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Benefits of Playing Numerical Card Games on Head Start Children's Mathematical Skills

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Abstract

Low-income preschoolers have lower average performance on measures of early numerical skills than middle-income children. The present study examined the effectiveness of numerical card games in improving children's numerical and executive functioning skills. Low-income preschoolers (N=76) were randomly assigned to play a numerical magnitude comparison card game, a numerical memory and matching card game, or a shape and color matching card game across four 15-minute sessions. Child who played either of the numerical games improved their numeral identification skills, while only children who played the numerical magnitude comparison game improved their symbolic magnitude comparison skills. These improvements were maintained eight weeks later. The results suggest that a brief, low-cost intervention can successfully improve the numerical skills of low-income children.

Keywords

numerical knowledge; executive functioning; early mathematics; low-income; interventions

Children from low-income households have lower performance on average on a range of educational outcomes than children from middle- and upper-income households. In the domain of mathematics, studies have documented income-based performance gaps before the start of formal schooling, appearing as significant differences in children's foundational numeracy skills like counting, recognizing written numerals, and comparing the magnitudes of numbers (Jordan, Kaplan, Olah, & Locuniak, 2006; Starkey, Klein, & Wakeley, 2004). These early numeracy skills lay the foundation for children's later understanding of arithmetic (Geary, Hoard, & Hamson, 1999) and predict children's mathematical achievement years later in third and fifth grades (Duncan et al., 2007; Watts, Duncan, Siegler, & Davis-Kean, 2014). Consequently, there is a need for developmentally appropriate resources that can be used by early childhood educators and parents to target children's early numeracy skills.

Previous studies have demonstrated significant gains in preschool children's early skills after brief, play-based numeracy interventions (e.g., Scalise, Daubert, & Ramani, 2017; Honoré &

Noël, 2016; Siegler & Ramani, 2008; Whyte & Bull, 2008). However, assessments of children's progress that immediately follow the intervention cannot address whether gains persist over time. Indeed, longitudinal studies of early childhood educational interventions often show patterns of "fade out" in students' outcomes, such that the large effects of comprehensive year-long curricular interventions found at the end of preschool decrease significantly by the end of kindergarten or later elementary school (Bailey et al., 2016; Bailey, Duncan, Watts, Clements, & Sarama, 2018; Barnett, 2011; Clements, Sarama, Wolfe, & Spitler, 2013; Puma et al., 2012). In addition, observational studies of teachers and parents of young children suggest that the majority of the numerical information provided to children relates to foundational skills such as counting, labeling set sizes, and labeling written numerals (Klibanoff et al., 2006; Ramani, Rowe, Eason, & Leech, 2015). It may be particularly important for young children to practice other key skills that fall beyond the typical focus of educators and parents such as numerical magnitude skills, like comparing numbers to say which is more and which is less. Numerical magnitude skills have been linked to concurrent and later mathematics achievement in children and adults (Chen & Li, 2014; De Smedt, Noël, Gilmore, & Ansari, 2013; Schneider et al., 2016; Siegler, 2016). Furthermore, given that parents and teachers already provide young children with exposure to early mathematics concepts, it is important to evaluate children's learning gains from interventions relative to their learning from other sources.

In addition to early numerical knowledge, domain-general executive functioning (EF) skills predict children's concurrent and future mathematics achievement (Duncan et al., 2007; Geary, 2011). In early childhood, executive functioning skills including working memory predict children's numerical magnitude knowledge (Kolkman, Hoijsink, Kroesbergen, & Leseman, 2013). Although children from low-income households tend to have lower EF skills on average than children from mid- and upper-income households (Davis-Kean, 2005; Fernald, Weber, Galasso, & Ratsifandrihamanana, 2011; Noble, McCandliss, & Farah, 2007), there is some evidence that executive functioning skills are malleable and can be improved with repeated practice (Diamond & Lee, 2011; Mackey, Hill, Stone, & Bunge, 2011).

In the present study, we tested the effectiveness of playing a numerical card game in improving the early numeracy and executive functioning skills of preschool children from lower-income backgrounds. Our previous work (Scalise et al., 2017) demonstrated that one hour of playing the numerical card games led to significant improvements in children's counting and numerical magnitude knowledge when children were assessed after the end of the training. The present study sought to replicate and extend the short-term improvements in children's numerical skills and determine whether the improvements were maintained up to eight weeks following the training. We further examined whether children's improvements could be attributed to experience with the numerical card games or their learning from educators and parents by randomly assigning children to play a numerical card game or a non-numerical control card game. Finally, we tested whether experience playing the card games improved children's executive functioning skills.

The Development of Early Numerical Skills

By preschool, children have acquired a range of numerical skills. Many children begin to recite the verbal counting sequence (“one, two, three...”) by 2 – 3 years old (Gelman & Gallistel, 1978) and achieve mastery of counting the numbers one through ten by four years old (Fuson, 1988; Siegler & Robinson, 1982). However, the transition from knowing verbal number words to recognizing that each word represents a set quantity is lengthy. Although there is evidence that humans are sensitive to numerical quantities in infancy (for a review, see Feigenson, Dehaene, & Spelke, 2004; c.f. Leibovich, Katzin, Harel, & Henik, 2017), children do not automatically understand that their final counting word when counting a group of objects represents the total amount, known as the cardinality principle (Sarnecka, 2015). Once children understand that “one” can refer to one button or one apple, but not two shoes or five fingers, it takes additional time for them to understand that “two” refers to sets of two items, “three” refers to sets of three items, and “four” refers to sets of four items. This mapping between the memorized ordered count list and small sets of individual items lays the foundation for children to infer (or “bootstrap”) the understanding that each additional number in the count sequence refers to an additional individual item in a set, which can ultimately be generalized to the entire count sequence (Carey, 2011).

