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Relations among language comprehension, oral counting, and numeral knowledge of ethnic and racial minority young children from low-income communities

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ABSTRACT

This study examined the relationship between language comprehension (receptive, expressive) and numeracy skills (oral counting, number identification, number relations) in a longitudinal sample of ethnic and racial minority (Black = 86%; Latino = 14%) children from low-income communities. Participants were $n = 79$ children between 1.42 to 3.42 years when early language skills were assessed, and between 4.5 to 6.33 years when school-age language and numeracy skills were assessed. Results indicated strong correlations between language and numeracy skills, independent of age and sex. Components of language comprehension were shown to positively predict numeracy outcomes. The results of subsequent mediation analyses revealed that language comprehension was indirectly related to number identification and number relations through oral counting. The findings are consistent with the perspective that linguistic skills serve as a pathway for the development of numeracy skills. This study adds to the literature by demonstrating the importance of general language comprehension measured in the first few years of life for school-age numeracy skills with a sample of children living in poverty. Implications for early childhood education and future research regarding cross-domain learning and development are discussed.

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1. Introduction

Children's early mathematical thinking is related to later mathematics skills (Duncan et al., 2007; Hooper, Roberts, Sideris, Burchinal, & Zeisel, 2010; Nguyen et al., 2016). However, mathematics skills do not develop in isolation of other cognitive competencies. Research indicates that mathematics skills are strongly related to executive function (Clark, Pritchard, & Woodward, 2010; McClelland, Acock, & Morrison, 2006), working memory (Holmes & Adams, 2006; Purpura & Ganley, 2014; Raghubar, Barnes, & Hecht, 2010), vocabulary (Negen & Sarnecka, 2012), phonological awareness (Krajewski & Schneider, 2009), and literacy (Davidse, Jong, & Bus, 2014; Purpura & Napoli, 2015). Overall, general cognitive and linguistic skills are related to early mathematical skills (Krajewski & Schneider, 2009; Stock, Desoete, & Roeyers, 2009). This point of interest is separate from the literature on mathematics-specific language and its relationship to mathematical skills. For example, some studies have focused on math-specific vocabulary (e.g., "more," "less," "bigger," "all") where the mathematical concepts rely on language terms (Barner, Chow, & Yang, 2009). Mathematical language has been shown to relate to numeracy skills in the preschool years and to mathematics achievement in kindergarten (Purpura & Reid, 2016) as well as across the elementary school years (Clements & Sarama, 2011; Toll & Van Luit, 2014). Yet, there is less empirical evidence demonstrating how early mathematics skills relate to general language comprehension (Purpura, Hume, Sims, & Lonigan, 2011) even though there is empirical support to conclude that language comprehension serves as an important pathway for mathematical (Vukovic & Lesaux, 2013a) and non-mathematical knowledge (Dickinson, McCabe, Anastasopoulos, Peisner-Feinberg, & Poe, 2003), particularly for children from low-income, racially and ethnically diverse communities.

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Most empirical studies specifically focusing on the cross-domain relations between language and mathematics, exist with samples of children outside of the United States (e.g., Praet, Titeca Ceulemans, & Desoete, 2013; Zhang et al., 2014). Studies within the U.S. context have predominantly focused on samples of White children growing up in middle and high-income communities (e.g., Negen & Sarnecka, 2012; Purpura & Napoli, 2015), as reviewed in greater detail below. Overall, the results presented by prior research limit the generalizability of findings to diverse children from low-income backgrounds. Other studies employing nationally representative datasets, which included diverse socioeconomic samples, focused on cross-domain development within the elementary and secondary school years (e.g., Duncan et al., 2007) – limiting the scope of what is known about children's varying cognitive skills during early childhood. Overall, many studies have consistently examined minority children's development in comparison to a non-minority group, thus neglecting the intra-group variability that exists and inherently replicating a model of deficiency through between-group comparisons (Garcia Coll et al., 1996; McLoyd, 1990). As scholars note, this approach is problematic at the very best, as generalizing results obtained on non-minority samples to minority children is not justified such that minority children's development cannot be implied by research that focuses on non-minority groups (e.g., Cabrera, Beeghly, & Eisenberg, 2012). Hence, the study herein reported employed a within-group approach by focusing solely on ethnic/racial minority children's early cognitive skills. We believe that minority children's position in society places them on a different, and not defective, trajectory for development and that research should take a position to identify the mechanisms of developmental competencies rather than prioritize the examination of group differences (see Garcia Coll et al., 1996).

Identifying the cognitive skills, and the interconnectedness among those skills, that place children on a trajectory of successful mathematics learning, is essential for understanding how to promote "numeracy readiness" and later mathematics achievement. Although this study takes a cognitive development approach at examining the relations between language and numeracy by only measuring individual-level child characteristics, we are simultaneously operating from the bioecological framework which acknowledges that development occurs in social contexts (Bronfenbrenner & Morris, 1998). Developmental and educational research have indicated that there are several critical, contextual factors influencing children's cognitive development, which include access to early childhood education and neighborhood resources (Brooks-Gunn & Duncan, 1997; Leventhal & Brooks-Gunn, 2000). Children growing up in affluent neighborhoods (i.e., lower rates of violence, low physiological hazards, higher access to parks and libraries) show significant gains across developmental outcomes later in life (Brooks-Gunn, Duncan, & Aber, 1997; Ludwig et al., 2013; Yoshikawa, Aber, & Beardslee, 2012). Additionally, meaningful and supportive experiences during the early childhood years promote children's later educational, social, and behavioral outcomes (e.g., reduced delinquency in adolescence) (Yoshikawa, 1995). This indicates that resourceful social contexts with opportunities for positive interactions are critical to children's subsequent developmental outcomes, and children growing up in poverty may lack these protective factors. Although it is expected that cross-domain cognitive skills will be interrelated, it is also important to attribute the development of these intraindividual skills to the social contexts that children grow up in, in contrast to solely focusing on child-level characteristics. Therefore, we also center part the discussion of this study on generating implications for practical applications in contexts of learning.

Within the field of early childhood development and education, there are many unanswered questions related to early cognitive skills, especially in regards to mathematical thinking *prior* to formal school-entry (i.e., kindergarten) *for* ethnic and racial minority young children growing up in poverty. In this study, we first explored relations between language and numeracy skills of young children and then use language skills as predictors of numeracy outcomes. More specifically, given the variability of mathematical thinking competencies of school-aged children within and between racial/ethnic backgrounds, we believe that understanding the precursors of minority children's mathematical thinking is of key importance. The present study accounts for the limitations of previous research by (1) employing a within group perspective by focusing on early cognitive skills of ethnically/racially diverse children from low-income communities and (2) examines cross-domain development between early language and numeracy skills with longitudinal data of children between the ages of approximately 2 to 5 years. Further, the study aims at extending existing research by investigating whether and to what degree early language skills predict mathematics skills at school-entry (i.e., prekindergarten and kindergarten).

1.1. Variability in Early Mathematics Skills

Prior to formal school entry, children have a sense of "everyday mathematics" (e.g., using number words, modeling counting, demonstrating informal ideas of more, less, size, etc.) (Clements & Sarama, 2007). By age 5, there are vast individual differences in mathematical knowledge and skills (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004). These differences are present before children enter elementary school and further widen over the elementary school years (Denton & West, 2002; Geary, 2011). As early as kindergarten, children who have difficulty with counting and simple number operations, are likely to be the same children who do not "catch up" to their peers in subsequent academic years (Aunio et al., 2015; Jordan, Kaplan, Ramineri, & Locuniak, 2009). Children from low-income communities with inadequate material and social resources, enter school with limited mathematical understanding (Aunio, Heiskari, Van Luit, & Vuorio, 2015; National Research Council, 2009) and may be at risk of developing a sense of everyday mathematical knowledge, which is primarily influenced by informal learning environments such as the home (Ginsburg, Lee, & Boyd, 2008). Differences noted in children's mathematical knowledge result from the variability of experiences throughout early childhood (Burchinal et al., 2011; Harris, Sideris, Serpell, Burchinal, & Pickett, 2014; National Research Council, 2009). Scholars agree that further empirical exploration of predicting critical school readiness skills is needed for children growing up in poverty (e.g., Welsh, Nix, Blair, Bierman, & Nelson, 2010).

1.2. Early Mathematics Skills and Later Learning

In the last decade, researchers emphasized the importance of school readiness skills and their effect on later learning and academic achievement (Duncan et al., 2007; Krajewski & Schneider, 2009). During the preschool and kindergarten years (ages 3 – 6), children learn concepts in the domains of language, literacy, and mathematics that place them on a trajectory for academic achievement in subsequent years. Nationally representative studies show that early understanding of counting, number symbols, letter symbols, and vocabulary are highly related to academic achievement in elementary school (Nguyen et al., 2016) and secondary school (Duncan et al., 2007; Hooper et al., 2010). Meta-analyses findings conclude that mathematical knowledge and understanding (e.g., numeracy, number concepts, magnitude, symbolism) in the early elementary school years predict overall academic achievement test scores in later grades (Duncan et al., 2007). The collection of the nationally representative studies presented in Duncan et al.

