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Role of linguistic skills in fifth-grade mathematics

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ABSTRACT

The current study investigated the direct and indirect relations between basic linguistic skills (i.e., phonological skills and grammatical ability) and advanced linguistic skills (i.e., academic vocabulary and verbal reasoning), on the one hand, and fifth-grade mathematics (i.e., arithmetic, geometry, and fractions), on the other, taking working memory and general intelligence into account and controlling for socioeconomic status, age, and gender. The results showed the basic linguistic representations of 167 fifth graders to be indirectly related to their geometric and fraction skills via arithmetic. Furthermore, advanced linguistic skills were found to be directly related to geometry and fractions after controlling for arithmetic. It can be concluded that linguistic skills directly and indirectly relate to mathematical ability in the upper grades of primary education, which highlights the importance of paying attention to such skills in the school curriculum.

Introduction

Becoming proficient in mathematics is an important goal of primary education. Previous research has consistently shown that linguistic skills directly predict arithmetic skills in the lower grades (e.g., Kleemans, Segers, & Verhoeven, 2014; LeFevre et al., 2010; Purpura & Reid, 2016). Far less is known, however, about the underlying mechanisms of advanced mathematics (i.e., geometry and fractions) in the upper grades. It has been suggested that these skills partly build on arithmetic representations (Cirino, Tolar, Fuchs, & Huston-Warren, 2016) but may rely on linguistic skills as well (Vukovic &

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Lesaux, 2013a; Vukovic et al., 2014). To acquire more theoretical insight and practical guidance into how to best support children's mathematical development, a deeper understanding of the relationship between linguistic skills and children's mathematical performance is needed (Vukovic & Lesaux, 2013b). Therefore, we investigated the extent to which linguistic skills directly and indirectly via arithmetic skills relate to advanced mathematics.

Mathematics consists of a broad range of skills. In primary education, the focus is on arithmetic skills, measurement, and fractions (Mullis, Martin, & Loveless, 2016). In the lower grades children learn the basic operations of addition, subtraction, multiplication, and division, whereas in the upper grades the emphasis lies on the application of these arithmetic skills in the domain of advanced mathematics (i.e., geometry and fractions; Mullis et al., 2016). During the past decade, the literature on the role of linguistic skills in arithmetic skills in the lower grades of primary education has rapidly expanded. Influential and widely accepted theoretical frameworks (e.g., Dehaene, Piazza, Pinel, & Cohen, 2003; LeFevre et al., 2010; Vukovic & Lesaux, 2013a) identified the linguistic system as predictive of performance on measures that require knowledge of the formal number system such as whole-number computations, measurement, and fraction concepts. Building on these models, previous research found the development of arithmetic skills to rely partly on basic linguistic representations such as phonological skills (De Smedt & Boets, 2010) and grammatical ability (Kleemans et al., 2014). Phonological skills are related to arithmetic given that the solution of arithmetic problems relies on verbal codes. These verbal codes are stored in a phonological format in long-term memory (Simmons & Singleton, 2008) and form the heart of the verbal system of the triple code model (Dehaene et al., 2003), which suggests that the development of arithmetic skills relies on language-related networks, whereas the estimation and approximation of numbers appears to operate independently from the language system (Pica, Lemer, Izard, & Dehaene, 2004). Furthermore, both grammatical ability and arithmetic skills are based on the same underlying rules and recursive principles (Hauser, Chomsky, & Fitch, 2002). For example, the order of words in a sentence determines its meaning (e.g., "She pushes him" vs. "He pushes her"), as does the order of the numbers and operations in an arithmetic problem (e.g., "64 ÷ 8 = __" vs. "8 ÷ 64 = __"). Kleemans et al. (2014) found that both phonological awareness and grammatical ability predict arithmetic skills in second grade, whereas a longitudinal effect of phonological awareness on arithmetic fact retrieval has also been evidenced in fourth- and fifth-grade children (De Smedt, Taylor, Archibald, & Ansari, 2010).

Although it has been clear from previous research that basic linguistic representations predict arithmetic skills, the theoretical framework on the role of linguistic skills in mathematical achievement is in need of expansion because the increasing complexity of advanced mathematics tasks in the upper grades builds on more advanced linguistic skills. Although little is known about which linguistic skills are related to advanced mathematics in the upper grades, two advanced linguistic skills can be identified from the literature: academic vocabulary and verbal reasoning. Academic vocabulary has been identified as one of the key factors that children need to acquire in order to comprehend texts in mathematics education and become independent science learners in general (Snow, 2010). In the domain of advanced mathematics, this academic vocabulary entails the general words (e.g., axiom, hypothesis) and domain-specific words (e.g., square, inch, fraction) that are needed to successfully comprehend and solve mathematical problems (Baumann & Graves, 2010). Mathematical vocabulary has been found to directly predict later general mathematics achievement in preschool and kindergarten children (e.g., Purpura, Napoli, Wehrspann, & Gold, 2017), but such studies have not yet been conducted in the upper grades.

Verbal reasoning refers to the ability to apply rule-based information, draw inferences, and consider alternative possibilities (Khemlani & Johnson-Laird, 2012), which is especially needed when mathematical problems require multiple steps in order to be solved. For example, solving the fraction problem "7/8 ÷ 3/4 = __" not only requires a conceptual understanding of the fraction relative to a whole number but also involves the ability to execute the correct action sequence out of a number of rules (i.e., flip the second fraction upside down, change the division sign into a multiplication sign, and multiply the tops and bottoms) (Rittle-Johnson, Siegler, & Alibali, 2001). Verbal reasoning appears to be of critical importance to being successful in mathematics in secondary education (e.g., Otten, Gilbertson, Males, & Clark, 2014; Stylianides & Stylianides, 2008), and because of this it has been suggested that children in elementary school should be trained in such skills (Stylianides, 2007). How-