THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY, 2015
http://dx.doi.org/10.1080/17470218.2014.979843

Routledge
Taylor & Francis Group

Grammatical number elicits SNARC and MARC effects as a function of task demands

Timo B. Roettger[1] **and Frank Domahs**[2,3]
[1]IfL Phonetik, University of Cologne, Cologne, Germany
[2]Department of Germanic Linguistics, University of Marburg, Marburg, Germany
[3]Neuropsychology and Clinical Cognition Research Sections, Department of Neurology, RWTH Aachen University Hospital, Aachen, Germany

Despite the robustness of the spatial–numerical association of response codes (SNARC) and linguistic markedness of response codes (MARC) effect, the mechanisms that underlie these effects are still under debate. In this paper, we investigate the extraction of quantity information from German number words and nouns inflected for singular and plural using two alternative forced choice paradigms. These paradigms are applied to different tasks to investigate how access to quantity representation is modulated by task demands. In Experiment 1, we replicated previous SNARC findings for number words—that is, a relative left-hand advantage for words denoting small numbers and a right-hand advantage for words denoting large numbers in semantic tasks (parity decision and quantity comparison). No SNARC effect was obtained for surface or lexical processing tasks (font categorization and lexical decision). In Experiment 2, we found that German words inflected for singular had a relative left-hand advantage, and German words inflected for plural a relative right-hand advantage, showing a SNARC-like effect for grammatical number. The effect interfered, however, with a MARC-like effect based on the markedness asymmetry of singulars and plurals. These two effects appear to be dissociated by response latency rather than task demands, with MARC being more pronounced in early responses and SNARC being more pronounced in late responses. The present findings shed light on the relationship of conceptual number and grammatical number and constrain current accounts of the SNARC and MARC effects.

Keywords: Grammatical number; SNARC; MARC; Polarity alignment

Numbers constitute an important aspect of our everyday life. We permanently use them to individuate, quantify, and rank concrete objects and abstract entities. The ability to discriminate and use numerical information has been found in human infants (e.g., Feigenson, Dehaene, & Spelke, 2004), as well as in nonhuman animals (e.g., Brannon & Terrace, 1998; Wilson, Hauser, & Wrangham, 2001); however, the symbolic representation of quantity using systems as Arabic numbers or number words is unique to human culture. Based on research on those symbolic formalizations of quantity, many researchers have argued that the mental representation of quantity is intimately connected to representations of space. Crucially, it has been shown that spatial response dimensions are associated to numerical magnitude, demonstrated, for example, by the spatial–numerical association of response codes (SNARC) effect (Dehaene, Bossini, & Giraux, 1993).

Correspondence should be addressed to Timo B. Roettger, IfL Phonetik, University of Cologne, Herbert-Levin-Str. 6, D-50931, Cologne, Germany. E-mail: timo.roettger@uni-koeln.de

We thank Bodo Winter for his valuable comments on earlier versions of this manuscript. We thank Bert Reynvoet and all anonymous reviewers for their comments and suggestions.

The SNARC effect

In their seminal work, Dehaene et al. (1993) found that in a parity judgement task (participants were asked to judge whether a number was even or odd), responses to larger numbers were consistently faster with the right hand than with the left hand, whereas responses to smaller numbers showed the opposite pattern. Several later studies have found similar effects without hand movements, suggesting that the SNARC effect is not genuinely due to a mapping to hands but rather to egocentric space (e.g., Fischer, Castel, Dodd, & Praat, 2003; Loetscher, Schwarz, Schubiger, & Brugger, 2008; Marghetis, Kanwal, & Bergen, 2013; Winter & Matlock, 2013). The SNARC effect has been demonstrated for both Arabic numerals and number words (cf. Landy, Jones, & Hummel, 2008; Nuerk, Iverson, & Willmes, 2004; Nuerk, Wood, & Willmes, 2005).

A number of studies suggest that the SNARC effect critically depends on response latency and/or task demands. First, studies have shown that longer response latencies elicit stronger SNARC effects: For instance, in their meta-analysis, Wood, Willmes, Nuerk, and Fischer (2008) found a positive correlation of the SNARC effect size and response latencies across studies. Second, studies have shown that tasks that required the semantic processing of numerical magnitude elicit more pronounced SNARC effects than tasks requiring the processing of surface attributes of the stimulus: Fias (2001) observed a regular SNARC effect for number words in a parity judgement task while he observed no SNARC effect in an asemantic phoneme monitoring task (participants were asked to judge whether the presented number word contains a certain phoneme or not). On a similar note, De Brauwer and Duyck (2008) were able to demonstrate that while speakers do not show a SNARC effect for a phoneme monitoring task in second language (L2) number words, they did show an effect when they had to either judge the parity of L2 number words or translate the number words. Fias (2001) interpreted his finding as evidence for two distinct routes of processing verbal numerals: A semantic route, which involves processing conceptual information like parity or the specific quantity, and an asemantic route, which involves processing information regarding the form of the stimulus such as phonological and morphological information.

Despite the fact that the SNARC effect appears to be a robust phenomenon, which has been replicated numerous times, its underpinnings are still heavily disputed. Most researchers have argued that the common stimulus-to-response mapping of horizontal SNARC effects is a result of a mental number line, which (in Western cultures) is oriented from left to right with decreasing acuity for increasing numerical quantity (Göbel, Shaki, & Fischer, 2011). In consequence, responses to large numbers are faster for the right hand, because the spatial location of the hand and spatial location of the magnitude on the mental number line are congruent (e.g., Dehaene et al., 1993). This interpretation is in line with the popular view that abstract concepts or conceptual domains adopt structures from more concrete conceptual domains, which are more directly linked to perceptual-motor experiences (see Santiago, Román, & Ouellet, 2011, for an overview). In this view, the SNARC effect can be interpreted as a spatial congruency effect of response and stimulus.

Polarity alignment

On an alternative account, the SNARC effect could be attributed to polarity alignment (Landy et al., 2008; Proctor & Cho, 2006; Santens & Gevers, 2008). This account posits that stimulus dimensions and response alternatives with binary values are asymmetrically represented: It has been argued that one value of binary dimensions is "generally more available than the other" (Landy et al., 2008, p. 358). This asymmetry rests on the concept of linguistic markedness (Clark, 1969; Waugh, 1982; Zimmer, 1964). For example, antonymous adjectives are assumed to be processed asymmetrically—for instance, the "positive" member (*tall, good, wide*) of an opposition is considered the unmarked member because it can be neutralized in certain contexts meaning that this member can represent the dimension itself (e.g., *How tall is he?)*. The negative member (*short, bad, narrow*), however, cannot (e.g., **How short is he?*) and is therefore considered as the marked member of the opposition (Clark, 1969, p. 390). Similarly, the opposition of right and left has been discussed intensively with regard to its asymmetrical relationship based, for example, on the overall majority of right-handedness in the population and, in turn, the general conceptualization of movement execution (see Waugh, 1982, p. 314f. and references therein). It is assumed that the unmarked member of a dimension has less complex memory representations, which in turn results in processing advantages. Now, the polarity account assumes that values of dimensions (e.g., *large/small*; *above/below*; *right/left*) are mapped onto [+] and [−] poles. The unmarked value of a dimension is referred to as [+] polarity; the marked value is referred to as [−] polarity. Congruent polarities are assumed to yield faster response selection than incongruent polarities. Thus, to account for the SNARC effect, it is assumed that *small* numbers are coded as [–] polarity and *large* numbers as [+] polarity. The response location is coded in a similar way: [–] polarity for a *left* response and [+] polarity for a *right* response, leading to facilitation of right-hand responses for large numbers.

The polarity account has been used to explain a wide variety of observations related to the SNARC effect and other phenomena such as the vertical SNARC effect (Ito & Hatta, 2004), the Simon effect (Lippa & Adam, 2001), spatial–musical association effects (SMARC; Lidji, Kolinsky, Lochy, & Morais, 2007), and pitch–number association effects (SNAP; Marghetis, Walker, Bergen, & Núñez, 2011).