(2007) demonstrated that the effects of mathematical knowledge at kindergarten were significant predictors over and above other domain-specific skills such as reading comprehension, working memory skills, and internalizing and externalizing behaviors (i.e., social-emotional competencies). Early numeracy concepts are prerequisites for later mathematical thinking (Krajewski & Schneider, 2009). The nature of mathematics is such that simple numerical concepts (e.g., counting) form the basis for more complex concepts and arithmetic (e.g., counting by 2s, addition). Jordan, Glutting, and Ramineni (2010) found consistencies in mathematical performance between first and third grade such that children who showed considerable competence in counting, number knowledge, number combinations, and non-verbal math problems in the first grade showed similar competencies at third grade. Delays in mathematics knowledge and skills at the beginning of formal schooling only lead to greater challenges in later grades (Morgan, Farkas, & Wu, 2011) – this research basis forms the need for identifying the factors that promote the development of mathematical thinking within the early childhood years, prior to formal school entry.

1.3. Numeracy Skills

Numeracy is comprised of several competencies that create a foundation for understanding more complex math topics in later grades (Entwisle, Alexander, & Olson, 2005). Early numeracy can be generally defined as the understanding of numbers (Passolunghi & Lanfranchi, 2012). This broad construct can be divided into several domain-specific skills including (verbal) counting, identifying number symbols, cardinality (e.g., knowing that the last number in a counting sequence refers to the entire set), subitizing, estimation, number identification (e.g., identifying the symbolic representation of a number), number comparison (e.g., which one is bigger, smaller), and number combinations (i.e., addition, subtraction, number compositions and decompositions), among other skills (National Mathematics Advisory Panel, 2008). Three specific numeracy skills were examined in this study[1]: oral (verbal) counting, number identification (identifying a symbolic representation of number), and number relations (discrimination of number magnitude).

Oral counting. Counting skills involve children's ability to verbalize a number sequence starting from a number (usually 1) and counting upwards without skipping or double counting numbers. This informal numeracy knowledge goes beyond producing a verbal string of words that relate to an ordered string of numbers. The counting sequence involves recognizing that numbers repeat to some extent, and that a predictable pattern occurs after the number 20 (Siegler & Robinson, 1982). In the English language, learning the number words that refer to 1 through 10, may be somewhat of an "arbitrary list with no patterns" (Clements, 2004). Arguably, oral counting, although conceptualized as an informal numeracy competency (Purpura & Napoli, 2015), is somewhat of an abstract skill. Gelman and Gallistel (1978) define several principles that come to play when counting items. In terms of oral counting, some of these principles still apply. That is, the stable order principle proposes that the list of oral words used to count must be in a specific repeatable, unchangeable order and the abstraction principle proposes that counting can be applied to tangible and non-tangible objects. Given these conditions, oral counting is worth investigating as an outcome on its own as well as a predictor of other numeracy skills. Krajewski and Schneider (2009) consider knowledge of number words (i.e., reciting number words, oral counting) as foundational, informal mathematics skills that provide a gateway to more complex mathematical skills (e.g., one-to-one counting).

In a sample of Finnish children, researchers found that counting sequence knowledge at preschool predicted arithmetic competence in elementary school (Aunola et al., 2004). More so, the study demonstrated that mathematics performance throughout elementary school and the growth in mathematics performance was best predicted by counting ability (Aunola et al., 2004, Nguyen et al., 2016). Counting skills measured in kindergarten, significantly predicted mathematics knowledge in first grade after controlling for child demographics (e.g., age, sex) and family factors (e.g., parental education) (Aubrey, Godfrey, & Dahl, 2006; Aunio & Niemivirta, 2010). By having automaticity in counting (i.e., avoiding pausing, not skipping or double counting numbers, transitioning between tens frames) children's memory representations of arithmetic facts increase. This fluency aids in more quick retrieval and representation of more complex numeracy tasks (LeFevre et al., 2010) and the use of more efficient strategies in addition and subtraction (Siegler & Shrager, 1984).

Numeral knowledge. As defined by Purpura, Baroody, and Lonigan (2013), numeral knowledge is "the ability to identify Arabic numerals and connect Arabic numerals to their respective quantities." Numeral knowledge stems from informal numeracy knowledge (counting, one-to-one correspondence, developing cardinality principle) and involves the understanding that number symbols (e.g., 2, 5, 8) are separate from alphabet letters (e.g., A, G, P) as well as the understanding that number symbols refer to distinct quantities (i.e., the symbol "4" refers to the quantity of ••••). Numeral knowledge is a prerequisite for formal mathematics knowledge since the mastery of the symbolic numeral system facilitates children's acquisition of formal mathematics (Song & Ginsburg, 1987; formal mathematics involves understanding around addition, subtraction place value, and the base-ten system, among other skills learned in school and in formal settings (Ginsburg, 1977)). Specific numeral knowledge skills include number identification and number relations – these skills have been found to predict formal mathematics ability (Clarke & Shinn, 2004) between the beginning of kindergarten and the end of first grade as measured by teacher ratings and norm-referenced achievement measures such as the Test of Early Mathematics Achievement-3 (TEMA-3; Ginsburg & Baroody, 2003) (Lembke & Foegen, 2009).

Number identification. Identification of number symbols is the understanding that number words can be represented in a symbolic way (i.e., with the use of Arabic symbols) and that number symbols represent an underlying quantity. Number identification is also the understanding that number symbols are different than letter symbols (e.g., alphabet) or other mathematical symbols (e.g., inequality signs, equality sign). Identifying numbers is important for later numeracy knowledge, such as making symbolic magnitude comparisons (Locuniak & Jordan, 2008). Number symbols can represent quantities of any magnitude, and those magnitudes can be manipulated (e.g., added, subtracted, multiplied, divided) to discriminate between quantities and to solve problems. It is thought that children learn to make connections between number quantities and their number representations (i.e., Arabic number symbols), referred to as set-to-numeral representation (Purpura et al., 2013) as they learn the names of numerals (i.e., the symbol 7 is "seven"). By learning the names to numerals, children become better able to compare numbers and their magnitudes. Empirical work indicates that 4-year-old children's number identification competency of numerals 1 to 100, predicts non-symbolic (e.g., ability to compare two arrays with dots and indicate the array with the highest amount of dots) and symbolic mapping (e.g., estimating the position of a number on the number line) skills one year later (Kolkman, Kroesbergen, & Leseman, 2013).

[1] The present study is drawn from a larger longitudinal study that evaluated the effectiveness of an early childhood intervention. Thus, the data on numeracy skills are limited by the nature of the original study.

Number relations. Relations skills involve the understanding of a set of quantities and how the items in the set compare to one another (i.e., quantity discrimination of magnitude comparisons). The nature of numerical magnitude comparison is usually in the form of "which number is larger/bigger" or "which number is smaller?" Beyond identifying number symbols with respect to their quantity, number relations involve the understating of how two numbers relate to each other (Clements & Sarama, 2007; Griffin, 2004). More specifically, determining the relationship between two numbers represented in Arabic numeral form involves number identification and numeral comparison (Clements & Sarama, 2007; Jordan et al., 2006). Longitudinal research of children from various socioeconomic backgrounds has identified that ability of mapping of Arabic numerals onto their respective quantities in composing and decomposing numbers in the 1st grade was predictive of 5th grade mathematics achievement (Geary, 2011). In a sample of American children from low-income families, number relations skills (referred to as symbolic mapping) at 4 years of age predicted mathematics knowledge at the end of first grade, after controlling for important demographic characteristics (e.g., sex, English language learner status in pre-kindergarten, ethnicity, and socioeconomic status (Rittle-Johnson, Fyfe, Hofer, & Farran, 2017).

1.4. Language Comprehension

Language comprehension refers to a child's ability to derive meaning from spoken words or discourse and produce meaningful utterances with the goal of communicating. It encompasses receptive (i.e., auditory) comprehension, which is what a child understands when hearing speech, and expressive communication, which refers to the vocabulary produced by a child to express meaning (Storch & Whitehurst, 2002). Receptive language comprehension refers to the ability to understand language from input (as can be indicated through gestures, actions, and/or non-verbal responses) (Rhea, 2007). Receptive language tasks involve following commands (e.g., Open the box and give me the bear) and understanding analogies (e.g., Look at this picture and finish the sentence: *You sleep in a bed. You sit on a* ...). Expressive language comprehension refers to the ability of using oral language to communicate (i.e., the "output" of language) (Rhea, 2007). Expressive communication tasks involve using plural nouns (e.g., airplane → airplanes, tree → trees) and using different tense forms of language (e.g., draw → drew, run → ran). We conceptualize language comprehension as an average of two general components: (1) auditory/receptive comprehension and (2) expressive communication such that receptive comprehension and expressive communication are each measures of general language comprehension.

