# **Language affects symbolic arithmetic in children:**

# **the case of number word inversion**

Word count: 5432

**Abstract**

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 7-9 year old German- and Italian-speaking children were tested on a symbolic addition task. While 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, i.e. when a manipulation within the place-value structure of the Arabic number system was particularly important. Most importantly, 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 WM. 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.

[207 words]

Keywords: addition, carry effect, number word inversion, verbal working memory

**Highlights**

* Response times are higher for sums when adding units leads to a decade change (carry-effect)
* Number word inversion: sequence of tens and units in words is inverted compared to Arabic notation
* 7-9 year old children were tested on a symbolic addition task
* Carry effect is stronger for children speaking a language with number word inversion as well as for children with larger verbal working memory
* Language of instruction is an important factor in children’s mathematical education

# **Language affects symbolic arithmetic in children:**

# **the case of number word inversion**

Language effects for arithmetic are well-documented. For example, participants are faster to solve addition problems in their native than in their second language (Campbell & Epp, 2004). In the current paper 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 multi-digit 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, Fürst & Hitch, 2000; Deschuyteneer, De Rammelaere & Fias, 2005) than when it does not (e.g., 11 + 12 = 23). This effect is known as the carry effect: in carry problems a one has to be carried from the unit 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 (2000) 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) suggest 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 having to transfer the carry from the units' 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, i.e. 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 etc.. Some languages (e.g., Japanese) have a highly regular number word structure; their number words closely reflect the sequence of units, tens, hundreds, etc. 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 have to learn the marker for a decade word (-ty), and the words for the first decades are not formed regularly (i.e., twenty, thirty instead of two-ty, three-ty). Generally, children from languages with regular number word structure tend to perform better in verbal counting, number reading, number comparison, base-ten and place-value understanding as well as in arithmetic (e.g., Dowker, Bala, & Lloyd, 2008; Miller, Smith, Zhu, & Zhang, 1995).

In addition there are languages with number word inversion, i.e. the sequence of tens and units in number words is inverted with respect to the sequence in the Arabic notation. In those languages (e.g., German) 26, for example, is named ‘sixandtwenty’. The current study takes advantage of this cross-lingual difference to investigate the influence of verbal factors on the carry effect.

When the order of constituent tens and units in a number word is inverted compared to the order in the Arabic notation, transcoding from one notation to another is more challenging. For example, when a child hears ‘sechsundzwanzig’ (sixandtwenty) and tries to translate this number word step by step into Arabic notation she/he may erroneously write down 62 or 620 instead of 26. These inversion errors are typical for children in languages with number word inversion and almost absent in languages without inversion (e.g., Zuber, Pixner, Moeller, & Nuerk, 2009).

Given the inconsistency of the mapping between verbal number words and Arabic numbers such an inversion effect on transcoding is to be expected. However, even nonverbal Arabic number processing is influenced by number word inversion. A unit-decade compatibility effect for two-digit number comparison was first described by Nuerk, Weger and Willmes (2001). Response times were higher when decade and unit comparisons led to opposing responses (e.g. 28\_61, 2 < 6 but 8 >1) than when they led to the same response (21\_68, 2 < 6 and 1 < 8), indicating unit interference in two-digit number processing even when the unit is not relevant for the decision. The unit-decade compatibility effect is modulated by language: it is less pronounced in languages without inversion (Nuerk, Weger, & Willmes, 2005; Pixner et al., 2011).

These data indicate that inversion has a negative effect on children’s performance in basic numerical tasks whenever place-value integration is required. However, to our knowledge, it has not been investigated yet whether inversion also affects more complex numerical tasks, especially in conditions that require place-value integration. Therefore, we examined whether complex two-digit addition, and in particular the carry effect, is influenced by number word inversion in children

**The current study**

In the present study 198 7-9 year old children were tested on addition problems presented in Arabic notation. Half of those problems required a carry operation. We tested Italian- and German-speaking children, i.e. children from a language background either with regular number word structure or with number word inversion. Due to the inconsistency in the position of tens and units between verbal number words and digital-Arabic notation we expected children with a language with number word inversion, i.e. German-speaking children, to show a larger reaction time cost for carry operations than children with a language with regular number word structure, i.e. Italian-speaking. Given the documented influence of WM on the carry effect we also assessed children's WM to ensure that any language differences found are not due to WM differences between the groups (with higher WM scores expected to be associated with a smaller carry effect).