The linguistic markedness of response codes (MARC) effect

Additionally, this account has also been argued to explain the linguistic markedness of response codes (MARC) effect (cf. Nuerk et al., 2004; Reynvoet & Brysbaert, 1999; Willmes & Iversen, 1995). In several studies of numerical processing, a parity effect has been observed, such that right-hand responses to odd numbers are slower than to even numbers and vice versa for left-hand responses. Crucially, the parity effect has been shown to differ between notations. In general, it tends to be stronger for number words than for Arabic numerals (Nuerk et al., 2004). This finding led to the assumption that this effect is closely related to the concept of linguistic markedness: In a parity judgement task, in which the hand-to-response relation is manipulated within participants, the adjectives “right” and “even” are assumed to be linguistically unmarked. On the contrary, the adjectives “left” and “odd” are assumed to be linguistically marked (Zimmer, 1964). Interference is observed if the markedness association between stimulus and response is incongruent, while facilitation is observed if the markedness association is congruent. Polarity alignment models account for the effect by coding the adjective *even* as [+] polarity and the adjective *odd* as [–] polarity, leading to facilitation of right-hand responses for *even* numbers.

Having discussed two relevant stimulus-to-response mappings attested for numerals (symbolic and linguistic), we now turn to a non-numeric linguistic phenomenon that also encodes quantity. While for numerals there are two opposing accounts to explain stimulus-to-response mappings, which make the same empirical predictions, we will see that grammatical number might enable us to pit those two accounts against each other.

Grammatical number

Various linguistic systems encode quantity distinctions in their grammar. In particular, many languages differentiate between singular (one entity) and plural (more than one entity) by inflecting nouns, for instance, by adding a suffix. For an example, compare (1), where for German the suffix –*n* and for English the suffix –*s* add plural meaning to the noun *Löwe*/*lion*.

1. Löwe/ "lion" (singular) vs. Löwen/ "lions" (plural)

As most research on mental quantity representation has focused on Arabic numerals or number words, much less is known about the semantic interpretation of grammatical number. This is even though several developmental, behavioural, and neurolinguistic studies demonstrated a tight connection between grammatical and conceptual number. For instance, during cognitive development, the acquisition of singular–plural morphosyntax helps in learning the conceptual distinction between sets of one and more than one object (Barnerm, Thalwitz, Wood, Yang, & Carey, 2007). Moreover, cross-linguistic studies showed that children acquiring a language with consistent grammatical number marking like Russian or English knew the exact meaning of small numbers (one, two, and three) earlier than children acquiring a language without overt number marking like Japanese (Almoammer et al., 2013; Sarnecka, Kamenskaya, Yamana, Ogura, & Yudovina, 2007). Moreover, Berent, Pinker, Tzelgov, Bibi, and Goldfarb (2005) asked their participants in a Stroop-like task to judge the quantity (one or two) of visually presented words while ignoring their contents. Letter strings consisted of both singular and plural nouns (Experiment 1) and of pseudowords with or without regular plural inflection (Experiment 3). Response latencies were higher when there was a mismatch between grammatical number and the quantity of words presented. The authors concluded that the extraction of semantic number from grammatical number is automatic and represented in a way that is related to the conceptual number that subjects extract from visual perception. Finally, studies using functional magnetic resonance imaging suggest that the processing of grammatical number involves activation of areas known to be associated to conceptual number (Carreiras, Carr, Barber, & Hernandez, 2010; Domahs et al., 2012).

Pitting SNARC against MARC

Given the above discussed studies, we assume that conceptual quantity is involved in the processing of grammatical number of nouns. Although the plural does not represent a specific quantity, we assume it to represent a quantity that is—on a (Western) mental number line—localized more towards the right (>1) than a singular quantity (=1). If this conceptual quantity is represented in the same way as conceptual quantities of numerals (Arabic numerals, number words) are represented, the difference between one entity and multiple entities might give rise to a SNARC-like effect. Thus, based on the idea of spatially organized quantity representation, we predict that singular forms should be responded to faster with the left hand whereas plural forms should be responded to faster with the right hand. This prediction based on the semantic reference to conceptual quantity, however, conflicts with the prediction based on the polarity correspondence principle. More specifically, grammatical number might elicit a MARC-like effect. Similar to polar adjectives, grammatical categories are assumed to bear markedness asymmetries too. In linguistic theory, the singular is thought to be the unmarked, and plural is thought to be the marked member of the singular–plural opposition (cf. Greenberg, 1963, 1966). For example, within a given language, singulars are typically used more frequently than plurals. Furthermore, if a language has a morphological coding of number (such as an affix), then the plural is overtly coded, thus formally more complex, whereas singulars often lack an overt coding (cf. Example 1). Most often, plurals are derived from singular forms. Moreover, it can be argued that plurals are conceptually more complex since they are referring not only to a particular entity with all its defining characteristics but, on top of that, also to the quantity of these entities. Thus, a markedness-based account predicts that if markedness of a stimulus (*singular* vs. *plural*) is congruent with the markedness of a response side (*right* vs. *left*), there should be facilitation: Singular forms should be responded to faster with the right hand (both unmarked); plural forms should be responded to faster with the left hand (both marked).

THE PRESENT STUDY

To sum up, the mechanisms that underlie the SNARC effect are still under debate. One account postulates that SNARC is a spatial congruency effect of behavioural responses and spatially organized representations of quantity. Another account assumes a structural asymmetry between binary representations of dimensions. Those two views are difficult to disentangle when investigating numerals only. One potentially promising avenue to shed light on the underlying mechanisms of SNARC effects is extending the SNARC paradigm to more complex linguistic stimuli that encode quantity. In addition to symbolic numerical notations, many languages encode quantity grammatically. While current accounts of the SNARC effects are mainly based on research into Arabic numerals and number words (see Wood et al., 2008, for an overview), the present paper expands the focus of investigation to nouns inflected for grammatical number.

As stated above, markedness-based accounts make different predictions for grammatical number than accounts that relate to the concept of a mental number line. According to a mental number line account, words inflected for singular should elicit a relative left-hand advantage, and words inflected for plural a relative right-hand advantage. Yet, according to a markedness account, words inflected for singular should elicit a relative right-hand advantage, while words inflected for plural should show a relative left-hand advantage.

Remember, however, that the SNARC effect has been reported to be dependent on task demands: Given the findings of Fias (2001) and De Brauwer and Duyck (2008), access to semantic quantity representations is not necessary in tasks requiring only superficial processing, resulting in the absence of a SNARC effect. A SNARC effect operating on conceptual quantity might be obtained in semantic tasks only. To further explore the task dependent character of SNARC, we introduced four different tasks involving different types of task-relevant information. Based on cognitive models of visual word recognition and reading (for a review, see Balota, Yap, & Cortese, 2006), we assumed three types of processing, corresponding to three levels of processing depth: surface, lexical, and semantic. At the first level, the level of *surface* (or prelexical) *processing*, visual features (e.g., font or case) are processed. Surface processing can be regarded as a prerequisite for further lexical processing but neither requires actual access to lexical forms nor necessitates access to semantic representations. For instance, patients with pure alexia may be able to process surface features of a written word form, but might neither be able to judge its lexical status nor access its meaning (Miozzo & Caramazza, 1998). Typical tasks tapping into surface processing are font classification tasks that focus on superficial features of the visual stimulus. Such surface tasks have repeatedly been used for both words and number words (for a review see Bolger, Perfetti, & Schneider, 2005, Table II).

At the second processing level, surface information is mapped onto orthographic word forms stored in the mental lexicon. These orthographic representations contain information on the sequence and identity of graphemes that characterize a written word. In addition to that, morphological information is accessed at this stage, including part of speech of the word (e.g., noun or verb) and the relationship with other members of the morphological paradigm (e.g., a singular noun is related to its corresponding plural noun). A typical task tapping into lexical processing is the lexical decision task—that is, judging whether a given stimulus is an existing word or not. This task has been used in numerous studies with words (e.g., Grainger, 1990) and number words (Domahs, Bartha, Lochy, Benke, & Delazer, 2006).

