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Parents' and Young Children's Attention to Mathematical Features Varies Across Play Materials

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Abstract

Children's attention to numerosity is reported to uniquely predict their later mathematical skills (e.g., Hannula-Sormunen, 2015), but there is some debate concerning the extent to which this attention to number is spontaneous or contextually driven, and it is not known how attention to numerosity varies with respect to other mathematical features, such as shape. In the present study, we used a within-subjects observational design to examine attention to mathematical features, during brief semi-structured play sessions, among parent-child dyads. Our aims were to address whether children's and parents' attention to mathematical features varies with play materials and whether attention to mathematical features is correlated between children and their parents. Specifically, we coded verbal references to quantitative (number, quantity, and part-whole relations) and spatial (size, shape, location, and orientation) features that emerged during Duplos and kitchen set play among 45 two- to four-year olds and their parents. Analyses of variance revealed that children and parents attended to mathematical features more frequently during Duplos compared to kitchen set play, and that this difference was largely accounted for by greater attention to spatial features, but not quantitative features. Correlations between children's and parents' attention to mathematical features differed between Duplos and kitchen set play, suggesting that these play materials also influence mathematics-oriented play dynamics. The results extend previous experimental laboratory findings on attention to number to additional mathematical features, and provide evidence for the contextual influences on attention to mathematical features in naturalistic settings.

Keywords: Attention to number, Spontaneous Focus on Numerosity, Parent engagement

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Parents' and Young Children's Attention to Mathematical Features Varies with Play Materials

Introduction

Findings that early numerical skills predict later mathematics achievement (e.g., Jordan, Kaplan, Locuniak, & Ramineni, 2007; LeFevre et al., 2010; Lyons, Price, Vaessen, Blomert, & Ansari, 2014; Mazzocco & Thompson, 2005) have led to a surge in research on how to promote early numerical development. One early numerical skill that predicts later mathematics is young children's tendency to simply notice or attend to number (Hannula & Lehtinen, 2005). Here we examine two potential influences on this tendency: play materials and parents' attention to number during play. Building on our previous experimental finding that attention to number may be influenced by features of materials with which children interact (Chan & Mazzocco, 2017), in this study we explore attention to number and other mathematical features in a more naturalistic parent-child play setting. Specifically, we examine children's and parents' attention to two categories of mathematical features, quantitative (i.e., number, quantity, part-whole relations) and spatial (i.e., size, shape, location, and orientation) features, during two play activities, and the relation between children's and parents' attention to these features during play.

Attention to Number and Other Mathematical Features

Early studies on the mathematics features to which young children attend have focused predominantly on *number* (Hannula-Sormunen, 2015; Levine, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2010), a trend that reflects the overall focus on number skills in early mathematics research in general (Mazzocco & Räsänen, 2013). For example, Hannula-Sormunen and colleagues proposed a construct they refer to as "Spontaneous Focus On Numerosity" (SFON), which they define as a tendency to focus on numerical features without prompting. According to these researchers, one defining characteristic of SFON is the unguided, self-initiated recognition

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or use of number across contexts (Hannula & Lehtinen, 2005), and much of the research on attention to number involves studies of this construct. In their studies, SFON tendency, scored as the frequency with which children reproduce the same number of items or actions they observe in the examiner, correlated with concurrent and later mathematics performance (e.g., Hannula-Sormunen, 2015; McMullen, Hannula-Sormunen, & Lehtinen, 2015) even when accounting for the contribution of other cognitive skills such as nonverbal IQ (McMullen et al., 2016), processing speed (Hannula et al., 2010), verbal comprehension (Hannula & Lehtinen, 2005), numerosity comparison, or the ability to map numerals to their corresponding sets (Batchelor, Inglis, & Gilmore, 2015). Likewise, Levine et al. (2010) found that the amount of “number talk” parents engage in with their toddlers, as observed during several home visits, predicts children’s conceptual number knowledge more than a year later, even when controlling for effects of socioeconomic status and parent or child language. These findings do suggest that young children’s and parent’s attention to number appears related to children’s mathematics knowledge over and above other cognitive abilities.

Despite the prominence of number in early mathematics research, there are other mathematical features to which parents and children may also attend. For example, although children may notice numerical features such as how many spikes are placed on a toy dinosaur, how many berries are fed to a toy parrot (Hannula & Lehtinen, 2005), or how many times an adult taps a drum; children may also notice other mathematical features such as whether a cup of sand is nearly full or nearly empty (continuous quantity), whether a cake is missing a slice (part-whole relation), and whether the napkins on the dinner table are big (size), square (shape), to the left side of a plate (location), or positioned sideways (orientation). Of course, children are likely to also notice mathematically irrelevant features, such as color. Since engaging in mathematical

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learning requires noticing or attending to relevant mathematical features, it is important to recognize *when* children attend to mathematically relevant rather than irrelevant features during play or other learning activities, and whether their attention to mathematical features can be elicited by varying aspects of play materials.

Expanding upon studies of children's tendency to focus on number, here we aim to help fill the gap in knowledge about attention to additional mathematical features related to quantitative and spatial thinking. Building on our earlier experimental study—where we found that manipulating the physical features of task materials influenced the frequency with which children attended to number or orientation (the two features addressed in Chan & Mazzocco, 2017)—here we propose that situational and physical contexts may play a prominent role in children's attention to many mathematical features during play. That is, although we agree that attention to mathematical features may reflect attention without explicit prompting, we believe that implicit prompting may occur through situational or physical contexts. Here we explore the influence of contexts on attention to the quantitative and spatial features specified earlier.

Context Influences Attention to Mathematical Features

In order to gain the potential benefits of promoting children's attention to mathematical features, it is important to determine whether attention to such features is indeed malleable. We and others have demonstrated that it is, at least for attention to number, based on experimental measures that require children to describe illustrations, imitate actions (Batchelor et al., 2015), or simply match pictures of objects (Chan & Mazzocco, 2017). From these studies of attention to number across different task contexts, only limited evidence emerges to support the idea that focusing on number is context-independent. Batchelor (2014) found only a modest correlation between children's SFON scores on tasks that involve imitating an examiner's action or

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reproducing an examiner's model animal (r_s = .26), and within subject performance on imitation and verbal description tasks were not correlated in preschool age children (Batchelor et al., 2015). In naturalistic studies, Rathé and colleagues found that children's SFON scores were not correlated with their number word utterances during book reading (Rathé, Torbeyns, Hannula-Sormunen, & Verschaffel, 2016), despite remarkable variation in children's scores for each measure. Edens and Potter (2013) also found that preschoolers' SFON scores were unrelated to activity choice during free play, in that children were equally likely to play with mathematics activities, such as block construction and puzzles, regardless of high or low SFON tendency. These findings suggest limited convergent validity for a context-independent attention to number and the influence of task contexts on—and thus the potential malleability of—attention to number. This contextual dependence may extend to other mathematical features.

Experimental studies provide direct evidence for the influence of co-occurring features on children's attention to number. Baroody, Li, and Lai (2008) tested the effects of co-occurring features (shape and color) on toddlers' attention to number using an imitation task, and found that toddlers in their study were more accurate at reproducing sets with two versus four items, particularly when sets consisted of heterogeneous items that varied in shape and color versus identical items. In a later study based on a picture-matching task (Chan & Mazzocco, 2017), participants viewed a target picture and selected a best match for the target from four simultaneously viewed response choices. For instance, a target picture could be comprised of three red, striped, triangles all located at the bottom of the picture stimulus. Each response choice matched the target on only one feature, but we varied whether the response choice corresponding to the feature *number* (i.e., the number of items in the set) was presented along with choices corresponding to one of two features that were either salient (the color or shape of the items in

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the set), or less salient (the pattern or location of the items in the set). We found that when number was pitted against color and shape, as opposed to pattern and location, preschoolers and adults were less likely to select number as a possible match to the target picture. Some children and adults showed this effect of context, attending to number more frequently when co-occurring features were of low versus high salience, but some children and adults *never* matched on number during the task. Specifically, children selected number as the best match on only 8% of trials, and adults selected number on only 21% of trials. We observed similar effects of salience on attention to orientation. On these trials, number was not a possible match (the target and response choices were sets that ranged from one up to five items, with no duplicate set sizes) but orientation of the items was. This finding suggests that contextual influences on attention to mathematical features is not limited to number. Considered together, these experimental studies suggest that although attention to number (and orientation) is relatively infrequent, it may be increased by the presence or absence of co-occurring features.

In view of the contextual influences on attention to number during experimental tasks, in the present study, we focus on the influence of context on the frequency of attention to number and other mathematical features in a semi-naturalistic setting, by observing parent-child interactions with two distinct sets of play materials. The primary aims of the study are to evaluate whether the two sets of play materials differentially elicit children's and parents' attention to quantitative and spatial mathematical features, and whether children's and parents' attention to these features are correlated.

Association between Children's and Parents' Attention to Mathematical Features

Parents and caregivers engage in various daily activities with children that draw upon their own attention to mathematics, which may influence their child's early mathematical

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development. For instance, parents' use of number words in every day interactions, such as during play and mealtime, varies widely across parents in terms of its quantity (Levine et al., 2010) and quality, and both quantity and quality of number word uses predict children's later number knowledge at 46 months of age (Gunderson & Levine, 2011; Levine et al., 2010) and their mathematics performance at 67 months of age (Susperreguy & Davis-Kean, 2016). The influence of parents' mathematics talk is not limited to number; frequency of parents' spatial talk, which also varies widely, correlates with children's spatial talk at 46 months and predicts children's spatial skills at 54 months (Pruden, Levine, & Huttenlocher, 2011). Interventions aimed at improving parental mathematics talk or other math behaviors may influence children's attention to mathematical features. Prompting parents to talk about spatial features during block play improves children's performance on puzzle solving (Polinsky, Perez, Grehl, & McCrink, 2017). Likewise, enhancing parents' awareness of opportunities to talk about mathematics in their daily lives increases their own discussions about mathematics at home, and also leads to gains in their preschoolers' knowledge of numbers, measurements, and geometry (Gervasoni & Perry, 2017). Following a four week intervention aimed at teaching caregivers how to direct preschoolers' attention to number in everyday situations, such as by increasing "mathematics talk" with "how many" questions throughout the day, children's counting performance improved, provided that the children had some initial SFON tendency, as measured by these researchers (Hannula, Mattinen, & Lehtinen, 2005). Across these observational and intervention studies, there is evidence to support the notion that parents' and caregivers' attention to mathematical features is related to their child's attention to mathematical features, but it is unclear what drives those relations and whether these associations vary across different situational contexts. We address the role of play contexts in the present study.