**Method**

The current study was part of a longitudinal cross-cultural project evaluating numerical development in Austrian (German-speaking) and Italian children from grade 1 to 4. In the present study, we focus on contrasting addition performance in grade 2.

## **Participants**

Ninety-four native German-speaking (48 girls) and 104 native Italian-speaking (50 girls) children were assessed at the end of grade 2, Austrian children were between 7 years 6 months and 9 years and 4 months (*M =* 8;3 years, *SD* = 4 months), Italian children between 7 years 3 months and 8 years 6 months (M = 7;9 years, *SD* = 3 months) old. All children had normal or corrected to normal vision. Children with an IQ score more than 1 *SD* below average were excluded (two Austrian, ten Italian children). Importantly, the mathematics curriculum is very similar in Austria and Italy.

## **Tasks, stimuli and procedure**

## All children were assessed individually in one-on-one sessions in a separate room. Intellectual ability was assessed by an adapted version of the Culture Fair Intelligence Test – Scale 1 (CFT-1, Cattell, Weiß, & Osterland, 1997) in grade 1 and is reported in T-Scores.

In second grade, working memory and addition performance were assessed. Three aspects of *working memory* (WM) were measured. 1. Verbal WM: children were asked to immediately recall spoken sequences of letters (presentation rate: one letter per second). Starting with two-item sequences sequence length was increased by one letter when at least two of three given sequences were recalled correctly, otherwise testing was stopped. The verbal WM score is the maximum sequence length at which at least two sequences were repeated correctly. 2. Visuo-spatial WM: in a block tapping task (Corsi, 1972) children had to repeat pointing to cubes in the same order as the experimenter. Again, children started with two-item sequences. The procedure and scoring were identical to letter repetition. 3. Central executive (CE): each child recalled sequences of letters and blocks in reversed order. The procedure and scoring were identical to the forward versions of the tasks. The two backward scores were averaged to generate a CE score for each child.

*Addition task:* Children were tested on a computerized addition verification task. The experiment started with ten practice trials. Addition problems (range of operands 2-19; problem size 7-36) and two solution probes were presented at the same time on the screen in white against a black background (font: Arial; size: 60). Problems were presented in the form xx + xx at the x-/y-coordinates (0/-120) while the two response options appeared at (-250/120) and (250/120) on a screen with the resolution set to 1024 x 768. There were 24 carry (e.g. 9 + 14) and 24 no-carry (e.g. 14 + 4) problems. Children had to choose the solution from two presented probes (e.g., 21 23; 18 16). Incorrect probes differed from the correct result by either ±2 or ±10 with average split matched at zero. Problem size was held constant between item categories. Problems and solution probes were presented until a response was given. Children indicated the correct solution by pressing the ‘Alt’ or the ‘Alt Gr’ button of a QWERTZ keyboard to choose the solution presented on the left or right. The inter-stimulus interval was set to 560 ms. No feedback was given.

**Results**

Trials with RTs three standard deviations above or below a child’s average RT were excluded. Children with a trial exclusion or error rate over 25% were not considered [five Austrian (mean age 8;3 years, 3 female) and 23 Italian (mean age years 7;11 years, 15 female) children]. For one Italian child no WM data were available. Thus, the data of 89 German- and 80 Italian-speaking children were considered in the analyses. Austrian children were on average significantly older and had higher CFT-1 and WM scores than Italian children (see Table 1).

Table 1

*Mean (Standard Deviations) of age, IQ and working memory for the Austrian and Italian sample*

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Austrian (N = 89) | | | |  | Italian (N = 80) | | |  | | | |  | | |  | | |  |
| Variable | | *M* | | *SD* |  | *M* | *SD* |  | | | *t§* | | | *p+* | | | *Cohen’s d* | | |
| Age (in months) | | | 99.72 | 4.48 |  | 95.24 | 3.42 |  | | | 7.25 | | | | <0.001 | | | 1.12 | |
| CFT (T-score) | | | 59.74 | 7.86 |  | 47.33 | 7.00 |  | | | 10.80 | | | | <0.001 | | | 1.67 | |
| Verbal WM  Visuo-spatial WM  Central Executive | | | 4.36  4.79  3.31 | 0.87  0.75  0.60 |  | 3.56  4.45  2.99 | 0.76  0.75  0.56 | | |  | | 6.36  2.93  3.58 | | | <0.001  0.004  <0.001 | | | 0.98  0.45  0.55 | |

§ Independent samples t-test, + two-tailed, Bonferroni-corrected significance level is 0.01

**The effect of language on the carry effect**

First, we investigated the effect of language group on the carry effect for response times and accuracy.

