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Automatic place-value activation

in magnitude-irrelevant parity judgement

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Abstract

Research on multi-digit number processing suggests that, in Arabic numerals, their place-value magnitude is automatically activated, whenever a magnitude-relevant task was employed: However, so far, it is unknown, whether place-value is also activated when the target task is magnitude-irrelevant.

The current study examines this question by using the parity congruency effect in two-digit numbers: It describes that responding to decade-digit parity congruent numbers (e.g., 35, 46; same parity of decades and units) is faster than to decade-digit parity incongruent numbers (e.g., 25; 36; different parities of decades and units). Here we investigate the (a-)symmetry of the parity congruency effect; i.e. whether it makes a difference whether participants are assessing the parity of the unit digit or the decade digit. We elaborate, how and why such an asymmetry is related to place-value processing, because the parity of the unit digit only interferes with the parity of the decade digit, while the parity of the decade digit interferes with both the parity of the unit digit and the integrated parity of the whole two-digit number.

We observed a significantly larger parity congruency effect in the decade parity decision than in the unit parity decision. This suggests that automatic place-value processing also takes place in a typical parity judgment task, in which magnitude is irrelevant. Finally, because of the cross-lingual design of the study, we can show that these results and their implications were language-independent.

Keywords: place-value processing, parity processing, parity congruency, automatic processing, number word inversion

Words count: 232

Introduction

Dealing with numbers plays a very important role in modern societies. Thus, it is crucial to investigate the cognitive processes underlying it. Traditionally, the domain of numerical cognition has focused mainly on the processing of single-digit numbers. Nevertheless, in everyday life, we mostly deal with multi-digit numbers (Huber, Klein, Willmes, Nuerk, & Moeller, 2014; Huber, Nuerk, Reips, & Soltanlou, 2017; Huber, Nuerk, Willmes, & Moeller, 2016 for a recent overview and a model). The studies on multi-digit number processing have shown that conclusions from investigations with single-digit numbers cannot automatically be transferred to multi-digit number processing (see Moeller, Huber, Nuerk, & Willmes, 2011 for a review). Of major importance for multi-digit number processing is the number system used. In the Arabic base-10 system, which is the most widespread system nowadays, the relative position of digits in a multi-digit number determines corresponding power of 10 (e.g., Krajcsi & Szabó, 2012), e.g., in the number 345.4 = [3] * 10^3 + [4] * 10^2 + [5] * 10^0 + [4] * 10^-1. Such a structure (power notation with base of 10, and without sub-bases, which are present in some systems) has several advantages for number processing and calculation (see eg., Zhang & Norman, 1995), but it also influences the way humans process numbers (e.g., Meyerhoff, Moeller, Debus, & Nuerk, 2012, for numbers beyond the two-digit number range; Nuerk & Willmes, 2005 for two-digit numbers). Nuerk, Moeller, and Willmes (2015) proposed three levels of place-value processing: (1) place identification (identifying the positions of numbers, possible without reference to power notation like in transcoding), (2) place-value activation (integration of positions and magnitudes, this is where the power notation starts playing a role, because the overall value of the number is determined),[1] and (3) place-value computation

[1] Place-value activation could in principle be further distinguished in approximate and exact place-value activation. Approximate place-value activation would refer to the approximate value of number magnitude on a fuzzy mental number line (Dehaene, 2001; Dehaene, Dupoux, & Mehler, 1990). A person (e.g., a child in a number line estimation task) would know that 92 is somehow larger than 29, which is comprised of the same digits, but on different positions, but may not be able to locate it exactly on a number line. For exact place-value activation, the exact value as indexed by the Arabic number system is derived. For the number 72, one would know that it is an

(manipulations of place-value structure, e.g., when one calculates additions with carry such as 34+28). In the current paper, we are mainly concerned with place-value activation in the taxonomy of Nuerk et al. (2015). One of the major issues of multi-digit number representation, which does not exist in single-digit number processing is whether the magnitude of multi-digit numbers in the place-value system is represented holistically, decomposed or in a hybrid fashion, combining holistic and decomposed representations.

Models underlying multi-digit number processing

According to the holistic model, multi-digit numbers are coded as a single entity onto a mental number line (Dehaene et al., 1990). The decomposed model suggests that multi-digit numbers are processed as a function of their components, namely, the position and magnitudes of their constituent digits (Huber et al., 2016; Moeller et al., 2011). Finally, the hybrid model (Moeller et al., 2011; Nuerk & Willmes, 2005) suggests that both holistic representations and decomposed representations contribute to processing multi-digit numbers.

Based on the research over the last 20 years, we can dismiss a purely holistic model. There are multiple effects (up to 18 in Nuerk et al., 2015) specific to multi-digit number processing, most of which suggest that some decomposed processing takes place. One effect suggesting decomposed processing is the unit-decade compatibility effect (Nuerk, Weger, & Willmes, 2001). The unit-decade compatibility effect describes the observation that in compatible magnitude comparison trials in which both decade and unit comparisons lead to the same response [e.g., 42_57, (4 < 5, and 2 < 7)], responses are faster than in incompatible trials, in which decade and unit comparisons lead to different responses (e.g., 47_62, 4 < 6, but 7 > 2). Evidence for decomposed processing can be found in parallel visual (Nuerk et al., 2001),

even number, a multiplication table result of 8*9, and not just some approximate magnitude between 70 and 80. The parity derived from such an exact integration of place-value activation of both digits (i.e., 90 and 2 for 92) is termed "integrated parity" or sometimes "place-value integration" in this manuscript.

sequential (Moeller, Klein, Nuerk, & Willmes, 2013), internalized (Moeller, Nuerk, & Willmes, 2009) and auditory numbers (Macizo & Herrera, 2008; Van Rinsveld, Schiltz, Landerl, Brunner, & Ugen, 2016) as well as in numbers in different symbolic formats (Ganor-Stern & Tzelgov, 2008). Thus, the evidence for decomposed processing does not rely on a single modality, notation or presentation mode, but can be observed fairly ubiquitously.

However, decomposed representations do not preclude that holistic representations of multi-digit numbers co-exist with them and recent studies suggest that holistic and decomposed processing accounts co-exist (Harris, Scheuringer, & Pletzer, 2018; Ratinckx, Nuerk, van Dijck, & Willmes, 2006). In sum, the question whether decomposed or hybrid processing can best explain the available results is still under debate.

Automatic place-value processing

So far, we have given examples where place-value processing was essential to solve the task. However, recent evidence suggests that place-value processing does not only occur when needed for the task, but rather is engaged automatically, even when it is task-irrelevant (Kallai & Tzelgov, 2012). Such automatic place-value processing in a magnitude comparison task has been demonstrated by Ganor-Stern, Tzelgov, and Ellenbogen (2007). They investigated the size congruity effect (i.e., an interference effect in a number comparison task caused by incongruities in the physical and numerical size of numbers to be compared; e.g., 2_5; Henik & Tzelgov, 1982) in two-digit numbers. Interestingly, size congruity was more affected by the magnitude of the decade number than by the magnitude of the unit number. This suggests that participants automatically processed the place-value of digits, sometimes even though this was disruptive to the task. This observation was also partly supported by García-Orza, Estudillo, Calleja, and Rodríguez (2017) for certain stimuli. To sum up, we have quite compelling evidence that place-value processing can be automatic at least when magnitude is relevant for the task.