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The Current Study

In the present study, we examined children's and parents' attention to mathematical features across two play activities, Duplo blocks (i.e., large Legos) and a kitchen play set. We selected these activities because each has been linked to rich math talk by parents (Ferrara, Hirsh-Pasek, Newcombe, Golinkoff, & Lam, 2011; Susperreguy & Davis-Kean, 2016) but may afford different types of math talk. Extending our previous experimental study, our primary research questions concerned (1) whether different play materials are associated with differences in children's and parents' attention to mathematical features such as number, shape, and orientation, and (2) whether children's and parents' attention to these features is related to each other.

From videotaped play sessions, we coded children's and parents' verbal communication as indicators of their attention to mathematical features. To address our first research question, we compared the frequency of our participants' attention to mathematical features across two types of play activities. To address our second research question, we tested the association between children's and parents' respective attention to these features. We hypothesized that play materials may influence both the frequency of attention to mathematical features and the association between children's and parents' attention to these features. Specifically, we hypothesized that Duplos and the kitchen set may afford different types of interactions and lead to variation in the frequency of, and the correlations between, children's and parents' attention to mathematical features during play. In addition to examining the quantity of children's and parent's attention to mathematical features, we explored the types of verbalization children and parents make when attending to mathematical features, and how parents and children direct each other's attention to mathematical features. Coding attention to mathematics features was based

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on children's and parents' verbal production, so we also measured and statistically controlled for the variation in children's and parents' word count during these activities.

Method

Participants

Our participants were drawn from a larger study of parent-child engagement in early mathematics. Participants in the present study were 50 parent-child dyads who engaged in a videotaped semi-structured play session. Although 67 dyads participated in these play sessions, seven declined to be videotaped. Of the remaining 60, ten were omitted due to faulty audio/video recording (*n* = 6), examiner procedural errors (*n* = 3), or no parent engagement during play (*n* = 1). The final sample was comprised of 50 child participants (24 girls) and their parents (39 females). Child participants were two to four years old (*M* = 43 months, *SD* = 10.6, range = 24 – 58) and were of White (*n* = 41; including 4 Spanish/Hispanic/Latino), Asian (*n* = 2), Black (*n* = 2), or multiracial (*n* = 5; including 2 Spanish/Hispanic/Latino) ethnicity. Their parents ranged in age from 25 to 53 years (*M* = 34.61 years, *SD* = 5.23), and were of White (*n* = 44; including 2 Spanish/Hispanic/Latino), Asian (*n* = 3), Black (*n* = 1), multiracial (*n* = 1), or American Indian or Alaskan Native (*n* = 1) ethnicity. Most parents had completed some college (*M* = 15.9 years of education, *SD* = 1.84); 2 completed high school, 11 completed one- or two-years of college, 19 completed four-year college, and 18 completed some graduate training.

Procedure

Enrollment occurred over several days during a state fair open to the public, in the upper Midwestern United States. A research site erected at the state fair served as a university-based effort to encourage research participation beyond the university campus. The research site housed ten booths, each of which functioned as a small, dedicated off-campus research lab.

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Signage was used to indicate the study topic and participation requirements, such as age. Research staff at each booth described the study to passersby, invited their participation, and enrolled participants.

For the present study, we deliberately excluded reference to early mathematics in signage, in order to avoid prompting for math talk. Instead, we labeled our study, "The Game Buffet," and invited parents to play games with their child for about 15 minutes (*M* = 15.50, *SD* = 3.60, range = 8.08 – 21.57), followed by a brief parent survey. After obtaining informed consent from the parent, the examiner directed the dyad to one of several small play areas (~ 4 ft x 4 ft) demarcated by floor mats and divider screens. In each play area, three sets of play materials were stored in a large transparent bin, set adjacent to the floor mat. These identical sets of play materials were comprised of a set of Duplo blocks, a kitchen set comprised of plastic dishware and wooden food, and a mathematics-oriented book focused on either number or spatial features, all appropriate for preschoolers. Alternative play materials included on a separate day of data collection were excluded from this study because of low enrollment on that day (*n* = 7). The ordinal position in which the play materials appeared within the larger bin was counterbalanced across play areas, but parents and children themselves determined the order in which they played with each set of materials. The examiner recorded the activity order, and the play sessions were audio and videotaped.

Sessions began with an examiner asking the dyad to choose a set of the materials they wished to play with first. After the dyad played with the first activity for five minutes, the examiner prompted the parent to switch to another activity "within two minutes." If the dyad did not switch to the next activity after two minutes, the researcher reminded parents that it was time to try another activity. The researcher repeated similar prompts (i.e., a two-minute notice and a

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reminder for activity transition, if needed) after the second activity. Dyads sometimes ended an activity before five minutes passed. Following the play sessions, parents completed a survey to report demographic information and their opinions about and experiences with reading and mathematics activities.

Materials

Play materials. In this study, of the three play materials included in the "Game Buffet" (described above), the Duplos and kitchen set were compatible with our interest in children's and parents' self-initiated attention to mathematical features. These two sets of materials did not explicitly direct participants' interactions. In contrast, text in the third play material, a mathematics-oriented book, explicitly directed readers' attention to number or spatial features, through statements such as "the two rabbits eat the two carrots," or, "How many rectangles do you spy?" Most dyads did not veer from the written text when interacting during shared reading of a book. Therefore, we excluded the book reading activity from the study. For the two remaining activities, all 50 dyads played with the kitchen set and 49 of the dyads also played with the Duplos.

Since dyads selected the order of play materials, the order in which Duplos and kitchen set play occurred was not counterbalanced. Most dyads (n = 36) played with the kitchen set before playing with the Duplos. It is unlikely that the book had a significant effect on dyads' interactions during the Duplos and kitchen set play, at least for most dyads, because most of the dyads chose to read the book last (n = 39) and some did not read the book at all (n = 5). Of the 45 dyads that chose to read the book, most devoted less than five minutes to the book (M = 3.39 minutes, SD = 2.03, range = 0.35 – 9.77). Still, we tested whether the presence of specific books affected dyads' attention to mathematical features.

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Duplos set. The Duplos consisted of 52 Duplo pieces varying in shape, size, and color. About half of the dyads (*n* = 26) played with these 52 Duplo pieces, and the remaining dyads (*n* = 23) had six additional Duplo pieces that each had one numerical decal depicting either a numeral (1 to 3) or numerosity (one radio, two mice, and three apples). We varied the presence of these decal pieces because they are included in commercially available Duplos sets, and this manipulation allowed us to examine whether children's and parents' attention to number is increased by simply incorporating these explicit numerical cues in play materials. The dyads spent an average of 5.95 minutes (*SD* = 1.45, range = 2.33 – 9.17) playing with the Duplos.

Kitchen set. The kitchen set consisted of 38 pieces, comprised of four sets of plastic cups and plates varying in color, one wooden knife, one cutting board, and eight types of wooden food items (sandwich bread, a baguette, carrot, cucumber, apple, tomato, pepper, and watermelon). All eight food items were divided into slices that were fastened by Velcro but could be separated, to allow for food preparation play with the knife. The number of slices per food item ranged from two to five, with 28 pieces in total. The dyads spent an average of 6.46 minutes (*SD* = 1.19, range = 3.67 – 8.67) playing with the kitchen set.

Mathematics-oriented books. The mathematics-oriented books included in this study focused on either number or a spatial feature. One book was an investigator-designed counting book designed to promote counting sets of one to three items; this book included pictures of animals and vegetables varying in set size, and text that prompted children to count the sets. One of two spatial books, both of which were trade books, was made available during play sessions, depending on child's age. The option provided for two-year-olds was *Up Down and Around* (Ayres, 2010), which concerned the directions in which different vegetables grow depending on their kind, whereas the option provided for three- and four-year-olds was *Round Is a Tortilla*

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(Thong, 2015), a book about the shapes of different objects. We varied our inclusion of a number or spatial book on alternating days of the study with half of the dyads seeing the number book (*n* = 22) and the remaining dyads seeing one of the spatial books (*n* = 23).

Video Coding of Attention to Features

Coding was based on the verbal communication that dyads exhibited during Duplos and kitchen set play. A word or a phrase that reflected or drew a partner's attention to a feature of the activity materials was coded as an *instance* of attention to that feature. Instances typically involved a parent or a child that identified, described, compared, matched, or posed questions about a feature of interest during play.

Features of interest. Our primary interest in this study was those instances during which a parent or a child attended to mathematical features. We coded attention to quantitative and spatial features to capture children's and parents' attention to these aspects of mathematics during play. The quantitative features consisted of number, quantity, and part-whole relations, and spatial features consisted of size, geometric shape, location, and orientation. Four of the features – number, shape, location, and orientation – corresponded to a subset of the mathematical features studied experimentally, in an earlier study (Chan & Mazzocco, 2017). To fully capture attention to numerical uses of number words specifically, we omitted instances where the number word "one" did not refer specifically to a cardinal value such as, "we need a different one" from select analyses. In addition to these four planned features of interest, we coded instances of the three following features that emerged during the play sessions and were relevant to mathematics: quantity, part-whole relations, and size. We included color as a salient non-mathematical feature to which children and adults often attend, as a comparison to the mathematical features. (See Table 1 for brief definitions and examples of each feature.) For each

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coded instance of attention to a feature, we coded whether the parent or child attended to the feature, and we categorized the type of verbal communication each engaged in, as specified below.

