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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 versus 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 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 (1914). A so-called disorder of digit-writing (Sittig, 1914, 1921) was detected in 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 (Peritz, 1918). 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 (Claros Salinas & von Cramon, 1987), as well as when matching number words they had heard with visually presented Arabic numbers (Blanken, Dorn, & Sinn, 1997). Moreover, Proios, Weniger, and Willmes (2002) 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 schoolbeginners (Schmidt & Weiser, 1982). Furthermore, a comparison of children aged 7 to 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; Dellatolas, von Aster, Willadino-Braga, Meier, & Deloche, 2000). 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, Pixner, Moeller, and Nuerk (2009) observed that for Austrian (German speaking) children aged 7, the inversion property poses a major problem in transcoding. Similarly, Krinzinger et al. (2011) 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 (Pixner et al., 2011). Moreover, Moeller, Pixner, Zuber, Kaufmann, & Nuerk (2011) 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., Miller, Smith, Zhu, & Zhang, 1995; Miura, Okamoto, Kim, Steere, & Fayol, 1993). Moreover, the fact that East Asian number words for two-digit numbers are 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 (Fuson &

Kwon, 1992).

Recently, first indications of an influence of the decade-unit inversion on arithmetic processes in children were reported. Göbel, Moeller, Pixner, Kaufmann, and Nuerk (2014) 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 (Dehaene, 1992), 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 (Dehaene, 1992). 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 twenty (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

2.3. Procedure

At the beginning of a trial, a fixation cross was presented in the center of a computer screen while an addition task was simultaneously presented via headphones. Owing to the shorter lengths of Chinese number words, the presentation of addition tasks took 3000 ms in German and 2000 ms in Chinese. Participants were instructed to look at the fixation cross while listening to the addition task. Following the presentation of the addition task, participants were able to enter the solution by using the digit-keys located on the right hand side of the keyboard. Since all solutions were two-digit numbers, participants had to press two buttons. The first button (decades) had to be pressed within 10 seconds after presentation of the task and the second one (units) within five seconds after pressing the first button. The answers given by the participants were not displayed on the screen and they could not be corrected. If the answer was right, the reaction time was shown in the center of the screen for 100 ms. In the case of answering too late or incorrectly, “0 ms” appeared on the screen. Once the trial had ended, a grey screen was presented for 2000 ms which served to separate consecutive trials from each other.

The experiment consisted of 192 trials and was divided into four blocks. Each block contained all of the 48 addition tasks and all four different conditions were equally distributed across the blocks. Otherwise the occurrence of stimuli was randomized. To get used to the experimental procedure, participants started with 16 practice trials. Visual stimuli were presented on a 14" VGA color monitor (800 by 600 pixels) against a grey background. The entire experiment was controlled by Presentation® software (Neurobehavioral Systems). Viewing distance was about 60 cm.

3. Results

Analyses of variance (ANOVA) were conducted separately for reaction times (RT) and error rates (ER). Trials for which no response was given were classified as errors. RT was determined by the first button press[1] after the presentation of the addition task and no trimming/outlier removal was performed[2]. In order to take into account the variability due to the tasks in addition to the variability due to the participants, ANOVAs with repeated measures were run over participants (F_1-analyses) and addition tasks (F_2-analyses) and, based on these, minF’ values were computed (see Clark, 1973). The significance level of alpha = .05 had to be reached in all three analyses to accept an effect as significant. The F_1-analyses included the repeated (within-subject) factors structure (inverted vs. non-inverted number words), function word (number words with ‘and’ vs. number words without ‘and’), carry (carry vs. no-carry trials), as well as the unrepeated (between-subject) factor language (Chinese vs. German) and the F_2-analyses included the repeated factors structure (inverted vs. non-inverted number words), function word (number words with ‘and’ vs. number words