An important inspiration for the current study is that all evidence for automatic processing so far has come from tasks in which magnitude had to be processed, either numerically or physically. One might argue that place-value processing is only automatically activated when semantic magnitude has to be processed, because then it is task-relevant. Support for such an argument comes from neuroimaging (Wood, Nuerk, & Willmes, 2006) and brain stimulation studies (Knops, Nuerk, Sparing, Foltys, & Willmes, 2006), which suggest that place-value activation is subserved by similar neural structures as magnitude processing (Nuerk, Klein, & Willmes, 2013). Moreover, patient data reported by Cipolotti and Butterworth (1995, see Figure 4 there) suggest that place-value activation is not necessary for number transcoding (specifically, writing numbers on dictation). At least in some patients, transcoding can be performed based on place identification, without activation of semantic magnitude.

To sum up, it is relatively well established that automatic place-value processing takes place in magnitude-related tasks. However, this does not warrant that it will also occur when the task does not rely on explicit processing of numerical magnitude. Here we show, that this is the case for parity processing, for which magnitude activation is not necessary.

Automatic magnitude activation in parity judgment tasks

Despite superficial similarities between magnitude comparison and parity judgement tasks, they differ considerably. In a parity judgment task, participants decide whether the presented number is odd or even (for overview of experimental tasks in numerical cognition see Cipora, Schroeder, Soltanlou, & Nuerk, 2018). The fundamental difference between these tasks is whether there is an explicit reference to number magnitude: this is the case for the magnitude comparison task but not for the parity judgment task. In parity judgement tasks, the magnitude information is irrelevant, and effects related to magnitude can be attributed to automatic processing. Nevertheless, magnitude is automatically processed in (some) parity judgement tasks. For instance, it can be observed via the SNARC effect (Spatial Numerical Association of Response

Codes; Dehaene, Bossini, & Giraux, 1993): in bimanual parity judgments relatively small/large numbers are responded to faster on left/right side, respectively. Thus, magnitude can be automatically activated in parity judgment tasks although it is task-irrelevant. However, so far it has not been shown that place-value processing is activated automatically in a parity task, where not only the magnitude of the digits, but even more their place-value activation is irrelevant for the task at hand. The goal of our study is to examine this question.

Decomposed processing in parity judgement tasks

In the few studies investigating parity in two-digit numbers, the results were indicative of decomposed number processing (Dehaene et al., 1993; Huber et al., 2015; Tan & Dixon, 2011). These three studies report that participants' reaction times were significantly slower when the parity of the decade digits was different from the parity of the unit digits (incongruent condition, e.g., 25, 36) compared to when the parity of both digits was the same (congruent condition, e.g., 35, 46). This effect has been termed the parity congruency effect (Dehaene et al., 1993; Heubner et al., 2018). Huber et al. (2015) suggest that it stems from a two-step process: First, parity information of both digits is extracted automatically; second, the parity of the decade digit needs to be inhibited with cognitive effort, leading to increased reaction times in incongruent trials (see also Macizo, 2017). It must be emphasized that in these studies participants only had to judge the whole number's parity, which is fully determined by the parity of the unit digit. The above explanation is based on a decomposed processing account, i.e., that the actual parity status of the irrelevant digit, which is nevertheless processed and represented, is causing interference.

The parity congruency effect shows that the parity status of the task-irrelevant decade digit influences the parity judgement of the task-relevant unit digit. Thus, it supports (at least partially) decomposed processing of the numbers. Therefore, the presence of the parity congruency effect contradicts the holistic model but does not provide evidence in favour of the decomposed model over the hybrid model (assuming partially decomposed processing) or the other way round. Therefore, place-value magnitude processing is not necessary to explain two-digit parity congruency effects.

Deriving predictions for parity congruency effects from multi-digit number processing models

For each two-digit number we can consider three types of parity representation:

(a) *unit parity*, e.g., odd for 25, because of 5

(b) *decade parity*, e.g., even for 25 because of 2

(c) *integrated parity*, that is the parity status of the whole two-digit number. In the place-value based-10 Arabic number system, the parity of the whole two-digit number (e.g., 25 or 36) is fully determined by the unit number (i.e., 5 or 6, respectively). While this seems natural for us, it is important to note that this is not the case for all number systems, e.g., not for base-5-systems, (Iversen, Nuerk, Jäger, & Willmes, 2006; Iversen, Nuerk, & Willmes, 2004).

Since the integrated parity is determined solely by the unit parity, within a typical experimental setup, one cannot directly distinguish between the influence of the unit parity and the integrated parity. However, as we will outline below, such a distinction can be investigated indirectly in an experiment in which apart from assessing the number parity (or unit parity) the participants also need to assess the decade digit parity because the incongruences differ when decade parity or unit parity is assessed (see Figure 1).

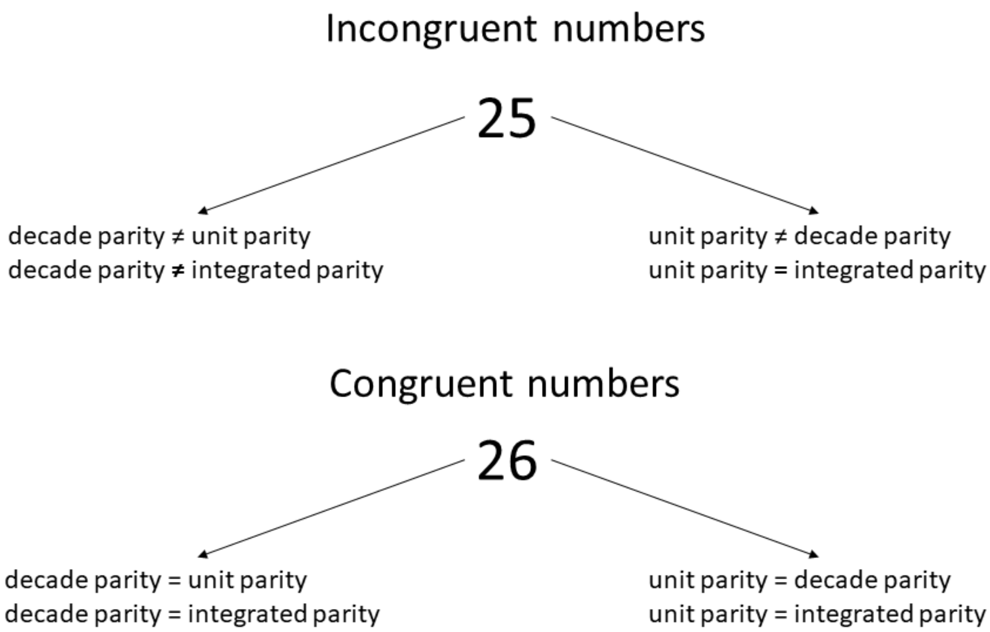


Figure 1. Schematic presentation of parity congruency between unit parity, decade parity, and integrated parity.

From this structure, we can derive two hypotheses according to different models:

1. *Hybrid processing:* The unit and decade digit parities are both activated separately in a decomposed fashion. Additionally, the place-value integrated parity is automatically activated. If the integrated parity is automatically activated during two-digit number processing, the congruency effect should be stronger when participants have to assess the parity status of the decade numbers than when they assess the unit parity. The reason is that in the decade parity, participants need to overcome two incongruencies (decade parity vs. unit parity and decade parity vs. integrated parity), whereas in the typical unit parity condition, one needs to overcome only one incongruency (unit parity vs. decade parity; cf. Figure 1).

2. *Decomposed processing:* In this case only the unit and the decade parities are activated, but not the place-value integrated parity of the whole number. Here, we expect parity congruency effects for both the unit parity judgement and the decade parity judgement, but no asymmetry in the congruency effect, because in both conditions incongruity refers only to the other digit, which could be viewed as a distractor.

