THE RELATIONSHIP BETWEEN CHILDREN'S SPONTANEOUS FOCUSING ON NUMBER AND MATH SKILLS

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Spontaneous focusing on numerosity (SFON) measures children's tendency to focus on numerical information without being prompted and has been linked to later math abilities. Past work has utilized various methods of quantifying children's SFON yet has not directly compared non-verbal and verbal behaviors. In this study, we investigated the individual differences in the speech and actions of children performing SFON tasks and examined how each measure of children's SFON tendencies were related to their math skills. 115 four-year-old children completed four imitation and modeling SFON tasks over two separate visits to the lab. Children also completed a math assessment two months later as a measure of their math abilities. Within each of the four tasks, no correlations were observed between children's speech and actions. However, children who focused on number in one modality during one task tended to focus on number in that same modality for other tasks. Further, children's focusing on number was predictive of their future math abilities, but specifically through action and not speech.

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PREFACE

I would like to give a special thanks to Dr. Melissa Libertus, Dr. Leanne Elliott, and the rest of the Kids' Thinking Lab for their support and guidance throughout the completion of my thesis.

1.0 INTRODUCTION

When children view a complex scene in their environment, they differ in what they attend to initially. For example, when seeing a busy classroom, one child might focus on describing the activities that students are engaged in, while another child might count the number of students, desks and chairs, and yet another child might talk about the size of the classroom and the location of the door and the windows. Even when children see a simpler scenario, they may differ in what they notice. For example, when seeing three oranges on the kitchen counter, one child might describe the color of the oranges, while another focuses on the number, and a third focuses on their sizes.

1.1 MEASURING CHILDREN'S SFON

Spontaneous focusing on numerosity, or SFON, measures the tendency of children to focus on numerical information in everyday situations without being prompted. This term was coined by Hannula and Lehtinen (2005) to describe a child's natural inclination to attend to numbers of objects or events among other stimuli, based on the child's responses to tasks such as imitating an experimenter's actions. In one of their SFON imitation tasks, preschool-aged children watched an experimenter feed glass berries to a toy parrot and were told, "Now you do exactly like I did." For three trials, the experimenter and the child fed the toy parrot small quantities of berries. In another imitation task, the "posting task," the experimenter set up a toy mailbox and separate piles of red and blue letters between them and the child. The child was asked to watch the experimenter mail a number of letters and then copy the experimenter's actions. The experimenter and the child mailed small quantities of a mix of both the red and blue letters for three trials. For the "model task," the experimenter put identical pictures of a dinosaur in front of themselves and the child. The experimenter used stamps to put a number of "spikes" on their dinosaur, turned their picture over, and then asked the child to replicate their dinosaur using the stamp. The experimenter and the child stamped three different dinosaurs.

For all of these imitation tasks, children's spontaneous focusing on number was coded through both action and speech. That is, the child scored one point for each trial of every task if he or she either replicated the correct number (ex: fed the puppet the same number of marbles as the experimenter), mentioned any number words (ex: "I'm going to mail two letters"), referenced counting or quantities (ex: "I'm going to feed him more than you"), mentioned the quantitative goals of the task (ex: "How many stamps did you do?"), or counted with their fingers. The child received a score of zero for the trial if he or she did not replicate the number of the experimenter's actions or did not verbally show they were focusing on number. Hannula and Lehtinen (2005) found sizable variation in children's tendency to spontaneously focus on number. Interestingly, children's SFON scores remained stable over time from 4 to 6 years of age.

Since the first study on SFON, other researchers have innovated different methods to study spontaneous focusing on number in young children. For example, Chan and Mazzocco (2017) designed an "Attention-to-Number" task in which preschool-aged children were given a booklet of pictures, and on each page, they were asked to match a target picture to four picture choices. The target picture could not be matched perfectly, but children were told to pick which of the four pictures was the best match. Aside from the foils, all of the pictures matched either by number, color, pattern, orientation, location, and shape. Children went through 32 trials of matching these pictures and were able to revisit up to eight trials to name other best possible matches. They were given a score out of the possible trials that number could be selected as the best match. Only around ten percent of children chose best matches based on number. Children’s attention to number also proved to be “malleable” as the greatest percentage of children chose number as the best match when number was pitted against location (rather than highly salient match options such as color or shape).