*Reaction times.* To control for differences in intra-individual variability all analyses of response speed were conducted on z-transformed RT using the mean and standard deviation per child for standardization (cf. Nuerk, Kaufmann, Zoppote & Willmes, 2004). Transformed RT of correct trials and error rates were analysed by repeated-measures ANOVAs with carry (carry, no-carry items) as within-subject factor and language (German-speaking, Italian-speaking) as between-subject factor. Raw RTs of correct trials are given when describing the results for reasons of readability. Children took on average 6909 ms (*SD* = 2204 ms) to choose the correct answer. Austrian children were on average 688 ms faster than Italian children, *F*(1,167) = 4.18, *p* = 0.04, *η*p2 = 0.02. The reliable main effect of carry, *F*(1,167) = 183.28, *p* < 0.001, *η*p2 = 0.52, indicated that RTs on trials requiring a carry operation were on average 1060 ms longer than RTs for trials without a carry operation.

Directly testing our hypothesis that the carry effect should be more pronounced in German- than in Italian-speaking children revealed that this was actually the case, *t*(167) = 1.92, *p* < .05, one-tailed testing a directional a priori hypothesis; ANOVA interaction: *F*(1,167) = 3.70, *p* = 0.06, *η*p2 = 0.02. The cost of a carry operation was significantly higher for German- than for Italian-speaking children (Figure 1, Table 2).

*Error rates.*For the error analysis an arcsine transformation was applied to approximate normal distribution. Transformed error rates were analysed by repeated-measures ANOVAs with carry (carry, no-carry items) as within-subject factor and language (German-speaking, Italian-speaking) as between-subject factor. Overall, children chose the incorrect answer on 8.97% of all trials. They made significantly more mistakes on carry, *M* = 10.21%, than on no-carry trials, *M* = 7.73%, *F*(1,167) = 13.92, *p* < 0.001, *η*p2 = 0.08. Error rates did not differ significantly between German- and Italian-speaking children, *F*(1,167) = 2.78, *p* = 0.10, *η*p2 = 0.02, 7.93% vs. 10.09%, respectively, and there was no significant effect of language on the carry effect for error rates, *F*(1,167) = 1.27, *p* = 0.26, *η*p2 = 0.008.

*Figure 1.* Mean RTs in ms for addition trials with and without carry for Austrian and Italian children (error bars reflect standard errors).

*Table 2.* Mean (Standard Deviations) RTs and error rates for addition trials

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | **Austrian children** | | **Italian children** | |
| **RT in ms** | **Carry** | 7167 | (2498) | 7741 | (2083) |
|  | **No carry** | 6000 | (2340) | 6801 | (2038) |
|  | **Carry Cost** | **1167** |  | **940** |  |
| **Errors in %** | **Carry** | 8.72 | (7.85) | 11.88 | (9.92) |
|  | **No carry** | 7.14 | (7.14) | 8.3 | (8.19) |
|  | **Carry Cost** | **1.58** |  | **3.54** |  |

**The relationship between the carry effect and WM subcomponents**

In a second step, we investigated the relationship between the carry effect and the WM subcomponents. First, because WM has been implicated in the carry effect we calculated correlations between children’s WM subscores and their carry effect (on RT) independent of language group (table 3). We included split size as additional factor here because processing distracters that differ either at the decade or unit position might affect strategy use and might therefore call on different WM components. Indeed, for verbal WM there was a significant correlation between children’s verbal WM score and the size of their overall carry effect as well as with the size of the carry effect for trials with split 2 and split 10 distracters. In contrast, spatial WM was not significantly correlated with the carry effect. Children with larger CE scores showed a significantly larger carry effect only for split 10 trials.