The third level of processing accesses semantic representations. Regarding nouns, semantic information includes knowledge on features, function, and properties of objects and the categories to which they belong including knowledge on the concreteness and animacy of a referent (Costanzo, McArdle, Xu, & Braun, 2013). Regarding number words, semantic representations comprise knowledge on their parity and the specific quantity they refer to (De Brauwer & Duyck, 2008; Domahs et al., 2006; Fias, 2001). Tasks tapping into semantic representation are semantic decision tasks. For words, semantic decisions may involve decisions about the animacy of referents (living or nonliving?; Hauk, Coutout, Holden, & Chen, 2012). For number words, semantic decisions may involve decisions about parity (odd or even?) or quantity (more or less than five? one or many?). Lexical access may be regarded as prerequisite for access to semantic knowledge; therefore semantic decisions may lead to slightly longer response latencies than lexical decisions (Hauk et al., 2012). Semantic decision tasks may be affected by task-relevant and task-irrelevant semantic properties of the stimulus (e.g., parity and quantity in a parity decision task).

To shed light on the potential task dependent character of SNARC and MARC effects, the present study involves binary decision tasks that correspond to the discussed processing stages: surface processing, lexical processing, and semantic processing. To tap into semantic processing, we use two different semantic decision tasks in which quantity information is either task relevant or not.

Given that this is the first investigation of SNARC and MARC effects elicited by grammatical number, it may be enlightening to compare the results for grammatical number to the SNARC and MARC effects elicited in a more standard type of stimuli—namely, number words. Thus we conducted a baseline experiment on number words using four binary decision tasks requiring different types of information processing that closely parallel the tasks used for grammatical number. This not only allows us to directly compare stimulus-to-response patterns in numerals to stimulus-to-response patters in nouns inflected for grammatical number, it also replicates and extends earlier findings on the task-dependent character of stimulus-to-response effects in number words.

EXPERIMENT 1: NUMBER WORDS

In the first experiment, we investigated the SNARC effect elicited by German number words as a function of task demands. To this end, we designed four different tasks. In the first task, participants had to decide whether the presented number words were written in italics or not (surface processing, SURF). The second task was a lexical decision task: Participants had to decide whether the presented letter strings were existing German words or not (lexical processing, LEX). In a parity decision task, participants had to decide whether the number words denoted an even or an odd number (nonspecific semantic processing, SEM). In a fourth task, participants had to decide whether the number words denoted a quantity larger or smaller than five (specific semantic quantity processing, QUANT). This experiment aimed to provide a baseline for Experiment 2. It further enables us to replicate previous findings on both SNARC and MARC effects in number words as well as their task-dependent character. Extending earlier findings (Fias, 2001), we differentiated four different tasks requiring different types of information retrieval. Specifically, we expected no SNARC or MARC effects in SURF, in which no access to semantic information is required. With regard to LEX, we had no clear expectation. On the one hand, lexical decision itself does not necessarily require access to semantic concepts, but on the other there is a vast body of evidence on semantic priming effects on lexical decision. In the light of these considerations, SNARC and MARC effects may or may not be observed in LEX. However, if it existed, it may be somewhat weaker than in the tasks obligatorily requiring semantic access (SEM and QUANT). Both SEM and QUANT should elicit SNARC and MARC effects. However, given the specific nature of task-relevant semantic information, we predict SNARC being more pronounced for QUANT than for SEM and MARC being more pronounced for SEM than for QUANT.

Method

Participants

Twenty native speakers of German (nine female, 11 male) with an average age of 24.7 years (*SD* = 3.2) were tested. All of them had normal or corrected-to-normal vision. Eighteen participants were right-handed. The two left-handed participants were included in the analyses since their performance pattern was not found to be principally different from that of the right-handed participants.

Stimuli

The numbers ranged from one to four and six to nine. They were presented in German orthography (*eins, zwei, drei, vier, sechs, sieben, acht, neun*). Additionally, 16 nonwords were added for the lexical decision task. For each number word, two nonwords were created, which differed from their target in just one grapheme (*elns, eifs, twei, zwel, dwei, drea, vler, vior, süchs, sels, sleben, sieren, ucht, aft, niun, neuf*).

Procedure

All participants performed eight blocks of trials—that is, two blocks per task (SURF, LEX, SEM, and QUANT). Half of the participants started with SURF and went through the four tasks ending with QUANT, the other half performed all tasks in reversed order. After the first block of each task, there was a short break, in which participants were instructed to reverse the assignment of response buttons. The order of response assignments to the right hand and the left hand, respectively, was counterbalanced across participants. Each block started with a training session, in which all numbers were presented once. In the test blocks, each target number word was presented 10 times in randomized order. After every two blocks there was a break of at least 30 seconds. Participants were able to continue in a self-paced manner.

The experiment was controlled using Superlab 2.04 software and a RB-830 response box (both Cedrus Corporation, San Pedro, CA, USA). Stimuli were displayed on a 16” monitor screen using black symbols against a white background. The number words were presented in Times New Roman, font size 90, resulting in a maximum height of 15 mm and a maximum width of 50 mm. Responses were recorded by two response keys placed at a distance of 30 cm in front of the participants and separated 10 cm from each other.

At the beginning of each trial, a fixation stimulus consisting of five asterisks (*****) was presented in the centre of the screen for 300 ms. Following this, the target appeared and remained on screen for 1300 ms. After response delivery, a white screen appeared for 150 ms. The importance of both speed and accuracy was stressed in the instructions.

Analysis

Four participants had to be excluded from the analysis because they showed difficulties in changing the response assignment in at least one block of trials. From the remaining data set a further 7.3% of trials were excluded due to wrong responses (2.8%), anticipations (reaction time, RT, faster than 200 ms; 0.1%), or RTs outside ±3 standard deviations from the individual mean of each task per hand association per participant (4.5%). There was no trade-off between mean RT and error rate ($r = -.260$, $p > .05$).[1]

Median RTs for correct responses were computed for each number, each response side, each participant, and each task separately. We performed a $2 \times 2 \times 2 \times 4$ analysis of variance (ANOVA) on correct median RTs. The design comprised responding hand (left vs. right), parity (odd vs. even), magnitude (small numbers 1–4 merged vs. large numbers 6–9 merged), and task (SURF, LEX, SEM, QUANT) as within-subject factors. This way of analysis enables us to compare the results more conveniently to the results of Experiment 2 (see below).

Results and discussion

There was a significant main effect of hand, such that right-hand responses (557 ms) were faster than left-hand responses (567 ms), $F(1, 15) = 5.78$, $p < .05$, $\eta^2 = .01$. Task showed a substantial impact on RT as well, such that SURF was responded to fastest (509 ms), followed by LEX (547 ms), QUANT (563 ms), and SEM (628 ms), $F(3, 45) = 19.96$, $p < .0001$, $\eta^2 = .42$. Neither the main effect of magnitude nor that of parity reached significance, $F(1, 15) \leq 0.86$. There was a significant Parity × Task interaction, $F(3, 45) =$

---

[1] The error rates exhibited a large amount of variance and consequently did not lead to any insightful results. For the sake of brevity, we only report RT analysis here and subsequently for Experiment 2.

4.62, $p < .01$, $\eta^2 = .009$. The Magnitude × Hand interaction (SNARC effect) turned out to be significant as well, $F(1, 15) = 4.92$, $p < .05$, $\eta^2 = .017$; however, this interaction appears to be dependent on the task performed, since there was a significant three-way interaction of Magnitude × Hand × Task, $F(3, 45) = 3.39$, $p < .05$, $\eta^2 = .022$. Neither the Parity × Hand interaction (MARC effect) nor the three-way Parity × Hand × Task interaction reached significance [$F(1, 15) = 0.72$, $p = .4$; $F(3, 45) = 0.63$, $p = .6$, respectively]. However, there was a significant three-way interaction of Magnitude × Parity × Hand, $F(1, 15) = 34.84$, $p < .0001$, $\eta^2 = .013$, indicating that there might be a MARC effect that is dependent on the magnitude of the numbers. An overview of the results is provided in Tables 1 and 2, as well as Figures 1–3.

With respect to the SNARC effect, in both SURF and LEX the two-way interaction Magnitude × Hand was not significant, $F(1, 15) \leq 0.18$, $p > .05$. In QUANT, the interaction was marginally significant, $F(1, 15) = 3.33$, $p = .09$, $\eta^2 = .12$. In SEM, the interaction was significant, $F(1, 15) = 8.72$, $p < .01$, $\eta^2 = .075$.[2] Just as in the regular SNARC effect, there was a left-hand advantage for small numbers (SEM: 23 ms and QUANT: 17 ms) and a right-hand advantage for large numbers (SEM: 27 ms and QUANT: 45 ms). This is reflected by the negative regression slope in Figure 1 that explains a large portion of the variance in SEM and QUANT.