Developing an understanding of numerical magnitudes and their relative amounts, like knowing that seven is larger than four, is theorized to be the hallmark of numerical development across the lifespan (Siegler, 2016; Siegler & Lortie-Forgues, 2014; Siegler, Thompson, & Schneider, 2011). Understanding numerical magnitudes is key to many formal and informal mathematics experiences, from solving arithmetic problems to calculating an appropriate tip. Siegler and colleagues describe the process of refining numerical knowledge as spanning four types of magnitude, including non-symbolic quantities like sets of objects, small whole numbers less than ten, larger whole numbers, and all rational numbers, including decimals and fractions. Across magnitude types, numerical magnitude knowledge predicts general mathematics achievement concurrently and over time (Schneider et al., 2016; Siegler, 2016). In particular, preschool children’s ability to compare non-symbolic quantities relates to their later arithmetic knowledge and scores on standardized math achievement assessments (e.g., Libertus, Feigenson, & Halberda, 2011; Toll, Van Viersen, Kroesbergen, & Van Luit, 2015; c.f. Fuhs & McNeil, 2013). Similarly, preschoolers’ ability to compare small symbolic numbers, represented by Arabic numerals or verbal number words, relates to their general math achievement (Kolkman, Kroesbergen, & Leseman, 2013; Toll et al., 2015). Thus, there is both theoretical and empirical evidence that non-symbolic and symbolic numerical magnitude knowledge in early childhood may lay the foundation for later mathematics achievement.

Before kindergarten, children from lower-income households tend to have lower performance on measures of symbolic magnitude knowledge than children from middle-income households, including small whole number comparison (e.g., “which is more, 7 or 2?”) and estimating the position of numbers on a number line (e.g., “if 0 goes here and 10 goes here on the number line, where should 4 go?”; Scalise et al., 2017; Ramani & Siegler, 2011). However, there is some evidence that children from lower-income households may perform equivalently to children from middle-income households on tasks of non-symbolic

magnitude comparison and arithmetic with small numbers (Scalise et al., 2017; Jordan & Levine, 2009). This suggests that providing multiple redundant cues representing numerical magnitude, such as numerical cards displaying an Arabic numeral and a set of objects in the corresponding amount, may allow children who are less proficient with symbolic magnitude to scaffold their understanding with the non-symbolic magnitude information (Scalise et al., 2017).

Numerical Magnitude Interventions for Young Children

Previous research has targeted children's numerical magnitude skills with promising results. Using a linear board game numbered from one to ten, Ramani and Siegler (2008) showed that playing for approximately one hour led to significant improvements in low-income preschoolers' symbolic numerical magnitude skills. These improvements were substantial enough that the magnitude skills of children from low-income households after the intervention were equivalent with the skills of children from middle-income households (Siegler & Ramani, 2008). These gains were maintained up to nine weeks following the brief intervention game (Ramani & Siegler, 2008) and were selective to practice with a numerical, linear board game but not a non-numerical, linear board game nor a numerical, circular board game (Ramani & Siegler, 2008; Siegler & Ramani, 2009). Taken together, the findings from numerical linear board game interventions suggest that low-income preschoolers' symbolic magnitude skills are malleable and sensitive to relatively brief amounts of practice.

More recently, Honoré and Noël (2016) demonstrated that preschool children who played a combination of magnitude comparison and number line estimation games with symbolic numbers significantly improved their symbolic magnitude and arithmetic skills. Interestingly, children who were randomly assigned to play a parallel set of non-symbolic magnitude games did not show similar improvements in their symbolic magnitude and arithmetic skills, suggesting that a focus on symbolic magnitude may be more important for producing gains in general math achievement. Other researchers have combined non-symbolic and symbolic magnitude practice into one form of training; Whyte and Bull (2008) had preschool children compare pairs of cards with different amounts of apples and asked them to determine which card had more apples. Once the children made their decision, the researcher turned over the cards to reveal the corresponding symbolic magnitudes and confirm or correct the children's response. After playing for four 25-min sessions children had significantly improved their symbolic magnitude comparison skills, suggesting comparing numerical magnitudes with both non-symbolic and symbolic formats can promote children's symbolic magnitude knowledge.

Building on prior magnitude interventions, in a previous study we examined the effectiveness of a numerical magnitude comparison card game with both non-symbolic and symbolic representations on promoting the magnitude skills of preschoolers from low-income backgrounds (Scalise et al., 2017). We randomly assigned preschoolers from low-income households to play one of two numerical card games across four 15-min sessions: a numerical magnitude comparison card game, where players labeled the number on their card and determined which was the larger value, and a numerical memory and matching card

game, where players turned over pairs of cards, labeled their numbers, and tried to find numerical matches (Scalise et al., 2017). By the end of the intervention, children in both conditions significantly improved their counting and numeral identification skills, while only children who played the numerical magnitude comparison card game significantly improved their symbolic magnitude skills. Similar benefits to the fraction magnitude understanding of elementary school students were found in a study where children played magnitude comparison and memory and matching card games with fractions (Gabriel et al., 2012).

Although our previous study focused on children from low-income backgrounds at risk for poor symbolic magnitude understanding and used an inexpensive and familiar resource for promoting early magnitude skills, it left several questions unanswered. By comparing two numerical card games, it was difficult to determine whether improvements in children's foundational numerical skills like counting and numeral identification were due to the intervention games or ongoing instruction from teachers and parents. Furthermore, it was not tested whether the improvements in children's numerical skills were sustained over time, or whether they faded after the intervention ended. In addition to improvements in children's numerical skills, it was unclear whether there were benefits to children's domain-general executive functioning skills, which relate broadly to numerical knowledge and mathematics achievement.

The Role of Executive Functioning Skills in Early Mathematics

Executive functioning (EF) is defined as a set of top-down cognitive processes consisting of three core skills: inhibition, working memory, and cognitive flexibility (Diamond, 2013). EF skills are thought to be central to the information processing required by mathematics, such as ignoring irrelevant information in a word problem (inhibition), keeping different quantities in mind and manipulating them while solving a multi-digit arithmetic problem (working memory), and being able to use a variety of strategies to generate a solution (cognitive flexibility; Geary & Hoard, 2005). In early childhood, EF skills relate to children's numerical magnitude knowledge, as well as how much children learned from a short-term numerical intervention (Kolkman et al., 2013). A number of studies have examined whether interventions to promote children's EF skills lead to domain-specific improvements in mathematics performance (e.g., Kroesbergen, van t' Noordende, & Kolkman, 2014; Ramani, Jaeggi, Daubert, & Buschkuhl, 2017; Wass, Scerif, & Johnson, 2012), with mixed results. There is also some evidence that playful intervention games intended to promote children's numerical knowledge may also lead to improvements in children's working memory skills (Kroesbergen et al., 2014; Ramani et al., 2017).