*Table 3:* WM subscores: relationship between the three subscores and the carry effect (on RT)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Verbal WM | | Spatial WM | | Central Executive | |
| Carry Effect | *r* | *p* | *r* | *p* | *r* | *p* |
| Split 2 | **0.17**\* | 0.03 | 0.11 | 0.14 | 0.04 | 0.59 |
| Split 10 | **0.21**\* | < 0.01 | 0.08 | 0.29 | **0.17\*** | 0.03 |
| Overall | **0.24**\* | < 0.01 | 0.12 | 0.13 | 0.13 | 0.09 |

Based on the results of the correlational analysis we run a repeated-measures ANCOVA with the covariates verbal WM and CE on transformed RT of correct trials with carry (carry, no-carry items) and split (2, 10) as within-subject factors. The carry effect was no longer significant, *F*(1, 166) = 0.12, *p* = 0.74, *η*p2 < 0.01, but was now strongly modulated by verbal WM, *F*(1, 166) = 7.15, *p* < 0.01, *η*p2 = 0.04. There was also a trend for split size modulating the carry effect, *F*(1, 166) = 3.35, *p* = 0.07, *η*p2 = 0.02. Children with larger CE, *F*(1, 166) = 2.69, *p* = 0.10, *η*p2 = 0.02, showed a trend towards responding faster. All other effects were not significant.

**Disentangling the effect of language from WM effects**

Given the relationship between verbal WM and the carry effect and the influence of split size described in the previous section and the significant differences between our language groups on age, CFT and WM subscores we decided to run another repeated-measures ANCOVA with the covariates age, CFT-1 score, verbal WM and CE on transformed RT of correct trials with carry (carry, no-carry items) and split (2, 10) as within-subject factors and language (German-speaking, Italian-speaking) as between-subject factor. The aim of this analysis was to ensure that the language effect described in the first part of the results section were not driven by differences between the language groups for the respective cognitive variables.

*Language effects.*There was a significant main effect of language group: Italian children, *F*(1, 163) = 3.97, *p* < 0.05, *η*p2 = 0.02, had significantly faster RTs. The carry effect was no longer significant, *F*(1,163) = 1.57, *p* = 0.21, *η*p2 = 0.01, nor was the interaction between carry effect and language group, *F*(1,163) = 1.61, *p* = 0.21, *η*p2 = 0.01. Yet, the latter was specified by a marginally significant three-way interaction with split size, *F* (1,163) = 2.88, *p* = 0.09, *η*p2 = 0.02. Breaking down this three-way interaction into the constituting two-way interactions to test our hypothesis revealed that Austrian children indeed showed a significantly larger carry effect for split 10 than Italian children, *F*(1, 163) = 4.75, *p* = 0.03, *η*p2 = 0.03, supporting our hypothesis that number word inversion adversely affects place-value integration. Overall, split size had no significant influence on RT, *F*(1, 163) = 0.02, *p* = 0.88, *η*p2 < 0.01, or the carry effect, *F*(1, 163) = 2.09, *p* = 0.15, *η*p2 = 0.01. There was no significant effect of the covariate age, *F*(1, 163) = 0.82, *p* = 0.37, *η*p2 < 0.01 and all interactions with age were non-significant.

*WM effects.* There was a significant effect of the covariate CE: children with larger CE scores, *F*(1, 163) = 4.01, *p* = 0.05, *η*p2 = 0.02, had significantly faster RTs. Verbal WM did not significantly affect overall RT, *F*(1, 163) = 1.40, *p* = 0.24, *η*p2 < 0.01, but counter-intuitively the carry effect was significantly more pronounced in children with higher verbal WM scores, *F*(1, 163) = 4.58, *p* = 0.03,  *η*p2 = 0.03. Interestingly, this effect was mainly driven by faster responses on non-carry problems: the higher their verbal WM score the faster they responded on trials not requiring a carry operation, *r* = - 0.23, *p* < 0.01, while the correlation between verbal WM scores and RT on carry trials was only marginally significant, *r* = - 0.14, *p* = 0.08. These correlations with verbal WM are significantly different, *Z* = -2.35, *p* < 0.05.

