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Solving arithmetic problems in first and second language: Does the language context matter?

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ABSTRACT

Learning mathematics in a second language is a challenge for many learners. The purpose of the study was to provide new insights into the role of the language context in mathematic learning and more particularly arithmetic problem solving. We investigated this question in a German–French bilingual educational setting in Luxembourg. Participants with increasing bilingual proficiency levels were invited to solve additions in both their first and second instruction languages: German and French. Arithmetic problems were presented in two different conditions: preceded by a semantic judgment or without additional language context. In the French session we observed that additions were systematically performed faster in the condition with an additional language context. In contrast no effect of the context was observed in the German session. In conclusion, providing a language context enhanced arithmetic performances in bilinguals' second instruction language. This finding entails implications for designing optimal mathematic learning environments in multilingual educational settings.

1. Introduction

1.1. Bilingual learning

Being taught in another language than the native language occurs very often in bilingual or multilingual populations (e.g., Extra & Gorter, 2001). Additionally, language immersion teaching programs, where for instance mathematics, sciences or geography courses are taught in the learner's second language, became more and more popular over the last years because such programs are perceived as an efficient and natural way to increase a second language's proficiency (Johnson & Swain, 1997). Nevertheless, it is well-known that non-native learners are more likely to have academic difficulties in general and more particularly with mathematical word problems, at least partially due to their lower command of the instruction language (Abedi & Lord, 2001; Gross, Hudson, & Price, 2009; Kempert, Saalbach, & Hardy, 2011; PISA report, 2012). Bernardo and Calleja (2005) showed that bilingual children's proficiency in the language of instruction is one of the most important factors influencing their mathematic proficiency.

In fact, growing up and/or being taught in more than one language raises the question whether and how instruction language(s) impact(s) the learned content and more generally the learners' academic achievement. Immersion programs mainly assume that the learned contents are sufficiently language-independent to be transferred to the learners' *mental* language. However, large-scale studies indicate that instruction language may significantly impact the learned contents (Cuevas, 1984; PISA report, 2012). Experimental evidence show that bilinguals' learned contents might strongly be associated to the language in

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which they were learned. Marian and Kaushanskaya (2007) reported that bilinguals responded differently to general knowledge questions according to the language in which these questions were asked. For example, to "name a statue of someone standing with a raised arm while looking into the distance", bilinguals responded more likely "the Statue of Liberty" when the question was in English while they responded more likely "the statue of Mao" when the same questions was asked in Chinese. Even closer to academic learning situations, Marian and Fausey (2006) presented Chemistry, Biology, and History contents to bilinguals either in Spanish or in English and then asked them questions about these contents in both languages. Participants responded faster when the language of the test matched the language of instruction than when they had to switch between languages. Together, these studies show how strong learned contents might be associated to the language of instruction.

Other authors trained bilingual participants to calculate in one language and then asked them to solve calculations in both of their languages. Spelke and Tsivkin (2001) showed that bilinguals could transfer calculations trained in one language to another for approximate calculations, but not for exact calculations. These results were replicated on trained multiplications and subtractions in German–French bilinguals (Saalbach, Eckstein, Andri, Hobi, & Grabner, 2013). Moreover, Venkatraman, Siong, Chee, and Ansari (2006) found similar advantages for the trained language in bilinguals performing exact additions in comparison to the untrained language and also corresponding brain activation networks related to the use of language in exact calculation. Taken together, these studies shed light on the importance of the instruction language in arithmetic and suggest that memorized calculations are represented verbally in a language-specific format, which seems to be difficult to transfer to another language. Similarly to the other aforementioned academic domains (Marian & Fausey, 2006), mathematical contents may thus also strongly be associated to the language of instruction. More generally, language is thought to play an important role in mathematical learning.