Language is thought to be a cognitive tool that supports the organization and modification of thoughts (Vygotsky, 1934/1986). As with mathematics, language ability in the early childhood years is related to school readiness and school success in the elementary and middle school years (Burchinal, Peisner-Feinberg, Pianta, & Howes, 2002; Entwisle & Alexander, 1999). Receptive and expressive oral language skills are related to the development of literacy (e.g., phonological awareness) (Cooper, Roth, Speece, & Schatschneider, 2002) and combined, these skills form the foundations for early reading competencies (Wagner & Torgesen, 1987) and reading achievement in elementary school (National Institute of Child Health and Human Development [NICHD] Early Child Care Research Network, 2005). Additionally, early language skills are shown to be related to non-literacy related outcomes such as emotional regulation at three years of age (Cole, Armstrong, & Pemberton, 2010), self-regulation throughout early childhood in longitudinal investigations (Montroy, Bowles, Skibbe, McClelland, & Morrison, 2016), self-regulation across preschool and kindergarten (Bohlman, Maier, & Palacios, 2015), and symbolic mathematics knowledge in pre-kindergarten (Purpura et al., 2011).

Language comprehension is an important indicator of cognitive development (Halle et al., 2009), especially for children from families with low socioeconomic status (SES) (Pace, Luo, Hirsh-Pasek & Michnick Golinkoff, 2017). Disparities between children from different income groups in language processing have been found in longitudinal studies of young children between 18 months to 24 months years of age (Fernald, Marchman, & Weisleder, 2013). Fernald et al. (2013) revealed that by age 2, there was as much as a 6-month gap in language skills between young children from low- and high-SES families. Other studies demonstrated that the gap between children from low and high SES backgrounds in language production and comprehension is evident as early as at 9-months of age (Halle et al., 2009) and that it widens throughout childhood (Farkas & Beron, 2004; Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010).

A study using a large, representative sample from the Early Childhood Longitudinal Study, Birth Cohort (ECLS-B) of approximately 11,000 children born in 2001 showed disparities between lower and higher SES infants on language measures (receptive vocabulary, expressive vocabulary, listening/comprehension) (Halle et al., 2009). By 24 months, disparities from the mean ranged from $-.5 < d < -.33$ in terms of effect size for toddlers living above 200% poverty (Halle et al., 2009). Studies on language development trajectories using large, representative datasets found that the vocabulary gap between Black and White children is consistent between three years of age and 13 years of age (Farkas & Beron, 2004). At school entry, the achievement gap in school performance in reading and mathematics between Black and White children is largely due to the variability of children's experiences throughout their early childhood years in formal (e.g., preschool) and informal (e.g., home) settings (Burchinal et al., 2011). That is, the disparities observed at school entry are due to the developmental processes and opportunities that took place years before school entry (Condron, 2009). The differences in these early experiences lead to about one-half of a standard deviation gap in reading and mathematics skills between Black and White children at the start of school (Hanushek & Rivkin, 2006).

Studies that are reviewed in following sections provide similar operational definitions of language comprehension to the one presented in the present study; however, they only measured very specific components of language such as vocabulary (as in Foster, Anthony, Clements, & Sarama, 2015; Negen & Sarnecka, 2012), verbal analogies (as in Vukovic & Lesaux, 2013b), or expressive vocabulary used as a proxy for general language skills (as in Purpura & Ganley, 2014; Purpura & Reid, 2016). A broader, more inclusive, culturally and linguistically validated measure of language comprehension is necessary (Pace et al., 2017). In a review of empirical work on the relations between SES and language development, Pace et al. (2017) emphasize a host of linguistic disparities between children from low and high SES groups. These language comprehension and production gaps have historically manifested themselves in prelinguistic (e.g., follow gaze or establish and maintain joint attention), vocabulary (i.e., receptive and expressive), grammatical, phonological, and narrative language development outcomes that appear in infancy and persist through the school years (Rodriguez & Tamis-LeMonda, 2011). However, many of these disparities in specific language outcomes may be due to the nature and form of assessing language skills in young children since these assessments are typically structured and not psychometrically validated with culturally and linguistically diverse children (Gutierrez-Clellen & Pena, 2001). Research suggests that language comprehension, in general, in contrast to specific language skills, is more important for the development and academic success of racial/ethnically diverse children from low SES backgrounds (Dickinson et al., 2003). In a large sample of children from Head Start preschool classrooms, Dickinson et al. (2003) found that a variety of language skills (i.e., the comprehensive language approach) interact to best explain the variability in early literacy when compared to vocabulary knowledge alone. A longitudinal, socioeconomic, geographically, and economically diverse study of children born in 1991 carried out by the NICHD Early Child Care Research Network explored the pathways by which children develop reading skills between the age of 3 through the 3rd grade (NICHD Early Child Care Research Network, 2005). Results indicated that a broad conceptualization of oral language (included measures of grammar, vocabulary, and semantics) at 54 months, was best related to literacy skills in 1st grade and reading comprehension in 3rd grade than did an isolated component of language (that is, vocabulary knowledge alone).

In this study, we employ a general, holistic measure of language comprehension measured through each, receptive comprehension and expressive communication validated on a diverse sample of children from various SES, ethic/racial, and linguistic (i.e., dialectically different) backgrounds. Additionally, we also make a distinction between early (i.e., toddlerhood) and school-age (i.e., pre-kindergarten, kindergarten) language skills to examine their separate and combined relations to numeracy outcomes measured at school-age. This approach is necessary given that the overall strength of the association between infant language skills and later language skills is variable (Reilly et al., 2010; Henrichs et al., 2011) and that the continuity of language skills over time is plausible, yet requires further examination (Lee, 2011; Duff, Reen, Plunkett, & Nation, 2015).

1.5. Numeracy and Language

Language is conceptualized as one of the main inputs for learning (LeFevre et al., 2010). It is hypothesized that the development of domain specific skills (e.g., numeracy) is dependent on the acquisition of basic language skills (e.g., Duncan et al., 2007), that language skills are necessary for the learning of mathematics (Dehaene, Piazza, Pinel, & Cohen, 2003), and that general language skills relate to mathematics skills (Romano, Babchishin, Pagani, & Kohen, 2010). As children acquire the ability to comprehend language, they become better able to refine their schemas around quantitative and nonquantitative concepts. In this study, we explored the extent to which children's skills in the language domain relate to, and are predictive of, skills in the mathematics domain. The acquisition of language may support the development of mathematical and non-mathematical concepts such that language skills in the first few years of life may explain the variability in mathematics skills observed prior to formal school entry. As Vygotsky (1978) noted, "Children's learning begins long before they attend school. . .children begin to study arithmetic in school but long beforehand they have had some experience with quantity" (p. 32). Thus, not only are cognitive skills interdependent within a given time point, they co-develop overtime. By utilizing the longitudinal nature of our study, we can more appropriately investigate cross-domain development between language and mathematics. We use general language comprehension components (receptive, expressive) measured at two time-points throughout early childhood (i.e., toddlerhood, school-age) and relate them to numeracy skills measured at school-age.

Cross-domain relationships. General vocabulary knowledge has been shown to be related to children's number word knowledge as studied in a sample of 2 to 5 year olds (Negen & Sarnecka, 2012). Other research indicated that definitional vocabulary skills (i.e., a task where children are asked to generate definitions to specific words) were significantly correlated with several mathematics skills (e.g., subitizing, verbal counting, numeral identification, formal addition, cardinality) in a sample of kindergarten children (Purpura, Schmitt, & Ganley, 2017) and informal numeracy knowledge in a sample of prekindergarten children (Purpura & Napoli, 2015). In a diverse sample of kindergarten children, vocabulary knowledge assessed by a one-word picture vocabulary test was correlated with numeracy (e.g., subitizing, number comparison, number sequencing) and applied problem solving (Foster et al., 2015). Although these studies highlight relations across language and numeracy, language was predominantly measured through vocabulary, limiting the scope of language comprehension and its relationship to numeracy.