[1] Instead of defining RT by the first pressing of a button, the second one was used in a supplementary analysis. This did not change the results considerably.
[2] Excluding responses (first button presses) below 200 ms from analysis resulted in 0.03% of response exclusions and did not change the results.

without ‘and’), language (Chinese vs. German), as well as the unrepeated factor carry (carry vs. no-carry trials). In separate analyses using ANOVAs and two-sample t-tests, we only considered familiar conditions (non-inverted number words without ‘and’ for Chinese participants vs. inverted number words with ‘and’ for German participants) and compared Chinese and German participants with regard to overall performance and costs of carry operations. Individual carry costs were determined by subtracting mean RT/ER in no-carry trials from mean RT/ER in carry trials.

Analyses of RT revealed a significant main effect for structure ($F_1(1, 38) = 13.84$, $p = .001$, $\eta2 = .27$; $F_2(1, 43) = 37.91$, $p < .001$, $\eta2 = .47$; $minF'(1, 63) = 10.14$, $p < .01$). This main effect was mediated by an interaction with the factor language ($F_1(1, 38) = 6.76$, $p < .05$, $\eta2 = .15$; $F_2(1, 43) = 16.52$, $p < .001$, $\eta2 = .28$; $minF'(1, 66) = 4.80$, $p < .05$). Separate ANOVAs for the different languages revealed a significant main effect for structure with faster RT for non-inverted number words for Chinese participants only (Chinese: $F_1(1, 19) = 16.40$, $p = .001$, $\eta2 = .46$; $F_2(1, 43) = 41.89$, $p < .001$, $\eta2 = .49$; $minF'(1, 34) = 11.79$, $p < .01$; German: $F_1(1, 19) = .80$, $p = .38$, $\eta2 = .04$; $F_2(1, 43) = 2.56$, $p = .12$, $\eta2 = .06$; $minF'(1, 31) = .61$, $p = .44$). Moreover, significant main effects for the factors carry (carry: 3107 ms, no carry: 2419 ms; $F_1(1, 38) = 175.56$, $p < .001$, $\eta2 = .82$; $F_2(1, 43) = 23.75$, $p < .001$, $\eta2 = .36$; $minF'(1, 54) = 20.92$, $p < .001$) and language (Chinese: 2420 ms, German: 3106 ms; $F_1(1, 38) = 4.81$, $p < .05$, $\eta2 = .11$; $F_2(1, 43) = 192.04$, $p < .001$, $\eta2 = .82$; $minF'(1, 40) = 4.69$, $p < .05$) and a significant interaction between these two factors were found ($F_1(1, 38) = 27.81$, $p < .001$, $\eta2 = .42$; $F_2(1, 43) = 27.33$, $p < .001$, $\eta2 = .39$; $minF'(1, 81) = 13.78$, $p < .001$). Separate ANOVAs for carry and no-carry trials revealed a significant main effect of language for trials with carry operations only (carry: $F_1(1, 38) = 7.61$, $p < .01$, $\eta2 = .17$; $F_2(1, 21) = 140.58$, $p < .001$, $\eta2 = .87$; $minF'(1, 42) = 7.22$, $p = .01$; no-carry: $F_1(1, 38) = 2.12$, $p = .15$, $\eta2 = .05$; $F_2(1, 22) = 51.14$, $p < .001$, $\eta2 = .70$; $minF'(1, 41) = 2.04$, $p = .16$). No other effects reached significance.