Language modulation of automatic place-value activation

Multi-digit number processing is also affected by specific properties of the language spoken by an individual (Dowker & Nuerk, 2016; Nuerk et al., 2015). One of the most thoroughly investigated linguistic properties in the context of multi-digit number processing is the inversion property of the corresponding number word. In most languages (e.g., English) while naming two-digit numbers, one first refers to the decade number, and then to the unit number (e.g., '*twenty-seven*'). On the contrary, in several Germanic (e.g., German, Dutch) and Arabic languages, the number of units is named first (e.g., number 27 is named '*seven-and-twenty*'). The inversion property has been shown to influence several aspects of multi-digit number processing, such as magnitude comparison (e.g., Nuerk, Weger, & Willmes, 2005). In general, inconsistent mappings between Arabic numbers and corresponding numbers words (in inverted languages, where the unit is spoken/heard/read/written first for number words, while the decade is written first in Arabic notation) lead to slower and more erroneous responses across tasks and samples.

As underlying mechanisms, it has been proposed that: (1) The inversion property makes the units more salient, because their corresponding verbal representation is processed first. This seems particularly important for parity judgment, because in languages with inversion the decisive unit number is spelled out first. Therefore, if there are language differences, the unit interference in a parity congruency effect might be larger in German compared to English, while the opposite might be true for the decade interference in the parity congruency effect. (2) Place-value integration, i.e., the built-up of an exact identity of a multi-digit number based on the place-value activation of decades and units digits (see Footnote 1) is harder and more erroneous in languages with inversion, because the Arabic order and the verbal order supporting such integration are inconsistent in such languages. Therefore, the integrated parity of a two-digit number, which is based on exact place-value integration of decade and unit digit, might not be built up as easily and robustly in German as it does in English. Therefore, the asymmetry between unit-parity congruency effects and decade-parity congruency effects might not be as strong in German as in English because this asymmetry relies on the automatic activation of integrated parity.

Hypotheses

To sum up, this work aimed at testing three hypotheses.

1. *(At least partially) decomposed processing of parity*: As a baseline and validation for the other hypotheses, we aimed to replicate the typical parity congruency effect, corroborating either decomposed or hybrid processing of multi-digit parity.
2. *Automatic place-value activation when magnitude is irrelevant:* Unit parity and decade parity effects should be asymmetrical if place-value integrated parity is automatically activated, which provides direct support for the hybrid model over the decomposed model.
3. *Language modulation of parity processing:* In inverted languages like German, the role of the unit parity should be enhanced and the role of decade parity and integrated parity reduced, because units are named first.

Method

Participants

There were 51 participants (40 females, age = 19.9 years, *SD* = 2.5). Of these, 27 were English speakers (23 females, age = 19.0 years, *SD* = 1.0, of which 3 were excluded due to technical problems with the computerized procedure) and 24 were German speakers (20 females, age = 21.0 years, *SD* = 3.1). Participants were undergraduate students and were compensated either by course credit points or their monetary equivalent. Participants themselves and both their parents had to be native speakers of their respective language, and participants had not lived abroad for more than a year in total. These selection criteria were used to minimize the possible confounding effect of linguistic features of non-native languages on the numerical processing in the participants' native language. All participants were right-handed, had never been diagnosed with neurological or psychiatric diseases or learning disabilities and had normal or corrected-to-normal vision. Informed consent was obtained from all participants. The study was approved by the Ethics committees of the University of Tuebingen and the Department of Psychology, University of York.

Materials

All numbers in the range 20-99 were used and presented in Arabic notation. Therefore, there were 80 unique numbers, 40 are odd and 40 are even (considering both unit parity as well as decade parity). Importantly, half of numbers within this range (i.e., 40) are parity congruent, and half are parity incongruent.

The experiment was built and data collected using Presentation® software (Version 18.1, Neurobehavioral Systems Inc., http://www.neurobs.com) running on a 13.3" laptop computer (resolution 1920 × 1080 pixels). In the bimanual parity judgment task, participants had to judge the parity of either decade or unit digit of a visually-presented two-digit number. For instance, being presented with number 54, in the unit parity block, participants had to give an "even" response, whereas in the decade parity block, the correct response was "odd".

Each trial started with a centrally presented fixation point (black square 25 × 25 pixels) displayed randomly for 175-250ms (jittered in intervals of 25ms). Subsequently, the target number was presented in black Times New Roman font; size 30. The location of the stimulus was varied horizontally (3 possible locations differing by the width of a single character) to prevent participants from attending to only one location on the screen. Participants gave their responses using their index fingers to press A and L keys on the computer keyboard marked with blue and purple stickers, respectively. After participants' response or 3000ms after stimulus onset, a mask (blurred grayscale texture, covering entire screen) was presented for 200ms. Throughout the experiment the screen background was light grey (210 210 210 in RGB notation) to avoid sharp contrasts.

Each block consisted of 400 trials (each number was presented 5 times). Presentation order was pseudorandomized: all 80 numbers were presented fully randomized and this routine was repeated five times in each block. Each block was preceded by a short practice session, in which a prompt reminding the response-to-key assignment was displayed and accuracy feedback was provided. Each practice session comprised eight different numbers. The practice session was terminated if an 80% average accuracy threshold was met for the eight numbers, otherwise the practice session was repeated until the threshold was met.

The task comprised four blocks: each unit-parity and decade-parity block was repeated twice with reversed response-to-key assignment[2]. In the unit-parity condition, the instruction stated "(…) assess the parity of the units (e.g., 2 in 32)", and in the decade-parity condition it was "assess the parity of the decades (e.g., 3 in 32)". Therefore, the instruction did not promote holistic processing of a two-digit number in the unit-parity condition, as it solely focused on parity status of the unit digit, not the parity status of the whole number. The order of blocks was counterbalanced across participants with the restriction that response-to-key assignment changed only once during the testing session. A printed card with the current response-to-key assignment was visible for participants throughout the whole experiment.

Procedure

Participants were tested individually and were asked to respond as accurately and quickly as possible. After two blocks, they had a short break in which they filled in a questionnaire

[2] This setup allows examining the SNARC effect (Dehaene et al., 1993) as well. This was not the main objective of this experiment, but we report the results in Appendix A.

concerning linguistic experiences and experiences abroad and a short fluid reasoning task. Upon completion of the computerized task, participants filled out the Abbreviated Math Anxiety Scale (AMAS; Hopko, Mahadevan, Bare, & Hunt, 2003) in their native language as well as a speeded calculation task. At the end of the experiment, participants were debriefed about the purpose of the study. Additional tasks are not reported here, because they were not the objectives of this study.

Analysis

One English male was excluded from the analyses due to low accuracy (61%, below 2.5 *SD* from the sample mean). The mean accuracy of the remaining participants was 93.98% (*SD* = 3.59%). Erroneous trials were excluded from Reaction time (RT) analyses, but a separate analysis was conducted on accuracy data. RTs shorter than 200ms (< 0.01% of trials) were treated as anticipations and discarded from further analyses. Concerning outlier RTs, a sequential trimming method was used, RTs outside ± 3 *SD* from individual's mean were removed sequentially (Cipora & Nuerk, 2013). Eventually 88.34% of all experimental trials were considered in the RT analysis.