Direction of relationships. While both language and mathematics domains may mutually influence each other (Hooper et al., 2010), there is more theoretical (LeFevre et al., 2010) and empirical support (Hooper et al., 2010; Purpura et al., 2011; Purpura & Ganley, 2014; Romano et al., 2010) for the directional link from language to mathematics knowledge and skills. In the empirical studies we reviewed, language (i.e., expressive skills, vocabulary, and/or reading) was used as a predictor of mathematics skills in cross-sectional research (Purpura et al., 2011; Purpura & Ganley, 2014) and was found to be a significant predictor of later mathematics skills in large, longitudinal research studies with nationally representative samples across the U.S. and Canada (Duncan et al., 2007; Hooper et al., 2010; Romano et al., 2010). In terms of theoretical perspectives, LeFevre et al. (2010) proposed that there were several pathways (linguistic, quantitative, and spatial attention), though which children acquire mathematical concepts (e.g., geometry measurement, numeration, and magnitude comparison) and Vygotsky's (1934/1986) contributions focused on the role of language as a tool for thinking. Other research on language development of low-SES children has emphasized that language is one of the most important indicators of cognitive development (Halle et al., 2009).

Basic oral language skills are predictive of competency with numeracy tasks later in childhood (Duncan et al., 2007; Hooper et al., 2010; Romano et al., 2010). Using the Study of Child Care and Youth Development (SECCYD) dataset, Hooper et al. (2010) found that children's expressive language measured at kindergarten was related to their math scores throughout elementary school. Purpura and Ganley (2014) also found that expressive vocabulary was a significant predictor of several mathematics skills including number comparison, set comparison, and number order. Further research on expressive language skills suggests that expressive language explains about one-quarter of the variability in arithmetic skills in kindergarten and first grade (Praet et al., 2013). However, Praet et al. (2013) looked at this relationship for kindergarten to first grade Belgian children, thus limiting the generalizability of findings for the present study. In a sample of ethnically/racially diverse elementary school children, Vukovic and Lesaux (2013a) found that language ability measured by picture vocabulary and listening comprehension in first grade was related to gains in mathematics skills (specifically, data analysis and geometry) throughout elementary school. The predictive power of language ability was not found in gains of mathematical knowledge as measured by arithmetic or algebra computation tasks. In a research study of ethnic/racial minority Black and Latino children, vocabulary knowledge measured at the beginning of kindergarten explained a significant portion of variability in applied problem solving but did not predict numeracy achievement after controlling for prior numeracy skills (Foster et al., 2015).

In terms of receptive language, listening comprehension has been found to be related to mathematical performance, as measured by knowledge of ordinal numbers, knowledge of cardinal numbers, number identification, and word problems in a sample of Finnish children (Aunola et al., 2004). and to formal school mathematics knowledge (e.g., calculations, word problem solving) in a sample of first graders between the beginning and end of the school year (Fuchs et al., 2010). Other relevant research has indicated that linguistic skills predicted numeracy measures that involved the symbolic number system (i.e., Arabic numerals) but not non-symbolic representations of quantity (Simmons & Singleton, 2008). LeFevre et al. (2010) used receptive vocabulary as an index of measuring linguistic skills and hypothesized that children's receptive vocabulary was related to the acquisition of number-related words and vocabulary of the number system. Results indicated that linguistic skills predicted number naming but not nonlinguistic arithmetic (i.e., producing numbers using objects without relying on verbalizations). This body of research suggests that, in general, language skills explain a significant portion of the variability in numeracy but that the influence of language skills on numeracy may depend on the nature of the mathematics outcome.

Mediating relationships. Mathematics skills are thought to develop in a hierarchical manner, where informal tasks such as counting serve as the pathway for more complex mathematics (Resnick, 1989). Oral counting has been conceptualized as a "gateway" skill that enables successive mathematical thinking (Clarke, Baker, Smolkowski, & Chard, 2008). Research has indicated that knowledge of counting mediated the relationship between phonological awareness and arithmetic (Cirino, 2011; Krajewski & Schneider, 2009). Krajewski and Schneider (2009) showed that the relation between phonological awareness and mathematics achievement in school was mediated by basic numerical skills, or, more specifically, the learning of the number word sequence. Other researchers also examined relations between language skills and mathematics outcomes mediated by informal numeracy skills. Vukovic and Lesaux (2013b) found that third graders' symbolic number skills mediated the relation between their verbal analogies and arithmetic knowledge. Purpura and Napoli's (2015) research study suggested that informal numeracy knowledge fully mediated the relation between language and numeral knowledge in a sample of preschool children. Lastly, Zhang et al. (2014) indicated that counting sequence knowledge mediated the relation between linguistic skills (i.e., written and spoken) and arithmetic. It is thought that children around the age of 5 use a process referred to as "mapping" to merge their understanding of nonsymbolic and symbolic representation of number (Mundy & Gilmore, 2009). It is unclear whether children use their pre-existing knowledge of nonsymbolic quantity to facilitate their understanding of symbolic numeral representations or vice versa. The directionality of this relation has not been well established although there is research to suggest that children who are skilled counters (versus unskilled counters) are more successful at completing tasks related to number estimation and nonsymbolic set comparison (Lipton & Spelke, 2005). In sum, a host of research findings indicate that counting skills (i.e., conceptualized as either informal numeracy, number word sequence, or counting sequence in other studies) serve as a mediator between language components and more complex numeracy tasks such as arithmetic. Additionally, limited research suggests that knowledge of number words (i.e., nonsymbolic number knowledge) relates to number comparison. Prior research forms the basis for our third research question to explore whether oral counting mediates the relation between language comprehension and (symbolic) numeral knowledge.

1.6. *Present Study and Research Questions*

Most research on cross-domain development that encompasses early mathematics skills has focused on numeracy and its relations to literacy skills (predominantly, phonological awareness) (see Hecht, Torgesen, Wagner, & Rashotte, 2001; Purpura et al., 2011; Simmons & Singleton, 2008). Few research studies have focused on the language domain and its links to mathematics, especially for school-entry age children (Purpura et al., 2011). Other efforts linking language and numeracy skills have been done in non-United States samples (e.g., Canadian school children as in Vukovic & Lesaux, 2013b; Belgian children as in Praet et al., 2013; Finnish children as in Zhang et al., 2014). Studies that have examined these relations within the U.S. context have drawn from samples where most children were classified as White (e.g., Fuchs et al., 2010; Negen & Sarnecka, 2012; Purpura et al., 2011; Purpura & Napoli, 2015; Purpura & Reid, 2016). Additionally, most of these and similar studies have solely focused on school-aged children starting in prekindergarten (e.g., Purpura & Ganley; Purpura & Reid, 2016) or in elementary school (e.g., Hooper et al., 2010; Praet et al., 2013; Vukovic & Lesaux, 2013a; Vukovic & Lesaux, 2013b). Research indicates that language is an important pathway by which children from low-income backgrounds develop their thinking (Halle et al., 2009; Pace et al., 2017). Further, LeFevre and colleagues (2010) hypothesized that mathematics knowledge is formed from the basis of the general language system rather than from mathematics-specific language knowledge. Given the established importance of general language comprehension as a foundation for the cognitive development of low-income, racial/ethnic minority children, we expect language comprehension to be a significant factor in understanding numeracy competencies, more so than what has been previously highlighted in previous research. We explore the extent to which language skills relate to, and predict, numeracy skills for ethnic and racial minority young children growing up in contexts of poverty. The following research questions were examined in this study:

1. How are early language (receptive, expressive), school-age language, and numeracy (oral counting, number identification, number relations) skills related?
2. What is the relation between early language and numeracy skills? How much variability is explained in numeracy from early language? What is the relation between school-age language comprehension and numeracy skills? How much variability is explained in numeracy from school-age language?
3. Do oral counting skills mediate the relation between general school-age language comprehension and number identification as well as number relations?

2. Method

2.1. *Data and Design*

The sample was derived from a subsample of a larger longitudinal randomized control trial evaluating the effectiveness of a home visitation program in low-income urban neighborhoods of a city in Northeastern United States (Astuto & Allen, 2017). The eligibility criteria for initially participating in the study were (1) families had to be eligible for government assistance programs (e.g., WIC, Medicaid, Food Stamps) and (2) be living within 100% of the federal poverty level. Early language comprehension skills were measured at the baseline assessment period of the study and school-age variables (school-age language comprehension, numeracy) were measured 18 – 24 months after the end of the intervention period (follow-up time point). These data points are not within the intervention implementation period but the effects of the intervention are still controlled for in all analyses to best detect the relations among the main study variables. All child data were collected in each child's home and measures were administered by trained, native English speaking data collectors using standardized procedures.