With respect to the MARC effect, there was no Parity × Hand interaction in any of the tasks, $F(1, 15) \leq 1.04$. However in SEM there was a significant three-way interaction of Magnitude × Parity × Hand, $F(1, 15) = 14.03$, $p = .002$, $\eta^2 = .052$, caused by a strong MARC effect in small numbers (cf. Figure 1, SEM).

Experiment 1 replicated earlier findings on the presence of a SNARC in number words (e.g., Fias, 2001; Nuerk et al., 2004, 2005). There was a left-hand advantage for words denoting small numbers and a right-hand advantage for words denoting large numbers, but only in the SEM and QUANT conditions, indicating that the SNARC effect was task dependent. In line with Fias (2001) and De Brauwer and Duyck (2008), there was no SNARC effect in the surface task, showing that number words can be processed without automatic activation of conceptual quantity (recall that Fias's surface task was a phoneme monitoring task that did not necessarily require lexical or semantic access). Extending earlier findings, the present data showed that lexical processing is still not sufficient to elicit access to conceptual quantity (i.e., the lack of SNARC in LEX). This is in line with models of visual word recognition that assume increasing processing demands for surface, lexical, and semantic processing (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Seidenberg & McClelland, 1989). The obtained overall reaction times support this account: SURF did not require lexical activation, thus is responded to fastest, followed by LEX, which required at least access to the phonological form of the number words without obligatory access to their meaning. SEM and QUANT, which required conceptual elaboration, were responded to even slower. Specifically, SEM was responded to slower than QUANT, suggesting that access to the quantity representation requires less time than access to the parity information. Interestingly, we were not able to replicate the MARC effect in any task, so there was neither a clear left-hand advantage for odd numbers nor a right-hand advantage for even numbers. However, SEM (the task explicitly asking for parity information) obtained some trends towards a MARC effect albeit restricted to small numbers.

Given this pattern, one might argue that the attribute processed slower (parity) may be subject to interference from the attribute processed faster (quantity; Schwarz & Ischbeck, 2003) explaining why both QUANT and SEM show a SNARC effect, but only SEM showed numerical MARC trends.

---

[2] If we include magnitude as a four-level factor (with pairs of numbers 1–2, 3–4, 6–7, and 8–9 merged together; see Dehaene et al., 1993, Fias, 2001), we get comparable results. Crucially, the Magnitude × Hand interaction for QUANT turns out to be significant, $F(3, 45) = 2.95$, $p < .05$. We refrain from reporting this analysis in detail here, to keep the analysis comparable to that in Experiment 2.

Table 1. *Overview of the mean RT and SNARC effects of Experiment 1 as a function of task*

	SURF	*LEX*	*SEM*	*QUANT*	*Overall*
Small numbers					
Left hand	516.6	555	614.4	549.6	558.9
Right hand	507.7	534.9	637.8	566.3	561.7
dRT (right – left)	−8.9	−20	23.4	16.7	2.8
Large numbers					
Left hand	509.6	557.5	643.5	590	575.1
Right hand	502.8	542	616.8	544.9	551.6
dRT(right – left)	−6.8	−15.4	−26.7	−45.1	−23.5
SNARC compatible	509.7	548.5	615.6	547.2	555.3
SNARC incompatible	508.6	546.2	640.6	578.2	568.4
SNARC effect	1.1	2.3	25	31	13.1

Note: RT = reaction time; dRT = difference in reaction time; SNARC = spatial–numerical association of response codes. SNARC compatible = left-hand association with small numbers (1 to 4) and right-hand association with large numbers (6 to 9).

To sum up, we replicated the SNARC effect, extending previous work on Arabic numerals and number words (e.g., Fias, 2001; Nuerk et al., 2004, 2005). Surprisingly, we failed to replicate clear MARC effects, even though we found numerical trends for the parity judgement task. We further showed that these effects are to some degree dependent on task requirements in line with the literature. Having shown the task-dependent character of stimulus-to-response mappings for linguistic stimuli common in research on the SNARC effect, we now turn to linguistic stimuli that have never been used within the SNARC paradigm. Experiment 2 investigates stimulus-to-response mappings for nouns inflected for grammatical number.

EXPERIMENT 2: GRAMMATICAL NUMBER INFLECTION

Experiment 2 investigated whether a stimulus–response association can be observed for nouns inflected for grammatical number and, if so, whether the observed effect supports a spatial–numerical congruency account (facilitation for singular/left and plural/right) based on the semantic reference to quantity or a markedness account (facilitation for singular/right and plural/left) based on the markedness asymmetry of the grammatical number categories singular and plural. In analogy to Experiment 1, we differentiated four different tasks requiring different types of information. In

Table 2. *Overview of the mean RT and MARC effects of Experiment 1 as a function of task*

	SURF	*LEX*	*SEM*	*QUANT*	*Overall*
Even numbers					
Left hand	527.2	562.1	639.7	582.5	577.9
Right hand	513.7	546.8	628.4	572.5	565.4
dRT(right – left)	−13.4	−15.3	−11.3	−10.1	−12.5
Odd numbers					
Left hand	524.7	567.7	644.9	568.8	576.5
Right hand	516.4	549.3	652.6	558.1	569.1
dRT(right – left)	−8.4	−18.4	7.7	−10.7	−7.4
MARC compatible	519.2	557.3	636.6	570.6	570.9
MARC incompatible	521.8	555.7	646.2	570.3	573.5
MARC effect	2.5	−1.6	9.5	−0.3	2.5

Note: RT = reaction time; dRT = difference in reaction time; MARC = linguistic markedness of response codes. MARC compatible = left-hand association with odd numbers and right-hand association with even numbers.

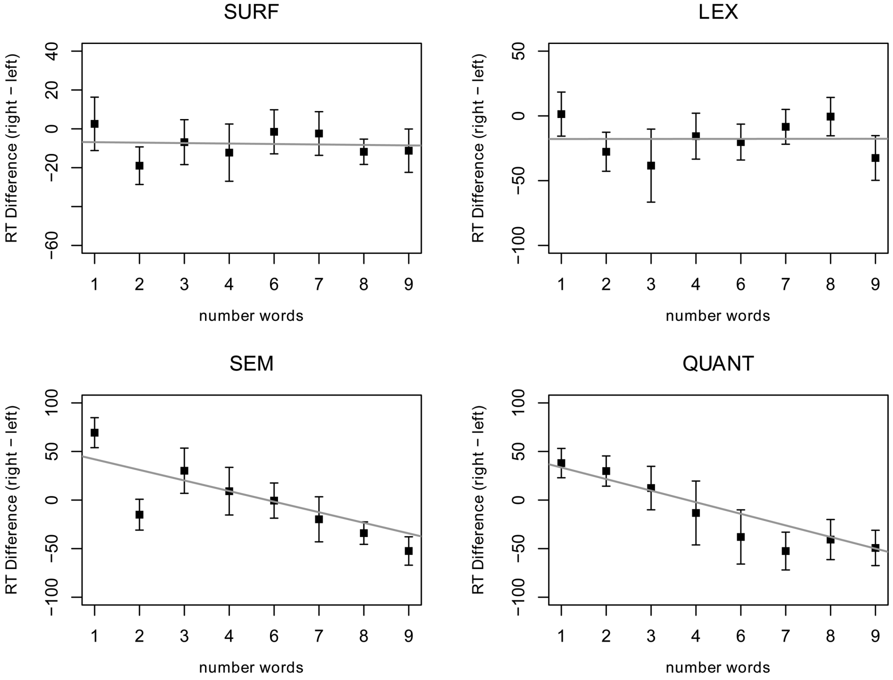

Figure 1. *Mean reaction time (RT) differences (dRT) between right-hand and left-hand responses as a function of numerical magnitude for each task in Experiment 1. Negative slopes indicate SNARC-like effects (SNARC = spatial–numerical association of response codes). Error bars indicate the standard error.*

Experiment 2, both surface and lexical processing tasks (SURF and LEX) were analogous to those in Experiment 1—that is, participants had to decide whether the presented letter strings were written in italics or not (SURF) and whether the presented letter strings were existing German words or not (LEX). In the third task, participants had to decide whether the nouns denoted an animate creature or an inanimate object (nonspecific semantic processing, SEM). In a fourth task, participants had to decide whether the nouns denoted one entity or more than one (specific semantic quantity processing, QUANT). So, similar to Experiment 1, quantity information is only task relevant in QUANT.