In our previous study, the numerical memory and matching card game required children to turn over pairs of face-down cards to find a matching set, theoretically offering repeated opportunities to remember the spatial location of the numerical cards. This repeated practice may have served to bolster children's visuo-spatial working memory skills. Furthermore, the act of playing a card game with another person required children to take turns, which may help children practice inhibiting their automatic response of playing their turn. In general, playful learning experiences that require turn-taking and cooperative play are thought to provide a developmentally appropriate context for young children to develop their executive

functioning skills (Hassinger-Das et al., 2017). Indeed, play-focused curricula like *Tools of the Mind* have been shown to be effective at promoting children's EF skills (Diamond & Lee, 2011). In the present study, we were interested in whether children's participation in the intervention would lead to improvements in their EF skills, which could ultimately promote their future mathematics success.

The Present Study

Our goals for the present study were threefold: to determine 1) whether children improved from the intervention; 2) if improvements varied by intervention condition; and 3) if improvements were maintained over time. To address whether children improved their performance from the intervention card games, we administered pretest and posttest assessments of their numerical and executive functioning skills before and after children played the games with an experimenter for four 15-min sessions. We also conducted an 8-week follow-up visit with the same assessments.

To determine whether children improved their numerical knowledge from playing the card games rather than their other exposure from parents and teachers, we randomly assigned children to one of three conditions. Children either played one of the two numerical card games from the previous study or a non-numerical, shape and color card game. Thus, we examined whether practice with the numerical card games led to significant improvements in children's foundational number skills relative to playing the non-numerical shape and color game.

We hypothesized that children who played either of the numerical card games would improve their verbal counting, numeral identification, object counting, and cardinality skills, given similar opportunities to count and label the magnitudes on the numerical cards. However, we thought only the children who were randomly assigned to play the magnitude comparison card game would show significant improvements in their non-symbolic and symbolic magnitude comparison skills, given their repeated practice comparing cards depicting non-symbolic sets with symbolic labels. Furthermore, we hypothesized that the children who played the numerical memory and matching game might selectively improve their visuo-spatial working memory skills, given their practice remembering the physical locations of hidden cards. We hypothesized that all children might improve their inhibitory control skills after participating in the intervention, from practice playing games with an experimenter and taking turns. Finally, we hypothesized that any gains in numerical or domain-general executive functioning skills from playing the card games would be maintained two months after the end of the intervention.

In a final exploratory analysis, we investigated whether there were individual differences in children's improvements within each intervention condition.¹ We examined whether improvements at the condition level were driven by gains from a few children versus many children, as well as whether children's initial numerical and executive functioning skills related to their improvements.

¹ We thank two anonymous reviewers for their suggestion to examine individual differences in children's improvements

Method

Participants

Participants were 83 preschoolers from four Head Start Centers in the mid-Atlantic region of the United States. Head Start is a federally funded early childhood education program for low-income families. To enroll a child in Head Start during the school year when these data were collected, a family of four was required to have an annual household income of \$24,250 or less. We excluded data from seven children due to: repeated declination to participate during pretest ($n = 1$) or intervention game sessions ($n = 1$) and significant distraction throughout one or more assessment sessions ($n = 5$). The final sample contained 76 preschoolers, ranging in age from 3 years, 4 months to 5 years, 6 months ($M = 4$ years, 6 months, $SD = 0.58$; 46% female; 63% Hispanic/Latino, 21% African American/Black, 11% Multiracial, 4% Asian, 1% Caucasian).

Procedure

Children participated in seven 15–20 min sessions individually with an experimenter in a quiet area of their school or classroom (Figure 1). During the pretest, posttest, and follow-up assessment sessions (1, 6, and 7), children completed six measures of their numerical knowledge and two measures of their executive functioning skills. Children were randomly assigned at the classroom level stratified by gender to play one of three card game interventions: a numerical magnitude comparison card game ($n = 27$), a numerical memory and matching card game ($n = 25$), and a shape and color matching card game ($n = 24$). There were no significant differences in the age of children across the three conditions, $F(2, 71) = 0.77$, $p = .47$.

Children played the game with an experimenter across two weeks (sessions 2 – 5). Pretest and posttest assessments occurred on average within a week of the card game intervention training, and follow-up sessions occurred eight weeks after the end of the intervention ($M = 60.4$ days, $SD = 5.6$ days). An experimenter blind to the intervention condition of the child conducted the majority of posttest (68%) and follow-up (71%) assessments.

Assessments.—Children completed six measures of their numerical knowledge (verbal counting, numeral identification, enumeration, cardinality, symbolic magnitude comparison, non-symbolic magnitude comparison) and two measures of their executive functioning skills (inhibitory control, working memory), presented in the following order during each assessment session: verbal counting, numeral identification, inhibitory control, symbolic magnitude comparison, enumeration, cardinality, working memory, and non-symbolic magnitude comparison. Children were given general encouragement throughout the assessment tasks, but were not provided with accuracy feedback on test trials of any measure.

Verbal counting.: Children were asked to count aloud starting with 1 and were stopped by the experimenter after they made an error or after they successfully counted to 25 (adapted from Ramani & Siegler, 2008). The dependent measure was the highest number counted to without errors divided by the highest possible score (i.e., 25).

Numeral identification.: Children were presented with 10 randomly ordered cards, each with an Arabic numeral from 1 to 10, and asked to identify the numeral verbally (Ramani & Siegler, 2008). The dependent measure was the percentage of numerals correctly labeled.

Enumeration.: Children were asked to count a set of stars presented on a piece of paper (adapted from Ramani et al., 2015). This was repeated three times, with four stars, five stars, and nine stars. The dependent measure is the percentage of trials in which the child correctly counted the stars.

Cardinality.: Children were given a pile of 10 plastic tokens and asked to give the experimenter three chips, five chips, and seven chips, respectively (adapted from Wynn, 1990). The dependent measure is the number of trials in which the child correctly provided the requested number of poker chips.