Verbal communication during instances. We coded four categories of verbal communication, specifically feature-focused questions, feature-focused responses, feature mentions, and repetitions. *Feature-focused questions* were direct inquiries about a specific feature such as, “how many cups are there?” or “what color is this plate?” These were questions that explicitly draw the partner’s attention to a specific feature (in this case, number or color, respectively) and aim to elicit a response also focused on that feature. Feature-focused questions did not always result in a feature-focused response, so we coded instances for which *feature-focused responses* did occur, such as responses like “four cups” or “it’s blue” to the questions noted above. An instance was coded as a *feature mention* when a parent or a child mentioned a feature without prompting the partner to refer to that feature, such as, “I’ve got two of these.” Finally, we coded *repetitions*, when a speaker repeated their partner’s feature-oriented speech immediately after the partner’s utterance. An example of a repetition would be a child stating, “blue cup” in response to a parent saying, “Look! It’s a blue cup” while holding up a blue cup. Because the feature-focused questions and feature mention instances were not explicitly prompted by the partner, we classified these instances as self-initiated verbalizations and focused on them in our primary analyses that concern self-initiated attention to features. As demonstrated in the examples provided in this paragraph, the feature-focused responses and repetitions were explicitly prompted by the partner, thus they were excluded from select analyses that concern self-initiated attention to features. These verbalization codes serve two purposes. First, by coding and excluding responses and repetitions, we could focus on children’s and parents’ *self-initiated*

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attention to mathematical features and their correlations beyond partner-prompted instances. Second, we could explore the ways in which children and parents attend to, and draw each other's attention to, these mathematical features during Duplos and kitchen set play.

Each play session was coded by two of three trained research assistants. Initially, the overall inter-rater reliability of identifying instances of attention to a feature was $\kappa = .75$, suggesting that the coders were reliable at identifying instances during Duplos and kitchen set play. All instances and verbal coding discrepancies were discussed and resolved during coding meetings, so the final set of data analyzed reflects full consensus among two or more coders.

Results

Preliminary Analyses

Descriptive analyses. Both children and parents attended to mathematical features during the play sessions, with much within group variation in the frequency of their attention (Table 2). Most instances of attention to mathematical features were self-initiated rather than prompted, and most of these instances were categorized as feature mentions (Table 3). Although repetitions or feature-focused responses to partners' instances were relatively infrequent, we nevertheless omitted these prompted instances in select primary analyses to focus on self-initiated attention to mathematical features and to avoid artificially inflating the correlation between parents' and children's attention to mathematical features.

Five children (two girls), all 2 years 6 months of age or younger, had no instances of attention to any of the mathematical features we coded, and including their data led to non-normal distributions. We thus classified these observations as outliers and omitted their data at the dyad level. Each of these five children produced fewer than 50 words throughout the two activities combined, but so did two other children with comparably low word counts who had at

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least one instance of attention to the features targeted in this study and whose data were included in analyses. This sample size included in the analyses afforded 80% power to detect large effects of activity materials (partial η^2 =.16; cutoffs of .01, .06, and .14, for small, medium, or large effect, respectively, Cohen, 1988) at α = .05 level.

For the dyads with one or more instances of attention to mathematical features, the average word count across the two activities was 252.05 (*SD* = 124.07, range = 22 – 540) for children and 839.20 (*SD* = 357.33, range = 282 – 2140) for parents (see Table 4). Children's and parents' total word counts were highly correlated with their unique word count for individual play sessions, *r*s >.916, *p*s < .001. Because participants with higher total word count may have more opportunities for talking about mathematics, we accounted for the variation in total word count by partialling out the effect of total word count in correlation analyses and including low versus high word count as a variable, based on a median split, in MANOVA and ANOVA analyses.

Age effects. To determine whether to collapse children's data across the wide age span (2 to 4 years of age), we used Spearman correlations to examine the relations among children's age, children's and parents' word counts, and children's and parents' attention to mathematical features. As expected, children's age was correlated with their word count and with their frequency of attending to mathematical features, during Duplos and kitchen set play, r_ss > .299, *p*s < .05. When total word count was partialled out in analyses on either activity, however, age was no longer a significant predictor of attention to mathematical features, *p*s ≥ .156, so age was excluded from further analyses. The relation between attention to mathematics features and word count was significant for each activity, for both children and parents, r_ss > .662, *p*s < .01. Not

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surprisingly, dyads who talked more during the activities had more instances of attention to mathematical features.

Attention to number in Duplos play. We considered the possibility that the presence of number decals may increase participants' attention to number during Duplos play. Using an independent sample t-test, we found that children who played with the Duplos set with number decal pieces attended to number more frequently (M = 2.65, SD = 2.60) than did those whose Duplos set excluded the decal pieces (M = 1.17, SD = 2.28), with a medium to large effect size, t (42) = 2.02, p = .050, Cohen's d = .61 (cutoffs of .20, .50, and .80, for small, medium, or large effect, respectively, Cohen, 1988). To test whether this decal effect simply reflects specific references to the decals (e.g., stating, "there is a two on that block") rather than an increase in general and non-decal specific attention to number, we repeated the analyses omitting only the instances of specific decal reference and found that frequency in attention to number no longer differed between the two groups, p = .707. Similar results emerged from parallel analyses of the effects of number decals on parents' attention to number during Duplos play. Independent sample t-test showed that frequency of parents' attention to number did not differ between parents whose Duplos set included as opposed to excluded number decals, p = .073. The findings suggest that the presence of number decals did not extend children's attention to number beyond simple decal references and did not significantly increase parents' attention to number; we therefore collapsed data from the two decal groups in the subsequent analyses of Duplos play.

Primary Analyses

Effects of play context.

Attention to mathematical features. In our first analysis on the effect of activity, we included gender and activity order to account for their potential influences on children's and

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parents' attention to mathematical features. We therefore conducted two parallel 2 (Activity: Duplos vs. kitchen set) × 2 (Child Gender) × 2 (Activity Order: Duplos first vs. Kitchen set first) ANOVAs on children's or parents' instances of attention to mathematical features, respectively. The main effect of activity was significant in favor of more instances during the Duplos play compared to during kitchen set play, for children (Duplos: M = 9.86, SD = 8.05; Kitchen: M = 5.34, SD = 4.36), $F(1,40) = 12.03$, $p = .001$, $\eta^2 = .231$; and parents (Duplos: M = 25.73, SD = 17.49; Kitchen: M = 19.02, SD = 11.57), $F(1,40) = 7.30$, $p = .010$, $\eta^2 = .154$. There was no main effect of child gender or activity order, and there were no significant interactions, ps > .215. Since most parents in these analyses were mothers (n = 34), we did not explore the effect of parent gender on these outcomes.

To better understand the nature of the main effect of activity, we examined the effect of activity on participants' attention to specific mathematical features. To maintain statistical power and alignment with our research goals, we conducted analyses on the two targeted categories of mathematical features, quantitative (i.e., number, quantity, and part-whole relations) and spatial (size, shape, location, and orientation) features, as opposed to the individual mathematical features. We also included "color" as a non-mathematical feature category, as a comparison to the two categories of mathematical features. With three categories of feature, we ran parallel repeated measures MANOVAs, with children or parents separately, on children's and parents' attention to quantitative features, spatial features, and color during Duplos versus kitchen set play sessions. We report the findings separately for children and parents.

Children's attention to quantitative compared to spatial features. The 2 (Activity: Duplos vs. kitchen set) × 2 (Word Count: high vs. low) MANOVA on children's frequency of attention to the features revealed that in addition to the previously reported main effect of

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activity, $F(3, 40) = 8.35$, $p < .001$, $\eta^2 = .385$, there was a main effect of word count, $F(3, 40) = 7.08$, $p = .001$, $\eta^2 = .347$, and a significant activity × word count interaction, $F(3, 40) = 3.37$, $p = .028$, $\eta^2 = .202$ (Figure 1). Univariate ANOVAs further indicated that activity was significant for only the spatial features, $F(1, 42) = 23.71$, $p < .001$, $\eta^2 = .361$, wherein children attended to spatial features more frequently during Duplos ($M = 6.20$, $SD = 5.45$) as opposed to kitchen play ($M = 2.59$, $SD = 3.24$; Figure 1). The main effect of word count was significant in favor of children with high word count, for quantitative features (high word count: $M = 8.95$, $SD = 4.33$; low word count: $M = 3.86$, $SD = 3.68$), $F(1, 42) = 17.67$, $p < .001$, $\eta^2 = .296$; spatial features (high word count: $M = 12.23$, $SD = 8.37$; low word count: $M = 5.36$, $SD = 4.03$), $F(1, 42) = 12.01$, $p = .001$, $\eta^2 = .222$; and color (high word count: $M = 3.91$, $SD = 3.32$; low word count: $M = 2.00$, $SD = 2.54$), $F(1, 42) = 4.58$, $p = .038$, $\eta^2 = .098$. The word count × activity interaction was significant for the spatial features, $F(1, 42) = 4.73$, $p = .035$, $\eta^2 = .101$, and color, $F(1, 42) = 4.31$, $p = .044$, $\eta^2 = .093$. The activity effect on spatial feature was limited to children with high word count, who attended to spatial features more frequently during Duplos play ($M = 8.73$, $SD = 6.20$) as opposed to kitchen set play ($M = 3.50$, $SD = 3.94$). In contrast, the activity effect on color was limited to children with low word count, who attended to color more frequently during Duplos play ($M = 1.73$, $SD = 2.49$) as opposed to kitchen set play ($M = .27$, $SD = .55$).

A simple rank ordering of the relative frequency of attention to individual features revealed that, during both activities, location was the most frequently attended to feature, and shape or part-whole relations were the least frequently attended to features. Children attended to size more frequently than quantity during Duplos play, and they attended to quantity more frequently than size during kitchen play. The small values for these variables precluded statistical comparisons.

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Parents' attention to quantitative compared to spatial features. The 2 (Activity: Duplos vs. kitchen) × 2 (Word Count: high vs. low) MANOVA on parents' attention to the features also revealed a main effect of activity, $F(3, 40) = 10.85$, $p < .001$, $\eta^2 = .449$, and a main effect of word count, $F(3, 40) = 12.42$, $p < .001$, $\eta^2 = .482$, but no effect of activity × word count interaction, $p = .127$ (Figure 2). Univariate ANOVAs revealed the main effect of activity was significant for spatial features, $F(1, 42) = 22.54$, $p < .001$, $\eta^2 = .349$, and color, $F(1, 42) = 7.65$, $p = .008$, $\eta^2 = .154$. Parents attended to spatial features (Duplos: $M = 17.43$, $SD = 11.64$; kitchen: $M = 10.23$, $SD = 7.72$) and color (Duplos: $M = 3.84$, $SD = 5.04$; kitchen: $M = 2.07$, $SD = 2.55$) more often during Duplos play as opposed to kitchen play. The effect of word count was significant for quantitative features, $F(1, 42) = 21.04$, $p < .001$, $\eta^2 = .334$, and spatial features, $F(1, 42) = 31.20$, $p < .001$, $\eta^2 = .426$, but not color, $p = .069$. Parents with high word count had more instances of attention to quantitative features than parents with low word count (high word count: $M = 23.00$, $SD = 10.81$; low word count: $M = 11.18$, $SD = 5.40$) and the same was true for instances of parents' attention to spatial features (high word count: $M = 38.55$, $SD = 16.49$; low word count: $M = 16.77$, $SD = 7.89$). Based on a simple rank ordering, the *relative* frequency of attention to the individual features was consistent across the play contexts for parents, with location and quantity being the most frequently attended to features, and shape and part-whole as the least frequently attended to features.