Batchelor and colleagues (2015) designed another SFON task, in which they showed three different cartoon pictures to four- and five-year-old children, explaining to them that the experimenter could not see the pictures. The experimenter asked each child to describe what was in each picture and wrote down everything the child said. For example, one picture depicted a girl standing next to baby chicks in a rainy field, holding an umbrella over her head. Critically, children’s SFON tendency was measured by the frequency with which they included numerical information in their explanations of the pictures. The children also completed the posting imitation task, adapted from Hannula and Lehtinen (2005). Children showed individual differences and huge variability in their SFON tendencies, ranging from children who didn’t focus on number during any trial to children who focused on number for each trial. However, researchers found no significant correlation between children’s performance in the two SFON tasks. Batchelor and colleagues (2015) argued that the lack of a correlation may be because the two tasks differ in their aims, demands, and underlying mechanisms. For example, while Batchelor’s picture task requires children to have well-developed verbal skills to communicate what they see, Hannula’s imitation tasks allow for both non-verbal and verbal responses and are primarily focused on children’s actions rather than their perception.

As can be seen from these previous studies, SFON can be measured in a variety of ways using both non-verbal and verbal responses depending on the task, but it is unclear whether children's speech or actions are a better reflection of their math abilities. This problem is not unique to the measurement of SFON but has indeed been raised in a variety of different domains of cognitive development. Previous studies have analyzed the relationship between young children's non-verbal and verbal communication. For example, Iverson and Goldin-Meadow (2005) recognized gesture as playing a significant role in language development, laying a foundation for children's learning that will later appear in their speech. Thus, non-verbal responses may be a precursor to verbal responses and a better early predictor of children's later cognitive abilities. Research has also pointed to a "gesture-speech mismatch" that is found when looking at the speech and actions of children performing number elicitation tasks. Gunderson and colleagues (2015) discovered that preschool-aged children can produce values for larger set sizes through number gestures, even if they could not do so in speech. Children communicate about number through actions and gestures in ways that are not revealed in their use of number words. Thus, the imitation tasks initially designed by Hannula and Lehtinen (2005) lend themselves well to examine both non-verbal as well as verbal SFON tendencies. However, no one has directly compared these behaviors both within the same task as well as across tasks. The proposed study will fill this gap.

1.2 RELATION BETWEEN SFON AND MATH

Children's tendency to spontaneously focus on number during SFON tasks has been linked to their math achievement across different studies. In one longitudinal study, Hannula and Lehtinen (2005) followed a population of children from age 3.5 to 6 years. Children's SFON tendencies were measured each year through the imitation, model, and finding tasks described earlier. In addition, children's number sequence production skills were tested yearly, their cardinality skills measured at age 3.5 years, and their object-counting skills measured at ages 5 and 6 years. Children's math skills at 3.5 and 5 years predicted their SFON scores at age 6. Further, children's SFON scores at age 4 predicted their math skills at age 5, demonstrating the reciprocal relation between children's math skills and SFON tendencies. Hannula and Lehtinen (2005) also tested young children aged 6-7 years on their SFON and math skills in a second study. The children completed the model, imitation, and finding SFON tasks. Children also completed different math tasks that measured their counting ability, number sequence elaboration, and basic arithmetic skills. Again, children's SFON tendencies were positively correlated with children's performance on all three math tasks.

In a follow-up study, Hannula, Lepola, and Lehtinen (2010) aimed to measure SFON in children before school age to see if these correlations with math would also be seen later in elementary school. In a two-year longitudinal study, they followed children from kindergarten to Grade 2. Children's math skills and verbal comprehension skills were tested once a year. In kindergarten, the researchers used the feeding imitation task to measure children's SFON tendencies. To measure math skills, children completed a number sequence elaboration task in kindergarten and different arithmetic tasks involving addition, subtraction, multiplication, and division in Grade 2. For the number sequence elaboration task, children were asked to count forward from 3, 8, 12, and 19 and were asked to count backward from 4, 8, 12, and 19. Hannula and her colleagues found that children's SFON tendencies were significantly correlated with children's number sequence elaboration skills in kindergarten. Further, children's SFON tendencies proved to be a domain-specific predictor of their math skills assessed in Grade 2, as children's SFON was significantly correlated with their math skills specifically and not their reading skills.

