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Capturing Math Language Use During Block Play: Creation of the Spatial and Quantitative Mathematical Language Coding System

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Supplementary Materials: Data, Materials [see Index of Supplementary Materials]

Abstract

The goals of the current study were: 1) to modify and expand an existing spatial mathematical language coding system to include quantitative mathematical language terms and 2) to examine the extent to which preschool-aged children used spatial and quantitative mathematical language during a block play intervention. Participants included 24 preschool-aged children (Age M = 57.35 months) who were assigned to a block play intervention. Children participated in up to 14 sessions of 15-to-20-minute block play across seven weeks. Results demonstrated that spatial mathematical language terms were used with a higher raw frequency than quantitative mathematical language terms during the intervention sessions. However, once weighted frequencies were calculated to account for the number of codes in each category, spatial language was only used slightly more than quantitative language during block play. Similar patterns emerged between domains within the spatial and quantitative language categories. These findings suggest that both quantitative and spatial mathematical language usage should be evaluated when considering whether child activities can improve mathematical learning and spatial performance. Further, accounting for the number of codes within categories provided a more representative presentation of how mathematical language was used versus solely utilizing raw word counts. Implications for future research are discussed.

Keywords

mathematical language, spatial language, quantitative language, preschool, block play

Highlights

- The study developed and utilized the Spatial and Quantitative Mathematical Language Coding System to evaluate preschoolers' use of mathematical language during semi-structured block play.
- Findings revealed that children used a higher raw frequency of spatial mathematical language terms compared to quantitative mathematical language terms during block play sessions.
- After adjusting for the number of codes in each category, children's use of spatial and quantitative language showed similar variability, suggesting both types are important for mathematical learning.
- The study identified that the most frequently used domains from each mathematical language category were Location and Direction (spatial) and Static Amounts (quantitative).
- This research highlights the importance of including both spatial and quantitative mathematical language assessments in activities aimed at improving children's mathematical skills.

Mathematical language encompasses children's comprehension and use of key terms and concepts in mathematics and is considered one of the strongest predictors of mathematical development during preschool (Purpura & Logan, 2015). Recently, it has been found that engagement in semi-structured block play (i.e., providing a prompt at the beginning of a block play session to guide building) promotes children's mathematical skills (Schmitt et al., 2018). One possible mechanism through which block play influences mathematics development is mathematical language. Yet, limited research has examined the extent to which block play elicits mathematical language (Ramani et al., 2014), and the majority of this work has focused on one specific type of mathematical language – spatial mathematical language (e.g., Borriello & Liben, 2018; Ferrara et al., 2011). Beyond spatial terms (e.g., right side up, upside down), mathematical language also includes quantitative terms (e.g., fewer, greater; Hornburg et al., 2018; Purpura et al., 2019) and terminology in both of these categories cut across and are relevant for children's learning across multiple mathematical domains. For example, children may use spatial terms such as "wide" (e.g., "We need to know how wide it is.") and quantitative terms such as "few" (e.g., "It's only a few inches shorter than the other one.") when making standard measurements. In addition, when engaged in a geometry activity, a child may employ spatial terms such as "round" to describe the properties of a set of circles or the quantitative term "more" to indicate that the quantity of circles is larger than that of rectangles in a shape configuration. The limited body of work on the usage of *both* quantitative and spatial mathematical language during block play may reflect the lack of a framework for systemically coding these terms and phrases.

Cannon and colleagues (2007) created the Language about Space in Structured and Unstructured Contexts system to code for spatial mathematical language use during parent-child puzzle play and to evaluate whether spatial mathematical language use was related to children's performance on spatial tasks. Though comprehensive, this system does not explicitly include quantitative mathematical language (although some quantitative terms are included under spatial mathematical language domains: none, some, a lot, a little, much, enough, more, less, same, equal; concepts related to increase and decrease), which is also elicited during block play (Ramani et al., 2014). Quantitative mathematical language encompasses a more expansive array of language to describe quantity (couple, few, ton), to compare quantities (fewer, similar, greater), and to change quantities (make the same, take away, add). Thus, the purpose of this study was to modify and extend the Cannon et al. coding system to include children's quantitative mathematical language and to comprehensively examine and compare the quantitative and spatial mathematical language used by children during semi-structured block play. As we focus on these two types of mathematical language, spatial mathematical language and quantitative mathematical language, we hereon refer to these categories as spatial language and quantitative language.

Mathematical Language

Mathematical language comprises children's understanding of terms used in mathematics and is one of the strongest predictors of mathematical development during preschool (Purpura & Logan, 2015). Children's understanding of mathematical terms (e.g., quantifiers) is thought to facilitate their mathematical learning (Barner et al., 2009), such that children need to master certain mathematical language (i.e., first, add, rotate) to be able to manipulate numbers in different ways (Gelman & Butterworth, 2005) and to reason spatially (Pruden et al., 2011). For example, knowing words such as "more" and "less" permits children to make comparisons between numbers or sets of objects, while knowledge of words such as "between" and "behind" allows children to discuss the spatial relations of objects or the ordering of numbers on a number line (Purpura & Reid, 2016).

Most research examining relations between mathematical language and children's mathematics knowledge has focused on numeracy skills (e.g., Purpura & Logan, 2015; Purpura & Reid, 2016; Toll & Van Luit, 2014a, 2014b). Although relations between children's general language skills and numeracy have been commonly documented (e.g. Fuchs et al., 2018; Purpura & Ganley, 2014; Romano et al., 2010), more recent work has demonstrated that mathematical language is more proximal to children's numeracy skills than is general language (Purpura & Reid, 2016; Toll & Van Luit, 2014a; Ünal et al., 2021), and further serves as a mechanism through which general language relates to early numeracy skills (Toll & Van Luit, 2014b). Beyond children's comprehension of quantitative terms, children's understanding of spatial mathematical language is also related broadly to their performance in mathematics (Bower et al., 2020a).

Spatial Language

Spatial language includes children's knowledge of the terms used to describe the spatial relations and locations of objects as well as the spatial features of objects, which includes their shape, dimensions, and orientation (Casasola et al., 2020). Some studies have conceptualized spatial language as words that describe the location (i.e., "where" words) and properties (i.e., "what" words) of objects (e.g., Bower et al., 2020a; Ramani et al., 2014). Other studies have used six dimensions proposed by Cannon et al. (2007) to examine children's spatial language (e.g., Casasola et al., 2020; Ferrara et al., 2011), including: 1) spatial locations (e.g., top, bottom), 2) deictic terms (e.g., here, there), 3) spatial dimensions (e.g., short, long), 4) spatial features and properties (e.g., curvy, straight), 5) shapes (e.g., circle, square), and 6) spatial orientations and transformations (e.g., turn, rotate).