Method

Participants

Fifty-two native speakers of German (33 female, 19 male), with an average age of 26.9 years ($SD = 7.0$), were tested. All of them had normal or corrected-to-normal vision. One participant was left-handed. He was included in the analyses since his performance pattern was not principally different from that of the right-handed participants. None of the participants had participated in Experiment 1.

Stimuli

The stimuli consisted of four German nouns in both their singular and plural forms [*Kuh/Kühe,* "cow(s)"; *Löwe/Löwen,* "lion(s)"; *Münze/Münzen,* "coin(s)"; and *Stuhl/Stühle,* "chair(s)"], resulting in eight distinct stimulus words, paralleling Experiment 1. The following selection criteria had been applied to the items: Two items were animate beings (*Kuh, Löwe*); the other two were inanimate entities (*Stuhl, Münze*). There were two grammatically masculine (*Stuhl, Löwe*) and two grammatically feminine nouns (*Münze, Kuh*). In German, there is no clear-cut distinction between "regular" and "irregular" plural inflection, although there are more and less frequent patterns. One of the masculine nouns had a frequent

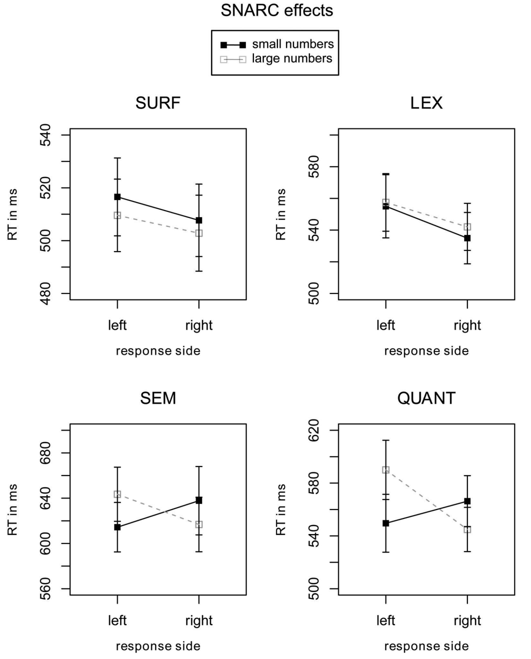

Figure 2. *Mean reaction time (RT) for right-hand and left-hand responses as a function of magnitude (small vs. large) for each task in Experiment 1. SNARC = spatial–numerical association of response codes. Error bars indicate the standard error. (Black continuous lines = small; grey dashed lines = large.)*

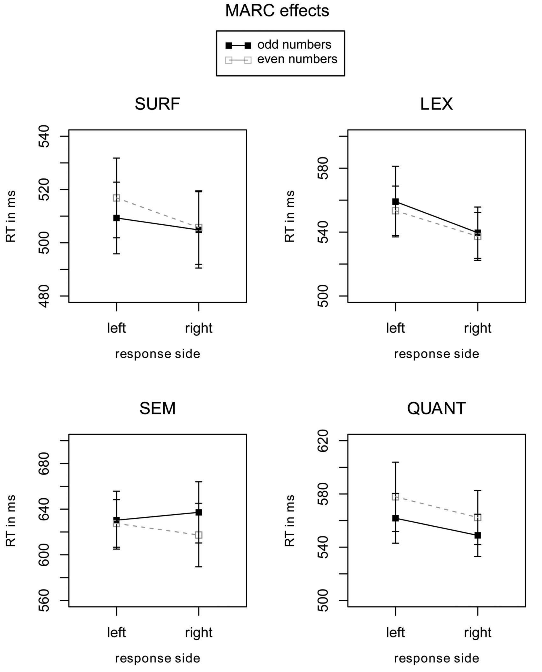

Figure 3. *Mean reaction time (RT) for right-hand and left-hand responses as a function of parity (odd vs. even) for each task in Experiment 1. MARC = linguistic markedness of response codes. Error bars indicate standard error. (Black continuous lines = odd; grey dashed lines = even.)*

occurring plural inflection (*Stuhl/Stühle*); the other was inflected with a less frequent pattern (*Löwe/Löwen*). The same was true for the feminine nouns (frequent: *Münze/Münzen*; less frequent: *Kuh/Kühe*). Plural forms of all nouns contained an umlaut. Because both singular and plural forms can have an *-e* suffix and an umlaut, neither of these cues was valid for unambiguously detecting plural inflection (see Table 3). This was done to ensure that participants access morpho-lexical knowledge rather than focus their attention just to one particular orthographic cue.

All nouns were matched for written frequency by the SUBTLEX database (Brysbaert et al., 2011).[3] Additionally, 16 nonwords were created for the lexical decision task. For each noun, two nonwords were designed, which differ from their target in just one grapheme (*Stuhm*, *Sturl*, *Stühfe*, *Stühme*, *Suh*, *Kub*, *Fühe*, *Küme*, *Rünze*, *Münle*, *Münten*, *Mülzen*, *Föwe*, *Löke*, *Göwen*, *Lömen*).

Procedure

The procedure was the same as that in Experiment 1. The nouns were given in font size 80, resulting in a maximum height of 20 mm and a maximum width of 60 mm.

Analysis

Six participants were excluded from the analysis, because they showed difficulties in changing the response hand assignment at least in one block of trials. In the remaining data set, 5.8% of the trials had to be excluded from analyses due to wrong

---

[3] $\text{LOG}_{\text{SUBTLEX}}$: *Stuhl/Stühle* (2.892/2.124), *Münze/Münzen* (2.418/2.279), *Kuh/Kühe* (2.825/2.223), and *Löwe/Löwen* (2.149/2.314).

Table 3. *Stimuli of Experiment 2 with corresponding number (singular, plural) and gender (feminine, masculine) structured by orthographic cues for grammatical number*

No umlaut, no suffix	*Umlaut, -e*	*Umlaut, -en*
Kuh (s, f)	Kühe (pl, f)	
Stuhl (s, m)	Stühle (pl, m)	
	Münze (s, f)	Münzen (pl, f)
	Löwe (s, m)	Löwen (pl, m)

Note: Number: s = singular, pl = plural; gender: f = feminine, m = masculine.

responses (3.4%), anticipations (RTs faster than 200 ms, 0.1%), or RTs outside ±3 standard deviations from the individual mean of each task per hand association per speaker (2.3%). There was no trade-off between mean RT and error rate ($r = -.182$; $p > .05$).

Analogously to Experiment 1, the median RTs for correct responses were computed for each grammatical number category, each response side, each participant, and each task separately. We performed a 2 × 2 × 4 ANOVA on correct median reaction times. The design comprised responding hand (left vs. right), grammatical number (singular vs. plural), and task (SURF, LEX, SEM, QUANT) as within-subject factors.

Results and discussion

The main effect of hand was only marginally significant, $F(1, 47) = 2.89$, $p = .096$, $\eta^2 = .004$, with right-hand (552 ms) responses being slightly faster than lefthand responses (556 ms). Similarly to Experiment 1, task showed a substantial impact on RT, such that SURF was responded to fastest (499 ms), followed by SEM (539 ms), LEX (566 ms), and QUANT (610 ms), $F(3, 141) = 111.4$, $p < .0001$, $\eta^2 = .6$. There was a significant main effect of grammatical number, $F(1, 47) = 30.2$, $p < .0001$, $\eta^2 = .014$), such that responses to singulars (550 ms) were slightly faster than responses to plurals (558 ms). The two-way interaction of Grammatical Number × Hand (SNARC/MARC effect) was only marginally significant, $F(1, 47) = 3.12$, $p = .084$, $\eta^2 = .003$; however, there was a significant three-way interaction of Grammatical Number × Hand × Task, $F(1, 141) = 8.1$, $p < .0001$, $\eta^2 = .018$, indicating that this interaction is qualified by the task performed. An overview of the results is provided in Table 4 and Figure 4.