2.2. Participants

The sample was drawn from an original sample size of $N = 133$ and after filtering out participants who did not meet the inclusion criteria for the present study, a sample of $n = 79$ remained, resulting in a large enough sample size to detect statistical significance with an alpha-level of 0.05. Power analyses for an a-priori sample size for multiple regression indicated a required minimum sample size of 70 for an anticipated small-medium effect size (Cohen's $f^2 = 0.2$), a statistical power level of $\beta = 0.8$, with 5 predictors, and an α-level of 0.05 (Cohen, 1988; Cohen, Cohen, West, & Aiken, 2003). Due to the limitations of the language comprehension measure used, non-English speaking participants and participants assessed in Spanish language comprehension were excluded from the analytic sample as language standard scores cannot be compared across different language assessment versions and language scores are not valid for non-English speaking participants (Zimmerman, Steiner, & Pond, 2002; Zimmerman, Steiner, & Pond, 2011). Additionally, the assessments used for language comprehension and numeracy have not been validated with samples of children with developmental delays. Prior research utilizing nationally representative datasets (e.g., the Early Childhood Longitudinal Study-Birth 2001 and Kindergarten 1998–1999 Cohort) indicated that children with cognitive or developmental delays or those with vocabulary difficulties were at risk for having persistent mathematics difficulties (Morgan, Farkas, Hillemeier, & Maczuga, 2016). Thus, in order to account for possible confounds in the present study resulting from linguistic differences and development delays, the sample inclusion criteria were: (1) children who were English-monolingual speaking (cases children's home language was Spanish, an African language or dialect, Haitian-Creole, or French, were removed from analysis) and (2) absence of developmental delays [children who were not diagnosed with developmental delays (e.g., autism, speech and language disorders, etc.)] each measured through parent-report.

Children in the remaining sample ($n = 79$) ranged in age from 1.42 to 3.42 years ($M = 2.15$, $SD = 0.45$) (i.e., toddlerhood) when early language skills were assessed and ranged in age from 4.5 to 6.33 years ($M = 5.25$, $SD = 0.47$) (i.e., pre-kindergarten and kindergarten entry years) when school-age language and numeracy skills were assessed. The split by sex was 70% girls and 30% boys. All children were born in the United States. At school-age, 41 children were enrolled in pre-kindergarten, 34 in kindergarten, 2 in first grade, and 2 were not enrolled in school. When early skills were assessed, the annual household income reported by the mother (i.e., primary caregiver) in the study was: under $10,000 for 44% of the sample, $10,000–$20,000 for 18%, $20,001-$30,000 for 22%, above $30,000 for 13% of the sample, where 3% of the data were missing. Maternal level of education was: less than a high school degree (19%), a high school degree or equivalent (25.3%), some college (27.8%), a college degree or higher for 11.4% of the sample, where 16.5% of the data were missing. Mothers of the children identified as either Black (86.1%) or Latino (14%). More specifically, the mothers of the children were African-American Black (49%) born in the United States, Afro-Caribbean Black (37%) (born in Haiti, Trinidad, West Indies Jamaica, St. Vincent, or St. Lucia), Latino born in the United States (10%), or Latino born in either Puerto Rico, Nicaragua, or the Dominican Republic (4%). Mother's racial/ethnic identification is used as a proxy for child's race/ethnicity in this study.

2.3. Instrumentation

Numeracy. Numeracy skills were assessed using the Test of Early Numeracy (TEN) measure (Clarke & Shinn, 2002) as a set of tasks from the Early Numeracy- Curriculum-Based Measurement (EN-CBM) (Clarke & Shinn, 2004). Three tasks from the measure were administered: oral counting, number identification, and quantity discrimination (i.e., number relations). The children had up to one minute to complete each task. For oral counting, children were instructed to count as high as they can starting from one. The score on the task indicated up to what number children counted correctly without skipping numbers, double-counting, and without hesitating (i.e., waiting more than 3 seconds to verbalize the next number in the sequence). For the number identification task, children were shown a matrix of numbers (seven rows of eight) represented in a symbolic form and were asked to identify each number by verbalizing their answer. The numbers represented on the page ranged from zero to twenty. Number relations was measured through the quantity discrimination task. For the quantity discrimination task, children were presented with pairs of numbers represented in a symbolic form (seven rows of four pairs). Children were instructed to indicate which number was bigger (i.e., "The box in front of you has two numbers in it. I want you to tell me the number that is bigger") within each set of numbers by verbalizing the bigger number. Each of the numeracy tasks were scored by total number correct; maximum scores were 100 for oral counting, 56 for number identification, and 28 for quantity discrimination. Concurrent validity correlations for oral counting ranged from .49 to .70 and predictive validity correlations ranged from .46 to .72 (Clarke & Shinn, 2004). Concurrent and predictive validity correlations ranged from .52 to .71 and from .45 to .65 for quantity discrimination and for number identification, respectively (Clarke, Baker, Chard, Braun, & Otterstedt, 2006). All three tasks demonstrated adequate reliability and criterion validity with the Woodcock Johnson Applied Problems (Woodcock & Johnson, 1989) and the Number Knowledge Test (Okamoto & Case, 1996) ranging from .60 to .79 (Chard, Clarke, Baker, Otterstedt, Braun, & Katz, 2005; Clarke & Shinn, 2004) (Cronbach's $\alpha = 0.789$ in our sample).

Language Comprehension. Early child language competence was assessed through an interactive, play-based assessment using the Preschool Language Scale – 4th Edition (PLS-4) English version (Zimmerman et al., 2002). The PLS-4 is an individually administered standardized assessment for use with infants and children from birth through 6 years of age. The standardization sample of PLS-4 included N = 2,400 children as a representative sample of the U.S. based on the 2000 U.S. Census, which was stratified based on parental education level, geographic region, and race/ethnicity. This measure assesses children's receptive and expressive language abilities, producing a Total Language score and two subscale scores: Auditory Comprehension and Expressive Communication. Each subscale contains 48 items and yields a raw score, standard score, and percentile rank. It has strong test- retest reliability across all age ranges for the two subscales ($r = .82$ to .95) and the Total Language score ($r = .90$ to .97). Overall internal reliability for the Auditory Comprehension subscale, Expressive Communication subscale, and Total Language score are $r = .86$, $r = .91$ and $r = .93$, respectively. Standard scores of the PLS auditory and expressive subscales were used in the analyses. The standard error of measurement for scores ranged from 3.67 to 8.75 for the language subscales (Cronbach's $\alpha = 0.79$ in our sample).

School-age language comprehension was assessed with the Preschool Language Scale – 5th Edition (PLS-5) English version (Zimmerman et al., 2011). The PLS-5 is an individually administered standardized assessment for use with infants and children from birth through 7 years and 11 months of age. The standardization sample of PLS-5 included N = 2,400 children as a representative sample of the U.S. based on the 2008 U.S. Census, which was stratified based on age, sex, parental education level, geographic region, and race/ethnicity. This version of the measure also assesses children's receptive and expressive language abilities, producing a Total Language score and two subscale scores (Cronbach's $\alpha = 0.966$ in our sample): Auditory Comprehension and Expressive Communication. Each subscale contains 48 items and yields a raw

Table 1
Descriptive Statistics of Study Variables.

	M	SD	Median	Range	Skewness (*SE*)	Kurtosis (*SE*)
Oral Counting	40.58	21.01	38	0 – 94	0.51 (.27)	−1.06 (.54)
Number Identification	30.23	20.61	30	0 – 56	−0.90 (.27)	−1.55 (.54)
Number Relations	7.58	10.08	1	0 – 28	1.04 (.27)	−0.46 (.54)
School-age Receptive Language (PLS-5 AC)	94.38	12.68	96	68 – 132	0.14 (.27)	−0.33 (.54)
School-age Expressive Language (PLS-5 EC)	92.58	14.80	92	61 – 135	0.18 (.28)	0.15 (.55)
School-age Total Language (PLS-5 TL)	92.89	14.19	92	64 – 136	0.27 (.28)	0.36 (.55)
Early Receptive Language (PLS-4 AC)	92.03	13.96	91	61 – 136	0.43 (.27)	0.42 (.54)
Early Expressive Language (PLS-4 EC)	93.25	14.18	95	56 – 126	-0.29 (.27)	0.04 (.54)

Note. One-sample t-tests indicated that the early receptive language mean score as well as the early expressive language mean score significantly differed from the normative sample average (M = 100); $t(77) = -5.05$, $p < .001$ and $t(76) = 8.01$, $p < .001$, respectively. School-age receptive language mean score as well as the school-age expressive language mean score significantly differed from the normative sample average (M = 100); $t(78) = -4.18$, $p < .001$ and $t(75) = -4.37$, $p < .001$, respectively.

score, standard score, and percentile rank. The test-retest reliability across all age ranges for the subscales and the total score ranged from $r = .86$ to .95. Overall inter-examiner reliability ranged from $r = .96$ to .99. Standard scores of the PLS measure were used – where the subscale scores were used in the correlation and regression analyses and the total score was used in the mediation analyses. The standard error of measurement for scores ranged from 2.1 to 5.2 for the language subscales.