Analysis of RT in familiar conditions (non-inverted number words without ‘and’ for Chinese participants vs. inverted number words with ‘and’ for German participants) revealed that Chinese participants answered faster (Chinese: 2206 ms, German: 3176 ms; $F_1(1, 38) = 10.44$, $p < .01$, $\eta2 = .22$; $F_2(1, 44) = 141.80$, $p < .001$, $\eta2 = .76$; $minF'(1, 44) = 9.72$, $p < .01$) and that the carry effect (Chinese: carry = 2441 ms, no carry = 1969 ms; $F_1(1, 19) = 20.58$, $p < .001$, $\eta2 = .52$; $F_2(1, 43) = 10.79$, $p < .01$, $\eta2 = .20$; $minF'(1, 62) = 7.08$, $p = .01$; German: carry = 3659 ms, no carry = 2693 ms; $F_1(1, 19) = 68.10$, $p < .001$, $\eta2 = .78$; $F_2(1, 43) = 22.65$, $p < .001$, $\eta2 = .35$; $minF'(1, 61) = 17.00$, $p < .001$) was more pronounced for German participants (Chinese: carry cost = 472 ms, German: carry cost = 966 ms; $t(38) = 5.27$, $p < .001$). Within the two language groups, carry costs did not significantly differ in the different conditions (Chinese: non-inverted number words without ‘and’ = 472 ms, non-inverted number words with ‘and’ = 401 ms, inverted number words without ‘and’ = 407 ms, inverted number words with ‘and’ = 378 ms, all $p >.05$; German: non-inverted number words without ‘and’ = 965 ms, non-inverted number words with ‘and’ = 998 ms, inverted number words without ‘and’ = 918 ms, inverted number words with ‘and’ = 966 ms, all $p >.05$). RT for all different conditions and results of paired-sample t-tests comparing the different conditions separately for Chinese and German participants as well as for carry and no-carry trials are shown in Figure 1.

