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Research Article

Does number word inversion affect arithmetic processes in adults?

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ABSTRACT

Neuropsychological and developmental findings suggest that number word inversion complicates numerical processing. The aim of this study was to look for adverse effects of number word inversion in neurologically healthy adults. Addition problems were presented verbally to native speakers from China and from Germany in two different ways: familiar vs. unfamiliar (i.e., inverted number words in Chinese and non-inverted number words in German). While Chinese participants had more difficulties when confronted with problems presented in unfamiliar Chinese number words, German participants did not show more difficulties solving addition problems presented in the unfamiliar structure. Moreover, for both groups, addition problems were more difficult when a carry operation was needed and this carry effect was more pronounced for German participants. Inverted number words thus seem to complicate arithmetic processing in populations where arithmetic processing is an accomplished skill, highlighting the relevance of finding ways to deal with inversion-related difficulties in mathematics education.

1. Introduction

Languages differ as to how numbers are named or read out aloud. In the German language, numbers are not named consistently from left to right (e.g., 24 is read 'vierundzwanzig', literally translated to 'four-and-twenty'). This so-called decade-unit-inversion can also be found in other languages such as Arabic, Danish, Dutch, Malagasy, Maltese, as well as partly in Czech and Norwegian. Even in English, numbers from 13 to 19 are named in reverse order of notation (e.g., 14 – 'fourteen'). Different lines of evidence suggest that the decade-unit-inversion may induce difficulties in number processing. First indications of such difficulties were presented by Sittig [22]. A so-called disorder of digit-writing [22,23] was detected in German-speaking patients with lesions in left parietal cortex: when asked to write numbers to dictation, these patients wrote two-digit numbers in reversed order (e.g., hearing 38 but writing 83). Similar mistakes occurred in arithmetic tasks (e.g., writing the answer '62' to the task '17 + 9'). In order to overcome these problems, one patient wrote two-digit numbers from right to left following the spoken sequence. Similar error patterns in patients with brain lesions have also been found during number reading [18]. More recent studies of brain-damaged patients also revealed violations of the German inversion rule, which appeared when writing numbers and less frequently when reading numbers [4], as well as when matching number words they had heard with visually presented Arabic numbers [1]. Moreover, Proios et al. [20] tested a Greek–German bilingual patient with a deficit in Arabic number production. Being asked to transcode two-digit numbers from German written number words to Arabic numbers, she consistently reversed the digits. In contrast, she was able to convert Arabic numerals into written or oral German number words. The difficulties encountered by this patient were specific to the German written language and were not found in the Greek written language.

Similar difficulties induced by the German inversion rule were found in school-beginners [21]. Furthermore, a comparison of children aged 7–10 years from Brazil, France and Switzerland with regard to basic number processing skills revealed specific difficulties of Swiss (German-speaking) children aged 8 and 9 years in transcoding (writing Arabic numerals to dictation and reading written Arabic numerals) and magnitude comparison (naming the larger number of orally or visually presented pairs of Arabic numerals [6]). According to the authors, these difficulties might be ascribed to the inversion property of the German number–word system. In line with this view, Zuber et al. [26] observed that for Austrian (German speaking) children aged 7, the inversion

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property poses a major problem in transcoding. Similarly, Krinzinger et al. [10] examined the transcoding performance of 7-year old children from France, Wallonia, Flanders, Germany and Austria, and showed that children speaking a language with inverted number words (i.e., Flemish, Austrian, German children) made more transcoding errors than those speaking a language without inversion. Investigating the influence of the number–word system on basic numerical processing within one culture, 7-year old Czech-speaking children (in Czech language a non-inverted as well as an inverted number–word system exists) revealed hardly any inversion-related errors in the non-inverted number–word system while about half of all errors were inversion-related in the inverted number–word system [19]. Moreover, Moeller et al. [14] showed that inversion errors in transcoding predict later arithmetic performance as well as mathematics grades of German-speaking children. Thus, the development of numerical skills seems to be related to the structure and transparency of a given number–word system. Indeed, it could be demonstrated that highly regular and transparent number word systems which are used in East Asian languages seem to make it easier for children to grasp multiplicative and additive relations between numbers (e.g., [12,13]). Moreover, the fact that East Asian number words for numbers between 10 and 20 are all composed of a tens value and a units value (e.g., 11 is read ten-one) appears to support children's strategic use of decomposition to solve arithmetic problems [7].