2.4. Analytic Plan

Statistical analyses were conducted to answer the research questions of the study by using IBM SPSS Version 21. The descriptive statistics of all study variables (see Table 1) were checked for skewness and distribution of scores and did not indicate a need to transform any variables. For the first research question, zero-order and partial Pearson *r* correlations were run to indicate the relationship among study variables. In all subsequent analyses we controlled for child age (at school age), child sex, and intervention/control group. Overall, age is a factor that contributes to children's mathematical knowledge (Jordan et al., 2006; Ransdell, & Hecht, 2003) and research has not clearly indicated whether there are sex differences in children's mathematical performance (Aubrey & Godfrey, 2003; Aunola et al., 2004), so these two variables were held constant.

To answer the second research question, two ordinary least squared (OLS) regressions were run for each of the numeracy tasks. Within each regression model, variables were entered with the use of a step-wise regression, where the control variables were entered in block 1 and the language comprehension variables were entered in block 2. In the results section, we report the adjusted R^2 of each model when language variables and control variables were in the model as well as the statistical significance of the $R^2\Delta$ (R-squared change), which shows the additional variability explained by language comprehension over and above the control variables. The language comprehension skills across time-points (early, $M = 2.15$ years old; school-age $M = 5.25$ years old) were not used simultaneously due to the primary interest of partialling out the effects of language skills (early versus school-age) and due to multicollinearity concerns. The variance inflation factor (VIF) in collinearity diagnostics ranged from 1.67 – 3.87 when all language comprehension variables were entered. Conventions indicate that the VIF should be < sqrt(4) (Fox, 2008; Weisberg, 2005) and therefore, indicated that multicollinearity was a concern with the data. Multicollinearity was addressed by separating the effects of early and school-age language skills by using those language variables across time points (early, school-age) as predictors in separate models. Therefore, each numeracy outcome had two separate regression models (6 regression models in total). Additionally, due to the skewed distributions of the outcome variables, several linear regression model assumptions and diagnostics were checked before finalizing the results. More specifically, partial-plots of residuals indicated that residuals were normally distributed, error variance was constant, and that the variables were best linearly associated with the outcomes (when compared to quadratic or cubic functions).

To address the third research question, we ran mediation analyses by following the macro PROCESS procedure of mediation using an add-on program for SPSS (see Preacher & Hayes, 2004). This analysis method used a series of OLS regressions to estimate path coefficients, standard errors, and *p*-values. Such mediation analyses allow researchers to test the indirect effect of a variable on an outcome by retrieving the effect's statistical significance through the bootstrapping method (Preacher & Hayes, 2004). The bootstrapping method offers benefits to estimating the indirect effect because it does not make assumptions about the normality of the distribution of the variables or the sampling distribution due to the resampling procedure. We used the bootstrapping method to derive means from 5,000 estimates to test the indirect effects and generate 95% confidence intervals for the indirect effects as suggested by Hayes (2009). Typical model fit indices (e.g., RMSEA, CFI, etc., such as ones provided with SEM or path analyses) are not available using the PROCESS method since most mediation models, such as the ones tested in this study, are saturated (Hayes, Montoya, & Rockwood, 2017). Therefore, no omnibus measure of model fit is required because saturated models tend to have perfect model fit when SEM procedures are used (for a distinction between PROCESS and SEM analyses see Hayes et al., 2017). In this study, mediation was tested through the significance of the indirect effect of the independent variable (IV = school-age total language comprehension skills), through the mediator (M = oral counting), on each dependent variable (DVs = number identification, number relations). The mediation analyses also included early language skills (receptive, expressive), school age, sex, and intervention group as control variables (see Fig. 1). School-age total language comprehension was used as the independent variable in this analysis in contrast to either of the subscale scores and in contrast to early language comprehension because: (1) mediation models allow only for one independent variable, (2) there was no predetermined assumption about which one of the language subscales would be most strongly related with the numeracy outcomes, thus the average of the two was used (i.e., which is the total score generated by the PLS measure), (3) it was assumed that variables measured concurrently would be more strongly related than variables measured across time – that is, there was no predetermined assumption that early language skills would be related to the numeracy outcomes above the school-age language skills.

3. Results

3.1. Correlation Analyses

To answer the first research question investigating the strength of the relations among early language skills, school-age language

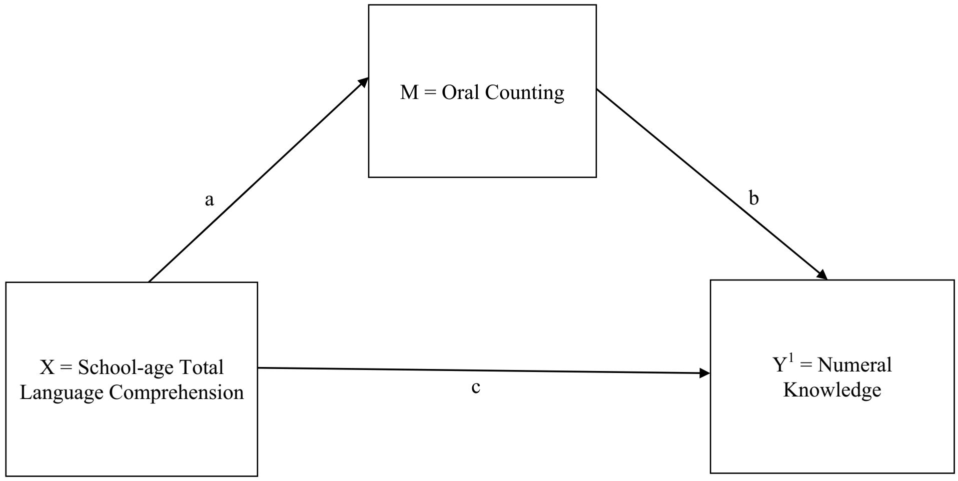

Fig. 1. Mediation model with path notations. [1]Two dependent variables were separately analyzed: number identification and number relations. The independent (X), mediating (M), and outcomes (Y) variables were all measured at the same time-point (i.e., school-age) and represent concurrent relations. Control variables in the mediation models included: intervention, child sex, child age, early expressive language, and early receptive language.

Table 2
Correlations Among Early Numeracy and Language Comprehension Skills.

Variable	1	2	3	4	5	6	7	8
1. Early Receptive Language (PLS-4 AC)	–	.68**	.57**	.58**	.62**	.64**	.11	.25*
2. Early Expressive Language (PLS-4 EC)	.67**	–	.46**	.53**	.55**	.38**	.25*	.16
3. School-age Receptive Language (PLS-5 AC)	.57**	.47**	–	.81**	.95**	.62**	.46**	.60**
4. School-age Expressive Language (PLS-5 EC)	.61**	.55**	.82**	–	.96**	.69**	.46**	.69**
5. School-age Total Language (PLS-5 TL)	.60**	.53**	.95**	.96**	–	.64**	.45**	.57**
6. Oral Counting	.38**	.38**	.57**	.63**	.71**	–	.61**	.76**
7. Number Identification	.17	.27*	.42**	.46**	.48**	.54**	–	.58**
8. Number Relations	.24*	.15	.47**	.58**	.68**	.71**	.51**	–

Note. Correlations above the diagonal are zero-order correlations. Pearson *r* correlations between intervention/control group and the numeracy outcomes were not statistically significant: $r = -.01$, $p = .91$ with oral counting, $r = -.02$, $p = .86$ with number identification, and $r = -.03$, $p = .79$ with number relations. Correlations below the diagonal are partial correlations that control for child sex, intervention/control group, and child age at the school-age time point.
* $p < .05$.
** $p < .01$.

skills, and numeracy skills, Pearson product-moment correlations and partial correlations were used (reported in Table 2). Results indicated that oral counting was significantly correlated with all measures of language comprehension skills (early, school-age); *r* ranged from .38 to .69 where $p < 0.01$ for all coefficients. Number identification was correlated with school-age receptive language, school-age expressive language, and early expressive language skills ($r = .46$, $r = .46$, $r = .25$, respectively). Number relations was correlated with school-age language comprehension skills (receptive $r = .60$, $p < 0.01$; expressive $r = .69$, $p < 0.01$) and with early receptive language comprehension ($r = .25$, $p < 0.05$). The pattern of correlations revealed that components of school-age language comprehension were more highly correlated with oral counting and number relations than with number identification. Fisher's *z* statistic indicated that the magnitude of the correlation between number identification and school-age language comprehension subscales (both $r = 0.46$) differed from the magnitude of the correlations between each, oral counting and number relations, with school-age language comprehension ($r = 0.60$ was tested); Fisher's $z\,(68) = -1.75$, $p < 0.05$.

3.2. Regression Analyses

The second research question aimed at understanding the relation between language and numeracy skills by using language components as predictors of numeracy outcomes. The results of these analyses indicated that language explained a significant portion of the variability across the numeracy outcomes and that language components were significant predictors of numeracy outcomes. Both school-age language components (expressive, receptive) were significant predictors of oral counting, early expressive language was a significant predictor of number identification, and school-age expressive language was a significant predictor of number relations. The patterns of the regression analyses results indicated (1) that there is variation in whether early and/or school-age language skills are important predictors of numeracy and (2) variations in which specific language components (expressive and/or receptive) are predictive of numeracy (see Table 3).