Symbolic magnitude comparison.: Children were asked to compare 20 pairs of symbolic numbers (Arabic numerals) ranging from 1–9 (Ramani & Siegler, 2008). After two practice trials with experimenter feedback, participants were shown and read 18 test pairs of numbers and asked to indicate which number was larger. Each number was counterbalanced for side of presentation (i.e., 3|8, 8|3). The ratio between pairs ranged from 1.1 (e.g., 8|9) to 9.0 (e.g., 9|1). The dependent measure was percentage of correct comparisons.

Non-symbolic magnitude comparison.: Children were asked to make a series of comparisons between non-symbolic magnitudes (dot arrays) on a laptop computer, using the Panamath program (Libertus, Feigenson, & Halberda, 2013). Participants were instructed to press one of two buttons to indicate which side had more dots. The program settings were chosen to replicate those used in other studies of preschool-aged children. Children were shown 32 pairs, displayed for 2.3 seconds each. The dot quantities ranged from 4–15 and included numerical comparisons with ratios of 2.0 (e.g., 4|8, 25% of trials); 1.5 (e.g., 4|6, 25% of trials); 1.3 – 1.4 (e.g., 8|11, 25% of trials); and 1.1 – 1.2 (e.g., 8|9, 25% of trials). The Panamath software automatically counterbalanced each magnitude for side of presentation (e.g., 4|6, 6|4) and controlled for dot area and density. The dependent measure was the percentage of accurate comparisons.

Working memory.: Children's visuospatial working memory skills were assessed with an adapted Corsi Blocks tapping task (adapted from Morales, Calvo, & Bialystok, 2013); participants were shown a 3×3 matrix on paper decorated like a pond, with a colorful lily pad in each cell. Children watched the experimenter tap a sequence of lily pads, then tried to repeat the sequence in the same order. After two practice trials of sequence length 2 with experimenter feedback, participants completed two trials at each sequence length, beginning at length 2 and ending at length 6. Sequence length increased by one after participants successfully completed at least one of the two trials at the sequence length. If a participant could not complete either trial at a given sequence length, the experimenter ended the task. Children were given one point for each lily pad accurately tapped per sequence (accuracy) and one point for each tap that occurred in the correct order within a given sequence (order). The dependent measure was the sum of accuracy and order scores across all sequences shown, for a maximum possible score of 80 points.

Inhibitory control.: Children were asked to touch their head when the experimenter said “feet” and touch their feet when the experimenter said “head” (adapted from Ponitz et al., 2008). After three trials with experimenter feedback, children completed 16 test trials. The dependent measure was the percentage of correctly completed test trials.

Card game conditions.—Children were randomly assigned to play one of three intervention card games individually with an experimenter across four 15-min sessions. If a game ended before 15-min had passed, the experimenter and child played the game again, repeating as necessary until 15-min had passed. Although there were differences in the average number of card games played by condition since the three games varied in length, we chose hold constant the amount of time spent playing the games across condition.

Numerical magnitude comparison game.: The experimenter divided in half a deck of 40 numerical cards, labeled with Arabic numerals and red circles (Figure 2; Scalise et al., 2017). The experimenter and child turned over their top cards, stated the numbers, and counted the dots to figure out the numeral if the child was unsure or incorrectly labeled the numeral. The child was then asked which card was more, and the player with the higher number kept both cards. At the end, both players counted their cards, and the player with the most cards was the winner.

Numerical memory and matching game.: The experimenter laid 10 numerical cards (Figure 2) face down in a 2×5 grid (Scalise et al., 2017). The experimenter alternated between two sets of 10 cards, each with pairs of five numbers between 1 and 10 (e.g., Set A had two cards each of 3, 5, 6, 9, and 10, and Set B had the remaining pairs). On each turn, the player turned over two cards, stated the numbers, and said whether or not the two matched (were the same number). If the child was unsure of or incorrectly labeled the numeral, the experimenter prompted them to count the dots to determine the number. If a player found two cards with the same number, they kept them, otherwise they put them back face down and the next player took their turn. The player with the most cards at the end of the game was the winner.

Shape and color matching game.: The experimenter shuffled a deck of 40 cards, each with a shape (circle, square, triangle, rectangle, pentagon) and color (red, yellow, green, blue; Figure 2). They gave each player five cards, left face-up, turned over one of the remaining cards, and placed the rest of the deck face down in the center. The players took turns trying to match one of their face-up cards to the center target card by shape or color. If the player had a card with the same shape or color, they placed it on top of the target card. If the player did not have a matching card, they drew one additional card from the deck in the center. The first player to use all of their face-up cards was the winner.

Results

We first conducted one-way analysis of variance (ANOVA) on each outcome measure at pretest with intervention condition (numerical magnitude, numerical memory, and non-numerical matching) as the grouping variable to determine whether there were any statistically significant differences between conditions prior to the intervention. There were

no statistically significant effects of condition on pretest scores on any of the outcome measures (all $ps > .09$). Table 1 reports the descriptive statistics by condition. Our use of random assignment (stratified by classroom and child gender) assumes that children across conditions would be approximately balanced on factors that relate to the variability in their skills, such as their IQ and the mathematical input they receive at home.

We next examined the data to answer three questions: 1) Did children improve from the intervention? 2) Did improvements vary by intervention condition?; and 3) Were improvements maintained over time? We conducted repeated measures ANOVAs on each outcome measure, testing the effects of condition (numerical magnitude, numerical memory, and non-numerical matching) and participant age at pretest (median split: younger than 54 months, 54 months and older) over assessment session (pretest, posttest, follow-up). The median split served as both a control for age effects on children's performance as well as a proxy for children's number of years attending preschool (i.e., the child's first versus second year). We report Pillai's Trace as the F -statistic and partial eta squared as the effect size. In the case of violations of sphericity, we report results from the adjusted Huynh-Feldt F -test (Lomax & Hahs-Vaughn, 2012). We report the results of the main effects test of age for evidence of performance differences for older versus younger children, the main effects of session for evidence of children's improvements in performance, and the interaction effect of condition and session to offer insight as to whether improvements varied by condition. Since a statistically significant interaction effect of condition and session is ambiguous in designs with more than two conditions, we followed up with planned posthoc comparisons using t -tests of children's pretest-to-posttest difference scores to examine our specific hypotheses on how children's improvements may have varied by condition.