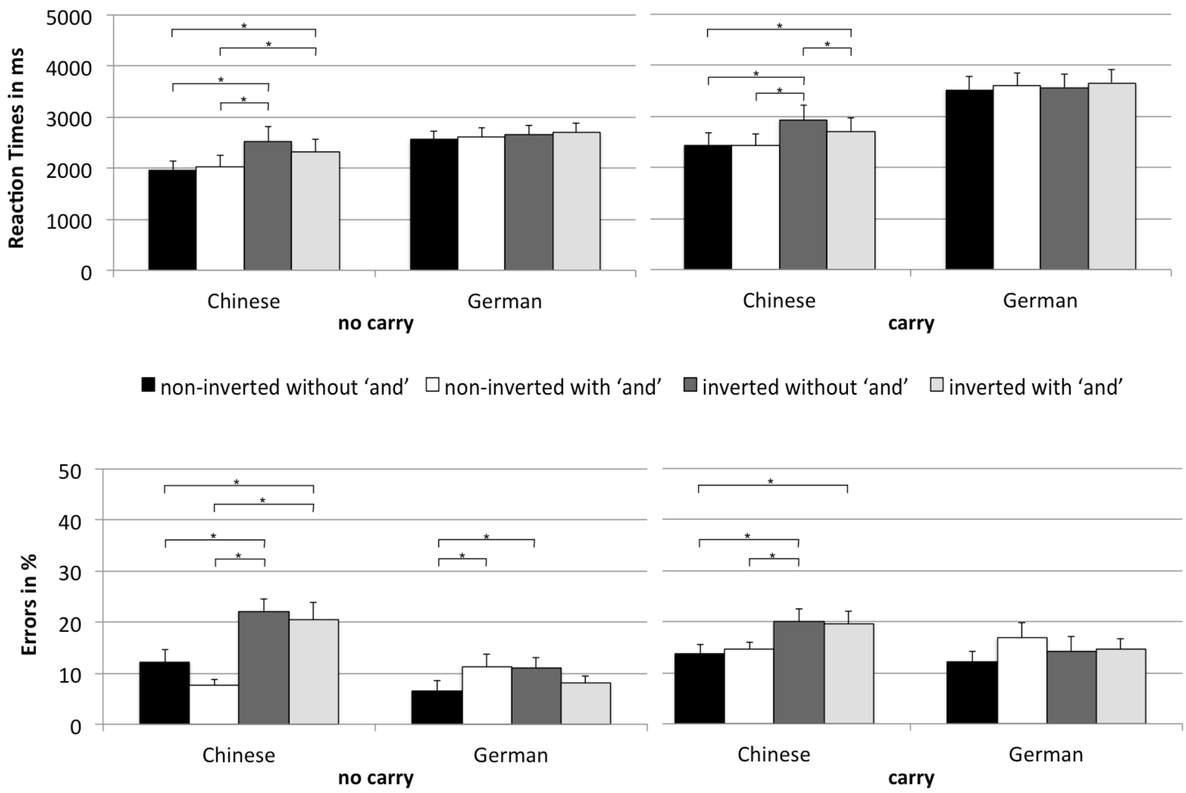

Figure 1. Mean performance for each language group. Mean reaction times for correct responses in ms and percentage of errors as a function of the factors language (Chinese vs. German), structure (inverted vs. non-inverted number words), function word (with 'and' vs. without 'and'), and carry (carry vs. no-carry trials). Error bars depict one standard error of the mean. Asterisks indicate significant differences ($p < 0.05$) between the respective conditions within one language group.

Based on ER, a significant main effect for structure ($F_1(1, 38) = 17.54$, $p < .001$, $\eta 2 = .32$; $F_2(1, 43) = 32.46$, $p < .001$, $\eta 2 = .43$; $minF'(1, 72) = 11.39$, $p = .001$), and a significant interaction (structure × language: $F_1(1, 38) = 15.46$, $p < .001$, $\eta 2 = .29$; $F_2(1, 43) = 14.75$, $p < .001$, $\eta 2 = .26$; $minF'(1, 81) = 7.55$, $p < .01$) were found. Again, separate ANOVAs for the two different languages revealed a significant main effect for structure with higher ER for inverted number words for the Chinese participants only (Chinese: $F_1(1, 19) = 23.04$, $p < .001$, $\eta 2 = .55$; $F_2(1, 43) = 30.88$, $p < .001$, $\eta 2 = .42$; $minF'(1, 47) = 13.20$, $p = .001$; German: $F_1(1, 19)$

= .06, $p = .81$, $\eta 2 = .00$; $F_2(1, 43) = .06$, $p = .80$, $\eta 2 = .00$; $minF'(1, 53) = .03$, $p = .86$). No other effects reached significance.

The analysis of ER in familiar conditions (non-inverted number words without 'and' for Chinese participants vs. inverted number words with 'and' for German participants) revealed that Chinese and German participants did not differ significantly with respect to ER (Chinese: 12.9%, German: 11.3%; $F_1(1, 38) = .51$, $p = .48$, $\eta 2 = .01$; $F_2(1, 44) = 1.67$, $p = .20$, $\eta 2 = .04$; $minF'(1, 60) = .39$, $p = .53$) and that the carry effect (Chinese: carry = 13.6%, no carry = 12.1%; $F_1(1, 19) = .24$, $p = .63$, $\eta 2 = .01$; $F_2(1, 43) = .26$, $p = .62$, $\eta 2 = .01$; $minF'(1, 62) = .18$, $p = .67$; German: carry = 14.5%, no carry = 8.0%; $F_1(1, 19) = 18.17$, $p < .001$, $\eta 2 = .49$; $F_2(1, 43) = 6.42$, $p < .05$, $\eta 2 = .13$; $minF'(1, 61) = 4.74$, $p < .05$) was not significantly more pronounced for one of the two groups (Chinese: carry cost = 1.5%, German: carry cost = 6.5%; $t(38) = 1.51$, $p = .14$). ER for all different conditions and results of paired-sample t-tests comparing the different conditions separately for Chinese and German participants as well as for carry and no-carry trials are shown in Figure 1.