Children's exposure to and use of spatial language has been linked to their performance on specific spatial tasks (Balcomb et al., 2011; Pruden et al., 2011; Simms & Gentner, 2008). Much of this work has shown that children with larger spatial vocabularies perform better on spatial tasks than children with more limited spatial vocabularies (Balcomb et al., 2011; Pruden et al., 2011; Simms & Gentner, 2008). Specifically, 16- to 24-month-old children's use of location terms has been linked to their performance on a spatial task that involved searching for a hidden target item (Balcomb et al., 2011). Using the Cannon et al. (2007) framework, Pruden and colleagues (2011) found that children who produce more spatial language between the ages of 14 to 46 months perform better on spatial problem-solving tasks, specifically a spatial analogies test in which children identified groups of objects spatially oriented in the same way at 54 months. Children's usage of spatial language during block play has also been found to relate to the number of features children include in their structures (e.g., patterns and symmetry; Ramani et al., 2014). Beyond the spatial realm, research has also shown that children's spatial language is broadly related to children's mathematics performance and even serves as a mechanism through which spatial skills relate to mathematical performance (Bower et al., 2020a).

Quantitative Language

Quantitative language is comprised of children's understanding of the terminology used to describe and manipulate numbers and sets (Purpura, Napoli, et al., 2017). Quantitative language includes terms that approximately describe amounts (e.g., many, a lot, few, a couple), changes to quantity (e.g., combine, add, take away, minus), and comparisons of amounts (similar, less than, equal, more). Specifically, these words capture approximate relations between quantities or sets and are considered fundamental for early mathematical knowledge (Purpura et al., 2019). This is distinct from number words, which represent exact amounts and quantities. Young children's understanding of quantitative language is associated with the acquisition of early mathematical skills (Barner et al., 2009). Assessments of quantitative and spatial language together have often been linked to children's numeracy performance (e.g., Hornburg et al., 2018; King & Purpura, 2021; Purpura, Napoli, et al., 2017) and researchers have suggested that quantitative language, specifically, drives the causal relation between mathematical language and numeracy growth (Purpura et al., 2019, 2021).

Mathematical Language Use During Block Play

Block play has been identified as an optimal early childhood activity for promoting children's spatial skills (Brosnan, 1998; Caldera et al., 1999; Casey et al., 2008; Ginsburg, 2006; Ness & Farenga, 2007) and is a ubiquitous classroom activity (Hirsch, 1974; Yelland, 2011). Beyond its relation to spatial reasoning, research has shown that block play is related more broadly to mathematics (Pirrone & Di Nuovo, 2014; Verdine et al., 2014; Wolfgang et al., 2001), and even literacy (Snow et al., 2015) and executive functioning (Schmitt et al., 2018). Early engagement in block play, specifically during the preschool years, is also predictive of later math achievement (Caldera et al., 1999; Stannard et al., 2001; Wolfgang et al., 2001). One intervention study utilized semi-structured block play (i.e., children were provided a prompt of what to build at the beginning of a play session by an interventionist and were then provided with minimal interaction while they planned and built) and found that semi-structured block play was causally linked to improvements in children's numeracy, shape recognition, and mathematical language (Schmitt et al., 2018). Block play may act as a context for children to both employ and hear mathematical language, which may, in turn, promote the development of their mathematical skills. In fact, observational studies have shown that block play elicits children's usage of both spatial (Ferrara et al., 2011; Ramani et al., 2014) and quantitative language (Ramani et al., 2014), and it promotes more spatial language use than other activity types (e.g., playing with pretend food, playing school; Ferrara et al., 2011).

Studies on block building have typically focused on whether children accurately created an end product (e.g., block structure or design) and whether participating in block play, in general, was related to later mathematical skills (Verdine et al., 2017; Wolfgang et al., 2001). Evaluating only the end result of block building instead of the process of block building itself precludes any understanding of *how* and *why* block play may promote mathematics and other academic or cognitive skills (Bower et al., 2020a), including the mathematical language they may use while building with blocks. When studies have examined the process of block building, they have primarily focused on nonverbal processes (e.g., Caldera et al., 1999; Kamii et al., 2004; Ramani et al., 2014). For example, Shelton et al. (2022) described the physical steps used to build a block configuration, such as actions, states, and paths. Bower et al. (2020b) focused on certain behaviors (e.g., gazes to block model) and complexity of building (using partial block overlaps and perpendicular arrangements) during block building and how these process variables predicted later spatial and math skills. When language has been examined during the block building process, limited coding strategies have been employed (i.e., broadly focusing on quantity or only a couple of types of spatial language) to describe children's usage of mathematical language. For example, Ramani et al. (2014) found that mathematical language only comprised a small amount of the total language children used during block play, but this may have been because a limited amount of quantitative and spatial language was examined. During block play, children may use a wide array of quantitative terms, such as *add, more, many,* and *few* to describe or compare quantity (e.g., "I need to add more blocks to this side." or "The big tower has many blocks and the tiny tower only has a few."), as well as spatial terms, such as *triangle, square, top, tall*, and *back* to describe the properties, orientations, or locations of blocks (e.g., "Put the triangle blocks on top of the squares." or "Put the tall blocks in the back."). Thus, this study addresses an important gap by implementing a fine-grained approach to extensively examine both quantitative and spatial language usage during block play, which may be a possible mechanism for why block play is linked with improvements in children's mathematics performance.