**Discussion**

# In this study we evaluated language influences on the carry effect in 7-9 year old German- and Italian-speaking children. For both groups a reliable carry effect was observed: it took children longer to choose the correct answer and they made more mistakes when the correct solution required a carry operation. Most importantly, as expected, this carry effect was more pronounced in response latencies for German- than for Italian-speaking children. These results are in line with the hypothesis that the carry effect is more pronounced in German-speaking children due to number word inversion in German number words. As a consequence this suggests that children - even when solving addition problems presented to them in digital-Arabic notation – at least co-activate Arabic digits into number words; possibly as some kind of subvocal verbalization of the addition problem. Furthermore, the current results add to the existing literature by showing that, at least in children, number word inversion specifically affects the size of the carry effect in addition. To our knowledge such a language-specific modulation of the carry effect has not yet been explored in adults. It is conceivable that this language-specific influence is only present early in arithmetic development and diminishes with increasing arithmetical experience: children during early numeracy acquisition in school may call more strongly upon a verbal representation even with stimuli presented in Arabic notation. With growing experience, however, access to numerical magnitude from Arabic notation might become automatic (Girelli, Lucangeli, & Butterworth, 2000) and verbalizing Arabic digits might subside later in development. A study by Colomé, Laka and Sebastián-Gallés (2010), however, suggests that even after years of experience with Arabic digits adults are still influenced by number word structure when solving additions in Arabic notation.

In the current study, responses to carry trials were influenced by number word structure in children. German-speaking children were overall faster to respond, but showed a relatively larger carry effect than Italian children. We interpret this finding as evidence for an influence of number word structure on place-value integration and suggest that place-value integration is easier when the mapping between number word structure and Arabic notation is consistent. The carry cost was smaller for Italian children because of the consistent mapping between the sequence of tens and units in Arabic notation and Italian number words. Positional information is more important during carry trials, because the essence of a successful carry operation is carrying the tens digit of the unit sum to the tens position of the result. It is more difficult to clearly identify and keep track of positions during a carry trial when the number word structure adds additional inconsistent positional information as it is the case for inverted number word in German. Our study provides direct support for this hypothesis: Italian children paid a smaller cost on carry trials than Austrians, especially when the distracter differed from the correct response on the tens position, indicating that it is easier for children to identify the relevant tens digit of the solution probes in carry trials when the mapping between the sequence of tens and units in number words is not inverted.

Our findings suggest that when addition problems are presented in Arabic notation, 7-9 year old children seem to activate verbal codes. In the Triple Code Model, Dehaene and Cohen (1997) proposed three different codes for number processing, an analogue, a visual and a verbal code. In this model simple arithmetic problems can be solved along two basic routes: a direct (between the visual and the verbal code) and an indirect (from the visual to the verbal code via the analogue code) route. The direct route for calculation is used in particular when associations between sums and answers have been learned verbally for fact retrieval from long-term memory. Arabic digits are identified and transcoded into number words and the corresponding verbally stored facts are retrieved. The degree of consistency of the number word system might influence the processing time along this route: when the mapping between the visual and the verbal code is inconsistent this may cause interference, such as the opposing order of tens and units in Arabic and verbal notation in German, which needs to be resolved. Interference resolution may then lead to a delay in overall processing speed. Given this difference in the consistency of the mapping between the visual and the verbal code between German and Italian, interference between the visual and verbal code should be more pronounced in German than in Italian. This predicts overall longer RTs for German children, but it does not predict a stronger effect of language particularly for addition problems with a carry. We argue that the cross-linguistic effect is due to higher demands in terms of place-value understanding for carry trials. While in no-carry trials any interference between the visual and verbal code in German can be resolved by simply focusing on units and decades separately during calculation and then exchanging the order of the words for tens and units, for carry trials the procedure is more complex: here, it is crucial to increase the decade word, but not the unit word, by one and this increase is a consequence of the operation on the unit digits. There is thus a consequence for the decade position from the calculation performed on the unit position. This process depends vitally upon keeping track of the correct positions of tens and units, i.e., a securely established positional place-value system, and is more demanding in languages with number word inversion. As a direct consequence further instruction on place-value understanding should be highly beneficial especially for children from languages with number word inversion.