In one longitudinal study of SFON, Hannula-Sormunen and colleagues (2015) followed a group of six-year old children until age 12 to test SFON's predictiveness of math skills. At age 6, children's SFON tendencies were measured through the imitation, model, and finding tasks, and their counting skills were evaluated through the children's number sequence production and elaboration. For the number sequence production task, children were asked to count as far as they could from one onward, until they were stopped at 50. At age 12, the children completed a standardized math test, standardized reading tests, and a non-verbal IQ test. Children's SFON tendencies at age 6 were a significant predictor of their school math achievement six years later. Like previous studies, these results were specific to math as SFON tendencies were only significantly related to math and not reading skills.

Finally, Nanu and colleagues (2018) wanted to study whether the long-term effects of SFON were applicable to other math skills, such as arithmetic fluency and whole number estimation. To this end, they conducted a longitudinal study that followed preschool children for seven years until Grade 5 and included a larger set of tasks at the two assessment points. At age 5, the children's SFON, cardinality skills, digit naming, verbal working memory, and IQ were evaluated. Researchers used two imitation tasks, the "parrot task" and "backpack task," based on the work by Hannula and Lehtinen (2005) to measure children's SFON tendency. The parrot task required children to feed the same number of fish to the toy parrot as the experimenter, whereas the backpack task required children to pack the same number of fruits into a small backpack as the experimenter. In Grade 5, children's arithmetic fluency, number line estimation, rational number knowledge, mathematical achievement, math motivation, and reading skills were assessed. The results revealed that children’s SFON tendencies at age 5 were correlated with cardinality skills in preschool and arithmetic fluency and number line estimation seven years later, but not rational number knowledge, math achievement, or math motivation. Again, there was no significant correlation between children’s SFON tendencies and their reading skills.

Despite much research supporting the link between SFON and math skills, it is unclear what the underlying mechanism could be. Some research has pointed to the link between interest and math achievement in young children. Children with an interest in math concepts would be more inclined to focus their attention on math-related tasks and activities and therefore perform better. Fisher and colleagues (2012) measured preschool-aged children’s math interest using self-reports, naturalistic assessments, observations, and teacher assessments. They found that a reciprocal relationship exists between the levels of math interest of preschool-aged children and their performance on a standardized math assessment. The relation between math interest and math performance could provide a possible bridge between SFON and math skills, as focusing attention on the tasks may be a factor of interest.

1.3 PRESENT STUDY

In the present study, we investigated individual differences in the speech and actions of children performing SFON tasks and saw whether children’s SFON tendencies were related to their math abilities. Our participants performed the imitation and model SFON tasks over two separate visits to the lab. To get a measure of math ability, participants completed the Test of Early Math Ability (TEMA-3; Ginsburg & Baroody, 2003) during a final lab visit. We investigated whether children’s speech was consistent with their actions within a SFON task (RQ1) and across different SFON tasks (RQ2). We also investigated if children's SFON tendencies as indexed through their speech or actions during the different SFON tasks was predictive of their later math abilities (RQ3).

For RQ1, we hypothesized that there would not be a correlation between children's $SFON_{speech}$ and $SFON_{action}$, based on the knowledge that children who focus on number through action may not feel the need to also mirror this action through speech. We hypothesized that children who are focusing on number through speech or action in one task are likely to do the same in other tasks (RQ2). Based on previous research that links children's SFON tendencies to their math skills, we also hypothesized that children's SFON at Visit 1 and 2 would predict their TEMA-3 scores at Visit 3 (RQ3).