Current Study

Although it is likely that using both spatial and quantitative language during block play facilitates the acquisition of children's mathematical knowledge (Ramani et al., 2014), only a narrow range of the quantitative language children potentially use during block play has been examined (Ramani et al., 2014). In addition, studies have primarily focused on spatial language use during block play (e.g., Borriello & Liben, 2018; Ferrara et al., 2011). Thus, while it is well understood that children integrate a wide range of spatial language into their block play, how children use quantitative language during block play is less well understood. Both quantitative and spatial language use are predictive of children's numeracy performance (Hornburg et al., 2018; King & Purpura, 2021), as well as broader mathematical competencies and outcomes. For example, quantitative language has been postulated to drive the causal relation between mathematical language and numeracy growth (Purpura et al., 2019, 2021). In contrast, spatial language usage has been identified as a mechanism that leads to improvements in both spatial (Balcomb et al., 2011) and mathematical performance (Bower et al., 2020a). As such, having an objective approach to determine the amount of quantitative and spatial language used during block play provides a window into understanding how mathematical language may act as a mechanism for the development of these critical mathematical skills. The current study had two primary aims: 1) to formally modify and expand an existing spatial language coding system to also incorporate quantitative language, and 2) to evaluate and compare the frequency and types of spatial and quantitative language used by children during semi-structured block play (i.e., using raw frequencies, general and weighted proportions). A third aim, including post-hoc analyses, was to examine the specific types (i.e., domains) of spatial and quantitative language children used the most during block play.

Method

Participants

The sample was part of a randomized controlled trial that utilized block play to improve executive functioning and mathematics (Schmitt et al., 2018). This manuscript focuses on the children who were assigned to the intervention group. Participants included 24 children recruited from nine local preschools in the Midwestern United States, five of which were Head Start centers. Twelve children were from a Head Start center. The breakdown of parent education level was as follows: Some high school (13.5%), GED (9%), high school diploma (18%), some college (9%), associate's degree (4.5%), bachelor's degree (14%), master's degree (18%), and doctoral degree (14%). Child age at baseline ranged from 42 to 66 months (M = 57.25 months; SD = 6.31 months) and all children were typically developing. Children were predominantly male (58%), White (78%), followed by Asian (9%), then other or Multiracial (4.3%), Latine or Hispanic (4.3%), and African American (4.3%).

Procedure

Children who were assigned to the intervention condition participated in up to 14 sessions of 15-to-20-minute block play across seven weeks. Children were randomly assigned to groups of two children (dyads) that were relatively consistent throughout the sessions. Due to absences, sometimes groups were combined to create groups of three, so children did not have to play alone. On average, two children were in each group and children attended 13 of the 14 sessions (range = 11-14 sessions). This resulted in 156 independent block play sessions that were recorded and transcribed. All block play sessions were video recorded using one camera. The camera was placed at a reasonable distance from the set of wooden blocks in order to capture the group of children. At the beginning of each session, children were given a set of wooden unit blocks that contained various shapes (i.e., rectangles, columns, pillars, squares, arches, triangles, and half-circles). After presenting the blocks, the interventionist delivered a specific prompt for that session that applied to the entire group (e.g., "Today your job is to build a castle for a king and queen. I can't wait to see the castle you build!"). Each session had a different prompt, which became more complex over the course of the intervention (see Schmitt et al., 2018 for example prompts). After administering each prompt, the interventionist stayed in the room to record the session but did not participate in the building process and allowed the children to build freely. Occasional reminders and/or scaffolding were used only if children were disengaged. Children's on-task behavior was assessed by coding from video in 15-s intervals of each session the proportion of on-task block building versus off-task behaviors. On average, children engaged in on-task behaviors 81% of the time. Children were asked to work together on their structure but were not stopped from building separate structures. We did not specifically code for how often interventionists provided prompts for re-engagement.

Spatial and Quantitative Mathematical Language Coding System

The Cannon, Levine, and Huttenlocher (2007) Coding System for Language about Space in Structured and Unstructured Contexts was used as the foundation for the Spatial and Quantitative Mathematical Language Coding System (see Appendix B, Supplementary Materials).

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Coding System for Language About Space in Structured and Unstructured Contexts

The coding system was originally created for two studies that focused on spatial language use and production elicited by children and caregivers during structured activities (e.g., puzzle play; Cannon et al., 2007). In these studies, investigators were interested in determining specific domains of spatial phenomena that children and caregivers discuss. As such, the creators identified eight domains of spatial phenomena: Spatial Dimensions, Shapes, Locations and Directions, Orientations and Transformations, Continuous Amount, Deictics, Spatial Features and Properties, and Pattern.

The authors listed a broad definition of each domain and detailed parameters and notes appropriate for each (Cannon et al., 2007). For example, the domain Shapes included the broad definition of “Words that describe the standard or universally recognized form of enclosed two- and three-dimensional objects and spaces”. In the Parameters/Notes, authors documented that the list did not contain words that describe portions of shapes, etc. Authors also identified domain-specific concepts (i.e., definitions of subcomponent phenomena) and identified words that fall under each concept. For example, in the domain Shapes, the concept “2D shapes with at least 3 straight sides” included several words that fit the concept (e.g., triangle, square, rectangle).

Using this structure, the Cannon et al. (2007) coding system allowed for two levels of analysis during specific spatial contexts (e.g., book reading, puzzle play, construction activities): utterance level and word-type level. Coders then would decide whether words or utterances were spatial, used spatially, and in which spatial domain they should be included. Finally, this coding system also listed non-spatial usages for all word types and non-spatial usages for prepositions. For example, in “I *left* my hat in the car,” *left* would not be identified as spatial. These distinctions for appropriate spatial usages were maintained in the Spatial and Quantitative Mathematical Language Coding System.

Spatial and Quantitative Mathematical Language Coding System

The first goal of the present study was to expand and modify the Cannon et al. (2007) coding system to include quantitative language so that it would be appropriate for additional contexts, such as semi-structured block play in preschool children. This expansion and modification focused on a word-type level analysis approach such that we were interested in children’s overall naturalistic mathematical language usage as elicited by the intervention (Cannon et al., 2007). Utilizing the Cannon et al. (2007) coding system, this approach focused on the three decisions necessary for coding: 1) Is the word type potentially spatial or quantitative? 2) If so, is the word type used spatially or quantitatively in the transcript? 3) If so, which spatial domain or quantitative domain? In addition, word types could contain more than one word in this distinction (e.g., far away).

The final version of the Spatial and Quantitative Mathematical Language Coding System included two primary categories: Spatial and Quantitative. Within the Spatial category, there are six domains: Spatial Dimensions (e.g., huge, thin, wide; n = 46 words), Shapes (e.g., square(s), rectangles; n = 24), Location and Direction (e.g., up, under, ahead; n = 83), Orientation and Transformation (e.g., rotate; n = 13), Deictics (e.g., here, there; n = 8), and Spatial Features and Properties (e.g., edge, side; n = 42). Within the Quantitative category, there are three domains: Static Amounts (e.g., few, all; n = 18), Comparing Amounts (e.g., more, same; n = 16), and Changing Amounts (e.g., combine, subtract; n = 9).