The results of Model 1 (y = oral counting) showed that early language comprehension in explained 14.2% of the variability in oral counting above the control variables, although neither of the language comprehension predictors were statistically significant; adjusted $R^2 = .308$, $R^2\Delta = .142$, $p < 0.01$. School-age language skills accounted for an additional 41% of the variability in oral counting and both language comprehension skills were statistically significant predictors of oral counting (Model 2 adjusted $R^2 = .580$, $R^2\Delta = .408$, $p < 0.01$).

For Model 3 (y = number identification), early language comprehension skills did not explain a significant change in variability in number identification above the control variables; adjusted $R^2 = .159$, $R^2\Delta = .064$, $p = 0.063$. Nonetheless, early expressive communication was shown to be a significant predictor of the outcome, $\beta = .305$, $p = 0.032$. In contrast, for Model 4, school-age language comprehension skills explained a significant change in variability above the control variables; adjusted $R^2 = .297$, $R^2\Delta = .187$, $p < 0.01$,

Table 3
Multiple Linear Regression Results Predicting Numeracy Outcomes.

	Oral Counting Model 1			Oral Counting Model 2			Number Identification Model 3			Number Identification Model 4			Number Relations Model 5			Number Relations Model 6		
Variable	B	SE(B)	β	B	SE(B)	β	B	SE(B)	β	B	SE(B)	β	B	SE(B)	β	B	SE(B)	β
Intervention	-.46	4.39	-.011	-1.12	4.44	-.03	-.64	4.43	-.02	.11	4.41	.00	-.48	2.10	-.024	-1.01	2.11	-.05
Child Sex	-.78	4.52	-.02	-2.84	3.56	-.06	2.51	4.84	.06	2.13	4.46	.05	-2.28	2.32	-.10	-4.31*	1.76	-.19
Age	1.48**	.36	.40	1.68**	.29	.44	1.24**	.38	.34	1.38**	.36	.38	.82**	.18	.47	.83**	.14	.46
Early Receptive Language	.31	.19	.20	–	–	–	-.13	.21	-.09	–	–	–	.16	.10	.22	–	–	–
Early Expressive Language	.34	.19	.23	–	–	–	.44*	.20	.31	–	–	–	.00	.10	.01	–	–	–
School-age Receptive Language	–	–	–	.48*	.22	.29	–	–	–	.38	.28	.23	–	–	–	.08	.11	.11
School-age Expressive Language	–	–	–	.57**	.19	.39	–	–	–	.32	.24	.23	–	–	–	.37**	.10	.54
Adjusted R^2		.31			.58			.16			.34			.23			.56	
$R^2\Delta$		.14**			.41**			.06+			.19**			.05			.37**	

Note. Results reported indicate the second block of the multiple regression analyses. The $R^2\Delta$ (R-squared change) indicates the change in proportion of variance explained between the blocks (Block 1 = intervention, child sex, child age; Block 2 = intervention, child sex, child age, and either early expressive language and receptive language or school-age expressive language and receptive language). + $p < .10$ * $p < .05$. ** $p < .01$.

however, neither of the school-age language comprehension predictors were statistically significant.

For Model 5, (y = number relations), early language comprehension skills did not explain a significant change in variability in number relations above the control variables; adjusted $R^2 = .225$, $R^2\Delta = .045$, $p = 0.123$, and neither early language predictor was statistically significant. For Model 6, school-age language comprehension skills explained a significant change in variability above the control variables; adjusted $R^2 = .562$, $R^2\Delta = .368$, $p < 0.01$, where school-age expressive language comprehension was a statistically significant predictor of number relations, $\beta = .539$, $p < 0.01$.

3.3. Mediation Analyses

The third research question aimed to test whether counting skills mediated the relationship between total school-age language comprehension and number identification as well as number relations. In this analysis, the set of control variables also included early language comprehension skills. Mediation analyses results indicated that oral counting partially mediated the relation between school-age total language comprehension and number identification as well as the relation between school-age total language comprehension and number relations (see Table 4). The magnitude of the indirect effect of language comprehension on number identification through oral counting was moderate; $b = .36$, 95% CI [.011, .794]. The magnitude of the indirect effect of language comprehension on number relations through oral counting was also moderate; $b = .23$, 95% CI [.103, .385]. Additionally, there were statistically significant relations between oral counting and each of the numeral knowledge outcomes as noted by path b (effect of M on Y); $b = .034$, $p < 0.05$ for number identification and $b = .22$, $p < 0.01$ for number relations. The link between language comprehension and the numeracy outcomes also remained statistically significant, after partialling out the effect of the mediating variable; the direct effects were $b = .48$, $p < 0.01$ for number identification and $b = .34$, $p < 0.01$ for numeral knowledge. The partial mediation findings signify that the relation between language comprehension and numeral knowledge (number identification, number relations) is partially explained through oral counting – even after controlling for prior language comprehension skills, child age, sex, and intervention.

4. Discussion

The goal of the study was to examine the relationship between language comprehension and numeracy skills in a longitudinal sample of ethnic and racial minority children growing up in contexts of poverty. Moderate to high correlations were found between early and school-age language skills (receptive comprehension and expressive communication) and numeracy measures (oral counting, number identification, and number relations). Consistent with previous studies (Foster et al., 2015; Negen & Sarnecka, 2012; Vukovic & Lesaux, 2013b), the findings from this study suggested that language skills were highly correlated with numeracy skills. However, most prior work investigating the link between language and numeracy has utilized measures of specific language skills (e.g., vocabulary) that limit the scope of understanding cross-domain relations. Extending beyond this prior work, we found that general language comprehension components of receptive comprehension and expressive communication relate to numeracy over-and-above child age and sex in partial correlation analyses.

Additionally, we found that a larger general language comprehension repertoire was related to producing number words, identifying number symbols, and relating the magnitudes of numbers. The study findings are consistent with previous studies which

Table 4
Oral Counting as a Mediator (M) between School-age Language Comprehension (X) and Numeral Knowledge (DVs).

	Effect of *X* on *M*	Effect of *M* on *Y*	Direct effect *X* on *Y*		Indirect effect *X* on *Y*		Total effect	R^2
Outcome Variable	(*a*)	(*b*)	(*c'*)	95% *CI*	(*ab*)	95% *CI*	(*c*)	
Number Identification	1.06**	0.34*	0.48**	(.026, .934)	.36	(.011, .794)	.840	.687
Number Relations	1.06**	0.22**	0.34**	(.181, .514)	.23	(.103, .385)	.573	.847

Note. Child sex, school age, intervention/control group, and early language skills (receptive, expressive) were included in each mediation analysis as control variables. No *p*-values were generated for the indirect effects; the confidence intervals are used instead. $^{*}p < .05$. $^{**}p < .01$

indicate that language skills predict numeracy skills (Praet et al., 2013; Purpura et al., 2011; Vukovich & Lesaux, 2013a; Vukovich & Lesaux, 2013b). LeFevre et al. (2010) suggested that linguistic skills created one pathway for mathematical cognition and the results presented here are in line with this conceptualization. Our results, however, differ from Purpura and Ganley's (2014) findings in that expressive vocabulary ability was only a marginally significant predictor of verbal counting. Results from this present study suggested that language comprehension components were important for numeracy skills. As previous work suggests, receptive comprehension is related to the acquisition of number-related concepts (LeFevre et al., 2010) and expressive communication supports children's conveyance of the mathematical and non-mathematical knowledge they have acquired (Mainela-Arnold, Alibali, Ryan, & Evans, 2011).

School-age language components (both receptive and expressive) explained a significant portion of variability in oral counting and were significant predictors of oral counting. Only early expressive language measured in toddlerhood was a significant predictor of number identification and only school-age expressive language was a significant predictor of number relations. The patterns of these results indicated that expressive language skills (versus receptive language skills), measured either during toddlerhood or school-age, were important predictors of all numeracy outcomes examined in this study. First, this suggests that expressive language may better indicate children's representation of mathematical thinking as measured by oral counting and numeral knowledge. Second, the predictive value of expressive communication for all numeracy outcomes may also just adhere to how the numeracy outcomes were specifically measured. That is, numeracy skills were measured through verbalizations, where children were asked to either count out loud, verbally indicate the symbolic representation of a number, and verbally indicate the larger number within a set of two numbers. The requirement of verbalizations may have tapped into the children's expressive communication skills more so than their receptive comprehension skills. This suggests that children may have used their expressive language skills to produce and sustain their verbalization of the oral counting sequence. Further, (school-age) receptive language was found to only predict oral counting. In particular, children may use their auditory processing to maintain a rhythmic pattern of counting by listening back to the last number they counted out loud in order to produce the next number in the counting sequence (e.g., twenty-sevennn. . ..twenty-eighttt). Fluency of oral counting relies on understanding the repetitive nature of counting (i.e., x-ty-two, x-ty-three) as well as its predictive pattern (i.e., four-ty, fif-ty, six-ty). Both skills may be supported through auditory comprehension to "keep track" of the number sequence and through expressive communication to produce the verbalization of the number-word. Working memory research indicates that the phonological loop, a specialized system of working memory for the retention of auditory information over short periods of time (Baddeley, 1986), is responsible for temporarily storing and rehearsing sound patterns to promote long-term memory construction (Baddeley, Gathercole, & Papagno, 1998). Further examining the effects of working memory (i.e., processing of the auditory loop) would be an effective way to better contextualize these results.