The main analysis was conducted in a 2 (Language: English vs. German) × 2 (Target digit: unit vs. decade) × 2 (Parity congruency: congruent vs. incongruent) design. Interactions were disambiguated with *t*-tests. The same ANOVA model was applied for mean reaction times and response accuracies. ANOVA models considering two additional factors (target-digit parity and hand) for both RTs and accuracies are reported in Appendix B.

Results

Reaction times

The descriptive statistics are reported in Table 1, and the results of the ANOVA are presented in Table 2. There was a robust main effect of parity congruency. Congruent trials were responded to faster than incongruent trials.

Table 1. Mean reaction times and corresponding standard deviations (in milliseconds) in each condition.

Language	**Decade Parity**			**Unit Parity**			**Overall**
	Congruent	**Incongruent**	**Total**	**Congruent**	**Incongruent**	**Total**	
English	529 (60)	550 (67)	539 (64)	526 (62)	540 (63)	533 (62)	536 (63)
German	535 (53)	554 (58)	545 (56)	539 (50)	553 (47)	546 (49)	545 (52)
Overall	532 (56)	552 (62)	542 (60)	533 (56)	546 (55)	540 (56)	541 (58)

Crucially, the parity congruency interacted with the target digit (cf. Figure 2). Namely, despite being present in both conditions, the parity congruency was more pronounced in the decade parity condition, $t(46) = 10.48$; $p < .001$, $d = 1.53$, than in the unit parity condition $t(46) = 8.86$, $p < .001$, $d = 1.29$.

Table 2. The ANOVA results on reaction times.

Effect	***F*(1,45)**	***p***	**η_p^2**
Language	0.30	.585	.01
Congruency	206.78	**< .001**	.82
Congruency × Language	0.08	.774	< .01
Target digit	0.58	.451	.01
Target digit × Language	1.17	.285	.03
Congruency × Target digit	6.18	**.017**	.12
Congruency × Target digit × Language	0.18	.678	< .01

Note. Significant effects are marked in bold.

Contrary to our predictions, none of the within-subject factors interacted with the language spoken by participants. There was also no main effect of the language nor a main effect of the target digit (cf. Table 1).

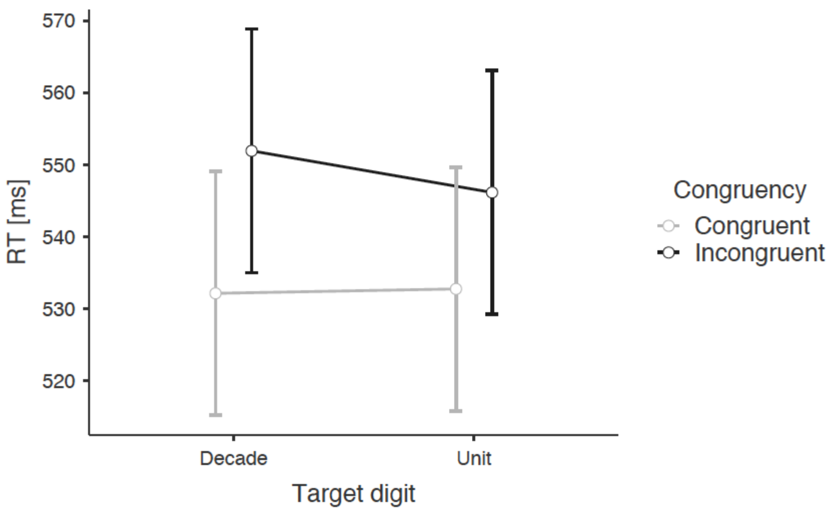


Figure 2. Parity congruency in both target digits on reaction times. Marginal means used, bars represent 95% confidence intervals.

Accuracies

The descriptive statistics are reported in Table 3, and the results of the ANOVA are presented in Table 4.

Table 3. Mean accuracies and corresponding standard deviations in each condition.

Language	**Decade Parity**			**Unit Parity**			**Overall**
	Congruent	**Incongruent**	**Total**	**Congruent**	**Incongruent**	**Total**	
English	.94 (0.03)	.91 (0.04)	.92 (0.04)	.94 (0.03)	.91 (0.04)	.93 (0.04)	.93 (0.04)
German	.97 (0.03)	.94 (0.05)	.95 (0.04)	.96 (0.03)	.94 (0.05)	.95 (0.04)	.95 (0.04)
Overall	.95 (0.03)	.92 (0.04)	.94 (0.04)	.95 (0.03)	.93 (0.04)	.94 (0.04)	.94 (0.04)

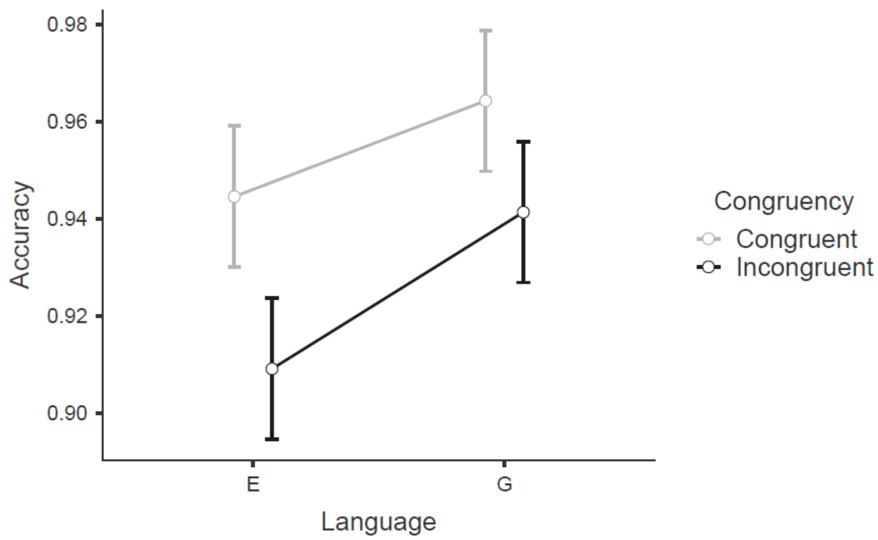
There was a main effect of Language. German speakers performed better than English speakers. The main effect of Congruency was robust. Accuracy was higher for congruent than in incongruent trials. There was also a significant Congruency × Language interaction. The Congruency effect, being present in both languages, was more pronounced in English, $t(22) = 9.97$, $p < .001$, $d = 2.08$, than in German speakers, $t(23) = 5.64$, $p < .001$, $d = 1.15$ (cf. Figure 3). The main effect of Target digit was not significant, and it did not interact with any other factor. The three-way interaction was also not significant.

Table 4. The ANOVA results on response accuracies.

Effect	***F*(1,45)**	***p***	**η_p^2**
Language	6.95	**.011**	.13
Congruency	116.12	**< .001**	.72
Congruency × Language	5.34	**.025**	.11
Target digit	0.05	.833	< .01
Target digit × Language	0.32	.572	.01
Congruency × Target digit	2.67	.109	.05
Congruency × Target digit × Language	0.16	.691	< .01

Note. Significant effects are marked in bold.

To sum up, the robust parity congruency effect was also reflected in response accuracies. The pattern of other effects was not very consistent. The crucial Target digit × Congruency interaction was not significant. Nevertheless, the accuracies were very high and results of this should be treated with caution due to ceiling effects. We acknowledge that these accuracy data are not in line with our predictions, however, we report them to provide an exhaustive overview of our findings[3].



[3] Discrepancy between RT and accuracy data in numerical cognition have already been reported (see eg., Ratcliff & McKoon, 2018; Ratcliff, Thompson, & McKoon, 2015). Such differential effects can be accounted for in future research by using the diffusion models.