In addition, there was also a Number Talk category (i.e., exact quantities such as 5, 10, or 1/3), an Additional Codes category (domains: Age, Dates, Time; exact quantities or uses of number distinct from Number Talk), and an Ordinality category that distinguishes a spatial placement in an ordered arrangement (e.g., “I’m *first* in line”, located in the Location and Direction domain of the Spatial category) from other ordinal uses (e.g., “I’m in *first* grade”; “*First* we have to go to the store”). Though these other categories are indicators of language that matter for mathematical learning (Gibson et al., 2020), they include exact quantities or other terms that go beyond the scope of spatial and quantitative mathematical language. As such, Number Talk, Additional Codes, and Ordinality categories were not used in this manuscript given the present study focused on spatial and quantitative mathematical language.

Mirroring Cannon et al. (2007), each domain in the expanded system had a broad definition as well as parameters and notes. These parameters almost always used the original language by Cannon and colleagues, whereas the notes may have included additional information, primarily whether certain words (and their variations) would be included in both Spatial and Quantitative categories, or whether they were in multiple domains (within or across both categories). For example, the Spatial Dimensions domain within the Spatial category includes the words *small(er/est)* and *large(er/est)*. Given the creation of the Quantitative category, *small* and *large* were also included in the Static Amounts domain to describe a static amount or number that is non-changing (e.g., 100 is a *large* number). Further, *smaller/est* and *larger/est* were also included in the Comparing Amounts domain as a comparison between amounts (e.g., 7 is *smaller* than 8). Although such words were listed in the coding manual under multiple categories and/or domains, words are only assigned one category and domain when coding from transcripts, based on the context in which it was used. In addition, each domain still included domain-specific concepts (i.e., definitions of subcomponent phenomena) and identified words that fall under each concept. Finally, examples (and non-examples, when appropriate) and notes were provided for each word. These modifications were made to provide clarity given several words were shared between domains and both categories (e.g., examples and notes could be word-type specific) and this organization provides the foundation for more accessible use of the codebook and quantitative evaluation of mathematical language use.

This coding system was reviewed by the research team using previous literature that focused on mathematical language (Purpura et al., 2019; Toll & Van Luit, 2014b). The recategorization and modification of the Spatial category as well as the development of the Quantitative category was completed before implementation of the coding system. These decisions were informed by previous assessment research (Bower et al., 2020a; Purpura, Logan, et al., 2017) and intervention work (Bower et al., 2020a; Purpura, Napoli, et al., 2017; Purpura et al., 2021) that explicitly defined and focused on mathematical language, particularly quantitative language. The final version of the coding system also includes novel usage of spatial and quantitative words/word-types that emerged during the coding process (e.g., humungous). These words were then assigned a domain and category.

Domain and Word Classification Modifications Between Coding Systems

Below we detail the rationale for the changes between the original Cannon et al. (2007) coding system and the Spatial and Quantitative Mathematical Language Coding System.

There was only one category (i.e., Spatial) for the Cannon et al. (2007) coding system, which included eight domains: Spatial Dimensions, Shapes, Locations and Directions, Orientations and Transformations, Continuous Amount, Deictics, Spatial Features and Properties, and Pattern. The expanded Spatial and Quantitative Mathematical Language Coding System included two primary categories (i.e., Spatial and Quantitative). The Spatial category domains in the expanded system only include six of the original domains, with words from Pattern and Continuous Amounts being removed or relocated elsewhere within the new system.

The Quantitative category includes three domains: Static Amounts, Comparing Amounts, Changing Amounts. In general, references to and comparisons of amounts, were moved to the Quantitative category based on previous work indicating that amounts may be more related to quantitative language (e.g., a lot, a little, much) than spatial language because they refer to quantities rather than spatial orientations, locations, or dimensions (Purpura et al., 2019, 2021). Static Amounts were defined as words that describe an unchanging number or amount. Comparing Amounts were defined as adjectives used to compare amounts and numbers. Changing Amounts were defined as verbs that indicate an amount or number is being changed (e.g., increasing, decreasing).

Relocated Words/Word-Types — Seven words that were included in Cannon's et al. (2007) Continuous Amount domain were moved to the Spatial Dimensions domain within the Spatial category: *part, piece, whole, half, section, fragment,* and *fraction.* These words were moved to the Spatial Dimensions domain because they are not considered quantitative amounts, but discrete spatial units, thus still fitting under the original Spatial category. Other words from the original Continuous Amount domain (Cannon et al., 2007) were relocated to the Quantitative category and its domains.

The words from the former Continuous Amount domain that were in the new Static Amount domain were: *none, some, a lot, a little, much.* The words from the former Continuous Amount domain that were included in the Comparing Amounts domain were: *enough, more, less, same, equal.* No Continuous Amount words fit in the Changing Amounts domain. The Pattern domain from the Cannon et al. (2007) coding system, unlike the other domains, did not include an exhaustive list of words. Rather, the Cannon et al. (2007) coding system pointed researchers to contexts where pattern talk may occur. In the Spatial and Quantitative Mathematical Language Coding System, the Pattern domain was removed and words that referred to a spatial position in an ordered arrangement like a line (i.e., positional ordinality) were moved to the Location and Direction domain. Conceptualizations regarding increasing and decreasing included in the Cannon et al. (2007) Pattern domain were relocated to the Changing Amounts domain. Fraction words referring to numerical magnitudes (e.g., *half, third, quarter, fifth, sixth, seventh, eighth, ninth, tenth,* etc.) that were part of the Continuous Amounts domain in Cannon et al. (2007) were considered Number Talk as they represented exact amounts.

Removed Word-Types — Words that were removed from the former Pattern domain were: *pattern, design, sequence, repeat.* The Pattern domain from the Cannon et al. (2007) coding system, unlike the other domains, did not include an exhaustive list of words. Rather, the coding manual pointed researchers to contexts where pattern talk may occur. In the *Spatial and Quantitative Mathematical Language Coding System*, words that referred to a spatial position in an ordered arrangement like a line (i.e., positional ordinality) were moved to the Location and Direction domain.

