count along. Do not count as correct.*

No matter response say: **If there are _____ trucks and I take away one (two), there would be _____ trucks.**

SHAPE B – Add/Subtract

Addition

There are _________ stars. *Identify number of stars on card*
What if I added one (two) more star(s)? How many stars would there be?

(Correct) **That's right. If there are _____ stars and I add one (two) more, there would be _____ stars.**

(Incorrect) **That's not quite right.** *Place card with one (two) stars(s) next to original card.* **If I added one (two) more star(s) how many stars would there be?**
If child still responds incorrectly count stars: **Let's count together**. *POINT to each star and have child count along. Do not count as correct.*

No matter response say: **If there are _____ stars and I add one (two) more, there would be _____stars.**

OR

Subtraction

There are _________ stars. *Identify number of stars on card*
What if I took away one (two) star(s)? How many stars would there be?

(Correct) **That's right. If there are _____ stars and I took away one (two) stars, there would be _____ stars.**

(Incorrect) **That's not quite right.** *Cover up one (two) stars on original card.* **If I took away one (two) stars(s) how many stars would there be?**
If child still responds incorrectly count stars: **Let's count together**. *POINT to each star and have child count along. Do not count as correct.*

No matter response say: **If there are _____ stars and I take away one (two), there would be _____stars.**