Independent of language and in line with previous studies (e.g., Fürst & Hitch, 2000), the size of the carry effect was related to verbal WM and, less consistently, to CE. Counter-intuitively children with larger verbal WM showed a larger carry effect. However, this was mainly due to faster responses on non-carry problems. This suggests that the larger a child’s verbal WM the more strongly she/he activated the direct route to retrieve arithmetical facts, particularly for non-carry problems. Thus, verbal working memory might be important for the acquisition of arithmetic facts (Holmes & Adams, 2007), because it supports the direct route in retrieving arithmetic facts from long term memory.

The contribution of the CE to the carry effect depended on the response options provided: there was a significant correlation between the size of the carry effect and CE only for problems where the distracter differed from the correct solution at the tens position . This might be due to the reliance on different strategies depending on the split between the distracter and the correct solution in children with smaller CE. Approximation as an alternative to exact calculation is more successful for larger differences between solution and distracter (i.e. split 10). When the correct response differs from the distracter on the unit position (split 2) the exact unit sum will have to be calculated in any case, whether the trial requires a carry or not. For carry problems the carry procedure then has to be executed and the tens digit to be increased, leading to a carry cost. However, in cases where the correct response and the distracter differ in the tens position, it is sufficient to establish the correct tens digit which can often be done by simple estimation. When this strategy is used the size of the carry effect is diminished. Our results support the idea that children with smaller CE are more likely to use estimation strategies, especially when interim results have to be maintained, for instance, in carry problems with split 10.

In summary, our results strongly indicate that independent of working memory influences the structure of the language of instruction is an important factor in children’s numerical development not only in basic numerical tasks such as transcoding or magnitude comparison but also in more complex arithmetic. Our results highlight that in addition to relevant other cultural and educational factors (e.g. Towse & Saxton, 1997) the precise nature of the language of instruction should be taken into account for mathematics education.

**References**

Ashcraft, M. H. (1995). Cognitive Psychology and simple arithmetic: a review and summary of

new directions. *Mathematical Cognition, 1,* 3-34.

Campbell, J. I. D., & Epp, L. J. (2004). An Encoding-Complex Approach to Numerical Cognition in Chinese-English Bilinguals. *Canadian Journal of Experimental Psychology, 58,* 229-244. doi: [10.1037/h0087447](http://dx.doi.org/10.1037/h0087447" \t "_blank)

Cattell, R. B., Weiß, R. & Osterland, J. (1997). *Grundintelligenztest CFT-1 - Skala 1.* 5. Auflage. Göttingen: Hogrefe.

Colomé, A., Laka, I., & Sebastián-Gallés, N. (2010). Language effects in addition. How you say

it counts. *Quarterly Journal of Experimental Psychology, 63,* 965-983. [doi:10.1080/17470210903134377](http://dx.doi.org/10.1080/17470210903134377)

Corsi, P. M. (1972). Human memory and the medial temporal region of the brain. *Dissertation Abstracts International, 34*, 891B.Dehaene, S. (1992). Varieties of numerical abilities. *Cognition, 44,* 1-42. [doi:10.1016/0010-0277(92)90049-N](http://dx.doi.org/10.1016/0010-0277(92)90049-N)

Dehaene, S., & Cohen, L. (1997). Cerebral pathways for calculation: double dissociation

between rote verbal and quantitative knowledge of arithmetic. *Cortex, 33,* 219-250. [doi: 10.1016/S0010-9452(08)70002-9](http://dx.doi.org/10.1016/S0010-9452(08)70002-9)

Deschuyteneer, M., De Rammelaere, S., & Fias, W. (2005). The additions of two-digit numbers:

exploring carry versus no-carry problems. *Psychology Science, 47,* 74-83.