Specifically, we conducted posthoc comparisons to test whether children in the numerical intervention conditions improved more than children in the non-numerical intervention condition on tasks that emulated features of playing the number card games (counting, numeral identification, enumeration, cardinality); whether the children in the numerical magnitude condition improved their magnitude skills (non-symbolic and symbolic) more so than children in the numerical and non-numerical control conditions; and whether children in the numerical memory condition improved their visuo-spatial working memory skills more so than children in the other two conditions. There were no a priori hypotheses for between-group differences for improvements on the measure of inhibitory control, thus we did not conduct any posthoc comparisons.

In order to provide evidence as to whether initial pretest-posttest gains are maintained over time, effect sizes (Cohen's d) of mean group differences between pretest and posttest and pretest and follow-up are presented (Table 1) as well as graphical representations of children's skills across sessions (Figures 2 – 4).

Finally, we conducted exploratory analyses to determine whether there were individual differences in children's improvements within conditions. We calculated the number of children in each condition who had positive difference scores from pretest to posttest and pretest to follow-up test on each outcome measure. We also conducted within-condition correlations between children's initial pretest performance scores and their pretest to posttest

difference scores to determine whether starting skills related to children's improvements over time.

Verbal Counting

The 2 (age: above or below median) $\times 3$ (condition: numerical magnitude, numerical memory, non-numerical matching) $\times 3$ (session: pretest, posttest, follow-up) repeated measures ANOVA revealed a statistically significant main effect of age, $F(1, 70) = 10.59$, $p = .002$, $\eta_p^2 = .13$, indicating that across sessions and conditions, older children tended to have higher accurate count sequences than younger children (highest average count of 18 versus 14). There was also a statistically significant main effect of session, $F(1.949, 69) = 14.02$, $p < .001$, $\eta_p^2 = .17$, indicating children showed improved performance on verbal counting after the intervention period (Figure 3). There was no main effect of condition, $F(2, 70) = 1.12$, $p = .332$, $\eta_p^2 = .03$.

The interaction of condition and session was not statistically significant, $F(3.899, 140) = 0.09$, $p = .987$, $\eta_p^2 = .002$. The planned posthoc comparison of the difference scores between pretest and posttest assessments for children who played a numerical card game (magnitude or memory) and children who played the non-numerical matching game was not statistically significant, $t(74) = 0.22$, $p = .824$, $d = 0.05$. This suggests that children across conditions improved their verbal counting skills and gains were not due to practice with the numerical card games. The effect sizes (Cohen's d) of mean group differences between pretest and follow-up by condition were statistically significant for each card game condition (Table 1), suggesting improvements were maintained over time. Exploratory analyses on individual differences in children's improvements suggest that across conditions between 40 and 50 percent of participants improved their verbal counting skills, and improvements were negatively correlated to children's initial verbal counting scores (Table 2). This implies that children with lower verbal counting skills at pretest improved more over the course of the study.

Numerical Identification

The $2 \times 3 \times 3$ repeated measures ANOVA results included no main effect of age, $F(1, 70) = 2.77$, $p = .101$, $\eta_p^2 = .04$, a statistically significant main effect of session, $F(1.701, 69) = 25.86$, $p < .001$, $\eta_p^2 = .27$, and no main effect of condition, $F(2, 70) = 0.23$, $p = .797$, $\eta_p^2 = .01$ (Figure 3).

The condition by session interaction was statistically significant, $F(3.402, 140) = 4.20$, $p = .005$, $\eta_p^2 = .11$. The planned posthoc comparison of the numerical games (magnitude and memory) and the non-numerical game (matching) revealed a statistically significant difference in gains scores by condition type, $t(74) = 2.22$, $p = .029$, $d = 0.57$, such that the average gain score of children who played the numerical card games ($M = .08$, $SD = .11$) was larger than the average pretest-to-posttest gain score of children who played the non-numerical card game ($M = .03$, $SD = .09$). The effect sizes of mean group differences between pretest and follow-up were statistically significant for both the numerical magnitude and numerical memory game conditions (Table 1), suggesting the improvements from playing the numerical card games were maintained at follow-up. Fifty-nine percent of

children in the numerical magnitude and 48 percent of children in the numerical memory condition improved their numeral identification skills. Children's initial numeral identification skills were significantly negatively correlated with their improvements, but only for children in the numerical memory and matching condition.

Enumeration

The $2 \times 3 \times 3$ repeated measures ANOVA on enumeration skills had no main effect of age, $F(1, 70) = 1.80, p = .184, \eta_p^2 = .03$, no main effect of session, $F(1.815, 69) = 0.88, p = .408, \eta_p^2 = .01$, and no main effect of condition, $F(2, 70) = 1.30, p = .280, \eta_p^2 = .04$ (Figure 3).

The condition by session interaction was not statistically significant, $F(3.630, 140) = 1.95, p = .112, \eta_p^2 = .05$. The planned posthoc comparison of the numerical games and the non-numerical game showed there was not a statistically significant difference in children's pretest to posttest gain scores, $t(74) = -0.44, p = .664, d = -0.11$. Few children improved their enumeration skills (less than 30 percent in each condition), and improvements were negatively correlated to children's initial scores for children in the non-numerical condition.

Cardinality

There was a statistically significant main effect of age on children's cardinality skills, $F(1, 70) = 5.61, p = .021, \eta_p^2 = .07$, such that older children were more accurate across sessions and conditions than younger children (average accuracy of 75 versus 57 percent). There was also a statistically significant main effect of session, $F(2, 69) = 8.47, p = .001, \eta_p^2 = .20$, but no main effect of condition, $F(2, 70) = 0.43, p = .652, \eta_p^2 = .01$ (Figure 3). The interaction of session and condition was not statistically significant, $F(4, 140) = 1.24, p = .299, \eta_p^2 = .03$. The planned posthoc comparison of the numerical games and the non-numerical game revealed a non-significant difference in pretest to posttest gains, $t(74) = 0.72, p = .475, d = 0.19$. The effect sizes of mean group differences between pretest and follow-up by condition were comparable in magnitude and statistical significance to the effect sizes from pretest to posttest (Table 1), suggesting the improvements were maintained over time. Comparable numbers of children in the numerical magnitude and the non-numerical control condition showed improvements (30 and 29 percent, respectively), while 40 percent of children in the numerical memory and matching condition improved. For children in the numerical conditions, initial performance was negatively related to improvements.