Coding Using the Spatial and Quantitative Mathematical Language Coding System

Coding for spatial and quantitative language was conducted in Dedoose (http://www.dedoose.com). Before coding, transcriptions of each session were prepared and reviewed (N = 156) for ease and efficiency of coding (e.g., term-specific searches). Using a transcription protocol addressing formatting, overlapping speech, and documenting inaudible speech, graduate and undergraduate students watched the session video and typed out the transcription in Microsoft Word. After the initial transcription was completed, the video was rewatched and the transcript was reviewed by a graduate student or postdoctoral researcher for accuracy using a transcription review protocol. The protocol included notes on the final review of the transcript (e.g., if words were marked as inaudible, someone went to review that section of text) as well as how to standardize the transcription document for Dedoose (e.g., formatting). Finalized transcripts were uploaded to Dedoose to be coded. Codes were applied at the child level. When coding mathematical language, the sentence(s) surrounding the term were used to determine whether it was used in mathematical way; however, if the term was used ambiguously, the coders would consult the original video for additional contextual information when making a decision on whether and how to code the term.

Coder Training

Two graduate students that were part of the creation of the coding systems coded eight randomly selected transcripts to prepare for the research assistant training and interrater reliability training. The master codes for these eight transcripts were used to train research assistants. All research assistants (n = 6) coded the randomly selected transcripts in the same order. The first transcript was used as the primary document for the first training session, during which the lead graduate students described the coding process for the first half of the transcript. The research assistants then practiced coding independently for the second half of the transcript and were allowed to ask questions and get assistance. The other seven transcripts were used to establish reliable, independent coding. Specifically, research assistants had to code three of the remaining seven transcripts independently maintaining above 85% accuracy with the established master codes. Once research assistants demonstrated reliability with master codes on at least three of the seven transcripts, they were assigned transcripts to code in Dedoose.

Coder Reliability — To ensure ongoing reliability throughout the coding process, reliability with a master coder (graduate student) was examined every seven transcriptions completed by the research assistant (i.e., the seventh transcript would be independently coded by both the research assistant and a master coder). If the research assistant's code reliability was found to be ≥ 85% accurate compared to the master codes, they were considered reliable and received more transcripts to code. After reviewing the transcript, the master coder would debrief with the research assistant and discuss any discrepancies and would send them any words that were both missed and/or miscoded. All research assistants maintained at or above the 85% accuracy threshold throughout the coding of the transcripts (κ = .96).

Results

Analytic Plan

Raw comparisons of mathematical language, proportions, weighted frequency counts, and their calculations are reported in the following sections. Weighted frequencies were necessary to compute when comparing the types of mathematical language because there was a much greater amount of spatial language codes (N = 216) than quantitative language codes (N = 43). Moreover, when children employed mathematical language, they had a much greater chance (82%) of using spatial language than quantitative language (18%) by default. Therefore, as opposed to only comparing raw usages of the terms, using weighted counts allowed for an analysis of variability within each of the spatial and quantitative categories. In this way, we could compare the amounts of variability in types of terms used within the spatial and quantitative categories.

Raw Comparison of Quantitative and Spatial Language

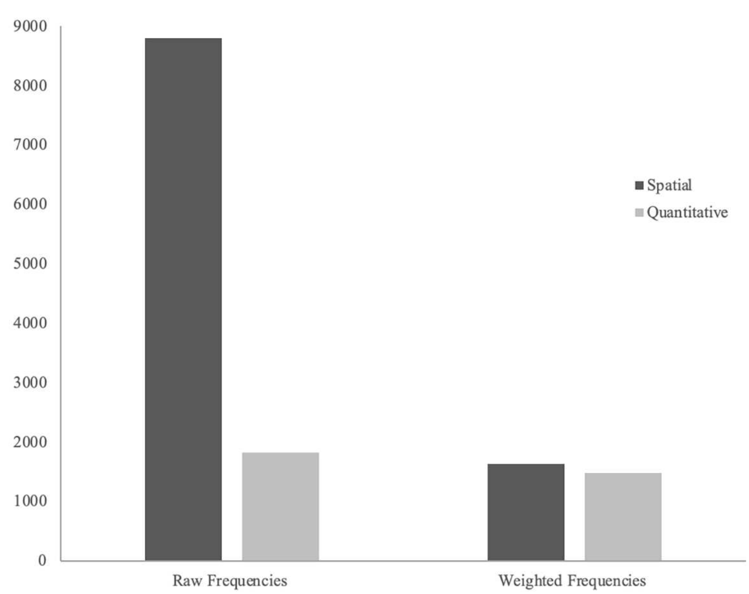
Approximately 7.35% of all language used across all 24 children and all block play sessions was mathematical language (10,628 mathematical language words and phrases/144,569 total words). Proportions of both quantitative and spatial language over all mathematical language usage were generated to compare the actual occurrences of the terms. The following formula was used to generate these proportions:

$$\frac{\text{Total \# of mathematical language terms in the category (i.e., Spatial or Quantitative)}}{\text{Total \# of mathematical language terms across both categories (i.e, Spatial and Quantitative)}} \times 100$$

For spatial language, 8,805 terms were uttered across all 24 children and all block play sessions, which represented 82.85% of the mathematical language children used (6.06% of total words spoken). For quantitative language, 1,823 terms were uttered across all 24 children and all block plays sessions, which represented 17.15% of the mathematical language children used (1.26% of total words spoken). Thus, when examining the raw counts of quantitative and spatial language, children used much more spatial language than quantitative language during semi-structured block play. The raw counts of spatial and quantitative language are graphically depicted in Figure 1. See Supplemental Table 1 (Appendix A, Supplementary Materials) for raw mathematical language usage at the child and dyad level.

