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Language affects symbolic arithmetic in children: The case of number word inversion

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A R T I C L E I N F O

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A B S T R A C T

Specific language influences have been observed in basic numerical tasks such as magnitude comparison, transcoding, and the number line estimation task. However, so far language influences in more complex calculations have not been reported in children. In this translingual study, 7- to 9-year-old German- and Italian-speaking children were tested on a symbolic addition task. Whereas the order of tens and units in Italian number words follows the order of the Arabic notation, the order is inverted in German number words. For both language groups, addition problems were more difficult when a carry operation was needed, that is, when a manipulation within the place-value structure of the Arabic number system was particularly important. Most important, this carry effect was more pronounced in response latencies for children speaking German, a language with inverted verbal mapping of the place-value structure. In addition, independent of language group, the size of the carry effect was significantly related to verbal working memory. The current study indicates that symbolic arithmetic and the carry effect in particular are modulated by language-specific characteristics. Our results underline the fact that the structure of the language of instruction is an important factor in children's mathematical education and needs to be taken into account even for seemingly nonverbal symbolic Arabic tasks.

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Introduction

Language effects for arithmetic are well documented. For example, participants are faster to solve addition problems in their native language than in their second language (Campbell & Epp, 2004). In the current article, we propose that not only the language of encoding but also language-specific number word structure has an effect on performance in addition tasks presented in Arabic notation. In particular, we show that a specific effect in multidigit addition, the carry effect, is modulated by number word structure.

The carry effect

Children and adults take longer and commit more errors when computing the solution to a sum for which adding the units leads to a change in the number of tens (e.g., 14 + 9 = 23) (Deschuyteneer, De Rammelaere, & Fias, 2005; Fürst & Hitch, 2000) than when it does not (e.g., 11 + 12 = 23). This effect is known as the carry effect; in carry problems, a one needs to be carried from the unit slot to the decade slot.

However, there is currently no agreement about the origin of the cost of a carry operation. Fürst and Hitch (2000) investigated the role of working memory (WM) in carrying. When participants performed a concurrent task tapping executive control, addition was impaired, in particular when requiring a carry. More specifically, loading verbal WM by articulatory suppression increased the number of errors on carry problems. Fürst and Hitch concluded that the phonological loop might be used to store the amounts to be carried. This is in line with Ashcraft's (1995) view that a successful carry operation (i.e., carrying the decade digit of the unit sum to the decade of the result) involves verbally counting up by one. As a consequence, children and adults with higher scores in tests of verbal WM and executive control are expected to show a smaller carry effect.

In contrast, Nuerk, Moeller, Klein, Willmes, and Fischer (2011) suggested that the carry effect is due to higher demands on the correct manipulation of single digits within the base-10 place-value structure of the Arabic number system when needing to transfer the carry from the units' position to the tens' position. Eye-tracking results support this idea. In an addition task with adults, reading time of the unit digits of the summands was specifically increased in carry trials (Moeller, Klein, & Nuerk, 2011b). Thus, reading time increased exactly for those digits that determine whether a problem requires a carry or not. A specific increase of the reading time of the unit digit of the summands in carry problems was already observed in third graders (Moeller, Klein, & Nuerk, 2011a). Furthermore, a longitudinal study by Moeller, Pixner, Zuber, Kaufmann, and Nuerk (2011) indicated that early place-value understanding is a significant predictor of later addition performance and the carry effect.

Given the combined influence of verbal factors and the place-value structure for the carry operation, we expect that cross-lingual differences in the structure of verbal number words differentially affect addition problems with higher demands on place-value integration, that is, those requiring a carry operation.

Number word structure

Arabic notation follows a strict system; the Arabic digits are read from left to right, the last digit specifies the number of units, the second from last digit specifies the number of decades, and so forth. Some languages (e.g., Japanese) have a highly regular number word structure; their number words closely reflect the sequence of units, tens, hundreds, and the like as found in Arabic notation (e.g., 62: roku jū ni → six ten two). This is not the case in most European languages, which usually have specific names for the multiples of ten. In English, for example, there is a relationship between the number word for multiples of ten and the corresponding unit, but children need to learn the marker for a decade word (-ty), and the words for the first decades are not formed regularly (i.e., twenty and thirty instead of two-ty and three-ty). In general, children from languages with regular number word structure tend to perform better in verbal counting, number reading, number comparison, base-ten, and