In summary, both children and parents attended to mathematical features more frequently during Duplos as opposed to kitchen set play. The effect of activity appears driven by children's and parents' frequency of attention to spatial, but not quantitative, features. Parents also attended to color more often during Duplos as opposed to kitchen set play, despite the colorful array of dishes and foods included in that activity. The main effects of activity on parents' attention to

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spatial features and color were significant regardless of parents' word count. The main effect of activity was limited to children with high word count for attention to spatial features and to children with low word count for attention to color, suggesting that word count reflects both the amount and type of talk in which children engage.

Based on simple rank ordering, the relative frequency of attention to individual features of interest was quite consistent across the two activities for parents, but some differences emerged in children's relative frequency of attention to these features.

Potential confounding variables. To rule out that the main effect of activity was driven by activity duration or word count, we ran paired-samples t-tests and found that the duration for Duplos play (M = 6.16 minutes, SD = 1.29) and kitchen set play (M = 6.49, SD = 1.18) were comparable, $t(43) = 1.54$, $p = .131$. Children were equally talkative during Duplos (M = 126.67, SD = 69.73) and kitchen set play (M = 125.05, SD = 67.64), $t(43) = .220$, $p = .827$, and parents actually talked more during kitchen set (M = 454.04, SD = 191.51) as opposed to Duplos play (M = 388.43, SD = 190.96), $t(43) = 2.96$, $p = .005$, $d = .64$ (see Table 4). Although word count was correlated with the frequency of attention to mathematical features in children and parents, the dyads did not play with the Duplo set longer than the kitchen set, and did not talk more during Duplos play compared to kitchen set play. Activity duration and word count did not, therefore, fully explain the higher frequency of attention to mathematical features during Duplos play compared to kitchen set play.

We considered the possibility that the presence of a number or spatial book may have affected children's or parents' attention to quantitative and spatial features, although this was unlikely given how infrequently children chose to look at a book prior to Duplos and kitchen set play. Two 2 (Book Topic: number vs. space) × 2 (Word Count: high vs. low) MANOVAs, run

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separately on children's or parents' attention to mathematical features, showed the previously reported main effect of word count for children, $F(3,38) = 7.45$, $p < .001$, $\eta^2 = .370$, and parents, $F(3,38) = 11.75$, $p < .001$, $\eta^2 = .481$, but no main effect of book topic nor any significant interaction, *p*s > .085. As reported earlier, the univariate ANOVAs revealed that children with high word count had more instances of attention to quantitative features, spatial features, and color than children with low word count, *p*s < .022. Parents with high word count had more instances of attention to quantitative and spatial features than parents with low word count, *p*s < .001. However, their attention to features did not differ depending on whether they saw the number or spatial book as an activity option.

Relations between children's and parents' attention to mathematical features.

We first compared children's and parents' performance directly with a 2 (Activity) × 2 (Parent vs. Child) ANOVA on instances of attention to mathematical features. Consistent with the earlier analyses, the main effect of activity held, $F(1,86) = 17.11$, $p < .001$, $\eta^2 = .166$, in favor of more instances of attention to mathematical features during Duplos play ($M = 17.80$, $SD = 15.71$) compared to kitchen set play ($M = 12.18$, $SD = 11.09$). As anticipated, parents ($M = 22.38$, $SD = 12.24$) had significantly more instances of attention to mathematical features during play than did their children ($M = 7.60$, $SD = 5.58$), $F(1,86) = 53.11$, p < .001, $\eta^2 = .382$, consistent with Table 2. There was no interaction, $p = .424$.

Since we were interested in the nature of the relation between children's and parents' attention to mathematical features, we ran several sets of Spearman correlations between children's and parents' attention to mathematical features. To maximize statistical power and explore general tendencies, we collapsed data across the two activities, first with instances of all mathematical features combined, and second separated by specific features except for the part-

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whole relation due to its rare occurrence. Since we found a significant main effect of activity on instances of attention to mathematical features, we ran Spearman correlations between children's and parents' attention to mathematical features in Duplos and kitchen set play separately. In view of the influences of word count on children's and parents' attention to mathematical features, word count was partialled out in these correlation analyses.

When collapsed across the two activities and all mathematical features, children's and parents' frequency of attention to mathematical features were correlated with each other, r_s = .373, p = .015. When limited to specific features, the correlations between children's and parents' frequency of attention to a feature were significant for number, quantity, size, shape, orientation, and color, r_ss > .347, ps < .024, but not location, p = .068.

Collapsed across all instances of attention to any mathematical feature, but examined separately for each activity, children's and parents' frequency of attention to mathematical features were correlated with each other during Duplos play, r_s = .439, p = .004, but not during kitchen set play, p = .068. When limited to children's and parents' attention to individual features of interest, the frequency of children's and parents' attention to a feature were significantly correlated for attention to number or orientation, during both activities, r_ss > .368, ps < .001, and for Duplos play only, significant correlations also emerged for attention to size, shape, and color, r_ss > .430, ps < .005. The frequency of children's and parents' attention to quantity were correlated during kitchen set play, r_s = .495, ps < .001, but not Duplos play, p = .156 (Table 5). In summary, children's and parents' frequency of attention to several of the mathematical features was significantly correlated with each other, but differences emerged in the pattern of these correlations between the two activities.

Types of self-initiated attention to mathematical features.

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Finally, to better understand *how* children and parents refer to mathematical features during play, we examined the frequency of each type of verbal communication coded. In both Duplos and kitchen set play, children and parents rarely asked feature-focused questions and rarely repeated or made responses that directly focused on these mathematical features. Most verbalizations were feature mentions (i.e., simple references to these features; Table 3). To test whether the differences between the two types of self-initiated attention to mathematical features (question vs. mention) were significant, we ran 2 (Activity) × 2 (Instance Type: question vs. mention) × 2 (Word Count: high vs. low) repeated measures ANOVAs on children's or parents' attention to mathematical features, respectively. As expected, the main effects of activity and word count held for children (activity: $F(1, 42) = 12.36$, $p = .001$, $\eta^2 = .227$; word count: $F(1, 42) = 20.02$, $p < .001$, $\eta^2 = .323$), and parents (activity: $F(1, 42) = 9.53$, $p = .004$, $\eta^2 = .185$; word count: $F(1, 42) = 45.41$, $p < .001$, $\eta^2 = .520$). Among children, feature mentions occurred significantly more frequently than feature-focused questions, $F(1, 42) = 133.44$, $p < .001$, $\eta^2 = .761$, but this was also true among parents, $F(1, 42) = 255.53$, $p < .001$, $\eta^2 = .859$. The frequency of feature mentions was quite high, and highly variable, for children ($M = 18.82$, $SD = 12.94$) and parents ($M = 48.52$, $SD = 26.00$), whereas the occurrence of feature-focused questions was very low for both children ($M = .82$, $SD = 1.43$) and parents ($M = 3.91$, $SD = 3.31$). The significant Activity × Instance Type interaction that emerged for children, $F(1, 42) = 11.46$, $p = .002$, $\eta^2 = .214$, and parents, $F(1, 42) = 7.95$, $p = .007$, $\eta^2 = .159$, was an interaction of magnitude. For each participant group, the low frequency of feature-focused questions did not differ between Duplos and Kitchen set play, and the frequency of feature mentions was more variable but significantly higher for Duplos compared to kitchen set play (Figures 3 and 4). Variability in feature mentions was partly explained by word count; the Instance Type × Word

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Count interaction was significant for children, $F(1, 42) = 20.97$, $p < .001$, $\eta^2 = .333$, and parents, $F(1, 42) = 34.86$, $p < .001$, $\eta^2 = .454$. For children, the word count effect was limited to frequency of feature mentions, in that children with high word count had more instances of feature mentions than children with low word count. Parents with high word count had more instances of feature mentions and feature-focused questions compared to parents with low word count, but the difference between the two groups of parents was greater for feature mentions than for feature-focused questions.

In summary, both children and parents rarely asked feature-focused questions during play, both made more feature mentions during Duplos as opposed to kitchen set play, and word count (as a proxy for expressive vocabulary) accounts for some but not all of the variation in the frequency of feature mentions.

Discussion

In the present study, we examined children’s and parents’ attention to number and other mathematical features during two semi-structured play scenarios, a type of block play (Duplos) and pretend play with a kitchen set (dishware and food). We did so to pursue two primary aims. First, we sought to directly compare the effects of different play materials on the frequency of children’s and parents’ attention to mathematical features in a semi-naturalistic setting. Second, we sought to examine the relation between children’s and parents’ attention to mathematical features, in order to address the degree to which spontaneous focus on mathematical features may be influenced by the kinds of interactions children experience with their parents in play contexts. These aims collectively contribute to the growing literature on attention to number (including but not limited to SFON), and to research on how parents support their young children’s early mathematical thinking and development.

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Attention to Mathematical Features during Semi-structured Play

Given some evidence that attention to mathematics is predictive of concurrent and later mathematics performance (Hannula-Sormunen, 2015; Hannula & Lehtinen, 2005; Hannula et al., 2010; McMullen et al., 2015), it may be important to consider what situations or contexts linked to parent-child play may promote engagement with mathematical features. In the present study, most children and adults *did* attend to mathematical features during play, at least some of the time, but to widely differing degrees (Table 2). Five two-year-olds *never* attended to any mathematical features. Four of these five children produced fewer than five words during the 10-12 minutes of play combined across both activities, and since our coding was based on verbal production, these children with few utterances were likely to have no instances of attention to mathematical features. However, word count alone did not account for the individual differences in attention to mathematical features, because the remaining fifth child with no instances of attention to mathematical features produced 47 words across the play sessions. By contrast, two additional children with similarly low word counts (i.e., 22 and 35 words across play sessions) did attend to mathematical features, albeit infrequently, three and seven times, respectively. The frequency of attention to mathematical features among the parents of the five children with no attention to mathematical features was highly variable (0, 23, 44, 45, or 54 instances among these parents), but lower in comparison to the parents (75, 89 instances) of the two other participants who did attend to mathematical features despite their low word count. This correlational information is limited to too few dyads to generate implications for the relation between children's and parents' attention to mathematical features, but it does support our position that word count alone (as a proxy for expressive vocabulary) does not explain individual differences in attention to mathematical features.