1.2. Learning mathematics with language

Even though all humans have a pre-verbal ability to approximate numerical quantities, learning to count with number words is mandatory to acquire exact numerical representations and master more complex mathematical skills, including arithmetic (Gordon, 2004; Xu & Spelke, 2000). Exact calculation is thus typically a mathematical skill acquired through instruction and which is thought to rely on language at different levels. During the exact calculation process, working memory resources are needed to execute solving procedures, keep in memory the intermediate solutions in memory and update the final solution (Ashcraft, 1995; Hitch, 1978). Particularly, the phonological loop of Baddeley's working memory model (1992) provides a support to verbally repeat the numbers in mental calculation (Fürst & Hitch, 2000; Logie, Gilhooly, & Wynn, 1994). Moreover, once simple calculations (i.e. usually calculations with operands <10) become overlearned with extensive practice, they can be retrieved directly from rote long-term memory (Ashcraft, 1992; McCloskey, 1992), where they are thought to be stored in a language-specific format (Campbell, 1994; Dehaene & Cohen, 1995). Because language plays such a key role in numerical learning, it is highly relevant to investigate arithmetic problem solving in bilinguals.

In line with the above-mentioned importance of language in arithmetic, the literature provides recurrent evidence that bilinguals calculate faster and more accurately in their first and better mastered language than in their second language, in which they are generally less proficient (Frenck-Mestre & Vaid, 1993; Geary, Cormier, Goggin, Estrada, & Lunn, 1993; Marsh & Maki, 1976; McClain & Huang, 1982). Neuro-imaging studies on Chinese-English bilinguals suggested that the verbal code of the first language is recruited to perform calculation and that extra language processing is needed in second language calculation (Lin, Imada, & Kuhl, 2011; Wang, Lin, Kuhl, & Hirsch, 2007). Although, one study showed that highly proficient bilinguals could achieve similar arithmetic performance levels in both of their languages (Campbell & Epp, 2004). Bilinguals' arithmetic performances in each language might also evolve across time with increasing language proficiency (Van Rinsveld, Brunner, Landerl, Schiltz, & Ugen, 2015). Besides bilinguals' language proficiency, the language of mathematic instruction also seems to play an important role. Indeed, it was observed that bilinguals calculated better in their non-native instruction language than in their native language, which was not used in the context of mathematic education (Bernardo, 2001; Salillas & Wicha, 2012). These findings have implications for bilingual or immersion education programs because they highlight the fact that some mathematical skills like arithmetic involve verbal processes and consequently the language in which they are taught may drastically influence performances.

1.3. The role of context in language selection

A key aspect of bilinguals' language competences is their ability to select and access the appropriate language for each situation (see Abutalebi, 2008 for a review about language control and L2 representations). According to the *Bilingual Interactive Activation Plus* or BIA + model (Dijkstra & Van Heuven, 2002), bilinguals access word meanings (i.e., lexical access) in a non-selective way via a shared lexicon for both languages at an early stage of the process (i.e., the words identification system). Later, the appropriate output language is then chosen by a decision sub-process. Hence, the linguistic context of a current task is thought to work as a decision threshold at this later stage. Similarly in language production, Kroll, Bobb, Misra, and Guo (2008) suggest that bilinguals activate both of their languages in parallel to produce words, but simultaneously, they use inhibitory processes to only produce words in the right language. These inhibitory processes are thought to occur with different efficiency degrees according to the relative levels of language proficiencies. Indeed, the less a language is mastered (e.g. second language), the more difficult it will be to use it without being interfered by the better mastered language (e.g. native language). Interferences in the other direction are possible too but to a lesser extend. Thus, it is more difficult to refrain the dominant language during the use of the non-dominant language than the other way around (Bialystok, 2009).

Additionally to language proficiency, the specific language context of each situation plays a fundamental role in the language selection process. Grosjean proposed a theoretical framework to account for the importance of language context in bilingualism: the *language mode hypothesis* (for a summary of his own studies see Grosjean, 2001). According to the language mode hypothesis, bilinguals' first and second language activation levels vary along a monolingual-bilingual continuum depending on their current so-called language mode. The language mode is determined by several factors such as the linguistic environment, the linguistic demand of a task, the nature and the topic of the interaction, etc. The effect of language context on bilinguals' performances has been broadly investigated in word recognition or lexical decision tasks by using inter-lingual homographs, i.e. words that have two different meanings according to the language in which they are