2.0 METHOD

2.1 PARTICIPANTS

One-hundred and fifteen preschool-aged children (60 boys, 55 girls) contributed data to the present study. These children were recruited as part of a larger longitudinal study that studies the development of children's math skills and the role that parents play in helping their children acquire these skills. Children completed four separate visits to the lab, approximately every two months. The current study includes data from the second, third, and fourth visits, later referred to as "Visit 1," "Visit 2," and "Visit 3." (Children did not perform any SFON tasks during the first visit, so it was omitted.) Children ranged in age from 3 years 11 months to 4 years 3 months at Visit 1 (mean age = 4.08, SD = 0.076). 81% of the children were White, non-Hispanic and 88% of their parents had at least a bachelor's degree.

2.2 MEASURES AND PROCEDURE

During Visit 1, participants completed the "model task" and the "puppet task." For the "model task," an experimenter stamped a quantity of spikes onto a picture of a dinosaur, flipped it over, and asked the child to do the same to an identical dinosaur picture. The child and experimenter stamped three different dinosaurs, each with a distinct quantity of stamps. During the first trial, the experimenter stamped two blue triangles. For the second trial, he or she stamped four red diamonds, and for the third trial, the experimenter stamped two green squares and three green rhombuses on the dinosaur. For the "puppet task," an experimenter fed quantities of marbles to a toy puppet and asked the child to repeat his or her actions. The experimenter and child each fed the puppet three times. For the first trial, the experimenter fed the puppet two marbles, followed by three marbles on the second trial, and then one marble during the final trial.

During Visit 2, participants completed the "model task" for a second time using differing quantities of stamps than during Visit 1 – three blue triangles during the first trial, two red diamonds at the second trial, and four green squares and one green rhombus at the final trial. The participants also completed the "posting task" instead of the "puppet task" to reduce the presence of practice effect from performing the same exact tasks as Visit 1. For the "posting task," the experimenter and child mailed different quantities of green and yellow letters into a toy mailbox for three separate trials. For the first trial, the experimenter mailed two yellow letters and one green letter. At the second trial, the experimenter mailed one green letter and one yellow letter, and for the third trial, the experimenter mailed two green letters and three yellow letters into the toy mailbox.

All three of the SFON tasks used at Visits 1 and 2 were adapted from Hannula and Lehtinen's (2005) imitation and model tasks. All SFON tasks were video-recorded and later transcribed by research assistants in the lab. Research assistants then coded the videos of the SFON tasks for verbal and non-verbal instances of children's tendency to spontaneously focus on number, following the criteria adapted by Hannula and Lehtinen (2005). Specifically, children were coded as focusing on number through action in a given trial if they replicated the number used by the experimenter (e.g., put exactly the same number of spikes on the dinosaur, mailed exactly the same number of letters; $SFON_{action}$). Children were coded as focusing on number through speech in a given trial if they mentioned number or quantity (e.g. "I'm going to feed him three."; $SFON_{speech}$).

Intercoder reliability in coding child speech was quite high, with two independent coders agreeing on 95% of the 384 double-coded trials of the SFON task. Additionally, to determine which children talked during a trial, any talk related to the trial was coded for each child.

Separate SFON scores for each task were calculated as the total number of trials the child spontaneously focused on number in speech or action respectively out of three total trials. For the "model task" and "posting task," which included some trials of mixed items (ex: experimenter stamps two green squares and three green rhombuses on the dinosaur; experimenter mails two yellow letters and one green letter), children were coded as focusing on number through action if they replicated the exact number of squares (or green letters) or the exact number of rhombuses (or yellow letters), or the exact same total number of stamps (or total letters).

During Visit 3, children completed the Test of Early Math Ability (TEMA-3; Ginsburg & Baroody, 2003), a standardized math assessment that taps into numbering skills, number-comparison facility, numeral literacy, mastery of number facts, calculation skills, and understanding of math concepts. The TEMA-3 was both administered and scored by a trained experimenter. The raw TEMA-3 score during Visit 3 was used as the dependent measure for children's math abilities.