Figure 1

Raw vs. Weighted Frequencies for Overall Spatial and Quantitative Language



Weighted Comparison of Quantitative and Spatial Language

Weighted frequency counts that reflect the number of codes in each category were then generated. The following series of equations was used to generate these weighted frequency counts:

(1) $$\text{Assigned Weight} = \frac{\text{\# of codes that were used at least once across both categories (i.e., Spatial and Quantitative)}}{\text{\# of codes that were used at least once for the category (i.e., Spatial or Quantitative)}}$$

(2) $$\text{Ratio Adjusted Count} = \text{\# of codes that were used at least once across both categories} \times \text{Assigned Weight}$$

(3) $$\text{Weighted Percentage} = \frac{\text{Ratio Adjusted Count}}{\text{Sum of the Ratio Adjusted Counts for both categories}}$$

(4) $$\text{Weighted Frequencies} = \text{Raw count of terms for the category} \times \text{Weighted Percentage}$$

When weighting the observed counts of children's spatial language, 1,636.83 terms were used across all 24 children and all block play sessions. When weighting the observed counts of children's quantitative language, 1,484.11 quantitative terms were used across all 24 children and all block play sessions. Thus, the variability in the types of spatial language used was only marginally higher (52.45%) than the variability in the types of quantitative language used (47.55%). The weighted frequencies of spatial and quantitative language are graphically depicted in Figure 1.

Raw Comparison of Spatial Language Domains

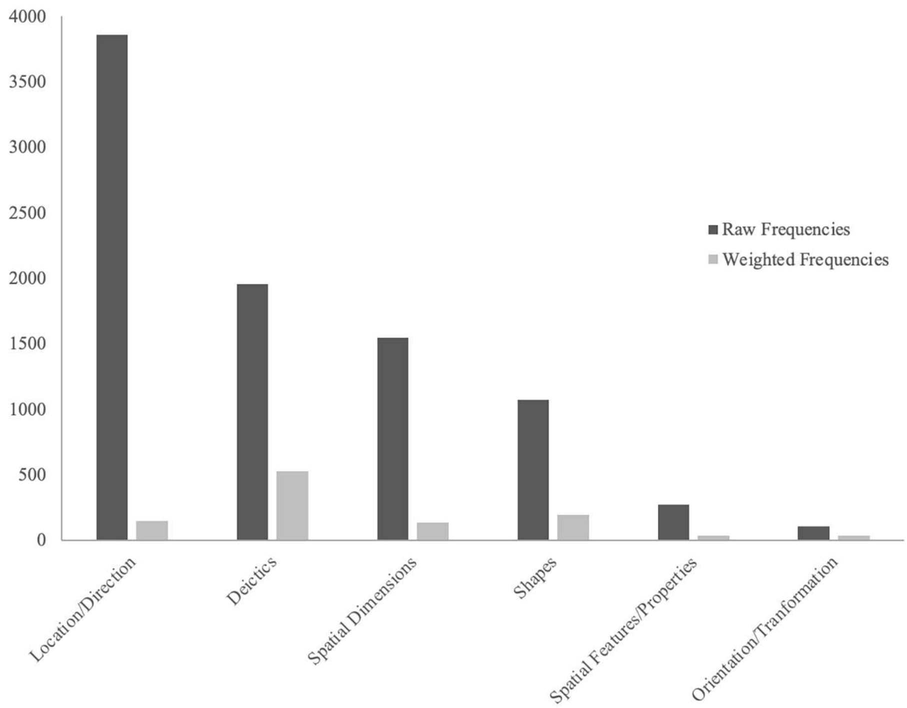
Raw frequencies of the spatial language domains uttered across all 24 children and all block play sessions are graphically depicted in Figure 2. Proportions were also generated for each domain of spatial language in which the total usage of terms within the domain (e.g., Shapes) was divided by the total usage of spatial language terms. Children uttered more Location and Direction terms (e.g., in, on, down) than any other spatial language domain (43.82%; 2.67% of total words spoken). Next were Deictic terms (e.g., here, there, where), which represented 22.24% of overall spatial language used (1.35% of total words spoken). Spatial Dimensions terms (e.g., big, little, part) represented 17.52% of overall spatial language used (1.17% of total words spoken). Shapes terms (e.g., square, triangle, circle) represented 12.17% of overall spatial language used (0.74% of total words spoken). Spatial Features and Properties terms (e.g., side, top, line) represented 3.07% of overall spatial language used (0.19% of total words spoken). Finally, Orientation and Transformation terms (e.g., turn, together, connect) represented 1.18% of overall spatial language used (0.07% of total words spoken).

Weighted Comparison of Spatial Language Domains

Weighted frequency counts that reflect the number of codes in each domain of spatial language were generated. Again, this was necessary due to discrepancies in the number of codes across the categories (N = 83 for Location and Direction, N = 42 for Spatial Features and Properties, N = 46 for Spatial Dimensions, N = 24 for Shapes, N = 13 for Orientation and Transformation, N = 8 for Deictics). Furthermore, children had a greater chance of using terms within certain domains (e.g., Location and Direction) than other domains (e.g., Deictics). The same set of equations used to generate the weighted frequency counts for the broad spatial and quantitative language categories were used to generate the weighted counts for each of the domains of spatial language. The weighted frequencies of the Spatial language domains are graphically depicted in Figure 2. When examining the weighted counts within the spatial language category, children used more terms from the Deictics domain (49.62%) than terms from the Location and Direction (13.73%), Shapes (18.11%), Spatial Dimensions (12.51%), Orientation and Transformation (2.98%), and Spatial Features and Properties (3.04%) domains.