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Children who played with the Duplos set that included the number decal pieces noticed the decals and made simple references to the decals themselves, generating comments like "oh, there's a two," but their attention to the decals did not lead to richer, non-decal specific, number talk among dyads. Parents seemed unaffected by the decals. The frequency of their attention to number did not differ regardless of whether they played with the Duplos set that included or excluded the number decal pieces. On the one hand, the findings illustrate that children *are* sensitive to the numerical cues in their physical environment, which supports the contention that number prompts should be avoided if we are to measure *self-initiated* attention to number, as is the standard practice in SFON research (e.g., Hannula & Lehtinen, 2005). Simply including number decals on play materials did not, however, elicit additional meaningful nor more non-decal specific attention to number, at least not during Duplos play, in either children or adults, suggesting that the decals did not further extend their discussion of number beyond these decal-specific utterances. This finding is aligned with educators' emphasis on making the math in mathematics play meaningful rather than arbitrary (Giardini, 2016), or, in the case of Duplos and kitchen set play, creating materials that lend themselves to a meaningful reliance on mathematics principles or attention to mathematical features.

The Duplos and kitchen set afforded different types of interactions, and children's and parents' attention to mathematical features varied across these two activities. Word count alone did not fully account for the effects of play materials on attention to mathematical features. Children were equally talkative during both types of play, but children with high word counts were more likely to attend to spatial features during Duplos as opposed to kitchen set play. Parents were actually more talkative during kitchen set play compared to Duplos play, but they were also more likely to attend to spatial features during Duplos play, consistent with previous

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findings that block play promotes spatial talk (Ferrara et al., 2011). Color, which we included as a potential contrasting non-mathematical feature, was subject to similar findings. Duplos play seems to elicit attention to color and spatial features, in most parents and in some children depending on their word count, perhaps because color is one of three primary identifying features (color, shape, and size) for otherwise non-descript Duplo pieces. Although the kitchen set is also colorful, individual items in the kitchen set have distinct labels (e.g., tomato, slice of bread, cucumber), and they vary from one another more than the blocks in the Duplo set, therefore children and parents may not need to rely on color as frequently to identify these items.

Unlike the effects we observed in attention to spatial features and color, there were no effects of activity on attention to quantitative features, and no Activity × Word Count interaction. One potential explanation for this null finding is that both activities elicit attention to quantitative features, but in different ways. In Duplos play, the dyads may attend to the number of blocks they need for the structure they are building. In kitchen set play, they may attend to the amount of food they have and the number of people they are serving.

Our main findings suggest that different play materials do influence the frequency and types of mathematical features that children and parents attend to during play. Activities that involve manipulating spatial features of the materials, such as building structures or orienting pieces to fit a specific location, seem to promote children's and parents' attention to spatial features. Similarly, materials that are non-descript, such as blocks or tiles, may prompt children and parents to attend to features such as color and shape, as alternatives to object labels, in order to communicate about the pieces of the materials. The results extend previous findings on attention to spatial features (Chan & Mazzocco, 2017) and spatial talk (Ferrara et al., 2011) in two important ways. First, the current study supports the notion that attention to spatial features

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may be malleable in laboratory and also quasi-naturalistic settings. This notion is consistent with our earlier experimental findings that preschoolers and adults selected positional orientation as the best-matching feature more frequently when the alternative matching features were of low, as opposed to high, salience (Chan & Mazzocco, 2017). Second, children's attention to spatial features can be influenced by explicit cues, such as experimenters' prompts (Polinsky et al., 2017) and parents' talk (Pruden et al., 2011), but also play materials. Even without explicit prompting, the contexts, in this case play materials themselves, influenced children's and parents' attention to, and discussion of, spatial features.

Children's and Parents' Attention to Mathematical Features

Children's and parents' attention to mathematical features in this study were correlated with each other, but this relation was not straightforward. Importantly, these correlations were not simply a reflection of parents and children answering each other's questions or reacting to each other's comments, because we explicitly omitted such responses or repetitions from analyses. Had we not omitted these instances, the correlations between parents' and children's attention to mathematical features would have been virtually guaranteed, and of little practical significance. Several significant correlations did emerge, but they varied with play materials and across mathematical features. Attention to *number* and *orientation* were each correlated between children and parents, for both play activities, even when controlling for word count and omitting instances of repetitions or responses to feature-focused questions. By contrast, the correlations for attention to size, shape, and color emerged only for Duplos play, and the correlation for attention to quantity emerged only for kitchen set play. These correlations do not explain the directionality of the influence (i.e., whether parent math talk prompts child math talk or the reverse), nor do they eliminate the possibility that some play materials simply elicit more math

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talk in children and parents alike, leading to spurious correlations. However, the differences in the correlations between the two activities suggest that Duplos may elicit more interactive discussion on size, shape, and color of the blocks (three identifying features) regardless of the mechanisms, whereas the kitchen set elicits more reciprocal discussion on quantity of food as it is being "prepared" or shared. The goal of our study was not simply to determine whether the specific materials and activities we focused on in this study elicit or fail to elicit attention to mathematical features. Instead, our aim was to explore the broader concept that play materials can shape the nature of parent-child play interactions, and specifically the mathematical nature of that play and corresponding dialogue. Our findings make a small but important contribution to the notion that thoughtful planning and design of physical play materials may increase attention to and reciprocal discussion of such features.

When exploring the nature of the mathematical feature instances themselves, verbalization codes were revealing. Most of children's and parents' attention to mathematical features (over 91%) were mere *mentions* of those features, such as "I've got two of these," or, "this sandwich is so big." These mentions outnumbered feature-focused questions, such as "how many cups are there?" by a magnitude of nine or more across play activities. Although feature mentions may be an expected characteristic of preschoolers' verbalizations, it is noteworthy just how infrequently parents asked their children questions that drew attention to or elaborated on any of the mathematical features we studied. These findings parallel results of prior research with teachers. For instance, even experienced preschool teachers rarely ask instructional questions to facilitate learning (Hamre et al., 2012); in studies focusing on second grade mathematics instruction, when teachers do engage in instructional math questioning, the frequency of their open-ended questions is positively associated with students' mathematics

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achievement (Clements, Agodini, & Harris, 2013). Our findings suggest that without guidance on when, how, or why to attend to mathematical features, parents rarely pose feature-focused questions to their children, even among this well-educated sample of parents.

Future Directions

A systematic examination of parents' questioning type is an important next step in this research, because if enhancing parents' or caregivers' attention to and discussion of mathematics promotes children's mathematical development (Hannula et al., 2005; Polinsky et al., 2017; Susperreguy & Davis-Kean, 2016), it is worthwhile to pursue ways to implicitly or explicitly guide parents' mathematics relevant behavior (including verbalizations), and determine whether these low intensity "interventions" change parents' behaviors and attitudes and children's mathematical development. If parental support proves to be effective, then researchers should explore ways to help parents guide children's attention to mathematical features.

Another direction for future studies is to compare children's and adults' performance across lab and naturalistic studies. Here we note three important similarities between the present quasi-naturalistic study and our earlier experimental research, based on informal comparisons. First, there are notable degrees of individual differences in attention to mathematical features in both the present study (Table 2) and the previously reported experimental picture-matching task that involved the same mathematical features (Chan & Mazzocco, 2017). Second, in both studies, these individual differences were apparent among both children and adults. Third, attention to number, specifically, was quite infrequent among children and adults, in both the present and completed studies. In the present study, attention to number occurred, on average, only once for children and three times for parents, per six-minute play session; and in our previous experimental study, preschoolers and adults selected number as a feature for matching pictures

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on only 8% or 21% of all trials, respectively. This suggests that attention to number occurs infrequently in both experimental and more naturalistic settings, which raises the questions of whether guided prompts can increase attention to number, what form such prompts should take, and how to best measure the effectiveness of these prompts. Exploring these questions across lab and naturalistic settings may be fruitful lines of inquiry into the ecological validity of experimental work in attention to mathematical features, particularly in light of differences between our studies, as noted below.

A marked difference observed between the present study and our earlier work concerns that the *relative* focus on number differed across these studies. In the present study, attention to number and color were quite comparable to each other, at least on average (Table 2). In the experimental matching task, preschoolers and adults were especially unlikely to select number as the best match to a target picture (2% or 11% of trials, respectively) when color was an alternative option, but they matched on color quite frequently (49% or 21% of trials, respectively; Chan & Mazzocco, 2017). Even when participants were not restricted to only one match response, preschoolers still matched pictures based on number less frequently (3%) compared to color (51%), as did adults (50% compared to 85%). Different task demands likely explain these inconsistent response patterns. The experimental task constrained participants' responses to matching pictures to the target stimuli, and—unlike the play scenarios—the matching task did not require that participants interact with, describe, or discuss materials in an open-ended way. Future studies should focus on the same or very comparable tasks across experimental and play scenarios.

Another direction for future works concerns the extent to which attention to mathematical features is ever truly self-initiated versus contextually or experientially determined. Similar to

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our experimental findings (Chan & Mazzocco, 2017), our current findings indicate that although children and adults rarely attend to number in a semi-naturalistic setting, *whether* or *how often* individuals attend to mathematical features is influenced by the types of materials and demands of the task with which they engage. Although these findings are consistent with earlier reports of individual differences in SFON tendencies (e.g., Hannula & Lehtinen, 2005), they also prompt us to interpret the “spontaneity” component of SFON cautiously. Even without *explicit* prompts to attend to mathematical features, the manipulation of the environment may affect individuals’ tendency to attend to these features. The influence of context does not rule out the possibility of an inherent SFON tendency in children, but it raises the possibility that contextual influences either *explain* alleged spontaneous attention to number or may operate *in addition to* SFON tendencies. Finally, an important direction for future studies concerns whether the malleability of attention to mathematical features offers potential pathways to promote mathematical development in young children.