Symbolic Magnitude

There was a statistically significant main effect of age on children's symbolic magnitude skills, $F(1, 70) = 7.93, p = .006, \eta_p^2 = .10$, such that across sessions and conditions, older children were more accurate in their symbolic magnitude comparisons than younger children (76 versus 64 percent). There was also a statistically significant main effect of session, $F(2, 69) = 5.86, p = .004, \eta_p^2 = .15$, but no main effect of condition, $F(2, 70) = 0.08, p = .925, \eta_p^2 = .002$ (Figure 4). The interaction of session and condition was non-significant, $F(4, 140) = 1.95, p = .105, \eta_p^2 = .05$. The planned posthoc comparison of the numerical magnitude game and the other games (numerical memory and non-numerical matching) revealed a significant difference in pretest to posttest gains, $t(74) = 2.80, p = .007, d = 0.70$, such that the average gain score of children who played the numerical magnitude game (M

$= .10$, $SD = .13$) was larger than the average gain score of children who played the numerical memory and non-numerical matching games ($M = -.01$, $SD = .16$). The effect size of the mean group difference between pretest and follow-up skills was statistically significant for the numerical magnitude condition (Table 1), suggesting the improvements were maintained at the follow-up assessment. Seventy-four percent of children in the numerical magnitude condition showed improvements, compared to 40 and 42 percent of children in the numerical memory and non-numerical conditions. The improvements of children in the numerical magnitude condition were not significantly related to their initial performance.

Non-Symbolic Magnitude

There was a statistically significant main effect of age on children's non-symbolic magnitude skills, $F(1, 70) = 11.80$, $p = .001$, $\eta_p^2 = .14$, indicating that across sessions and conditions, older children were more accurate in their non-symbolic magnitude comparisons than younger children (70 versus 60 percent accurate). There was also a statistically significant main effect of session on children's non-symbolic magnitude skills, $F(2, 69) = 8.97$, $p < .001$, $\eta_p^2 = .21$, but no main effect of condition, $F(2, 70) = 2.44$, $p = .095$, $\eta_p^2 = .07$ (Figure 4). The interaction of session and condition was non-significant, $F(4, 140) = 0.41$, $p = .800$, $\eta_p^2 = .01$. The planned posthoc comparison of the numerical magnitude game and the other games revealed no statistically significant difference between the conditions, $t(74) = 0.85$, $p = .396$, $d = 0.21$. This suggests that children's improvements in non-symbolic magnitude comparison may be due to repeated exposure to the task or other experiences outside of the intervention games. The effect sizes of mean group differences between pretest and follow-up by condition were comparable in magnitude and statistical significance to the effect sizes from pretest to posttest (Table 1), suggesting the improvements were maintained over time. Half or more of the children in each condition showed improved performance on the measure of non-symbolic magnitude understanding (Table 2), with improvements negatively related to initial skill level for children in the numerical magnitude condition only.

Working Memory

There was a statistically significant main effect of age on children's working memory performance, $F(1, 65) = 21.72$, $p < .001$, $\eta_p^2 = .25$, such that older children across sessions and conditions had higher scores than younger children (average scores of 39 versus 26). The main effect of session was statistically significant, $F(2, 64) = 3.75$, $p = .029$, $\eta_p^2 = .11$, while the main effect of condition was not significant, $F(2, 65) = 2.20$, $p = .119$, $\eta_p^2 = .06$ (Figure 5). The interaction of session and condition was also not statistically significant, $F(4, 130) = 0.42$, $p = .793$, $\eta_p^2 = .01$. The planned posthoc comparison of the numerical memory game and the other games (numerical magnitude and non-numerical matching) revealed no significant difference in children's gain scores, $t(74) = 0.72$, $p = .473$, $d = 0.18$. Approximately half of the children in each condition improved on working memory (Table 2), with improvements negatively correlated to children's initial working memory skills across conditions.

Inhibitory Control

There was a statistically significant main effect of age on children's inhibitory control performance, $F(1, 70) = 12.95, p = .001, \eta_p^2 = .16$, such that across sessions and conditions, older children were more likely to successfully inhibit their responses on each trial than younger children (average of 61 versus 34 percent of trials). There was also a statistically significant main effect of session on children's inhibitory control performance, $F(1.798, 69) = 10.41, p < .001, \eta_p^2 = .13$, but no main effect of condition, $F(2, 70) = 1.87, p = .162, \eta_p^2 = .05$ (Figure 5). The session by condition interaction was not statistically significant, $F(3.596, 140) = 1.38, p = .247, \eta_p^2 = .04$. There were no a priori hypotheses that a particular intervention condition would improve inhibitory control more so than other conditions, thus no posthoc comparisons were conducted. The effect sizes of mean group differences between pretest and follow-up by condition were comparable in magnitude and statistical significance to the effect sizes from pretest to posttest (Table 1), suggesting the improvements were maintained at follow-up. Between forty and fifty-six percent of children per condition showed improvements on inhibitory control measures, with improvements significantly and negatively correlated to initial inhibitory control skills for children in the numerical memory and non-numerical control conditions.

Discussion

Children's numerical skills set the stage for their later mathematics learning, making the early performance gaps between children from low-income backgrounds and their middle- and upper-income peers especially concerning. In the present study, we tested the effectiveness of a brief mathematical card game intervention on promoting low-income preschoolers' numerical skills. Overall, we found evidence that children improved from playing the numerical card games, their improvements on certain tasks varied by the card game that they played, and that much of the improvement visible immediately after the intervention phase was maintained up to eight weeks later. Our findings extend previous work by demonstrating the benefits of numerical card games relative to a non-numerical control card game and assessing the longer-term impact on children's numerical and executive functioning skills with a delayed follow-up assessment.