Recently, first indications of an influence of the decade-unit inversion on arithmetic processes in children were reported. Göbel et al. [9] compared 7- to 9-year old German-speaking and Italian-speaking children regarding their performance on addition tasks presented in Arabic code. For both groups, addition problems were more difficult when so-called carry operations were needed, i.e., when having to compute the solution to a problem for which adding the units leads to a change in the number of tens (e.g., 17+9). This carry effect was found to be more pronounced in response latencies for German-speaking children, indicating that symbolic arithmetic and the carry effect in particular are modulated by language-specific characteristics. According to the authors, this finding represents evidence for an influence of number word structure on place-value integration and suggests that it is more difficult to identify and keep track of positions during a carry trial when the number word structure is inconsistent with the Arabic notation. As neuropsychological and developmental psychological findings suggest that the decade-unit inversion complicates transcoding and arithmetic processes, it is tempting to ask whether such effects can still be captured in neurologically healthy adults. The present study therefore aimed to look for adverse effects of the decade-unit-inversion in neurologically healthy adults. We orally presented addition problems involving two two-digit addends to native speakers of Chinese and German and asked them to type the answers. For both groups the tasks were presented in a familiar way (non-inverted number words in Chinese and inverted number words in German) and in an unfamiliar way (inverted number words in Chinese and non-inverted number words in German). Moreover, inverted and non-inverted number words were presented with or without 'and' because the function word 'and' is used in German but not in Chinese. According to the triple code model for numerical cognition [5], multi-digit arithmetic operations involve a mental manipulation of the operation in Arabic notation. Therefore, solving arithmetic problems that are presented verbally should involve transcoding of the verbal input into visual Arabic code. If the decade-unit inversion complicates these transcoding processes, native speakers of Chinese should have more difficulties (significantly longer reaction times and more errors) working on unfamiliar (inverted) Chinese number words than working on familiar (non-inverted) Chinese number words. In contrast, confronting native speakers of German with unfamiliar (non-inverted) German number words should not necessarily cause longer reaction times or more errors, because the transcoding processes should be less complicated based on non-inverted input for which the number word structure is consistent with the Arabic notation. Furthermore, it is assumed that calculation with multi-digit numerals involves the sequential combination of elementary arithmetical operations, e.g. the calculation of the unit as well as of the tens sum based on the retrieval of verbally stored arithmetic facts [5]. If the calculation of the unit sum involves a carry operation and thereby a verbalization of a two-digit result, these arithmetic processes should be subject to an influence of the decade-unit-inversion. Hence, the German-speaking group can be expected to show a more pronounced carry effect than the Chinese-speaking group at least when considering familiar conditions.

2. Method

2.1. Participants

Twenty (20 right-handed, 19 female) native speakers of Chinese (mean age 19.6, range 19–20 years) were tested in China and 20 (18 right-handed, 15 female) native speakers of German (mean age 25.5, range 19–46 years) were tested in Germany. All participants were college students.

2.2. Stimuli

The stimulus set consisted of 45 addition tasks involving two two-digit addends. Except for the decade numbers (30, 40, 50, 60, 70, 80, and 90), all the two-digit numbers above 20 are named by inverted number words in German. Number words for teens (11–19) are not consistently inverted and they were therefore not used as stimuli. Terms of sums beginning with 21 were used, resulting in tasks with two-digit solutions ranging from 42 to 99. Tasks with solutions up to 49 were used as practice trials, whereas tasks with solutions from 51 to 99 were used as stimuli. Tasks with decade numbers as solutions or as addends were not included. Out of the 45 addition problems, 22 tasks required carrying. Each of these tasks was presented four times but in four different conditions. As the function word 'and' is used in German but not in Chinese, inverted and non-inverted tasks were presented with or without 'and' (see Table 1).

Table 1
Examples of the four different conditions (literal translation).

Condition	Chinese	German
Non-inverted without 'and' (common Chinese pronunciation)	Two-ten-six + two-ten-five	Twenty-six + twenty-five
Non-inverted with 'and'	Two-ten-and-six + two-ten-and-five	Twenty-and-six + twenty-and-five
Inverted without 'and'	Six-two-ten + five-two-ten	Six-twenty + five-twenty
Inverted with 'and' (common German pronunciation)	Six-and-two-ten + five-and-two-ten	Six-and-twenty + five-and-twenty