Limitations and Conclusions

This study had several limitations. First, although the data were collected in a public venue, the study participants were not representative of a diverse population. There was no doubt that a self-selection bias was operating in terms of parents choosing to approach the research booths at the state fair. Most parents (96%) in the study had completed at least some college and most participants (82% of children and 88% of adults) were White. Still, we observed large individual differences in the amount of verbal communication and attention to mathematical features among children and parents, and contextual influences on attention to these features remained significant when the variation of word count was accounted for. Second, it is likely that the play area in this public data collection venue did not simulate a home-like naturalistic play

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setting. However, our findings of infrequent attention to number and spatial features are consistent with rates of number and spatial words used during in-home naturalistic observations (Levine et al., 2010; Pruden et al., 2011). Third, in this study, we examined parent-child interaction only during Duplos play and kitchen set play, and we could not control for dyads' previous exposure to these toys. Future studies would benefit from recruiting a more diverse sample, observing children's and parents' attention to mathematical features in a more naturalistic context, controlling or accounting for children's and parents' prior experience with the task materials, and exploring a broader range of play materials representative of those with which children and parents interact on a regular basis (e.g., storybooks, puzzles, shape sorters), and then testing variations within those categories of materials (e.g., paper storybooks vs. E-books).

In conclusion, if play materials affect individuals' attention to mathematical features during play, it behooves scientists to identify the underlying mechanisms that account for these contextual effects. Educators, parents, and developers of play or educational materials would benefit from a deeper understanding of the effects of context. Potential starting points from which to launch further inquiries include studies of how play materials themselves influence children's and parents' attention to mathematical features, whether it is possible to promote attention to mathematical features by structuring play materials to support meaningful reliance on mathematics, and whether increasing parents' use of questions relative to declarative "feature mentions" plays a role in children's attention to mathematical features during (and after) parent-child play interactions.

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Table 1

Brief definitions and examples of feature instance codes

Feature	Definition	Example
Quantitative features		
Number*	Attend to numerical feature of the activity materials by using or prompting cardinal number words (e.g., 1, 2), ordinal number words (e.g., first, second), or counting.	"I've got **two** of these."
Quantity	Attend to quantity of the activity materials without using exact number words (e.g., some, a lot, both, more).	"Do you want **some** watermelon?"
Part-Whole	Attend to parts, whole, or part-whole relations of the activity materials.	"I think we are missing **a part of the watermelon**."
Spatial features		
Size	Attend to the size of the activity materials (e.g., big, small, tall, short).	"This sandwich is so **big**."
Shape	Attend to the geometric shapes (e.g., circle, square) or attributes of the geometric shape (e.g., pointy, rounded) of the activity materials.	"It's a **rectangle**."
Location	Attend to the location of the activity materials (e.g., on top, middle) within the activity space.	"Can I have my carrots **on** the plate?"
Orientation	Attend to the orientation or direction of the activity materials (e.g., tilted, upside down).	"The tower is **tilted**."
Non-mathematical feature for contrast		
Color	Attend to the colors (e.g., red, blue) or shades of a color (e.g., light, dark) of the activity materials.	"**What color** plate would you like?"

Note. * The number instances specific to the number decals were coded separately, and were omitted in select analyses on the effects of the number decals on children's and parents' attention to number.

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Table 2

Mean, standard deviation, and range of feature instances (excluding repetitions and responses) by person and activity. Frequency of repetitions and responses for mathematical features are reported separately.

	Children				Parents			
	Duplos (*N* = 49)		Kitchen Set (*N* = 50)		Duplos (*N* = 49)		Kitchen Set (*N* = 50)	
Feature	*M* (*SD*)	Range	*M* (*SD*)	Range	*M* (*SD*)	Range	*M* (*SD*)	Range
Quantitative								
Non-cardinal One	1.96 (2.61)	0 – 13	2.16 (3.44)	0 – 15	4.86 (4.67)	0 – 22	2.98 (3.73)	0 – 18
Number*	1.65 (2.45)	0 – 10	0.78 (1.11)	0 – 4	2.98 (4.22)	0 – 20	2.94 (3.79)	0 – 19
Quantity	1.49 (1.87)	0 – 8	1.68 (1.99)	0 – 7	4.61 (4.90)	0 – 23	5.52 (3.98)	0 – 23
Part-whole	0.14 (0.41)	0 – 2	0.02 (0.14)	0 – 1	0.22 (0.69)	0 – 4	0.14 (0.35)	0 – 1
Subtotal*	3.29 (3.65)	0 – 16	2.48 (2.54)	0 – 8	7.82 (7.49)	0 – 34	8.60 (5.94)	0 – 28
Spatial								
Size	1.73 (2.79)	0 – 12	0.26 (0.75)	0 – 4	3.49 (3.59)	0 – 13	0.84 (1.49)	0 – 6
Shape	0.14 (0.50)	0 – 2	0.04 (0.20)	0 – 1	0.88 (2.82)	0 – 17	0.28 (0.70)	0 – 3
Location	3.39 (3.52)	0 – 12	1.92 (3.04)	0 – 16	10.24 (7.06)	0 – 29	7.88 (6.18)	0 – 23
Orientation	0.31 (0.77)	0 – 4	0.12 (0.39)	0 – 2	1.90 (2.59)	0 – 13	0.92 (1.26)	0 – 5
Subtotal	5.57 (5.50)	0 – 24	2.34 (3.14)	0 – 17	16.51 (11.50)	0 – 56	9.92 (7.41)	0 – 30
Total mathematical feature instances* (sum of the above)								
	8.86 (8.20)	0 – 33	4.82 (4.40)	0 – 20	24.33 (17.24)	0 – 81	18.52 (11.27)	0 – 45
Repetitions and responses of mathematical features								
	1.27 (1.88)	0 – 7	0.76 (1.26)	0 – 6	2.33 (2.75)	0 – 13	1.34 (1.67)	0 – 7
Non-mathematical feature (presented for contrast)								
Color	1.59 (2.45)	0 - 9	1.08 (1.63)	0 – 7	3.61 (4.86)	0 – 21	2.00 (2.47)	0 – 11

Notes. *We report instances of “one” that did not refer to cardinal value, but exclude these instances from the following: totals for attention to number, subtotals for quantitative features, and totals for all mathematics features.

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Table 3

Verbal code mean, standard deviation, and range values for total mathematics instances (including instances of referring to one)

	Children				Parent			
	Duplos (*N* = 49)		Kitchen Set (*N* = 50)		Duplos (*N* = 49)		Kitchen Set (*N* = 50)	
	M (*SD*)	Range	*M* (*SD*)	Range	*M* (*SD*)	Range	*M* (*SD*)	Range
Mention	10.35 (8.98)	0 – 32	6.54 (6.35)	0 – 31	26.69 (18.49)	0 – 80	20.00 (12.19)	0 – 55
Question	0.39 (0.91)	0 – 5	0.36 (0.69)	0 – 3	2.20 (2.53)	0 – 9	1.46 (1.87)	0 – 6
Responses	0.80 (1.35)	0 – 7	0.62 (1.16)	0 – 6	0.19 (0.61)	0 – 3	0.10 (0.30)	0 – 1
Repetitions	0.47 (1.04)	0 – 5	0.14 (0.40)	0 – 2	2.15 (2.56)	0 – 13	1.24 (1.59)	0 – 6

Table 4

Word Count mean, standard deviation, and range values by person and activity.

	Children			Parents		
	Duplos	Kitchen Set	Total	Duplos	Kitchen Set	Total
Mean (SD)	127.00 (69.73)	126.67 (67.75)	252.05 (124.07)	388.43 (190.96)	454.04 (191.51)	839.20 (367.33)
Range	13 – 315	9 – 255	22 – 540	94 – 1126	150 – 1014	282 – 2140

Note. For parents and children, Duplos: *n* = 44. Kitchen set: *n* = 45.

Table 5

Spearman correlations between children's and parents' attention to individual features after controlling for total word count (n = 44 for Duplos and n = 45 for Kitchen set)

Features	Duplos	Kitchen Set
Number	.412**	.385**
Quantity	.223	.495**
Size	.614**	.237
Shape	.430**	–.058
Location	.286	.158
Orientation	368**	.395**
Color	.537**	.067

** *p* < .01

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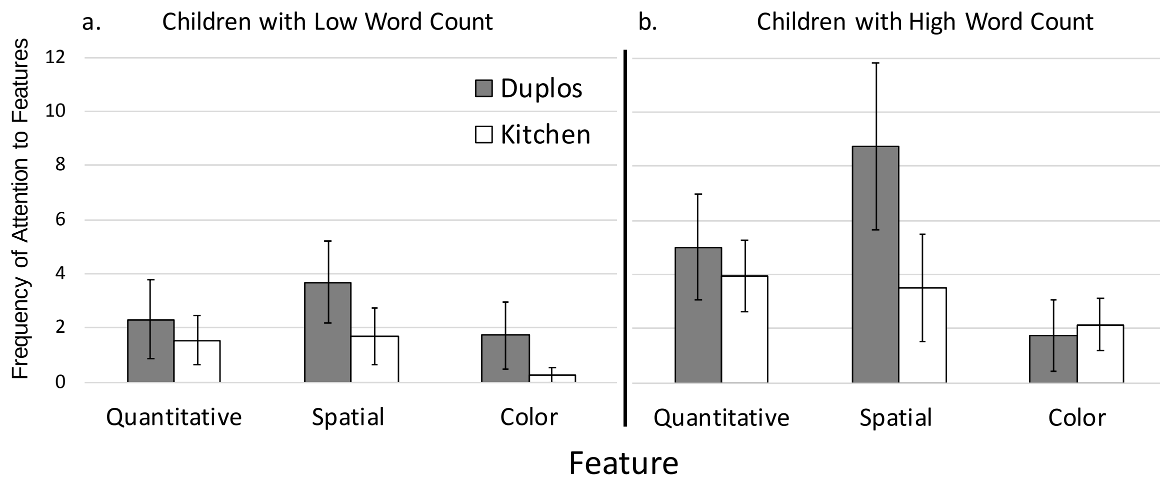

Figure 1. Effect of activity on frequency of attention to features in children with low (a) or high (b) word count. Quantitative features were comprised of number, quantity, and part-whole relations. Spatial features were comprised of size, shape, location, and orientation. Error bars represent standard deviations.