Subset analyses reveal that the Grammatical Number × Hand interaction was not significant in LEX and SEM ($F < 1$). In QUANT the interaction reached significance, $F(1, 47) = 8.8$, $p < .01$, $\eta^2 = .098$. Just as in the regular SNARC effect, there was a left-hand advantage for singulars (10 ms) and a right-hand advantage for plurals (27 ms). This is reflected by the apparent interaction of number and response side in Figure 4. Interestingly in SURF, the Grammatical Number × Hand interaction was marginally significant too, $F(1, 47) = 3.9$, $p = .054$, $\eta^2 = .017$. As predicted by the MARC effect, there was a right-hand advantage for plurals (8 ms), while responses to singulars were not dependent on response side (0 ms).

To sum up, Experiment 2 investigated stimulus-to-response mappings when processing grammatical number in binary forced-choice classification tasks. We demonstrated that German nouns inflected for grammatical number elicit a SNARC-like effect—that is, words inflected for singular had a relative left-hand advantage; plurals had a relative right-hand advantage. This SNARC-like effect was restricted to a magnitude classification task (QUANT). This result would be consistent with a spatial–numerical congruency account. However, at the same time we demonstrated a MARC-like effect that showed the opposite pattern—that is, words inflected for singular had a relative right-hand advantage. This MARC-like effect was restricted to a font classification task (SURF). This finding would be consistent with a markedness-based stimulus-to-response mapping. So, contrary to our expectations, we found evidence for both accounts. The question arises as to what causes the dissociation of SNARC and MARC effects in our experiment. At first glance, it looks like the effects are dissociated by task demands. However, since the mean response latencies of the tasks differed substantially, one

Table 4. *Overview of the mean RT and the SNARC/MARC effects of Experiment 2 as a function of task*

	SURF	*LEX*	*SEM*	*QUANT*	*Overall*
Singular					
Left hand	503	560.7	540.2	596.1	550
Right hand	495.1	560.9	534.8	606.8	549.4
dRT(right – left)	−7.9	−0.2	−5.5	10.8	−0.6
Plural					
Left hand	499.7	570.4	541.5	633.1	561.2
Right hand	499.3	572.1	537.5	606.3	553.8
dRT(right – left)	−0.4	1.8	−4	−26.8	−7.4
SNARC compatible	501.2	566.4	538.9	601.2	551.9
SNARC incompatible	497.4	565.7	538.2	620	555.3
SNARC effect	−3.8	−0.7	−0.7	18.8	3.4

Note: RT = reaction time; dRT = difference in reaction time; SNARC = spatial–numerical association of response codes; MARC = linguistic markedness of response codes. SNARC compatible = left-hand association with singular forms and right-hand association with plural forms. SNARC compatible = MARC incompatible; SNARC incompatible = MARC compatible.

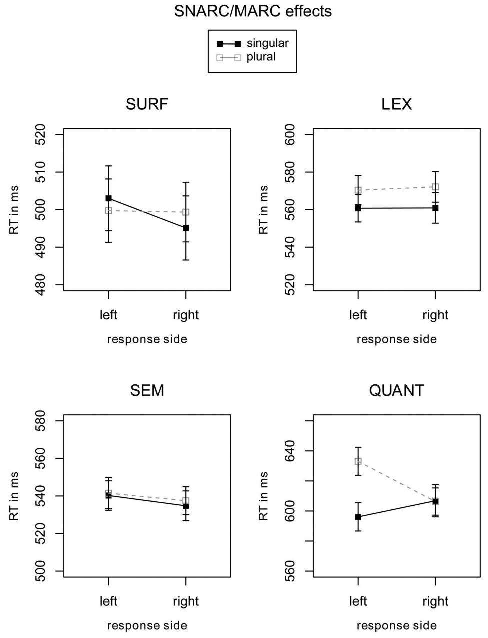

Figure 4. *Mean reaction time (RT) for right-hand and left-hand responses as a function of grammatical number (singular vs. plural) for each task in Experiment 2. SNARC = spatial–numerical association of response codes; MARC = linguistic markedness of response codes. Error bars indicate the standard error.*

might alternatively argue that this dissociation is due to overall processing time rather than related to information type.

To explore the impact of the time course of processing, we rank-ordered RTs for each subject and task and divided them into four equal bins (Ratcliff, 1979; cf. Figure 5, right panel). Taking the aggregated means over all subjects, we calculated dRTs (right hand − left hand) for each grammatical number for each bin in each task. We then subtracted dRTs for singular forms from dRTs for plural forms to get one value that reflects the stimulus-to-response mapping. Positive values reflect MARC-like effects (relative right-hand advantage for singulars), and negative values reflect SNARC-like effects (relative right-hand advantage for plurals). We find a negative correlation of stimulus-to-response mapping with response latency—that is, MARC-like effects in relatively early responses and SNARC-like effects in relatively late responses.

To get a better understanding of the time course of SNARC and MARC effects, we did the same rank-ordered analysis with the results of Experiment 1 for SNARC and MARC effects separately (cf. Figure 5, left and middle panels). Again, SNARC effects are more pronounced in relatively late responses. Opposed to that, there is no apparent relation of MARC and response latency. Note, however, that the lack of a relation to the response latency could be due to the general weak manifestation of MARC in Experiment 1.

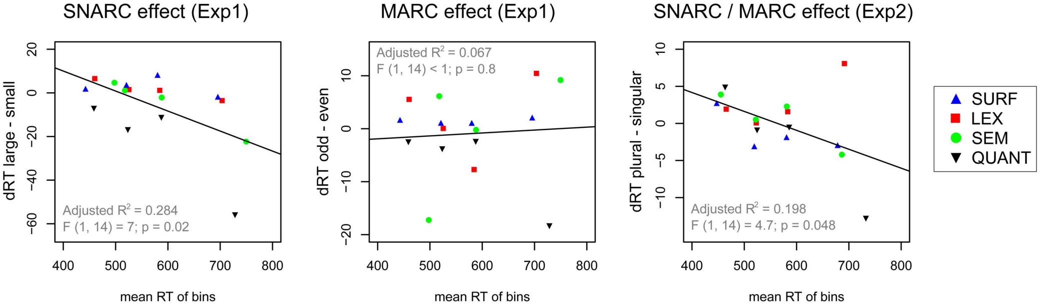

Figure 5. *Linear fitting of SNARC/MARC effects per reaction time (RT) bin and task. SNARC = spatial–numerical association of response codes; MARC = linguistic markedness of response codes; dRT = difference in reaction time. Left panel: dRT large numbers − dRT small numbers. Negative values indicate SNARC-like effects. Middle panel: dRT odd numbers − dRT even numbers. Negative values indicate MARC-like effects. Right panel: dRT plural − dRT singular. Negative values indicate SNARC-like effects; positive values indicate MARC-like effects. To view this figure in colour, please visit the online version of this Journal.*

Taken together, this pattern of evidence suggests that the observed SNARC effects could be accounted for by processing time rather than specific task requirements.

In the light of our task-dependent pattern of results, this evidence suggests that the SNARC effect is elicited in relatively late processing stages. A look at the overall RT pattern reveals that QUANT indeed required the longest processing time. A significant correlation of reaction times and stimulus-to-response mapping (cf. Figure 5) underpins this interpretation. So, one may conclude that a simple explanation based on processing time is sufficient to account for the present pattern of results (a MARC-like effect already appears in early responses while a SNARC-like effect only appears in late responses, overwriting the MARC-like effect). The appearance of SNARC in relatively late responses is in line with earlier findings on Arabic numerals and number words (e.g., Wood et al., 2008) and highly compatible with Experiment 1.

GENERAL DISCUSSION

Using binary forced-choice classification tasks, the present study investigated stimulus-to-response mappings when number words (Experiment 1) and grammatical number (Experiment 2) were processed. Earlier findings for number words were replicated, in that we observed a SNARC effect (a left-hand advantage for number words denoting small numbers and a right-hand advantage for number words denoting large numbers). Evidence for a MARC effect was weak at best (a left-hand advantage for number words denoting odd numbers and a right-hand advantage for number words denoting even numbers). The SNARC findings have been interpreted as evidence for an automatic access to a mental quantity representation. However, access to quantity representations was task dependent. In surface tasks, which, in principle, could be performed without deep conceptual processing, no SNARC effect was observed. Previous findings showing the task-dependent nature of the SNARC effect were extended such that we could demonstrate that there was no access to the mental quantity representation in a task tapping into word form processing (lexical decision). This task-dependent character, however, might be a response latency effect in disguise. The tasks that show significant SNARC effects are those tasks that exhibited the greatest mean response latencies. In line with earlier work (Wood et al., 2008), SNARC is more pronounced in late responses.