Figure 3. Parity congruency in response accuracies in English (E) and German (G) speakers. Marginal means used, bars represent 95% confidence intervals.

Discussion

In this study we investigated three hypotheses. First, as a baseline for testing other hypotheses, we aimed to confirm an at least partially decomposed processing of parity. Second, we wanted to test whether the automatic place-value activation is present in the context of parity processing, which favours the hybrid over decomposed model of multi-digit number processing. Third, we aimed to check whether the abovementioned effects are modulated by a language property such as unit-decade inversion, present in German but not in English.

We observed a robust parity congruency effect showing that parity processing is partially decomposed as predicted by the hybrid model. That is, the presence of the task-irrelevant digit influences the time needed for parity judgment. We also found that the parity congruency effect was more pronounced when participants decided on parity status of the decade digit, than when they decided on parity status of the unit digit. This finding supports the claim that automatic place-value activation occurs also in magnitude-irrelevant tasks. Lastly, contrary to our predictions, we did not observe any effects of language on reaction times, neither main effect nor interaction. However, there was an effect in response accuracies. These findings will be elaborated in following sections.

Hybrid processing

The substantial evidence of the parity congruency effect (Dehaene et al., 1993; Huber et al., 2015; Tan & Dixon, 2011) lends strong support to the claim of hybrid processing of parity. Parity decisions were much faster if the task-irrelevant digit had the same parity status as the task-relevant digit. In terms of effect sizes, this effect can be considered very strong. Importantly, the conclusion derived from the parity congruency effect, that multi-digit numbers are at least partly processed in a decomposed way, converges with conclusions drawn from studies on magnitude processing (Huber et al., 2016; Moeller et al., 2011). Converging results from two different tasks (i.e., requiring processing of two fundamental numerical features: magnitude and parity) suggest that hybrid processing can be considered as a universal principle of multi-digit number processing.

Nevertheless, in the case of the parity congruency effect, one can think of an alternative explanation, that the effect has more domain-general origins – i.e., that it may be an instance of a more general flanker effect (Eriksen & Eriksen, 1974). Namely, that the effect could originate solely from the automatic processing of task-irrelevant stimuli presented in spatial proximity to the target stimulus. We discuss this in more detail below in the section on the asymmetric congruency effect.

Automatic place-value activation

The parity congruency effect was present irrespective of whether the participants were judging the parity status of the decade or unit digit. However, the effect was more pronounced when participants were responding to the parity of the decade digit than when they were responding to the parity of the unit digit. This is in line with the claim of automatic place-value activation outlined in the Introduction. In line with findings of the automatic place-value activation in magnitude tasks (Kallai & Tzelgov, 2012), we found similar effects in the case of parity processing. On the one hand, the parity information of the overall two-digit number is automatically activated, and thus reduces observed interference in the tasks when an individual needs to judge the parity of unit digit in an incongruent trial (cf. Figure 1). On the other hand, when one evaluates parity status of the decade digit, in the incongruent trial, the interference caused by the unit digit is amplified by interference caused by the automatic parity activation. Ganor-Stern et al. (2007) argue that only the magnitude of the components, but not the magnitude of the whole number is automatically processed. However, they show that the magnitude-related size congruency effect is more affected by the magnitude of whole number – determined by magnitude-relevant decade digit – than by the magnitude of the unit digit. This result indicates automatic place-value processing in the magnitude task. Here we show that the automatic place-value processing occurs also in magnitude-irrelevant parity task.

Apart from differences between parity and magnitude tasks discussed before, it is worth mentioning that making magnitude and parity decisions in two-digit numbers, written in a base-10 system, requires focusing either on decade or unit numbers. The saliency of each component may depend on the linguistic features such as whether one first names the number of decades or number of units while naming a given number. Therefore, we also expected effects to be modulated by the language spoken by the participants.

Are there alternative explanations, when an asymmetric congruity effect is observed?

Noteworthy, there is no main effect of target digit. Reaction times did not differ between unit parity and decade parity conditions. This shows that there is no evidence for overall differences in task difficulty between these conditions. Especially in the case of parity congruent trials (i.e., when the number of congruencies is the same for unit parity and decade parity trials), there was virtually no difference between unit parity and decade parity trials (cf. Figure 1). Therefore, the observed interaction also cannot be explained by the fact that stronger interference can only be observed in a more complex condition.

The parity congruency effect can also be at least partly accounted for by attentional processes. The presence of a task-irrelevant stimulus in the proximity of the target influences reaction times. Depending on whether the irrelevant stimulus is associated with the same or an alternative response as the actual target, responses are either faster or slower. This observation is referred to as a flanker effect (Eriksen & Eriksen, 1974) and has also been shown for numbers (Nuerk, Bauer, Krummenacher, Heller, & Willmes, 2005). While judging the parity of a two-digit number, the task-irrelevant decade digit appears in the proximity of the task-relevant unit digit (for discussion see Hohol, Cipora, Willmes, & Nuerk, 2017). Thus, the parity congruency effect could be seen as a special instance of the flanker effect, where actually the “target number” is flanked by one “distractor”.

Importantly, in the case of assessing the parity of multi-digit numbers, the task-irrelevant “flanker” (i.e., the decade digit) appears only on the left side of the task-relevant stimulus. Several studies investigated whether the flanker effect depends on whether irrelevant stimuli are presented symmetrically around the target stimulus or not. Hommel (2003) showed that in tasks using letter stimuli, the flanker effect is stronger when the flanker is located to the left of the target stimulus than when it is located to the right.

Thus, if an attentional account were true, the interference should be more pronounced in unit parity condition (i.e., the irrelevant stimulus is located to the left from the target) than in decade parity condition (i.e., the irrelevant stimulus is located to the right from the target). Therefore, predictions drawn from studies on asymmetries of the flanker effects are in the opposite direction of the interaction effects observed in our study. Thus, attentional asymmetries could not explain our hypothesized effects of the hybrid processing account.

Another alternative explanation can be brought from classical studies on the Stroop effect (MacLeod, 1991). Already in the classic experiment by Stroop (1935), it was shown that interference is not symmetric between different dimensions of the stimulus. Specifically, in the Stroop task, the interference is stronger when the more salient dimension (e.g., the meaning of the word) is causing interference to the less salient dimension (the actual ink colour). In our case, one can argue that parity status of the unit digit is more salient than the parity status of the decade digit. Nevertheless, one might ask *why* the unit parity is the more salient dimension than the decade parity. The answer is that parity status of the unit digit determines the parity of the whole number. However, such an answer brings us back to the explanation of automatic parity processing and supports the hybrid processing account.

A third alternative explanation proposes that participants automatically activate their pre-existing meta-knowledge that the last digit determines multi-digit number parity. In this framework, there are not separate parity representations for the different digits (i.e., for the different powers) or for the whole number activated. Rather there is a pre-existing bias for choosing the appropriate digits the parity decision should be based on, which in some conditions needs to be overcome. If the selection of the last digit is indeed a strong and automatic mechanism, then the asymmetric congruency effect could be observed even without holistic processing, i.e., the processing could be purely decomposed.[4] Nevertheless, one might argue that in this account, despite not referring to multiple representations of parity, observing that such (meta-)knowledge structures are automatically activated during the parity judgment task of multi-digit numbers might also be an argument for some automatic place-value processing, because such a pre-existing bias for the leftmost symbol is not found in non-numerical flanker tasks (see above argument). However, such alternative accounts can be tested in future studies, for instance by altering the bias, which digit is decisive for the parity judgement in a systematic way by changing experimental proportions and probabilities of digit relevance.