2.3 DATA ANALYSIS

To address RQ1, we ran correlations between the $SFON_{action}$ and $SFON_{speech}$ scores in each task to see if there was consistency between the two SFON indices. To address RQ2, we also ran correlations of the two indices across tasks to see if there was consistency in children's SFON tendencies regardless of the way in which SFON was elicited. To address RQ3, we ran correlations between children's SFON scores ($SFON_{action}$ plus $SFON_{speech}$ on each task) during Visit 1 and Visit 2 with their TEMA-3 scores at Visit 3 to see if we could predict math abilities from SFON. Six children's TEMA-3 scores were missing, making the total N = 109 for these analyses. We also ran regressions to determine the unique contributions of $SFON_{action}$, $SFON_{speech}$, and general talk on children's math abilities.

3.0 RESULTS

Children varied widely in their methods of focusing on number during the SFON tasks. For each task, children's SFON scores ranged from 0 to 3 and were calculated independently for action and speech. On average, children focused on number through action on 2.06 trials (*SD* = 0.911) for the model task at Visit 1, on 2.03 trials (*SD* = 0.809) for the puppet task, on 2.22 trials (*SD* = 0.98) for the model task at Visit 2, and on 2.24 trials (*SD* = 0.923) for the posting task. Children focused on number through speech on 0.47 trials (*SD* = 0.809) for the model task at Visit 1, on 1.03 trials (*SD* = 1.12) for the puppet task, on 0.40 trials (*SD* = 0.673) for the model task at Visit 2, and on 0.757 trials (*SD* = 0.854) for the posting task.

We ran a correlational analysis between children's $SFON_{action}$ scores for each task (see Table 1). All correlations were significant ($p < .01$), except for the correlation between the puppet and mailbox tasks, which was only marginally significant ($p = .07$). Similarly, we ran a correlational analysis between children's $SFON_{speech}$ scores for each task (see Table 2). All correlations were significant ($p < .05$), demonstrating that children's tendency to focus on number in one modality was consistent across tasks. As such, composite scores for speech and action were compiled across the different tasks. However, correlational analyses ran between these two composite measures of focusing on number, speech and action, found these variables to be unrelated. Children's tendency to focus on number through speech was not correlated with their tendency to focus on number through action, $r(113) = .001$, $p > .05$.

Table 1. Correlations of children's actions across SFON tasks.

SFON Actions	Model – Visit 1	Puppet	Model – Visit 2	Posting
Model – Visit 1	1.00			
Puppet	**0.33**	1.00		
Model – Visit 2	**0.43**	**0.32**	1.00	
Posting	**0.34**	0.17	**0.44**	1.00

Significant correlations (p < .01) are shown in **bold**

Table 2. Correlations of children's speech across SFON tasks.

SFON Speech	Model – Visit 1	Puppet	Model – Visit 2	Posting
Model – Visit 1	1.00			
Puppet	**0.25**	1.00		
Model – Visit 2	**0.39**	**0.21**	1.00	
Posting	**0.31**	**0.35**	**0.35**	1.00

Significant correlations (p < .05) are shown in **bold**

Children's raw scores on the TEMA ranged from 5 to 40 (M = 17.4, SD = 7.22). We ran correlational analyses between children's TEMA scores and their separate $SFON_{action}$ and $SFON_{speech}$ scores to test whether children's future math abilities were related to children's earlier tendency to focus on number. As shown in Figure 1, children's TEMA scores were strongly correlated with their tendency to focus on number through action, $r(107) = .323$, $p < .001$. However, children's TEMA was not correlated with their tendency to focus on number through speech, $r(107) = .135$, $p > .05$ (see Figure 2).