Figure 2

Raw vs. Weighted Frequencies for Each Spatial Language Domain



Raw Comparison of Quantitative Language Domains

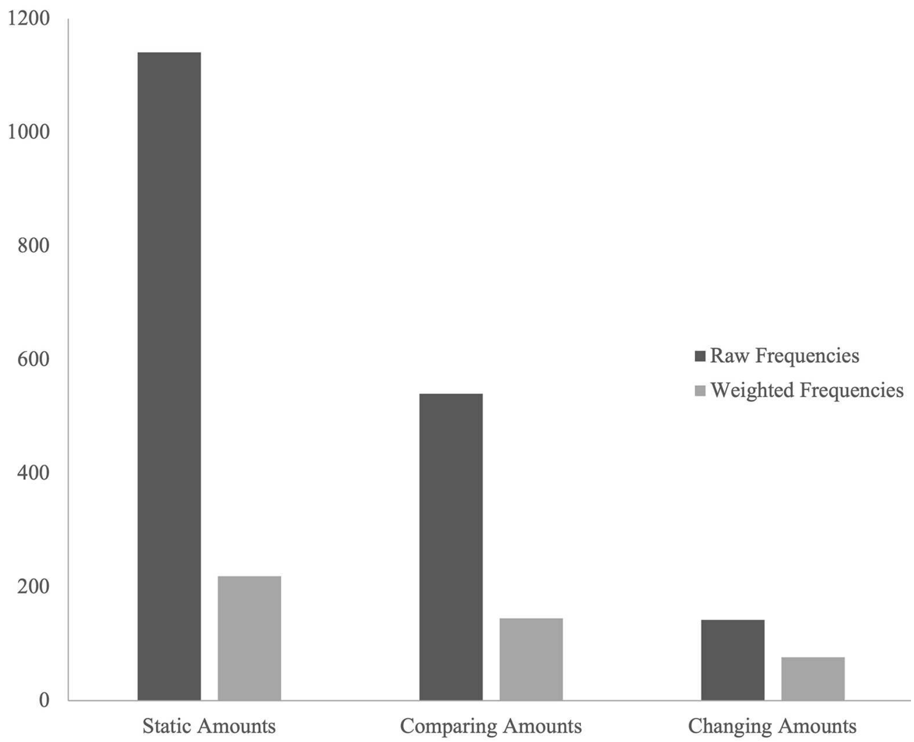
Raw frequencies for the domains of quantitative language uttered across all 24 children and all block play sessions are graphically depicted in Figure 3. Proportions were also generated for each domain of quantitative language in which the total usage of terms within the domain (e.g., Static Amounts) was divided by the total usage of quantitative language terms. Static Amounts terms (e.g., all, some, a lot) represented the largest amount of overall quantitative language used (62.59%; 0.79% of total words spoken). Comparing Amounts terms (e.g., more, enough, same) represented 29.62% of overall quantitative language used (0.37% of total words spoken). Finally, Changing Amounts terms (e.g., give, add, plus) represented 7.78% of overall quantitative language used (0.10% of total words spoken).

Weighted Comparison of Quantitative Language Domains

Weighted frequency counts that reflect the number of codes in each domain of quantitative language were generated due to discrepancies in the number of codes across the categories (N = 18 for Static Amounts, N = 16 for Comparing Amounts, N = 9 for Changing Amounts). Furthermore, children had a greater chance of using terms within certain domains (e.g., Static Amounts) than other domains (e.g., Changing Amounts). The same set of equations used to generate the weighted frequency counts for the broad spatial and quantitative language categories were used to generate the weighted counts for each of the domains of quantitative language. Weighted frequencies for the domains of quantitative language are graphically depicted in Figure 3. When examining the weighted counts within the quantitative language category, children used more quantitative language to describe static amounts (49.73%) than to compare (32.95%) or change amounts (17.33%).

Figure 3

Raw vs. Weighted Frequencies for Each Quantitative Language Domain



Discussion

This study is the first to comprehensively examine preschoolers' spatial and quantitative language use during block play by using the newly developed Spatial and Quantitative Mathematical Coding system. Although quantitative studies can provide evidence of statistical relations between block play and children's mathematics and spatial performance, this mixed-method study provides unique insight into frequencies and types of mathematical language used during semi-structured block activities that may act as a mechanism linking similar activities (e.g., puzzle, block play) to developing mathematical knowledge. Findings showed that the raw frequency count of all spatial language use was considerably higher than quantitative language use; however, when considering weighted frequencies, the variability in types of spatial language terms used was only marginally higher than the variability in types of quantitative language terms used. Specific to domains within each category, Location and Direction spatial language terms had the highest raw frequencies, whereas Deictics were used most when considering the number of codes in each spatial language domain. In contrast, Static Amounts were uttered the most for the quantitative language category, both as raw counts and after accounting for the number of codes in each quantitative language domain. These results provide insight into the role of both spatial and quantitative language usage during children's block play and inform the importance of conceptualizing and determining the usage of these terms.

Given that mathematical language is one of the strongest predictors of children's mathematical development and understanding (Purpura & Logan, 2015), helping determine its usage in activities that are known to improve early mathematical outcomes is imperative. Block play has been found to elicit children's usage of mathematical language; however, the coding systems employed to examine mathematical language in previous work have primarily focused on children's spatial language (e.g., Ramani et al., 2014). Thus, there were three aims. First, using an existing coding scheme for spatial language coding (Cannon et al., 2007), as well as both research-informed and grounded theory-informed processes to include or omit terms (Purpura & Logan, 2015; Purpura et al., 2021; Toll & Van Luit, 2014b), an updated mathematical language coding system was created to include both spatial and quantitative language. The second and third aims used the coding system to evaluate and compare the broad usage of spatial and quantitative language and their respective domains in a semi-structured block play intervention. Although studies have provided us with evidence of relations between interventions that elicit mathematical language and children's mathematical competencies (Purpura et al., 2021; Schmitt et al., 2018), examining the specific usage of mathematical language during these activities sheds light on the types and frequencies of terms children use during these interventions that may drive these relations. In addition, understanding variability in the usages of all the different mathematical language terms has important implications for future work aimed at eliciting children's mathematical language such that important terms that are used less often by children during block play can be targeted.

Spatial vs. Quantitative Language Usage

Upon examining the raw counts of spatial and quantitative language usage during the block play activities, it was revealed that children used more spatial language than quantitative language. However, after adjusting the proportions to account for the number of codes within each broad category, results indicated that children used similar amounts of both quantitative and spatial language. Although prior work has demonstrated that block play elicits children's spatial language (Borriello & Liben, 2018; Ferrara et al., 2011), this study extends previous findings by demonstrating that children engage in proportionally similar amounts of quantitative language while interacting with blocks. Moreover, it appears that the amount of discussion spent describing the spatial locations and properties (e.g., "Put this block *on* the *top*" or "Pass me the *triangle* blocks") of the blocks when building structures is similar to the amount spent describing amounts ("I need *a lot* of blocks" or "I am adding *more* blocks to the tower"). Ultimately, when considering how block play interventions may promote children's mathematical skills, it is important that the role of quantitative language usage in addition to spatial language usage is examined in future work.