Language modulations of automatic parity processing

Contrary to our prediction, we did not find any language modulation of parity processing. German-speakers (inverted language) did not differ from English-speakers with regards to the strength of parity congruency effect as well as in the automatic parity processing. Despite the large body of evidence showing the inversion effect in numerical processing, there are also studies in which such effects were not observed. For instance, the inversion effect was not found in case of three-digit numbers in adults (Bahnmueller, Moeller, Mann, & Nuerk, 2015). Huber et al. (2017) recently reported no effect of inversion on the magnitude processing of two-digit numbers as well. Nevertheless, the role of the inversion property for multi-digit number

[4] We would like to thank Attila Krajcsi for pointing out this alternative explanation.

processing remains unresolved because several other studies have demonstrated such effect both in children and in adults (Göbel, Moeller, Pixner, Kaufmann, & Nuerk, 2014; Imbo, Vanden Bulcke, De Brauwer, & Fias, 2014; Macizo, Herrera, Román, & Martín, 2011; Moeller, Shaki, Göbel, & Nuerk, 2015; Pixner, Moeller, Hermanova, Nuerk, & Kaufmann, 2011). A possible reason for the apparent incoherence is the proportion of unit- and decade-relevant items in an experimental block (Bahnmueller, Maier, Göbel, & Moeller, 2019) – too high and too low proportions might make the language effect disappear, because it then no longer alters the experimental attentional bias on the unit or decade digit, possibly because the digit is too salient or not salient at all anyway. Since the unit and the decade digit were 100% relevant in one experimental block, inversion might not have brought any additional bias on the decade or the unit in our design.

It is also possible, that in the current setup, the power to detect the language effects was too low. One could hardly estimate the size of such an effect a priori, and in general, to ensure enough power to detect between-subject effects (especially interactions) requires very large samples (Brysbaert, 2019). In sum, these findings corroborate the conclusion of Bahnmueller et al. (2015) that language effects seem to exist, but have their limitations with regard to stimuli and type of number representations. Finally, we found some language differences in the accuracy analysis. The parity congruency effect was more pronounced in English speakers than in German speakers. This would strongly support our predictions if we only used traditional unit-parity task only. However, as the target digit varied between conditions, and there was no three-way interaction, the observed effect does not seem to be specific to the inversion property in German.

Other observations

In addition to our hypotheses, several robust phenomena in numerical cognition literature were replicated in our study, which can serve as validity checks to our procedure. These analyses are reported in detail in the Appendices. These findings lend indirect support to the claim of automatic place-value processing in the parity task. Noteworthy, none of these effects was modulated by language.

Firstly, two well-established effects in numerical cognition, the odd effect, i.e., faster responses to even than to odd numbers (Hines, 1990), and the SNARC effect, i.e., faster left / right hand responses to small / large magnitude numbers (Dehaene et al., 1993), were observed. The pattern of the SNARC effects in different conditions also suggested a strongly decomposed processing of two-digit numbers, as these effects differed according to target digit condition (cf. Appendix A; see also Weis, Nuerk, & Lachmann, 2018 for parallel SNARC effects for decades and units of two-digit numbers if both are attended). On the other hand, the MARC effect, i.e., faster left/right responses to odd/even numbers (Nuerk, Iversen, & Willmes, 2004), was absent. This is not very surprising, because due to the linguistic nature of this effect, it is relatively weak when Arabic numbers are used (Nuerk et al., 2004). Furthermore, it could have been distorted by the fact that the procedure required switching between assessing parity of units and decades. Moreover, the MARC effect has been shown to be a very heterogeneous phenomenon in between participants (Cipora, Soltanlou, Reips, & Nuerk, 2019; Huber et al., 2015 for the reversed effect in left handers; for variability within participants unrelated to handedness see Krajcsi, Lengyel, & Laczkó, 2018), and also within participants (Krajcsi et al., 2018). In sum, the conditions in this experiment were not very favorable for detecting a linguistic MARC effect.

Conclusions

The current results lend further support to the claim of hybrid processing of two-digit numbers. At the same time we acknowledge that generalizing this finding to entire multi-digit number processing is not fully warranted and requires further investigations. Our results show that automatic place-value magnitude processing takes place in a parity judgment task, in which magnitude is irrelevant. In other words, these results show that a magnitude relevant task is not needed to elicit automatic place-value processing in two-digit numbers. Like the well-known

SNARC effect is considered evidence for automatic magnitude processing even in the absence of a magnitude-related task (Fias, Brysbaert, Geypens, & d'Ydewalle, 1996), the asymmetric parity congruency effect seems to indicate automatic place-value activation in two-digit numbers even in a magnitude-related task. However, there are also some alternative explanations left, some of which can be eliminated based on the literature, while others should be more thoroughly tested in future studies.

Importantly, none of the observed effects nor interactions were modulated by language in this study. We suggest that the boundary conditions needed for observing the language-effects of inversion on multi-digit number processing like specific stimulus and task choice need to be considered and differentiated carefully.

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Compliance to the Ethical Standards

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

Informed consent was obtained from all individual participants included in the study.

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Conflict of interest

The authors declare that they have no conflicts of interest.

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Appendix A – The SNARC effect

In this additional analysis, we tested for the presence of the SNARC effect (Spatial-Numerical Association of Response Codes; Dehaene et al., 1993). This term refers to the observation that small magnitude numbers are responded to faster with left-side responses, whereas large magnitude numbers are responded to faster with right-side responses (see Fischer & Shaki, 2014 for a current review; Wood, Willmes, Nuerk, & Fischer, 2008 for a meta-analysis). The SNARC effect is considered as a behavioural signature of the semantic processing of numerical magnitude (Fias et al., 1996). The presence of the SNARC effect was evaluated using the method proposed by Fias et al. (1996). Namely, for each participant separately we calculated regression slopes where dRT (differences in right-hand - left-hand reaction times) were regressed on number magnitude. Slopes that are more negative represent a stronger SNARC effect. In the case of two-digit numbers, three types of SNARC effects can be calculated (Huber et al., 2016): (a) an overall SNARC effect – whole numerical magnitude considered, (b) a decade SNARC effect – decade number considered (collapsed across unit numbers), (c) a unit SNARC effect – unit number considered (collapsed across decade numbers). Each type of the SNARC slope was calculated separately for decade parity and unit parity condition. None of the SNARC slopes differed between English and German speakers (ts < 0.5, ps ≥ .630), thus the data was collapsed across language groups. Results are summarized in Table A1.

Table A1. SNARC slopes.

SNARC type	**Condition**	**Slope (SD)**	***t* (46)**	***p***	**Proportion of participants with slopes < 0**	**Reliability**
Overall	Unit	0.04 (0.33)	0.89	.377	.52	-.38
Overall	Decade	- 0.28 (0.62)	-3.05	**.004**	.68	.69
Unit digit	Unit	-3.25 (4.49)	-4.96	**< .001**	.72	.51
Unit digit	Decade	-0.64 (3.49)	-1.25	.218	.59	.25
Decade digit	Unit	0.82 (2.93)	1.91	.062	.45	-.86
Decade digit	Decade	-2.75 (6.19)	-3.05	**.004**	.68	.71

Note. Significant effects are marked with bold font.