Improvements in Numeracy Skills

We found mixed support for our hypotheses that children who played the numerical card games would improve on their foundational numeracy skills more so than children who played the non-numerical shape and color matching game. On average, children across card game conditions significantly improved their verbal counting and cardinality skills over the course of the intervention. Between 30 and 50 percent of children in each condition improved their counting and cardinality skills, with significant negative relations between children's initial skills at pretest and their later improvements. Taken together, this suggests that their improvement is due to other experiences beyond our numerical games. Observational studies of preschool-aged children report that counting and cardinality are among the most frequent types of numeracy-related talk spoken by parents and early childhood educators (e.g., Klibanoff et al., 2006; Ramani et al., 2015), which may explain children's improvement in verbal counting and cardinality over the course of our study,

particularly for children with lower initial skills. Additionally, there were no statistically significant improvements in children's enumeration skills, which may be due in part to the lack of explicit training on counting objects. Although children were encouraged to count the non-symbolic circles on the cards to determine the numeral, the protocol did not include specific training on counting principles like each object can only be assigned one counting word (one-one principle; Gelman & Gallistel, 1978).

As hypothesized, children who played the numerical card games significantly improved their numeral identification skills compared to children who played the non-numerical shape and color matching game. Roughly half of the children in each numerical game condition improved their numerical identification skills. In both the numerical magnitude comparison and numerical memory and matching card games, children were prompted on each turn to identify the numeral on their cards. Unlike many contexts when children are asked to name a numeral, the numerical cards offered children a method of problem-solving when they were not sure of the answer – they were able to count the circles on the card to remind themselves of the number word associated with the numeral. The improvements in children's numeral identification skills were maintained through the follow-up assessment eight weeks later, while children who played the non-numerical game remained at skill levels comparable to their pretest assessment.

We hypothesized that children who played the numerical magnitude comparison card game would improve significantly more on their symbolic and non-symbolic magnitude comparison skills. Children who played the numerical magnitude comparison game significantly improved their symbolic magnitude comparison skills on average, replicating our previous study (Scalise et al., 2017). Furthermore, nearly 75 percent of children in the numerical magnitude comparison condition improved their symbolic magnitude skills from pretest to posttest, and children's improvements were unrelated to their initial symbolic magnitude skills. In addition, their improvements on symbolic magnitude skills were maintained after eight weeks. This lends additional support to the use of numerical magnitude comparison card games to broadly promote the symbolic magnitude knowledge of young children.

However, the patterns of children's non-symbolic magnitude knowledge did not match our hypothesis: children across card game conditions significantly improved on the non-symbolic magnitude comparison task, with individual improvements for half or more of the children in each condition. The non-symbolic magnitude task was the only task in the study administered on a laptop computer, and was both novel to the children and had a limited presentation time for the stimuli. Children's improvements on the non-symbolic magnitude task could reflect their growing familiarity with the task format as they completed the assessment for a second and third time. Alternatively, it is possible that not all children originally understood the instructions of the task to mean selecting the greater numerical magnitude and not the greater surface area. Negen and Sarnecka (2015) describe a detailed training procedure to scaffold preschoolers' understanding of the numerical comparison task instructions and suggest that children's performance would differ based on their interpretation of "more dots". Over the course of the study, children across conditions may have figured out that numerosity, rather than surface area, was the appropriate basis for their

magnitude judgment. However, offering a scaffolded introduction to the non-symbolic magnitude comparison task that clarified the goal of selecting a response based on the greater numerosity may have led to different results.

Improvements in Executive Functioning Skills

The numerical memory and matching card game involved turning over pairs of face-down cards to find two of the same cards, requiring children to remember the location of cards from previous trials. We hypothesized that practice with the numerical memory and matching card game may bolster children's visuo-spatial working memory skills, however, there were no condition-specific improvements. The lack of significant gains in working memory skills may be due in part to the relatively brief exposure to the numerical memory card game, or that the focus of the game was not solely on training WM. Indeed, a recent intervention designed to target the working memory skills of kindergarten children from low-income households found only modest improvements in children's skills after ten 15-min sessions of training, suggesting that children may need substantially more practice than the one hour training we provided (Ramani et al., 2017). In addition, posthoc power analyses suggest that the sample size of the current study ($N = 76$) was underpowered to detect small effects when testing session by condition interactions. Thus, it is possible that future research with larger sample sizes could reveal small, condition-specific improvements to children's working memory skills.

As predicted, children across conditions significantly improved their inhibitory control skills between assessment sessions, with approximately half of the children in each condition demonstrating individual improvements. Part of the gains may be due to increased familiarity with the task format over time, as the task was unusual for children in that it asked them to do the opposite of what the experimenter said. It is also possible that the experience with playing a game with an adult experimenter, taking turns and more critically, waiting to take their turn until the other player finished, helped children practice inhibiting their automatic responses. Playful learning experiences like card games may offer children a context to develop their executive functioning skills, and in turn be better prepared learners (Hassinger-Das et al., 2017). However, the results of the inhibitory control analyses should be interpreted with caution, as the design of the present study does not provide conclusive evidence that playing games can help children improve their inhibitory control skills. Future research should include a business as usual control or non-playful intervention condition to isolate the effects of playing games.

Educational Implications

The present study has several key implications relevant to parents and educators of young children. In replicating the effects of our previous work (Scalise et al., 2017), the present study offers additional evidence that important numerical skills like numeral identification and symbolic magnitude understanding are malleable with brief exposure to numerical card games. Furthermore, the effects are maintained over eight weeks without additional training, which suggests that even the limited experience may have lasting impacts.

The numerical playing cards used in the game training are a readily accessible and affordable resource that educators and parents may already own. Providing dual representations of numerical magnitude information to aid in children's numeral identification, cardinality, and magnitude comparison decisions may be a particularly effective context for promoting early numeracy. Finally, while playing numerical card games may help children with a range of initial knowledge develop their more advanced numerical knowledge, they may be particularly helpful for children with lower skills who are at risk for poor mathematics achievement.

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Figure 1.
Study procedure.

Figure 2. Cards used in numerical magnitude and matching games (a) and shape and color matching game (b).

Figure 3.
Mean performance on numerical skills across assessment phases.

Figure 4.
Mean performance on magnitude tasks across assessment phases.