In terms of taking a developmental approach to understanding these findings, the results indicated that language skills measured at separate times throughout the early childhood years, had differential relations to numeracy outcomes. These differential links between early versus school-age language skills and numeracy serve as important indicators of *when* language skills related to specific numeracy competencies may develop. The longitudinal effect beginning in toddlerhood has not been previously well understood in the context of cross-domain development. Previous studies exploring these relationships predominantly focused on preschoolers (Purpura & Ganley, 2014; Purpura & Napoli, 2015), kindergarteners (Hooper et al., 2010; Praet et al., 2013), first graders (Fuchs et al., 2010; Vukovic & Lesaux, 2013a), or upper elementary school-aged children (Hecht et al., 2001; Vukovic & Lesaux, 2013b). In this study, early language measured in toddlerhood, and school-age language skills measured when children were in prekindergarten or kindergarten, explained significant variability in oral counting. Additionally, early expressive communication measured in toddlerhood, but neither language comprehension components measured at school-age, was found to be a predictor of number identification. In contrast, only school-age expressive communication was found to be related to number relations. Given that oral counting is a demanding, language-based task, it should be expected that language skills over time would matter for developing fluency in counting. It should also be expected that cognitive skills measured within the same time-point, would be related (as was the case between expressive communication and number relations, measured at school-age). However, it may be unanticipated that early expressive language, but neither school-age language component, was predictive of number identification – which furthermore indicates the need for further examining cross-domain perspectives across developmental ages.

Lastly, the results from the mediation analyses indicated that oral counting only partially mediated the relations between language comprehension skills and number identification as well as number relations. Language comprehension skills still had a significant direct effect on the numeracy outcomes in the mediation models. This suggests that language skills is related to numeral knowledge (i.e., number identification, quantity discrimination) independent of oral counting ability. This result provides a contrasting conclusion from Purpura and Napoli (2015) who found that informal numeracy fully mediates the relation between language and numeral knowledge with a sample of predominantly White children. One reason for this may be that Purpura and Napoli (2015) had a more robust measurement of informal numeracy that included several tasks, whereas our study relied on verbal counting as an indicator of informal numeracy.

4.1. Implications

Early mathematics involves concepts that are important for later learning (Purpura et al., 2013). To date, most of the work on the development of early mathematics skills has focused on school-age children (i.e., kindergarten and on) looking at a within-domain perspective – how mathematics skills develop over time and how they are related to later, advanced skills, using samples of predominantly White children from high-income backgrounds (e.g., Fuchs et al., 2010; Negen & Sarnecka, 2012; Purpura et al., 2011; Purpura & Napoli, 2015; Purpura & Reid, 2016). However, more work is needed to understand the sources of variability of young children's numeracy skills prior to formal school entry, particularly in communities that can benefit from additional supports and interventions for their youngest children. In a joint position statement, the National Association for the Education of Young Children (NAEYC) and the National Council of Teachers of Mathematics (NCTM) encourage the field of early childhood education to promote mathematical foundations for 3 to 6-year-old children (NAEYC & NCTM, 2002/2010). Children enter school with a variety of skills and experiences across several academic and nonacademic domains. Understanding children's development from a holistic perspective puts us at a better position to address the ways, in which children's early learning skills can be improved. This emphasizes the need for more intentional support prior to formal school entry.

Language is a strong predictor of numeracy skills. Thus, children's language skills should be accounted for when designing interventions, discussing implications for early childhood developmentally appropriate practice, forming appropriate assessments, and informing developmental science research for promoting mathematics-related knowledge. The importance of language as a pathway for the development of numeracy serves as an implication for ways in which language and mathematics could be naturally integrated in both formal (e.g., early childhood centers and classrooms) and informal (e.g., the home) learning environments through non-didactic, interaction-focused, and developmentally appropriate ways. There is extensive research supporting the findings that the negative effects of poverty on language outcomes can be reduced by positive interactions in resourceful, social contexts (Huttenlocher, Vasilyeva, Cymerman, & Levine, 2002). To mitigate the effects of poverty on child outcomes, contexts of learning should provide experiences for rich acquisition of language. In terms of cross-domain teaching and learning, supporting the development of general language skills across the early childhood years could affect the co-development of numeracy skills. Teachers could promote children's expressive communication by eliciting verbalizations through open-ended questions, by asking children to elaborate on their responses during meaningful conversations, and by encouraging self-talk. For promoting receptive comprehension, children's thinking could be facilitated by labeling, using cues, and drawing analogies. Such forms of language interactions have been shown to promote children's language comprehension and structure (Huttenlocher et al., 2002). Using these approaches strengthen the pathway between language and numeracy for cross-domain development. Promising research in this area has specifically focused on the quality of teachers' language (Sonnenschein, Thompson, Metzger, & Baker, 2013) and teachers' mathematical language use (Klibanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006), which have shown to be positively related to children's mathematics knowledge in samples of racial/ethnic minority children.

4.2. Limitations and Future Directions

Numeracy skills in this study were inferred from three specific tasks, that do not fully represent a range of early mathematics skills children possess during the early childhood years. More holistic measures of numeracy skills spanning across cardinality, enumeration, and arithmetic, among others, should be utilized. Multiple mediation analyses are needed to incorporate a host of informal numeracy skills such as one-to-one correspondence, subitizing, and cardinality, as mediators between language comprehension and numeral knowledge to further explore these effects. Further, in this study, language comprehension was measured in a general sense, which provides several benefits to the goal of understating cross-domain development between language and numeracy. However, partialling out mathematical language from general language comprehension could provide more insight into the extent to which language influences the development of numeracy skills. On the other hand, because language and numeracy skills are related, it would be useful to find ways in which numeracy competencies could be measured in non-verbal ways. For example, instead of asking children to count out loud (which requires verbal communication), children could be instead asked to identify errors in counting or identify the missing numbers in a counting sequence, where minimal verbalization would be required. Other research efforts could incorporate measures of the approximate (nonverbal) number system (ANS) (as in Lipton & Spelke, 2003).

Due to strong correlations among early and school-age components of language comprehension, these two data points were investigated independently. Future studies should examine the relation between language and numeracy and the ways in which they covary between the early childhood years into later elementary school years. By taking this approach, future research can account for autoregressor effects in the cross-domain development of language and numeracy over time. More specifically, other studies interested in numeracy as an outcome variable could model longitudinal relations by accounting for initial levels of numeracy (i.e., the autoregressor) prior to school-age (as in Foster et al., 2015). These approaches should be taken with studies of larger samples sizes where repeated measures of language and numeracy skills could be explored over time to examine mediating effects through a longitudinal lens.

Additionally, research should integrate both cognitive and non-cognitive domains of academic and pre-academic skills. For example, in this study, auditory comprehension (i.e., receptive language skills) was related to oral counting. The auditory skills, however, do not develop independently of working memory skills – and in particular, the phonological loop. Understanding how working memory, language comprehension, executive functioning, and literacy skills (such as phonological awareness), impact specific components of numeracy would be invaluable to the field of early childhood cognitive development. Other non-cognitive skills such as social-emotional and self-regulation domains should be integrated within research exploring cross-domain development.

5. Conclusion

With a sample of ethnically and racially diverse children living in contexts of poverty, we examined whether language skills were related to numeracy skills and whether oral counting mediated the relation between language skills and numeral knowledge. Results indicated that expressive communication skills (either measured in toddlerhood or at school-age) were related to all numeracy outcomes: oral counting, number identification, and number relations. In contrast, receptive comprehension skills were only related to concurrently measured fluency in oral counting. Additionally, oral counting only partially mediated the relation between general language comprehension and numeral knowledge outcomes (number identification, number relations). The findings are consistent with the perspective that linguistic skills are associated with various numeracy skills. Results suggest that expressive language skills and to a lesser extent, receptive language skills, are associated with numeracy. Future research should consider expressive and receptive language comprehension in cross--domain developmental research.

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