A significant decade SNARC effect was found in the decade parity condition and a significant unit SNARC effect was found in the unit parity condition. The overall SNARC effect was only observed in the decade condition, but this might be due to a measurement artefact: decade digit largely determines the overall magnitude of a two-digit number. Note, however, that in principle, both decade and unit SNARC effects can be observed for multi-digit numbers in an appropriate setting (Weis et al., 2018).

Additionally, we calculated reliabilities of each SNARC effect by using split-half method and adjusting for double test length with Spearman-Brown formula. Specifically, we adapted scripts described by (Cipora, van Dijck, et al., 2019), which are available at https://osf.io/n7szg/. In general, reliabilities for those conditions in which the SNARC effect was present were satisfactory, and did not differ from values reported elsewhere in the literature. However, in those conditions in which SNARC was not significant, the reliabilities were very low or even negative. Please note that due to properties of Spearman-Brown formula, the negative values are more affected than positive ones: denominator of the formula is 1+ reliability. This is the reason why a relatively low negative correlation between halves (-.30) was amplified to very low one of -.86. This value is hardly interpretable (as any negative reliability estimate), and we present it for completeness only.

A 2 (Target digit: unit parity vs. decade parity) × 2 (SNARC type: unit SNARC vs. decade SNARC) repeated-measures ANOVA on mean SNARC slopes revealed no main effect of Target digit, $F(1, 46) = 0.44$, $p = .510$, $\eta_p^2 = .01$, and no main effect of the SNARC type, $F(1, 46) = 3.12$, $p = .084$, $\eta_p^2 = .06$. Crucially, there was a robust interaction between Target digit and SNARC type, $F(1, 46) = 21.55$, $p < .001$, $\eta_p^2 = .32$. The SNARC was present only for target digits which were task-relevant (see Table A1 for descriptive results). An asymmetry was observed for the overall SNARC effect. It was only present in the decade parity condition. The overall SNARC slopes differed significantly between conditions, $t(46) = -3.05$, $p = .004$, $d = 0.44$.

These findings imply that spatial mapping can only be observed for numbers that were relevant in a given condition. The irrelevant numbers (unit number in the decade parity condition and decade number in the unit parity condition) did not evoke spatial mapping indexed by the SNARC effect.

In the last step of the analysis, we investigated correlations between slopes. In both conditions, we observed extremely strong correlations between decade SNARC slopes and overall SNARC slopes (*r*s > .92). This is due to the fact that decade magnitude plays a crucial role in overall number magnitude, thus these correlations are trivial. The overall SNARC slope in the unit condition correlated weakly with the unit SNARC slope from the unit condition ($r = .32$, $p = .028$). Interestingly, the two most robust SNARC effects, namely unit SNARC slope in the unit parity condition and the decade SNARC slope in the decade parity condition did not correlate with each other ($r = .03$, $p = .859$). None of the other correlations reached significance.

Appendix B – Complete ANOVA model

Reaction times

Additionally we conducted an ANOVA model considering all factors included in the design. Therefore, a 2 (Language: German vs. English, between subject) × 2 (Hand: right vs. left) × 2 (Parity of the target number: odd vs. even) × 2 (Congruency: congruent vs. incongruent) × 2 (Target digit: unit vs. decade) mixed-design ANOVA was conducted (cf. Table B1). Effects reported here reflect those reported in the main text, however for the sake of completeness, we report them here again.

Right-hand responses (539ms, *SD* = 64ms) were significantly quicker than left-hand responses (544ms, *SD* = 64ms; i.e., a main effect of hand). Responses to even numbers were significantly faster than responses to odd numbers (535ms, *SD* = 63ms and 547ms, *SD* = 64ms, respectively; i.e., a main effect of parity). Congruent trials were responded to quicker (533ms, *SD* = 62ms) than incongruent trials (549ms, *SD* = 64ms; i.e., a main effect of congruency). Reaction times did not differ depending on Target digit (i.e., no main effect of Target digit). Thus, we replicated effects typically observed in such setups, that is, the dominant hand advantage, the odd effect (Hines, 1990) as well as the parity congruency effect.

There was no main effect of language and this factor did not interact with any other factor (cf. Table B1), thus not confirming our predictions on linguistic influences on place-value processing.

As concerns the automatic activation of integrated parity, there was a significant Congruency × Target digit interaction (cf. Fig. B1, panel A). Incongruent trials were responded to significantly slower in the decade condition compared to the unit condition. To disambiguate this interaction, the congruency effect was calculated separately for each target digit by subtracting RTs incongruent – RTs congruent. Subsequently the congruency effect was tested against zero with one-sample *t*-tests. In both conditions, decade and unit parity judgement, the congruency effect was highly significant (*p*s < .001). However, the congruency effect differed significantly between conditions, $t(46) = 2.54$, $p = .014$, $d = 0.37$ with a larger effect size in the decade condition than in the unit condition (Cohen's d of 1.54 and 1.29, respectively). This is in line with the idea of automatic processing of integrated parity.

Table B1. The repeated measure ANOVA by Hand, Parity, Congruency, Target digit, and Language.

Effect	***F*(1, 45)**	***p***	**η_p^2**
Language	0.32	.575	.01
Hand	5.52	**.023**	.11
Hand × Language	0.32	.572	.01
Parity	31.81	**< .001**	.41
Parity × Language	0.04	.836	< .01
Congruency	210.61	**< .001**	.82
Congruency × Language	0.12	.736	< .01
Target digit	0.51	.478	.01
Target digit × Language	1.19	.282	.03
Hand × Parity	0.01	.942	< .01
Hand × Parity × Language	0.07	.781	< .01
Hand × Congruency	4.32	**.043**	.09
Hand × Congruency × Language	1.75	.192	.04
Parity × Congruency	5.00	**.030**	.10
Parity × Congruency × Language	0.20	.655	< .01
Hand × Target digit	3.12	.084	.07
Hand × Target digit × Language	0.48	.494	.01
Parity × Target digit	0.42	.520	.01
Parity × Target digit × Language	0.03	.855	<.01
Congruency × Target digit	6.40	**.015**	.13
Congruency × Target digit × Language	0.19	.663	< .01
Hand × Parity × Congruency	0.44	.510	.01
Hand × Parity × Congruency × Language	1.93	.171	.04
Hand × Parity × Target digit	0.12	.730	< .01
Hand × Parity × Target digit × Language	0.01	.930	< .01
Hand × Congruency × Target digit	7.97	**.007**	.15
Hand × Congruency × Target digit × Language	0.98	.328	.02
Parity × Congruency × Target digit	0.11	.737	< .01
Parity × Congruency × Target digit × Language	3.84	.056	.08
Hand × Parity × Congruency × Target digit	0.09	.771	< .01
Hand × Parity × Congruency × Target digit × Language	0.27	.608	.01

Note. Significant effects are marked with bold font.

The significant Hand × Congruency × Target digit interaction indicated that the effect of interest differed depending on the responding hand. To disambiguate this three-way interaction, the Target digit × Congruency interactions were tested for each hand separately. No interaction was present in the case of left-hand responses, $F(1,46) = 0.66$, $p = .420$, $\eta_p^2 = .01$ (cf. Fig. B1, panel

B). For right-hand responses, this interaction was robust, $F(1,46) = 15.02$, $p < .001$, $\eta_p^2 = .25$. A follow-up one-sample *t*-test indicated that the congruency effect was robust in both conditions (*p*s < .001) for right hand responses, but the congruency effect differed significantly between conditions, $t(46) = 3.88$, $p < .001$, $d = 0.5$ (cf. Fig. B1, panel C) with a larger effect size for the decade condition than for the unit condition (Cohen's *d* of 1.52 and 1.07, respectively).