Figure 5.
Mean performance on executive functioning tasks across assessment phases.

Table 1.

Descriptive statistics on outcome measures across sessions, by condition

Condition	Assessment Sessions			Effect sizes (Cohen's <i>d</i>)	
	Pretest	Posttest	Follow-up	Pretest to posttest	Pretest to follow-up
<i>Verbal counting</i>					
Numerical Magnitude	13.70 (7.41)	16.11 (6.33)	16.33 (6.20)	0.50 [*]	0.53 [*]
Numerical Memory	15.00 (6.90)	17.00 (5.97)	18.04 (6.35)	0.63 ^{**}	0.65 ^{**}
Shape/Color Matching	13.33 (6.90)	15.29 (5.65)	16.58 (6.30)	0.37 [†]	0.57 [*]
<i>Numerical identification</i>					
Numerical Magnitude	0.66 (0.33)	0.76 (0.32)	0.80 (0.26)	0.88 ^{***}	0.97 ^{***}
Numerical Memory	0.69 (0.34)	0.76 (0.29)	0.84 (0.25)	0.69 ^{**}	0.97 ^{***}
Shape/Color Matching	0.76 (0.31)	0.78 (0.33)	0.79 (0.34)	0.27	0.19
<i>Enumeration</i>					
Numerical Magnitude	0.32 (0.43)	0.46 (0.47)	0.46 (0.45)	0.36 [†]	0.37 [†]
Numerical Memory	0.56 (0.49)	0.48 (0.47)	0.55 (0.47)	-0.33	-0.06
Shape/Color Matching	0.57 (0.46)	0.64 (0.43)	0.54 (0.47)	0.19	-0.05
<i>Cardinality</i>					
Numerical Magnitude	0.58 (0.41)	0.63 (0.41)	0.69 (0.31)	0.15	0.32
Numerical Memory	0.56 (0.37)	0.76 (0.33)	0.73 (0.30)	0.70 ^{**}	0.53 [*]
Shape/Color Matching	0.58 (0.40)	0.65 (0.40)	0.71 (0.36)	0.29	0.53 [*]
<i>Symbolic magnitude comparison</i>					
Numerical Magnitude	0.64 (0.18)	0.73 (0.20)	0.75 (0.20)	0.76 ^{***}	0.70 ^{***}
Numerical Memory	0.69 (0.22)	0.67 (0.23)	0.73 (0.23)	-0.14	0.26
Shape/Color Matching	0.65 (0.19)	0.66 (0.20)	0.73 (0.20)	0.07	0.42 [†]
<i>Non-symbolic magnitude comparison</i>					
Numerical Magnitude	0.58 (0.15)	0.63 (0.14)	0.64 (0.15)	0.38 [†]	0.51 [*]
Numerical Memory	0.63 (0.12)	0.67 (0.23)	0.68 (0.16)	0.25	0.41 [†]
Shape/Color Matching	0.66 (0.13)	0.67 (0.20)	0.70 (0.16)	0.10	0.29
<i>Working memory</i>					
Numerical Magnitude	33.88 (13.48)	32.48 (14.08)	32.78 (12.87)	-0.09	-0.06
Numerical Memory	32.20 (12.82)	35.48 (17.48)	38.42 (16.91)	0.20	0.42 [*]
Shape/Color Matching	27.39 (17.24)	31.09 (17.69)	35.75 (18.89)	0.27	0.50 [†]
<i>Inhibitory Control</i>					
Numerical Magnitude	0.42 (0.39)	0.53 (0.42)	0.59 (0.39)	0.39 [†]	0.50 [*]
Numerical Memory	0.44 (0.40)	0.57 (0.32)	0.69 (0.29)	0.47 [*]	0.69 ^{**}
Shape/Color Matching	0.33 (0.37)	0.43 (0.40)	0.39 (0.40)	0.28	0.17

Note. Numerical magnitude $n = 27$ for all outcomes except working memory, $n = 26$; numerical memory $n = 25$ for all outcomes except working memory follow-up session, $n = 24$; shape/color matching $n = 24$ for all outcomes except working memory posttest session $n = 21$ and follow-up session $n = 23$. Cohen's d effect size = $[(M_1 - M_2)] / [((2(1 - r_{12})) \times (SD_1 + SD_2)) / 2]$.

$$\dagger p < .10,$$

$$* p < .05,$$

$$** p < .01,$$

$$*** p < .001.$$

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Table 2.

Individual differences in children's improvements on outcomes, by condition

Outcome	Condition		
	Numerical Magnitude	Numerical Memory	Shape/Color Matching
	<i>% of participants with pretest-posttest improvements (n)</i>		
Verbal counting	48% (13)	44% (11)	42% (10)
Numeral identification	59% (16)	48% (12)	17% (4)
Enumeration	26% (7)	4% (1)	21% (5)
Cardinality	30% (8)	44% (11)	29% (7)
Symbolic magnitude	74% (20)	40% (10)	42% (10)
Non-symbolic magnitude	59% (16)	64% (16)	50% (12)
Working memory	46% (12)	52% (13)	52% (11)
Inhibitory control	41% (11)	56% (14)	50% (12)
<i>Correlation between pretest scores and pretest-posttest improvements</i>			
Verbal counting	-.54 **	-.50 *	-.60 **
Numeral identification	-.32	-.54 **	.02
Enumeration	-.33 †	-.31	-.48 *
Cardinality	-.41 *	-.53 **	-.29
Symbolic magnitude	-.16	-.31	-.38 †
Non-symbolic magnitude	-.54 **	-.24	-.09
Working memory	-.56 **	-.34 †	-.46 *
Inhibitory control	-.23	-.62 **	-.43 *

Note. Numerical magnitude $n = 27$ for all outcomes except working memory, $n = 26$; numerical memory $n = 25$ for all outcomes; shape/color matching $n = 24$ for all outcomes except working memory, $n = 21$. Participants were considered to show pretest-posttest improvements if $[\text{posttest}_i - \text{pretest}_i] > 0$. Correlations between pretest scores and pretest-posttest improvements use Pearson's r , with significance reported for a two-tailed test.

† $p < .10$,

* $p < .05$,

** $p < .01$,

*** $p < .001$.