Domains of Spatial Language Usage

Initially when comparing the raw proportions of each domain of spatial language, it appeared that children used terms from the Location and Direction domain (e.g., up, down) most often. However, after adjusting the proportions to account for the number of codes within each domain of spatial language, it was revealed that children used terms from the Deictics domain (e.g., there, where) most often. Following Deictics and Location and Direction, children used terms from the Shapes (e.g., square, oval) and Spatial Dimensions (e.g., tall, short) domains less frequently in both the raw and weighted comparisons of spatial language usage. Finally, children rarely used terms from the Orientation and Transformation (e.g., rotate, flip) and Spatial Features and Properties (e.g., side, corner) domains in both the raw and weighted comparisons of spatial language usage. This pattern of findings is similar to previous work conducted on parent-guided block play in that children used terms from both the Deictics and Location and Direction domains the most and used terms from the Orientation and Transformation domain the least (Ferrara et al., 2011). It is likely that terms that are used to describe how items are oriented (e.g., upside-down) or how they are manipulated (e.g., rotated) are more challenging and may be outside of the range of vocabularies for many 3-to-5-year-old children, particularly during block play. In contrast, terms used to describe the location of items (e.g., on top) as well as spatial deictic expressions (e.g., here) are likely more common to the vocabularies of young children. Future research should examine the usages of terms from these domains of spatial language during block play at multiple time points to examine whether children incorporate a wider and more complex range of spatial language over time.

Domains of Quantitative Language Usage

This is the first study to date to descriptively compare different domains of quantitative language usage during children's block play. The pattern of findings for both the raw and weighted comparisons of the domains of quantitative language were similar in that terms from the Static Amounts (e.g., many, few) were used most often, followed by Comparing Amounts (e.g., more, less), and then Changing Amounts (e.g., add, take away). It is possible that terms used to compare and change amounts were used less often because they are more challenging and are connected to performing more complex mathematical skills. Further, children's understanding of mathematical language is believed to contribute to the development of their basic numeracy skills by giving them the language to describe and think about numbers and amounts (Purpura, Logan, et al., 2017). Thus, an understanding of quantitative language that is used to change or compare amounts may help children master more complex numeracy skills that are shown to develop over time, such as comparing quantities (e.g., "You have fewer blocks in your tower than I do.") or completing basic addition or subtraction problems (e.g., "If you give me three blocks, then I'll have five."). Future research should examine the usage of terms from these domains of quantitative language during activities over time.

Implications

The revised mathematical language coding system was used to demonstrate the types and frequencies of mathematical language that are used during semi-structured block play with preschool-aged children. This coding system can be used in future research in activities beyond block play and with children whose ages are outside of the preschool range. Given that there were similar amounts of spatial and quantitative language usage during the block play activities when the proportions were adjusted to account for the number of codes in each category, it is important that future research on children's mathematical language usage during structured, semi-structured, and unstructured activities should examine both types of mathematical language. In addition, examining the raw counts of children's spatial and quantitative language has important implications for future research aimed at improving children's mathematical language and skills. Further, important terms that are used less frequently during block play (e.g., Changing Amounts) can be emphasized in future intervention work.

Limitations and Future Directions

Though this study is the first to expand a coding system to include both spatial and quantitative language, as well as apply it to semi-structured block play in preschool children, limitations must be noted. First, this coding system was built and applied to a relatively small sample of preschool-aged children. However, it is important to note that the data were produced from the block play activities conducted with this sample of children. Moreover, each child participated in up to 14 15-to-20-minute sessions of block play across seven weeks, which yielded about 3-to-5 hours of video data per child. Further, the study that informed the creation of the coding system only focused on semi-structured block play. It is possible that spatial and quantitative language could be used differently during unstructured block play (i.e., not in a block-play intervention) or during specific parts of block play (e.g., to guide building, to describe building, other conversations between or within and across block play sessions, prompt complexity), and thus could be addressed in future research. In addition, terms that are not included in the current coding system could also arise in contexts outside of semi-structured block play, though the list included in the current system is comprehensive. The framework for examining children's mathematical language usage developed within this study can and should be applied and used within other contexts and activities in future research. In addition, how these codes were related to child outcomes associated with block building (e.g., numeracy, executive functioning, spatial ability) was not assessed. Future studies that investigate the effects of block play could use this coding system to explore potential mechanisms for efficacious interventions. Specifically, exploring how both broad categories (e.g., spatial, quantitative) and domains (e.g., Location and Direction, Static Amounts) relate differentially to specific mathematical skills and domains (e.g., numeracy, spatial ability) or other socioemotional or pre-academic skills (e.g., language, executive functioning) at both the group and individual level. Though all individual mathematical language words were considered here for an in-depth look at mathematical language during block play, future work could focus on specific terms or domains.

Conclusions

The present study expanded an existing coding system to evaluate quantitative and spatial mathematical language usage in a semi-structured block play. Findings from this research have potential implications for future examinations of mathematical language use in child activities. Specifically, as both quantitative and spatial mathematical language are important indicators of mathematic competencies, being able to assess and compare the usage of both can better inform the potential mechanisms in how these activities improve mathematical learning. This formal coding system could be used across child activities (both structured and unstructured) in order to target support of the development of mathematical language skills.

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Publisher Note: This Corrected Version of Record (CVoR) differs from the original Version of Record (VoR) published on July 16, 2024, by correcting an error in the article title. The original incorrect title "A Capturing Math Language Use During Block Play: Creation of the Spatial and Quantitative Mathematical Language Coding System" has been replaced with the correct title "Capturing Math Language Use During Block Play: Creation of the Spatial and Quantitative Mathematical Language Coding System" throughout the document at all relevant locations. This correction was made on July 26, 2024.

Data Availability: The datasets generated and/or analyzed during the current study are not yet publicly available due to ongoing work. The data that support the findings of this study are available on request from the corresponding author, Lindsey M. Bryant. The research team will consider the data request and will only be approved if the proposed use aligns with the data protection regulations and the consent provided by the study participants.

Supplementary Materials

The Supplementary Materials include Appendix A, which provides raw mathematical language usage data at the child and dyad level in Supplemental Table 1, and Appendix B, which presents the Spatial and Quantitative Mathematical Language Coding System. This coding system is based on the Cannon, Levine, and Huttenlocher (2007) Coding System for Language about Space in Structured and Unstructured Contexts (for access, see Bryant et al., 2024S).

Index of Supplementary Materials

Bryant, L. M., Westerberg, L., Devlin, B. L., Paes, T. M., Geer, E. A., Katyayan, A., Morse, K. M., O'Brien, G., Purpura, D. J., & Schmitt, S. A. (2024S). *Supplementary materials to "Capturing math language use during block play: Creation of the spatial and quantitative mathematical language coding system"* [Online appendices]. PsychOpen GOLD. https://doi.org/10.23668/psycharchives.14699

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