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Bilingualism and symbolic abstraction: Implications for algebra learning

Marta K. Mielicki [a, *], Natalie A. Kacinik [b], Jennifer Wiley [a]

[a] University of Illinois at Chicago, 1007 West Harrison Street (M/C 285), Chicago, IL 60607, United States
[b] Brooklyn College and Graduate Center of the City University of New York, 2900 Bedford Avenue, Brooklyn, NY 11210, United States

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ABSTRACT

Much of the research on bilingualism and math learning focuses on the potential challenges that bilinguals and language learners may face. The current line of research took an alternative approach and explored whether a bilingual advantage may emerge for a novel algebraic problem solving task that requires symbolic thought, the Symbol Math task. No differences were seen between bilingual and monolingual samples on basic math or executive control tasks; however, a bilingual advantage was seen in performance on the Symbol Math task across two experiments. The results suggest that bilingualism may improve the ability to engage in more abstract or symbolic thought processes, which may have important implications for algebra learning.

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1. Introduction

1.1. Algebra and symbolic abstraction

Although algebra is foundational for higher-level mathematics and considered to be a gatekeeper subject for careers in STEM fields, the shift from arithmetic to algebra is notoriously challenging for students (Herscovics & Linchevski, 1994; Humberstone & Reeve, 2008). Algebraic understanding requires moving beyond calculation of exact values to consideration of relationships among quantities and operations involving unknown values and variables. Thus, symbolic abstraction is an important component of algebraic understanding (Arcavi, 2005). One particularly important algebraic topic is functions, and many researchers have advocated teaching other algebraic topics, such as solving equations and manipulating expressions, within the context of functions (Chazan & Yerushalmy, 2003; Kieran, 2007). Students typically treat functions as recipes for obtaining an answer, and struggle with understanding functions as expressing a relationship between variables (Kalchman & Koedinger, 2005). The present research tests whether bilinguals demonstrate a performance advantage on a task that presents algebraic functions in a novel way, as part of a Symbol Math task.

1.2. Bilingualism and symbolic abstraction

Research on bilingualism and math learning has focused on the ways that bilinguals and language learners can be disadvantaged in traditional academic environments (Campbell, Davis, & Adams, 2007). For instance, certain features of items found on common mathematical assessments, such as the number of words in an item and grammatical features common to academic language, are associated with differential item functioning (DIF) with a bias against language learners (Haag, Heppt, Stanat, Kuhl, & Pant, 2013). Even in bilingual immersion programs, where learning in multiple languages is encouraged and supported, there may be costs associated with switching languages while learning mathematics. Saalbach, Eckstein, Andri, Hobi, and Grabner (2013) demonstrated that, despite the assumption that mathematics is a language-independent subject, the mismatches between the language of instruction and the language of testing can impact performance on mathematical tasks. High school students enrolled in a bilingual education program were trained to complete subtraction and multiplication problems either in their L1 (German) or L2 (French). Each participant was then tested on trained and untrained problems in both L1 and L2. Saalbach et al. (2013) found a switching effect (lower accuracy and higher response time) when the testing language differed from the training language, and this effect was greater when participants were trained in L1 and tested in L2. These results suggest that mathematics performance can be language dependent, and that educators in bilingual immersion programs

* Corresponding author.
E-mail addresses: mmieli2@uic.edu (M.K. Mielicki), NKacinik@brooklyn.cuny.edu (N.A. Kacinik), jwiley@uic.edu (J. Wiley).

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should be mindful of the potential costs associated with teaching and testing in different languages.

Although understanding the ways that bilinguals can be disadvantaged in traditional learning environments is an important endeavor, a full understanding of the bilingual experience should consider not only the potential costs but also potential benefits that come with the bilingual experience with the goal of understanding how these costs and benefits are related (Cummins, 1976; Kempert, Saalbach, & Hardy, 2011). Planas (2014) argues that, contrary to viewing bilingualism as a disadvantage in math learning, bilingualism can actually create opportunities for learners to engage more deeply with mathematical concepts. Planas (2014) observed a small sample of Catalan language learners interacting with native Catalan speakers while solving algebra problems in groups. Because the Catalan learners lacked specific mathematical terminology to describe the problems, they attempted different problem solving strategies (e.g., using a geometric approach to understand an algebraic expression). The language learners also focused more on the meaning of mathematical terms than their native-speaker group members did because they were unfamiliar with the requisite terminology.