In Experiment 2, we showed that grammatical number markers elicit both a MARC-like and a SNARC-like effect. However, these effects interfere with each other since they operate on the same stimulus dimension, the formal coding for grammatical number. The SNARC-like effect was only present in relatively late responses, while the MARC-like effect was only obtained in relatively early responses. Linear trends in slope as a function of response time indicate that those effects might conflict with each other, cancelling each other out at medium response latencies. Generally, however, the presence of a SNARC-like effect in late responses demonstrates that a mental quantity representation may—in principle—be accessed from grammatical number in a similar way as during the processing of Arabic numbers and number words.

Interestingly, the specificity of task-relevant information required to elicit a SNARC-like effect seems to increase in a systematic fashion across stimulus types: While a SNARC-like effect has been already observed in surface tasks (phoneme monitoring) with Arabic digits (Fias, Brysbaert, Geypens, & d'Ydevalle, 1996), it was only found in nonspecific or specific semantic tasks (parity judgement, translation, quantity comparison) with number words (present Experiment 1; De Brauwer & Duyck, 2008; Fias, 2001), and only with a specific quantity-related task (number categorization) with grammatical number markers (present Experiment 2). Thus, the degree of automaticity in which mental quantity representations are accessed seems to vary with the complexity of stimulus decoding and/or the familiarity of accessing quantity representations from certain stimulus formats.

Polarity alignment accounts (Landy et al., 2008; Proctor & Cho, 2006; Santens & Gevers, 2008) explain both the SNARC and the MARC effect in number words within the same framework. According to this type of account, congruent polarities lead to faster response selection than incongruent polarities. However, while this account predicts a MARC-like effect for nouns inflected for grammatical number, it does not straightforwardly predict a SNARC-like effect. Based on the linguistic markedness dimension, singulars should be coded as [+] polarity and plurals as [−] polarity, thus leading to a facilitation of right-hand responses for singular forms. We found this effect in the early responses, but not in the late ones. A conceptual or quantity-based account makes the opposite prediction: Plurals, indicating more quantity than singulars, should lead to a right-hand advantage. That is what we found in relatively late responses.

The present data seem to be ambivalent with respect to the question of whether the quantity representation accessed by grammatical number can be conceived as a left-to-right-oriented mental number line or not. One could, of course, stick with a more structural polarity account arguing that there is a coding of singular as [−] polarity and a coding of plural as [+] polarity. This interpretation does not require any reference to spatial quantity representation. However, this account has two problems: First, one would have to explain why singular is associated with [−] polarity and plural with a [+] polarity. In number words, we have a relative categorization of numeric magnitude into *small* numbers and *large* numbers triggering a potential polarity alignment. Given the specific design of our study, this might not be a valid interpretation. Participants were asked whether the presented noun denotes *one* entity or *more than one* entity. One would have to explain why *one* aligns with [−] polarity and *more than one* with [+] polarity. *More than one* (or even *more*) is certainly the formal and conceptual more complex member of this opposition and should therefore be associated with [−] polarity resulting in the observed MARC effect. This issue touches on a general conceptual issue with polarity alignment accounts. There are numerous definitions of markedness (Clark, 1969; Haspelmath, 2006; Waugh, 1982; Zimmer, 1964), and it is unclear which markedness concept should be applied to certain stimuli pairs. So we are left with an interpretation that semantic number elicited by grammatical number is represented similarly to number words and Arabic numerals. If this is true, polarity alignment accounts could account for our SNARC-like effect, too, through the following mechanism: When some sort of magnitude representation is processed, an abstract magnitude code is activated, which in turn can be associated with either [−] or [+] polarity. Relatively small magnitudes are coded as [−] polarity; relatively big magnitudes are coded as [+] polarity resulting in SNARC effects. This account would thus not make any reference to a structural asymmetry based on linguistic labels like *small* and *large*, rather than assuming an abstract magnitude code.

However, a second problem with polarity accounts is the apparent conflicting stimulus-to-response mapping. When processing grammatical number, two contradicting polarity alignments are at work (resulting in conflicting stimulus-to-response mappings). Polarity alignment accounts, in their present state, do not predict which polarity associations occur in a given setting and—if competing associations interfere with each other—how their interaction affects behaviour.

The present data indicate a temporal dissociation of two conflicting stimulus-to-response associations with MARC-like effects being more dominant in early responses and SNARC-like effects being more dominant in late responses. Given the apparent linear change of slopes as a function of processing time, we might speculate that both effects co-occur, interfering with each other. Over time, the relative strength of one stimulus-to-response mapping (MARC) decreases (or remains constant) while the alternative mapping strength (SNARC) increases.

An excellent testing ground to further our understanding of these issues are languages that have more complex morphological number systems (e.g., Corbett, 2000). In addition to singular and plural, some number systems also use a *dual* to refer to two distinct real-world entities. Other, more rarely occurring grammatical systems also contain a *trial*, in which nouns are marked for groups of exactly three distinct entities, or even a *paucal*, in which a separate grammatical marker is used to refer to a small number of distinct entities. Grammatical systems in which more than two morphological categories are used to refer to quantity might further our understanding of the interrelationship of linguistic and conceptual number and our understanding of the nature of the SNARC and MARC effects in general.

CONCLUSION

To conclude, German speakers access quantity representations when processing grammatical number. Similar to Arabic numbers and number words, the quantity representation accessed seems to be organized in a rightward direction for increasing quantities as shown by the SNARC-like effect. Thus, magnitude codes extracted from processing grammatical number can be argued to be tightly linked to the conceptual domain of space, which in turn leads to a spatial congruency effect of stimulus (magnitude) and response (e.g., Dehaene et al., 1993). This interpretation is very much in line with the view that abstract conceptual domains (e.g., number) adopt structures from more concrete conceptual domains (e.g., space). Moreover, similar to what has been observed in number words, the SNARC-like effect in processing grammatical number is only present in relatively late responses. Based on asymmetries of linguistic markedness, grammatical number also elicits a MARC-like effect, which is constrained to relatively early responses. This demonstrates that contradicting stimulus-to-response associations can operate at different time scales. Both the MARC-like and the SNARC-like effect might also be explained by the polarity correspondence account (Proctor & Cho, 2006). This account, however, remains too vague as to which attributes of certain linguistic stimuli are corresponding to each other.

The utilization of more complex linguistic stimuli appears to be a fruitful avenue to further our understanding of the representation of magnitude information. This study, thus, did not only shed light on the relationship of conceptual quantity and grammatical number; it also constrains current accounts of spatial numerical mappings.

Original manuscript received 26 November 2013
Accepted revision received 3 October 2014

REFERENCES

Almoammer, A., Sullivan, J., Donlan, C., Marušič, F., Žaucer, R., O'Donnell, T., & Barner, D. (2013). Grammatical morphology as a source of early number word meanings. *Proceedings of the National Academy of Sciences*, *110*(46), 18448–18453.

Balota, D. A., Yap, M. J., & Cortese, M. J. (2006). Visual word recognition: The journey from features to meaning (a travel update). In M. Traxler & M. A. Gernsbacher (Eds.), *Handbook of psycholinguistics* (2nd ed., pp. 285–375). London: Academic Press.

Barner, D., Thalwitz, D., Wood, J., Yang, S., & Carey, S. (2007). On the relation between the acquisition of singular-plural morpho-syntax and the conceptual distinction between one and more than one. *Developmental Science*, *10*, 365–373.

Berent, I., Pinker, S., Tzelgov, J., Bibi, J., & Goldfarb, L. (2005). Computation of semantic number from morphological information. *Journal of Memory and Language*, *53*, 342–358.

Bolger, D. J., Perfetti, C. A., & Schneider, W. (2005). Cross-cultural effect on the brain revisited: Universal structures plus writing system variation. *Human Brain Mapping*, *25*(1), 92–104.

Brannon, E. M., & Terrace, H. S. (1998). Ordering of the numerosities 1 to 9 by monkeys. *Science*, *282*, 746–749.