4. Discussion

Effects of the decade-unit-inversion on arithmetic processes were investigated by confronting native speakers from China and from Germany with addition problems presented in familiar and unfamiliar number words (i.e., inverted number words in Chinese and non-inverted number words in German). Results demonstrated that Chinese participants had more difficulties (significantly longer RT and higher ER) when confronted with problems presented in unfamiliar (inverted) Chinese number words than when having to process problems presented in familiar (non-inverted) Chinese number words. For German participants who were used to inverted number words, addition problems presented in unfamiliar (non-inverted) German number words were overall not more challenging, suggesting that effects of familiarity seem to have been compensated by a decreased use of resources during processing non-inverted number words with a structure that corresponds to the Arabic notation. Thus, even in neurologically healthy adults processing of inverted number words seems to affect arithmetic processes. As it is assumed that multi-digit arithmetic operations involve a mental manipulation of the operation in Arabic notation (Dehaene, 1992), these findings might be ascribed to the fact that inverted number words complicate transcoding of verbal input into visual Arabic representations.

In line with previous findings in children (see Göbel et al., 2014), it could also be demonstrated that the carry effect (based on RT) was more pronounced for German-speaking adults than for Chinese-speaking adults when considering familiar conditions (non-inverted number words without 'and' for Chinese participants vs. inverted number words with 'and' for German participants). According to Göbel et al. (2014), inverted number words complicate the place-value integration especially in carry trials. Positional information is indeed of special importance during carry trials because the tens digit of the unit sum has to be carried to the tens position of the result. As calculation of the unit as well as of the tens sum involves the retrieval of verbally stored arithmetic facts (Dehaene, 1992), these operations should proceed in verbal code allowing for the influence of the decade-unit inversion in carry trials which entail a verbalization of a two-digit result. It can thus be inferred that inverted number words not only complicate the transcoding of verbal input into visual Arabic representations but also the transcoding and the place-value integration of verbally coded results of carry operations into visual Arabic representations. Moreover, within the two language groups, carry costs did not significantly differ in the different verbal input conditions suggesting that calculation processes in all conditions involved the retrieval of arithmetic facts stored as non-inverted number words without 'and' in Chinese participants and as inverted number words with 'and' in German participants. In line with this notion, arithmetic facts are assumed to be stored in the language they were acquired in (e.g., Campbell & Epp, 2004). It might be argued that the carry effect was more pronounced for German-speaking participants than for Chinese-speaking participants because of lower working memory capacities of German compared to Chinese participants. However, it could be demonstrated that German-speaking children show a larger carry effect than Italian-speaking children and that this difference was not driven by differences in working memory capacities (see Göbel et al., 2014). It can therefore be assumed that the more pronounced carry effect in German adults detected in our study can be ascribed to differences in the number word systems.

Comparing only familiar conditions (non-inverted number words without and for Chinese participants vs. inverted number words with and for German participants) indicated an advantage for Chinese participants with significantly faster RT and comparable ER. Cross-cultural assessments of mathematical achievement have repeatedly demonstrated that Asian students outperform their non-Asian peers at various ages (e.g., Mullis, Martin, Foy, & Arora, 2012; OECD 2013; Wang & Lin, 2009, 2013). This superior Asian performance has been attributed to various factors including number naming systems, cultural beliefs and values, parental involvement, as well as educational systems and practices (Ng & Rao, 2010). Regarding the language-related factors, not only the regular and transparent structure but also the shorter length of Chinese number words has been suggested to play a role (e.g., Geary, Bow-Thomas, Liu, & Siegler, 1996). Faster RT for Chinese participants might therefore be due to a higher speed of number pronunciation and a smaller load of working memory capacities (e.g., Lüer, Becker, Lass, Yunqiu, Guopeng & Zhongming, 1998).

To sum up, results of this study revealed that inverted number words seem to complicate the transcoding of verbal input into visual Arabic representations as well as carry operations in populations where arithmetic is an accomplished skill. Accordingly, difficulties induced by inverted number words during the acquisition of numerical and arithmetic skills do not disappear in adulthood, highlighting the importance of finding ways to deal with inversion-related difficulties in mathematics education.

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