Recently, more research has taken the approach of exploring potential cognitive benefits associated with bilingualism. Several theories have been developed that are consistent with the idea that prolonged experience managing more than one language may place unique demands on bilingual minds, resulting in cognitive advantages (Adesope, Lavin, Thompson, & Ungerleider, 2010). The exact nature of these advantages, however, has been difficult to pin down. Some researchers have explored the idea that bilinguals' need to suppress competition from one language when using another may lead to improved inhibitory control (Bialystok, Craik, & Luk, 2012), more efficient allocation of executive control resources in the face of conflict, or an advantage in overall response time on tasks that feature competition (Costa, Hernández, Costa-Faidella, & Sebastián-Gallés, 2009; Hilchey & Klein, 2011). However, others have failed to find evidence of a bilingual advantage in executive control (de Bruin, Treccani, & Della Sala, 2015; Paap & Greenberg, 2013; von Bastian et al., 2016).

Despite increasing evidence that bilingual young adults do not outperform their monolingual counterparts on executive control tasks, it is still possible that bilingual experiences could confer other cognitive benefits. Recent research has demonstrated that bilinguals may learn novel rules more efficiently than monolinguals (Stocco & Prat, 2014). The bilingual experience may also impact the development of metalinguistic awareness (Adesope et al., 2010; Bialystok, 1997; Galambos & Hakuta, 1988), which could have implications for algebra learning (MacGregor & Price, 1999). Even Vygotsky believed that bilingualism could have positive consequences on the flexibility and sophistication of human thought (Cummins, 1976; Vygotsky, 1962). He argued that being able to express the same thought in different languages enables one to see that any particular language is just one system among many, to separate labels from their referents, to understand the symbolic function of words, and to view words in more abstract, semantic, and general terms. The present research takes up this suggestion and builds on the intuition that bilingualism may potentiate the ability to engage in more abstract or symbolic thought processes, which play a crucial role in algebra learning.

1.3. The present study

In order to test for a bilingual advantage in symbolic abstraction, we developed a new experimental task: the Symbol Math task. In the Symbol Math task algebraic functions are presented in an unfamiliar way using a novel symbol to represent a particular sequence of basic mathematical operations. Task items are of the form:

$$x\Theta y = xy + x - y \quad \text{What is } 5\Theta 3?$$

The task requires symbolic abstraction because participants must understand that the novel symbol denotes a relationship between variables—a relationship defined by a set of mathematical operations. Further, participants must manipulate letters representing unknown quantities in order to obtain a solution for several items, and several items require using the output of one function as the input for another function. This task was developed to test for symbolic abstraction in a way that does not depend on previous experience with algebraic functions. The present experiments sought to address the question of whether bilinguals would outperform monolinguals on the Symbol Math task. If bilingualism confers specific advantages in symbolic abstraction, a bilingual advantage may emerge in performance on the Symbol Math task.

2. Experiment 1

In addition to the Symbol Math task, a basic math task was also included in this experiment in order to control for the impact of general mathematical ability. No differences were expected between monolinguals and bilinguals in basic math performance.

2.1. Method

2.1.1. Participants

Sixty-one undergraduates at an urban college in the northeastern U.S. (40 female) between the ages of 18 and 35 participated in this experiment for course credit in introductory psychology. Participants were classified as bilingual (N = 29) if they reported prolonged exposure to more than one language before the age of 7 (with prolonged exposure defined as both parents speaking a language other than English or attending school taught in a language other than English), or monolingual (N = 32) if they were native English speakers with no early prolonged exposure to another language. The decision to test for effects using only early bilinguals was based on previous literature exploring cognitive advantages associated with early bilingualism (see Luk, De Sa, & Bialystok, 2011 for a review) as well as prior work in creative problem solving that has identified benefits specifically among early (but not late) bilinguals (Cushen & Wiley, 2011).

For the bilingual sample, 90% reported English as their dominant language, and 31% reported English as the first language acquired (L1). Other dominant languages reported were Chinese (3%), Haitian Creole (3%), and Urdu (3%). Bilingual participants reported 13 different non-dominant languages: Russian (14%), Spanish (14%), Arabic (10%), Haitian Creole (10%), English (10%), Urdu (10%), Bengali (7%), Chinese (7%), French (3%), Hebrew (3%), Hindi (3%), Polish (3%), and Tagalog (3%). Bilingual participants reported using their dominant language 69.48% of the time. Participants indicated their speaking and comprehension proficiency for L1 and second language (L2) on a 0–10 scale (0 = none, 10 = perfect). Bilinguals reported similar speaking proficiency for L1 ($M = 8.34$, $SD = 1.59$) and L2 ($M = 8.69$, $SD = 1.14$), $t < 1$. Bilinguals also reported similar comprehension proficiency for L1 ($M = 8.76$, $SD = 1.27$) and L2 ($M = 8.93$, $SD = 1.07$), $t < 1$.

All monolingual participants reported English as their dominant language. The mean age of reported exposure to a second language was 14.13 ($SD = 2.54$). In contrast to the bilingual participants, monolinguals reported higher speaking proficiency for English ($M = 9.41$, $SD = 0.98$) than for their second language ($M = 2.41$, $SD = 1.76$), $t(31) = 22.74$, $p < 0.01$. Monolinguals also reported

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