Brysbaert, M., Buchmeier, M., Conrad, M., Jacobs, A. M., Bölte, J., & Böhl, A. (2011). The word frequency effect: A review of recent developments and implications for the choice of frequency estimates in German. *Experimental Psychology (formerly Zeitschrift für Experimentelle Psychologie)*, *58*, 412–424.

Carreiras, M., Carr, L., Barber, H. A., & Hernandez, A. (2010). Where syntax meets math: Right intraparietal sulcus activation in response to grammatical number agreement violations. *NeuroImage*, *49*(2), 1741–1749.

Clark, H. H. (1969). Linguistic processes in deductive reasoning. *Psychological Review*, *76*(4), 387–404.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review*, *108*(1), 204–256.

Corbett, G. (2000). *Number*. New York: Cambridge University Press.

Costanzo, M. E., McArdle, J. J., Xu, J., & Braun, A. R. (2013). Spatial and temporal features of superordinate semantic processing studied with fMRI and EEG. *Frontiers in Human Neuroscience*, *7*, 293.

De Brauwer, J., & Duyck, W. (2008). The SNARC effect in the processing of second-language number words: Further evidence for strong lexico-semantic connections. *The Quarterely Journal of Experimental Psychology*, *61*, 444–458.

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number quantity. *Journal of Experimental Psychology: General*, *122*, 371–396.

Domahs, F., Bartha, L., Lochy, A., Benke, T., & Delazer, M. (2006). Number words are special: Evidence from a case of primary progressive aphasia. *Journal of Neurolinguistics*, *19*(1), 1–37.

Domahs, F., Nagels, A., Domahs, U., Whitney, C., Wiese, R., & Kircher, T. (2012). Where the Mass counts: Common cortical activation for different kinds of nonsingularity. *Journal of Cognitive Neuroscience*, *24*(4), 915–932.

Feigenson, L., Dehaene, S., & Spelke, E. (2004). Core systems of number. *Trends in Cognitive Sciences*, *8* (7), 307–314.

Fias, W. (2001). Two routes for the processing of verbal numbers: Evidence from the SNARC effect. *Psychological Research*, *65*(4), 250–259.

Fias, W., Brysbaert, M., Geypens, F., & d'Ydevalle, G. (1996). The importance of Magnitude information in numerical processing: Evidence from the SNARC effect. *Mathematical Cognition*, *2*, 95–110.

Fischer, M. H., Castel, A. D., Dodd, M. D., & Pratt, J. (2003). Perceiving numbers causes spatial shifts of attention. *Nature Neuroscience*, *6*(6), 555–556.

Göbel, S. M., Shaki, S., & Fischer, M. H. (2011). The cultural number line. A review of cultural and linguistic influences on the development of number processing. *Journal of Cross-Cultural Psychology*, *42*(4), 543–565.

Grainger, J. (1990). Word frequency and neighborhood frequency effects in lexical decision and naming. *Journal of Memory and Language*, *29*(2), 228–244.

Greenberg, J. H. (1963). Some universals of grammar with particular reference to the order of meaningful elements. In J. H. Greenberg (Ed.), *Universals of language* (Vol. 2, pp. 73–113). London: MIT Press.

Greenberg, J. H. (1966). *Language universals, with special reference to feature hierarchies.* The Hague: Mouton.

Haspelmath, M. (2006). Against markedness (and what to replace it with). *Journal of Linguistics*, *42*(1), 25–70.

Hauk, O., Coutout, C., Holden, A., & Chen, Y. (2012). The time-course of single-word reading: Evidence from fast behavioral and brain responses. *NeuroImage*, *60*(2), 1462–1477.

Ito, Y., & Hatta, T. (2004). Spatial structure of semantic representation of numbers: Evidence from the SNARC effect. *Memory & Cognition*, *32*, 662–673.

Landy, D. H., Jones, E. L., & Hummel, J. E. (2008). Why spatial-numeric associations aren't evidence for a mental number line. *Proceedings of the 30th Annual Conference of the Cognitive Science Society*, 357–362.

Lidji, P., Kolinsky, R., Lochy, A., & Morais, J. (2007). Spatial associations for musical stimuli: A piano in the head? *Journal of Experimental Psychology: Human Perception and Performance*, *33*(5), 1189–1207.

Lippa, Y., & Adam, J. J. (2001). An explanation of orthogonal S-R compatibility effects that vary with hand or response position: The end-state comfort hypothesis. *Perception & Psychophysics*, *63*, 156–174.

Loetscher, T., Schwarz, U., Schubiger, M., & Brugger, P. (2008). Head turns bias the brain's internal random generator. *Current Biology*, *18*(2), R60–R62.

Marghetis, T., Kanwal, J., & Bergen, B. K. (2013). Placing numbers in behavioral space: Activity-specific interactions between number and space with a single response button. *Proceedings of the 35th Annual Conference of the Cognitive Science Society*, 972–977.

Marghetis, T., Walker, E., Bergen, B., & Núñez, R. (2011). Making SNAP judgments: Rethinking the spatial representation of number. *Proceedings of the 33rd Annual Conference of the Cognitive Science Society*, 1781–1786.

Miozzo, M., & Caramazza, A. (1998). Varieties of pure alexia: The case of failure to access graphemic representations. *Cognitive Neuropsychology*, *15*(1), 203–238.

Nuerk, H. C., Iversen, W., & Willmes, K. (2004). Notational modulation of the SNARC and the MARC (linguistic markedness of response codes) effect. *Quarterly Journal of Experimental Psychology*, *57A*, 835–863.

Nuerk, H. C., Wood, G., & Willmes, K. (2005). The universal SNARC effect—The association between number quantity and space is amodal. *Experimental Psychology (formerly "Zeitschrift für Experimentelle Psychologie")*, *52*, 187–194.

Proctor, R. W., & Cho, Y. S. (2006). Polarity correspondence: A general principle for performance of speeded binary classification tasks. *Psychological Bulletin*, *132*, 416–442.

Ratcliff, R. (1979). Group reaction time distributions and an analysis of distribution statistics. *Psychological Bulletin*, *86*, 446–461.

Reynvoet, B., & Brysbaert, M. (1999). Single-digit and two-digit Arabic numbers address the same semantic number line. *Cognition*, *72*, 191–201.

Santens, S., & Gevers, W. (2008). The SNARC effect does not imply a mental number line. *Cognition*, *108*, 263–270.

Santiago, J., Román, A., & Ouellet, M. (2011). Flexible foundations of abstract thought: A review and a theory. In A. Maass & T. W. Schubert (Eds.), *Spatial dimensions of social thought* (pp. 41–110). Berlin: Mouton de Gruyter.

Sarnecka, B., Kamenskaya, V., Yamana, Y., Ogura, T., & Yudovina, Y. (2007). From grammatical number to exact numbers: Early meanings of 'one', 'two', and 'three' in English, Russian, and Japanese. *Cognitive Psychology*, *55*(2), 136–168.

Schwarz, W., & Ischebeck, A. (2003). On the relative speed account of number-size interference in comparative judgments of numerals. *Journal of Experimental Psychology: Human Perception and Performance*, *29*, 507–522.

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review*, *96*(4), 523–568.

Waugh, L. R. (1982). Marked and unmarked: A choice between unequals in semiotic structure. *Semiotica*, *38*, 299–318.

Willmes, K., & Iversen, W. (1995, April). On the internal representation of number parity. *Paper presented at the Spring Annual Meeting of the British Neuropsychological Society*, London.

Wilson, M. L., Hauser, M. D., & Wrangham, R. W. (2001). Does participation in intergroup conflict depend on numerical assessment, range location, or rank for wild chimpanzees? *Animal Behaviour*, *61*, 1203–1216.

Winter, B., & Matlock, T. (2013). More is up... and right: Random number generation along two axes. *Proceedings of the 35th Annual Conference of the Cognitive Science Society*, 3789–3974.

Wood, G., Willmes, K., Nuerk, H.-C., & Fischer, M. H. (2008). On the cognitive link between space and number: A meta-analysis of the SNARC effect. *Psychology Science Quarterly*, *50*(4), 489–525.

Zimmer, K. (1964). Affixed negation in English and other languages: An investigation of restricted productivity. *Word*, *20*(2), Monograph No. 5.