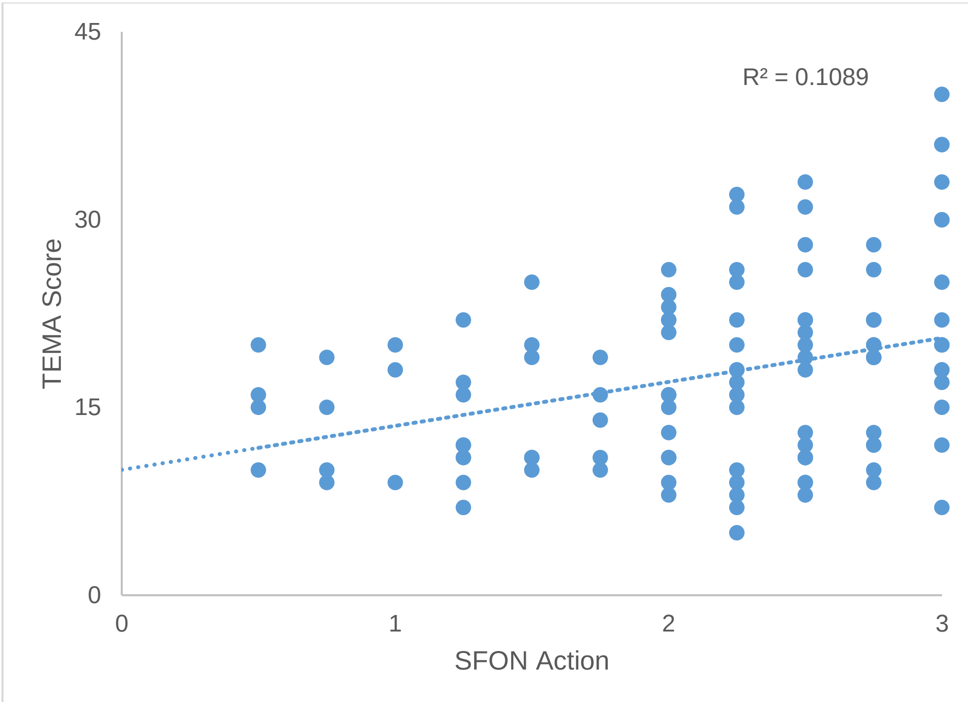

Figure 1. Scatterplot of children's SFON action and math abilities.

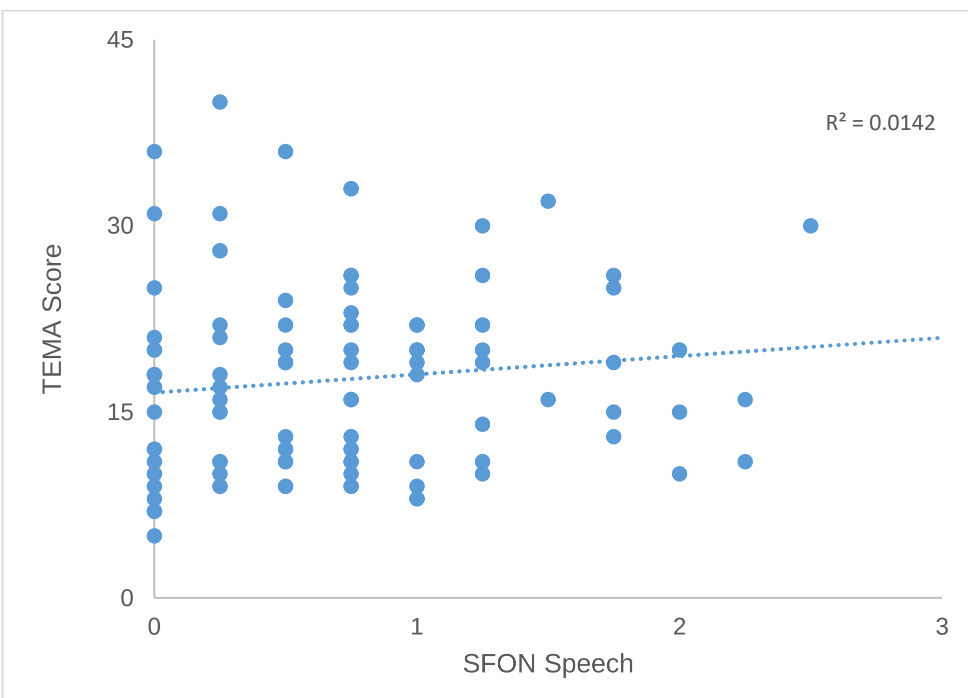

Figure 2. Scatterplot of children's SFON speech and children's math abilities.