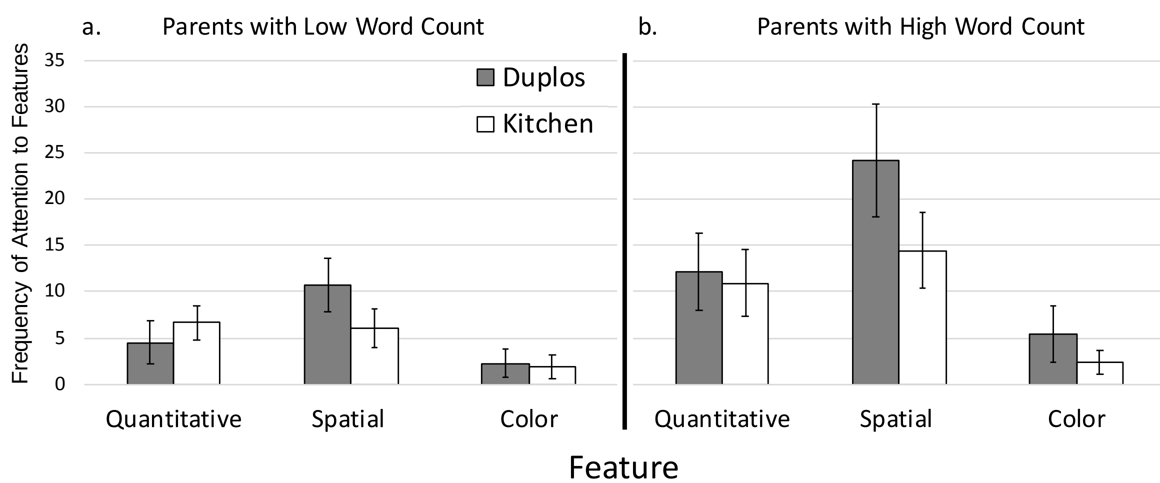

Figure 2. Effect of activity on frequency of attention to features in parents with low (a) or high (b) word count. Quantitative features were comprised of number, quantity, and part-whole relations. Spatial features were comprised of size, shape, location, and orientation. Error bars represent standard deviations.

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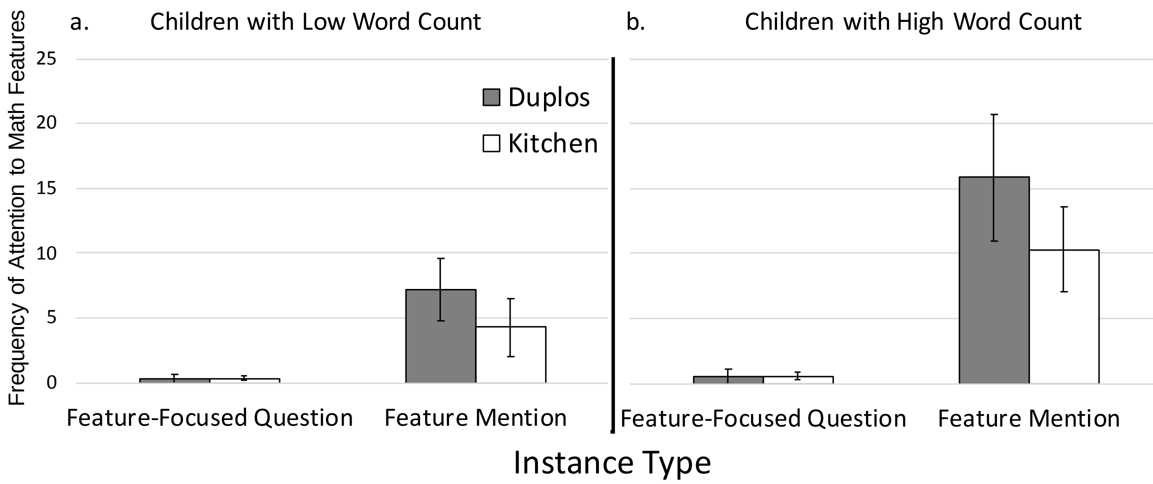
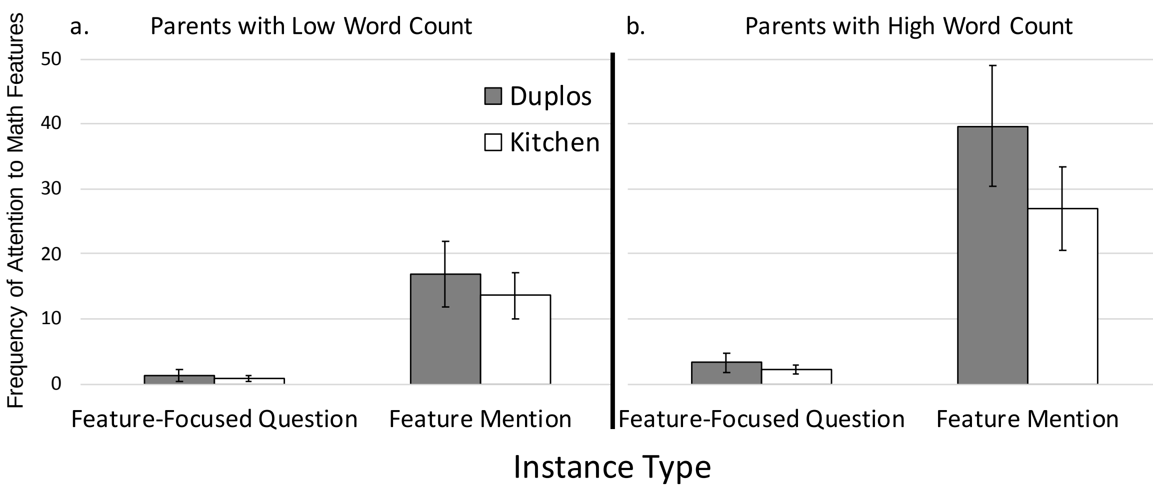


Figure 3. Effects of activity and instance type on frequency of attention to mathematical features in children with low (a) or high (b) word count. Error bars represent standard deviations.



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Highlights

- Children and parents attended to math features during Duplos and kitchen set play.
- Attention to spatial features was more frequent during Duplos vs. kitchen set play.
- Attention to quantitative features did not vary across the two activities.
- Parent-child correlations on attention to math features varied across activities.
- Dyads mentioned math features but rarely posed questions focused on these features.

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Color	1.59 (2.45)	0 - 9	1.08 (1.63)	0 – 7	3.61 (4.86)	0 – 21	2.00 (2.47)	0 – 11

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Responses	0.80 (1.35)	0 – 7	0.62 (1.16)	0 – 6	0.19 (0.61)	0 – 3	0.10 (0.30)	0 – 1
Repetitions	0.47 (1.04)	0 – 5	0.14 (0.40)	0 – 2	2.15 (2.56)	0 – 13	1.24 (1.59)	0 – 6

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Table 5

Spearman correlations between children's and parents' attention to individual features after controlling for total word count (n = 44 for Duplos and n = 45 for Kitchen set)

Features	Duplos	Kitchen Set
Number	.412**	.385**
Quantity	.223	.495**
Size	.614**	.237
Shape	.430**	–.058
Location	.286	.158
Orientation	368**	.395**
Color	.537**	.067