Dowker, A., Bala, S., & Lloyd, D. (2008). Linguistic influences on mathematical development:

how important is the transparency of the counting system. *Philosophical Psychology, 21,* 523-538. doi: 10.1080/09515080802285511

Fürst, A. J., & Hitch, G. J. (2000). Separate roles for executive and phonological components of

working memory in mental arithmetic. *Memory & Cognition, 28,* 774-782. [doi: 10.3758/BF03198412](http://dx.doi.org/10.3758/BF03198412)

Girelli, L., Lucangeli, D., & Butterworth, B. (2000). The development of automaticity in

accessing number magnitude. *Journal of Experimental Child Psychology, 76,* 104-122.  [doi: 10.1006/jecp.2000.2564](http://dx.doi.org/10.1006/jecp.2000.2564)

Holmes, J., & Adams, J.W. (2007). Working memory and children’s mathematical skills:

implications for mathematical development and mathematics curricula. *Educational Psychology, 26 (3),* 339- 366. doi: 10.1080/01443410500341056.

Miller, K.F., Smith, C.M., Zhu, J., & Zhang, H. (1995). Preschool origins of cross-national

differences in mathematical competence: the role of number-naming systems. *Psychological Science, 6,* 56-60. doi: 10.1111/j.1467-9280.1995.tb00305.x

Moeller, K., Klein, E., & Nuerk, H.-C. (2011a). (No) Small adults: Children’s processing ofcarry addition problems. *Developmental Neuropsychology, 36,* 702-720. [doi: 10.1080/87565641.2010.549880](http://dx.doi.org/10.1080/87565641.2010.549880)

Moeller, K., Klein, E., & Nuerk, H.-C. (2011b). Three processes underlying the carry effect in addition – Evidence from eye-tracking. *British Journal of Psychology, 102*, 623-645.  [doi: 10.1111/j.2044-8295.2011.02034.x](http://dx.doi.org/10.1111/j.2044-8295.2011.02034.x)

Moeller, K., Pixner, S., Zuber, J., Kaufmann, L., & Nuerk, H.-C. (2011). Early place-value

understanding as a precursor for later arithmetic performance – a longitudinal study on numerical development. *Research in Developmental Disabilities, 32,* 1837-1851. [doi: 10.1016/j.ridd.2011.03.012](http://dx.doi.org/10.1016/j.ridd.2011.03.012)

**Nuerk, H.-C., Kaufmann, L., Zoppoth, S., & Willmes, K.** (2004). On the development of the

mental number line. More, less or never holistic with increasing age. Developmental Psychology, 40, 1199-1211. [doi: 10.1037/0012-1649.40.6.1199](http://dx.doi.org/10.1037/0012-1649.40.6.1199)

Nuerk, H.-C., Moeller, K., Klein, E., Willmes, K., & Fischer, M.H. (2011). Extending the mental number line – a review of multi-digit number processing. *Zeitschrift für Psychologie/Journal of Psychology, 219(10),* 3-22. [doi: 10.1027/2151-2604/a000041](http://dx.doi.org/10.1027/2151-2604/a000041)

Nuerk, H.-C., Weger, U., & Willmes, K. (2001). Decade breaks in the mental number line? Putting the tens and units back in different bins. *Cognition, 82,* B25-B33. [doi: 10.1016/S0010-0277(01)00142-1](http://dx.doi.org/10.1016/S0010-0277(01)00142-1)

Nuerk, H.-C., Weger, U., & Willmes, K. (2005). Language effects in magnitude comparison: Small but not irrelevant. *Brain and Language, 92,* 262-277.  [doi: 10.1016/j.bandl.2004.06.107](http://dx.doi.org/10.1016/j.bandl.2004.06.107)

Pixner, S., Moeller, K., Hermanova, V., Nuerk, H.-C., & Kaufmann, L. (2011). Whorf reloaded: Language effects on nonverbal number processing in first grade – A trilingual study. *Journal of Experimental Child Psychology, 108*, 371-382. [doi: 10.1016/j.jecp.2010.09.002](http://dx.doi.org/10.1016/j.jecp.2010.09.002)

Towse, J., & Saxton, M. (1997). Linguistic influences on children's number concepts:

methodological and theoretical considerations. *Journal of Experimental Child Psychology, 66,* 362-375. doi: 10.1006/jecp.1997.2389

Zuber, J., Pixner, S., Moeller, K., & Nuerk, H.-C. (2009). On the language specificity of basic number processing: Transcoding in a language with inversion and its relation to working memory capacity. *Journal of Experimental Child Psychology, 102,* 60-77. [doi: 10.1016/j.jecp.2008.04.003](http://dx.doi.org/10.1016/j.jecp.2008.04.003)