Given that some children did not speak during the SFON tasks, we then calculated a multiple linear regression modeling the association between math abilities and children's focusing on number through speech, controlling for children's talk in general, $F(2, 106) = 1.42$, $p = .247$. This analysis was important given that children's focusing on number through speech was correlated with their general talk, $r(107) = .53$, $p < .001$. A marginally significant association was found between children's TEMA and children's focusing on number through speech, $B = 2.25$, $p = .096$, when controlling for overall talk.

Finally, we calculated a multiple linear regression modeling the association between math abilities and children's focusing on number through speech and through action, controlling for children's talk in general, $F(3, 105) = 5.10$, $p = .003$. A significant association was found between children's TEMA and children's focusing on number through action, $B = 3.70$, $p = .001$, but no association was found between children's TEMA and children's focusing on number through speech, $B = 1.21$, $p = .357$.

4.0 DISCUSSION

In this study, we aimed to investigate the individual differences in the speech and actions of children performing SFON tasks and determine whether children's SFON tendencies are related to their math skills. Consistent with our hypotheses, we found that children's tendency to focus on number through one modality (either speech or actions) was consistent across tasks. This finding indicates that there is a reliability among the SFON tasks used in our study, as they evoked consistent responses from the children.

Interestingly, children's tendency to focus on number through action was not related to their tendency to focus on number through speech. One possible explanation for this is that our imitation tasks instructed the child, "Now you do exactly what I did," which makes this task action-focused and does not require children to speak. Compared to children who spoke, there were more children who performed actions during the SFON tasks. This much smaller sample of children who tended to focus on number through speech could explain the lack of a relation between the two modalities of SFON.

Consistent with prior research, children's focusing on number was predictive of children's future math abilities (Hannula & Lehtinen, 2005; Hannula, Lepola, & Lehtinen, 2010; Hannula-Sormunen, Lehtinen, & Räsänen, 2015). Unlike the present study, these studies only focused on combined speech and action scores and did not differentiate to study speech and action separately. Here, we showed that children's focusing on number through action was particularly relevant for their math abilities. Contrary to previous research (Batchelor et al., 2015), children's focusing on number through speech was not correlated with their math abilities in our study. Interestingly, children's performance on the SFON picture task used by Batchelor and colleagues, which focuses on speech, was correlated with math skills but not with their performance on Hannula & Lehtinen

(2005)'s posting task. Thus, it is possible that the imitation tasks are not as adequately suited to measuring children's focusing on number through speech, as these tasks require different skill sets. Many of the children who talked during our imitation tasks said things like "How many did you do?" which indicates that they understood the aim of the task and were reasoning through it, even if they could not accurately replicate the experimenter's actions. Thus, children's $SFON_{speech}$ may be measuring other aspects of math, such as reasoning and analytical abilities that help with problem-solving and these are skills that would not be easily picked up by the math assessment that we used.

Another possibility could point to the mismatch between speech and gesture that occurs in young children, due to verbal abilities taking longer to fully develop (Iverson & Goldin-Meadow, 2005; Gunderson et al., 2015). As the children in the present study are only four years old, they are still developing their language abilities, especially in the domain of math. In the future, it would be interesting to look at the relationship between SFON and math abilities in older children. Since verbal abilities at age 5 or 6 are more developed than at age 4, perhaps older children's tendency to focus on number through speech would be more predictive of their math abilities.

We must also consider a number of limitations in our study. Our sample consisted of primarily White, educated families, preventing us from generalizing our results to a broader, more diverse population. Further, children's future math abilities were only tested two months later than the SFON tasks. It would be interesting to carry out a follow-up study with the children years later to see how their early individual differences in SFON are linked to their math performance in school. Finally, we were unable to explore causality in our study, which would be beneficial to explain the relation between SFON and math skills.

However, despite these limitations, this study showed a significant relation between children's SFON and their future math abilities, specifically their tendency to focus on number through action. Given that certain measures of SFON predict math over others, future work could directly compare different measures of SFON that tap into children's speech and actions to determine which is a stronger predictor. By understanding how to accurately measure spontaneous focusing on number, SFON interventions could be implemented in classrooms and homes in the future to easily facilitate the development of children's math abilities.

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