** $p < .01$

Figure 1

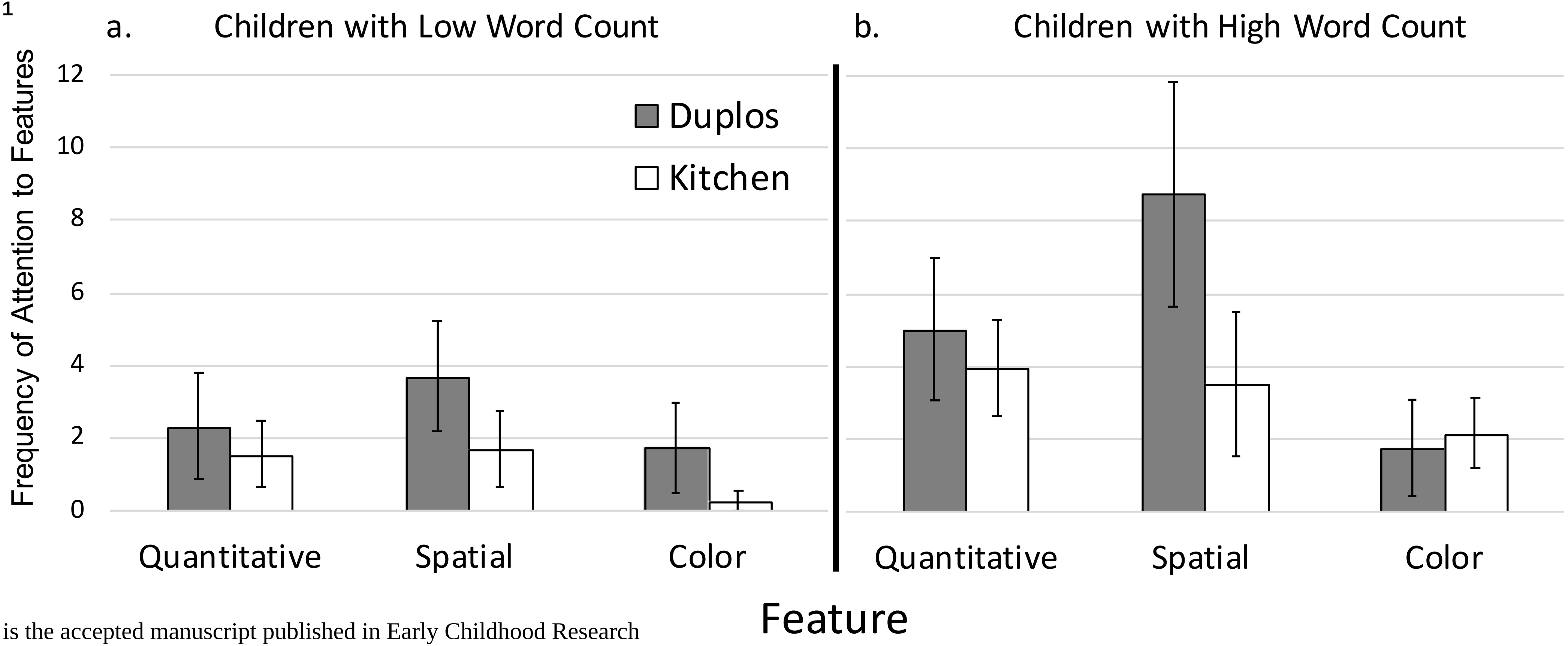

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Figure 2

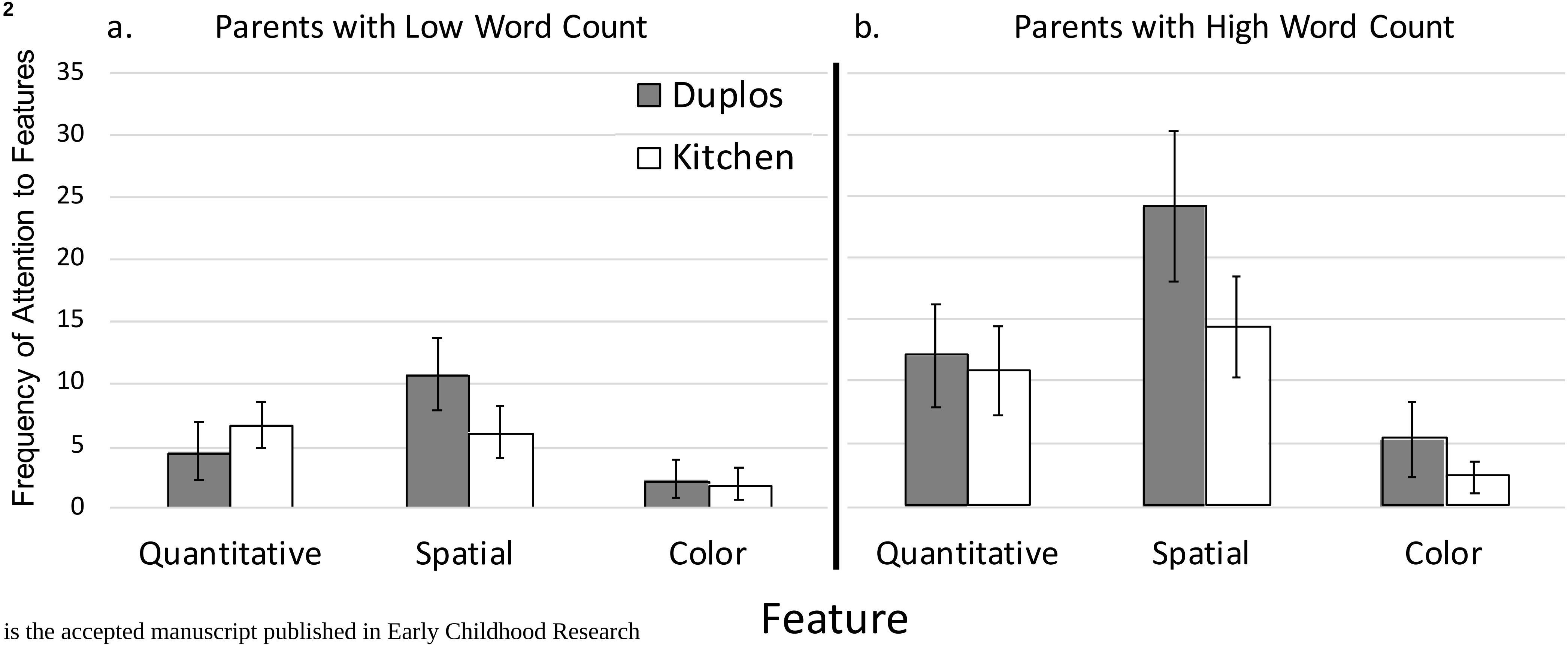

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Figure 3

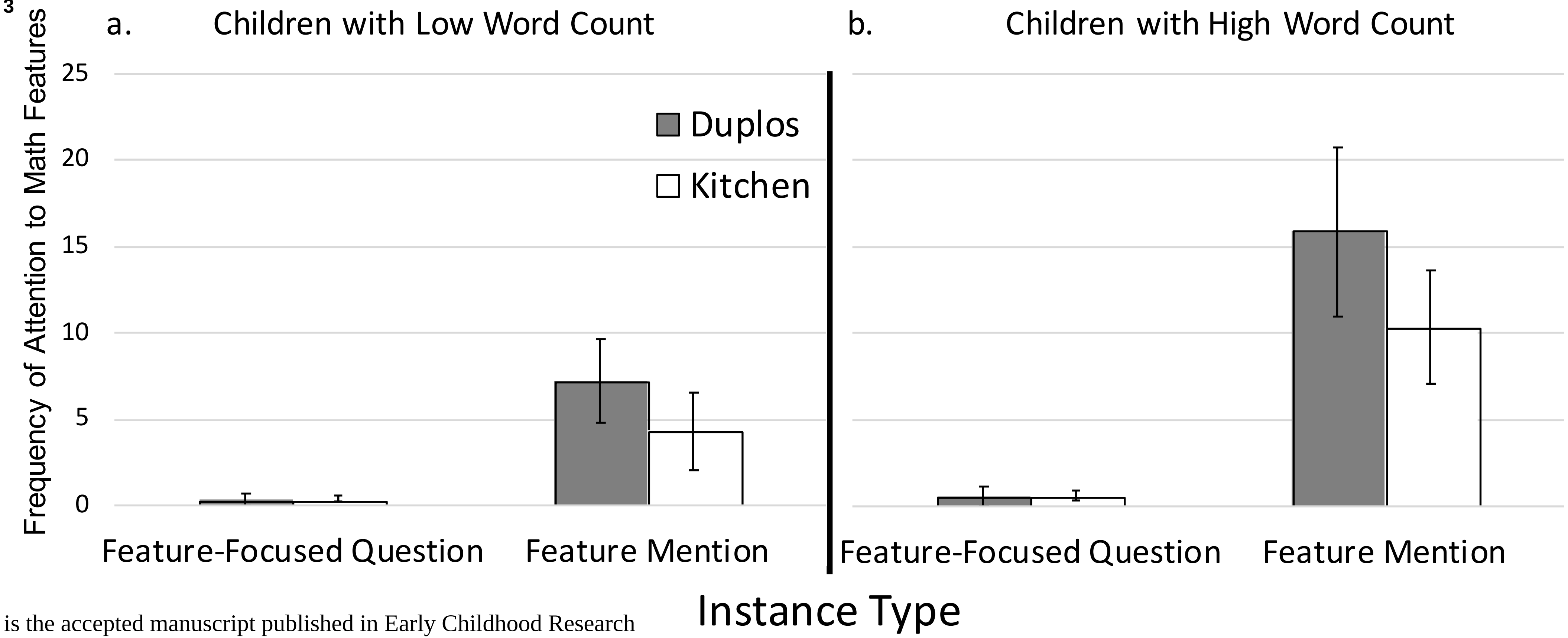

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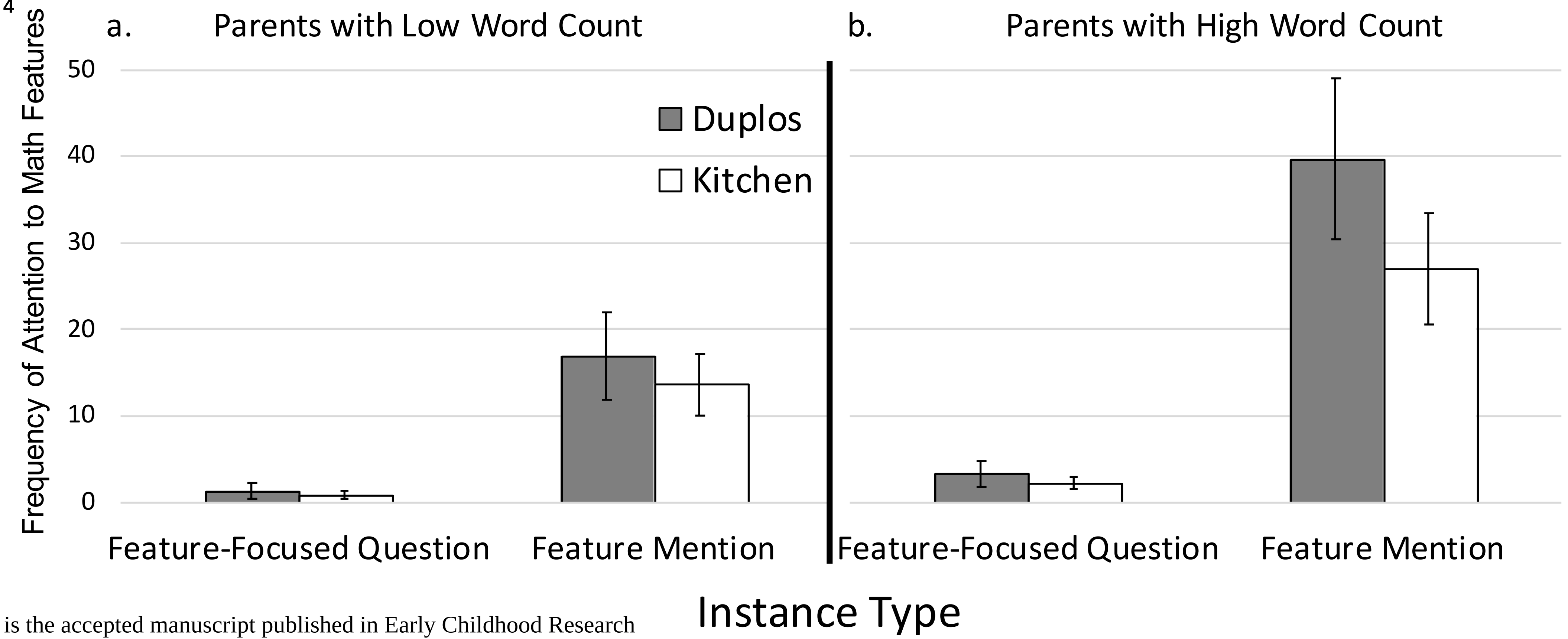
Figure 4



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