Interestingly, there was also a significant Hand × Congruency interaction. As already suggested by the results of the three-way interaction described above, the congruency effect was more pronounced in right-hand responses compared to left-hand responses (cf. Fig. B1, panels B and C). For both hands the congruency effect was robust (*p*s < .001), however, the effect was more pronounced for right-hand responses than for left-hand responses (Cohen's *d* of 1.73 and 1.59, respectively). The difference between conditions was also significant, $t(46) = 2.04$, $p = .048$, $d = 0.30$.

There was also a significant Parity × Congruency interaction, whereby even numbers were more affected by the congruency effect than odd numbers. The congruency effect was robust in both conditions (*p*s < .001, Cohen's *d* of 1.68 and 1.64 for even and odd numbers, respectively) and the difference between the congruency effects for even and odd numbers was also significant, $t(46) = 2.25$, $p = .029$, $d = 0.33$.

The Hand × Parity interaction was not significant, thus revealing no MARC effect (see Nuerk et al., 2004). This interaction was also not modulated by the Target digit (non-significant three-way Hand × Parity × Target digit interaction). No other interactions reached significance.

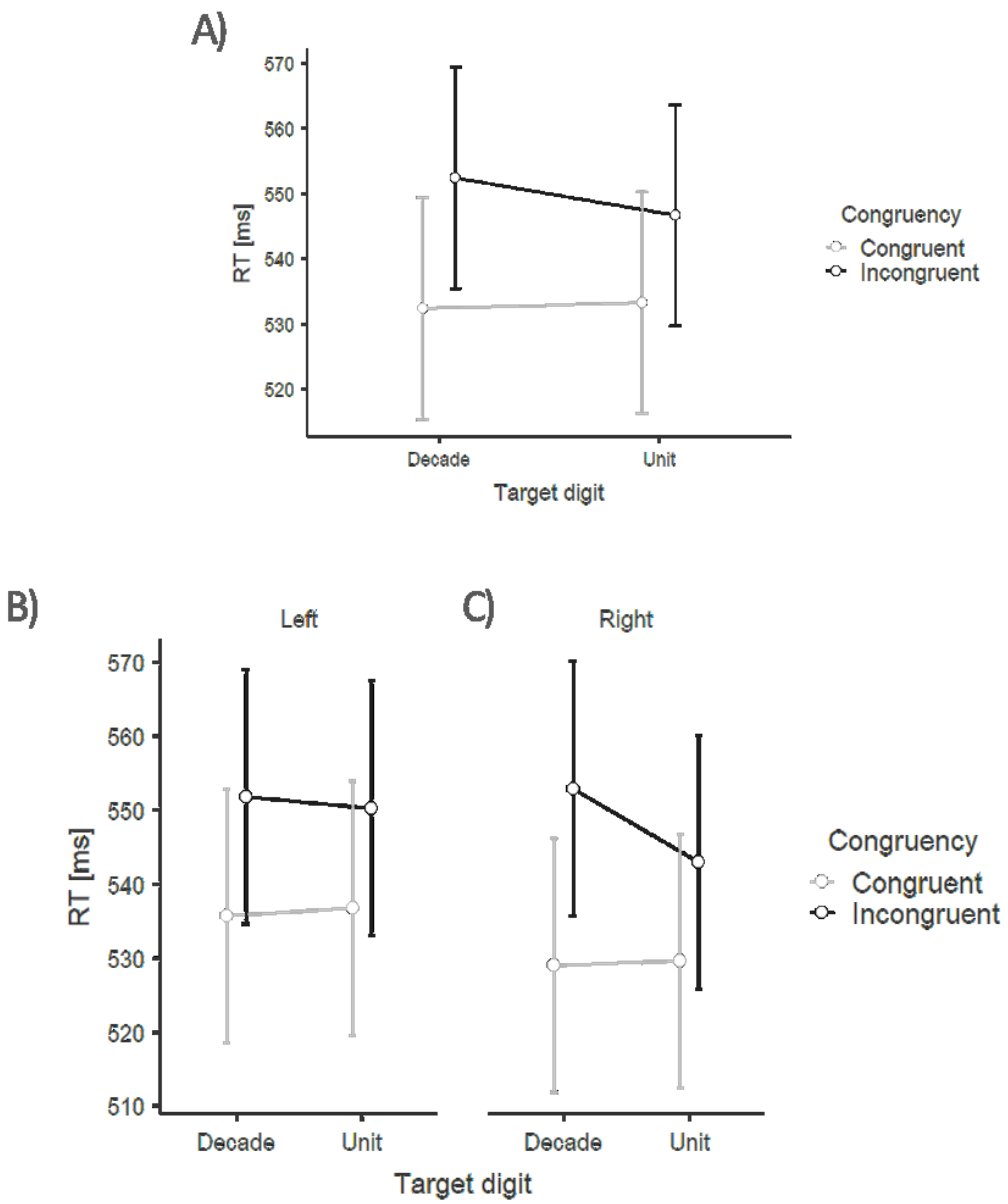

Figure B1. Panel A: the Congruency × Condition interaction as reported in the main text. Panels B and C: Hand × Congruency × Condition interaction. Marginal means used, bars represent 95% confidence intervals.

Accuracies

Similar analysis for accuracies is summarized in Table B2.

Table B2. Full model, accuracy analysis.

Effect	$F(1, 45)$	p	η_p^2	Interpretation
Hand	1.87	.179	.04	-
Hand × Language	0.01	.915	.00	-
Parity	6.26	**.016**	.12	Higher accuracy for odd numbers

Parity × Language	0.07	.798	.00	-
Congruency	116.12	**< .001**	.72	Higher accuracy for congruent trials
Congruency × Language	5.34	**.025**	.11	Effect of congruency more pronounced in English speakers
Target digit	0.05	.833	.00	-
Target digit × Language	0.32	.572	.01	-
Hand × Parity	0.02	.879	.00	-
Hand × Parity × Language	0.10	.758	.00	-
Hand × Congruency	0.05	.823	.00	-
Hand × Congruency × Language	2.37	.130	.05	-
Parity × Congruency	40.32	**< .001**	.47	Congruency effect more pronounced in even numbers
Parity × Congruency × Language	1.57	.217	.03	-
Hand × Target digit	1.04	.313	.02	-
Hand × Target digit × Language	0.03	.862	.00	-
Parity × Target digit	2.45	.124	.05	-
Parity × Target digit × Language	4.12	**.048**	.08	Cross-over Parity × Target digit interaction (i.e., difference in accuracy between odd and even numbers in unit parity but not in decade parity condition) present in English but not in German. Hardly interpretable.
Congruency × Target digit	2.67	.109	.06	-
Congruency × Target digit × Language	0.16	.691	.00	-
Hand × Parity × Congruency	0.17	.685	.00	-
Hand × Parity × Congruency × Language	2.39	.129	.05	-
Hand × Parity × Target digit	1.14	.291	.02	-
Hand × Parity × Target digit × Language	< .01	.985	.00	-
Hand × Congruency × Target digit	0.17	.682	.00	-
Hand × Congruency × Target digit × Language	4.67	**.036**	.09	Non-interpretable four-way interaction
Parity × Congruency × Target digit	0.67	.419	.01	-
Parity × Congruency × Target digit × Language	0.51	.481	.01	-
Hand × Parity × Congruency × Target digit	0.19	.665	.00	-
Hand × Parity × Congruency × Target	1.87	.178	.04	-

digit × Language	

Note. Significant effects are marked with bold font.