The spatial representation of grammatical number

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Abstract

Research on numerical cognition suggests a strong link between mental representations of space and quantity. The SNARC effect (Spatial-Numerical Association of Response Codes effect) is characterized by the association of small quantities with left space and large quantities with right space. While the majority of research on the spatial representation of number has been on number words or Arabic numerals, this study investigates quantity representations that are involved in the processing of grammatical number. We found that German words that were inflected for singular had a relative left hand advantage, and conversely, plurals had a relative right-hand advantage. However, this pattern was only found in relatively late responses. Moreover, it appeared to interfere with the opposite pattern caused by the MARC effect (Markedness Association of Response Codes effect) leading to a relative right-hand advantage for singulars. This interference appeared to depend mainly on response latency with MARC effects being more pronounced in early responses and SNARC-like effects being more pronounced in late responses. This work sheds light on the interaction of different stimulus-to-response mappings operating on the same stimulus dimension – grammatical number. Moreover, it suggests that spatial numerical associations go beyond explicit numerical information, as in number words or Arabic numerals.

Keywords: grammatical number, MARC effect; numerical representation; SNARC effect.

Introduction

Many researchers have argued that the mental representation of quantity is intimately connected to space. This connection is often described using the metaphor of a mental number line, which (in Western cultures) is oriented from left to right. In line with this assumption, it has been shown that spatial response dimensions are associated to numerical magnitude: the SNARC effect is characterized by the association of small quantities to the left hand and large quantities to the right hand. In their seminal work, Dehaene, Bossini, and Giraux (1993) found that in a parity judgment task ("is the number 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. As the task was not explicitly focused on quantity information but on parity, the interaction between quantity and spatial orientation was taken to suggest automatic access to quantity representations which are organized horizontally. Several studies have found similar effects without hand movements, suggesting that the SNARC effect is not genuinely due to a mapping to hands but to perceptual space (e.g., Fischer, Castel, Dodd, & Praat, 2003; Loetscher, Schwarz, Schubiger, & Brugger, 2008). The SNARC effect has been shown for both Arabic numbers and for spoken or written number words (cf., Landy, Jones, & Hummel, 2008; Nuerk, Iverson, & Willmes, 2004; Nuerk, Wood, & Willmes, 2005).

In 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 in binary representations of dimensions, across both stimulus and response properties, one value of the dimension is "generally more available than the other" (Landy et al., 2008: 358). To account for the SNARC effect, e.g. the polarity correspondence principle (Proctor & Cho, 2006) assumes 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. Congruent polarities (small numbers/left space, large numbers/right space) cause faster response selection than incongruent polarities.

This model also accounts for the MARC effect (Markedness Association of Response Codes effect, cf., Nuerk et al., 2004; Reynvoet & Brysbaert, 1999; Willmes & Iversen, 1995). An example of the MARC effect are faster right hand responses to even numbers and faster left hand responses to odd numbers (see e.g., Nuerk et al., 2004). It is assumed that this effect is closely related to the concept of linguistic markedness (see Haspelmath, 2006, for an overview) which refers to the formal and conceptual asymmetry between linguistic categories: in a parity judgment task, in which the hand-to-response relation is manipulated within participants, the adjectives "right" and "even" are assumed to be linguistically unmarked (Zimmer, 1964). On the contrary, "left" and "odd" are assumed to be linguistically marked. Interference is observed if the markedness association between stimulus and response is incongruent, while facilitation is observed if the markedness association is congruent.

At least for numerals, SNARC and MARC effects may co-occur (e.g., Nuerk et al., 2004). However, they do not interfere with each other since they are linked to independent stimulus properties (SNARC is linked to relative magnitude, MARC is linked to parity).

Grammatical number, quantity, and markedness

In addition to symbolic and lexical number representations, many languages encode quantity grammatically. In particular, languages such as English and German employ morphological markers that decode the distinction between one entity ("singular") and more than one entity ("plural"). Most commonly, nouns are grammatically marked for number by inflection, e.g., by adding an affix such as *–s* to English nouns. The most frequent grammatical number systems restrict the number of available categories to singular (one entity) and plural (more than one entity) (Corbett, 2000). For a German example, compare (1), where the suffix *–n* adds plural meaning to the noun lion.

(1) *Löwe* 'lion' vs. *Löwen* 'lions'

While, 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. Several developmental and behavioral studies demonstrated a tight connection between grammatical and conceptual number (Barner, Thalwitz, Wood, Yang, & Carey, 2007; Berent, Pinker, Tzelgov, Bibi, & Goldfarb, 2005; Sarnecka, Kamenskaya, Yamana, Ogura, & Yudovina, 2007). For example, in a Stroop-like task, Berent et al. (2005) asked their participants to judge the quantity (one or two) of visually presented words while ignoring their contents. Letter strings consisted of both singular and plural nouns (Exp. 1), and of pseudowords with or without regular plural inflection (Exp. 3). Response latencies were higher when there was a mismatch between grammatical number and the quantity of words presented (e.g., *dog dog* vs. *dogs dogs*). The authors concluded that the extraction of semantic number from grammatical number is automatic and represented in a way that is comparable to the conceptual number that they extract from visual perception.

The present study follows up on those findings and links it to numerical cognition research. Grammatical number is an excellent testing ground for the interaction of contradicting stimulus-to-response mappings because it allows us to pit SNARC-based and MARC-based accounts against each other.

The present study

The present study applies a binary classification task to German nouns inflected for singular or plural. Conceptual quantity is involved in the process of specifying the grammatical number of nouns because, typically, singular nouns refer to one entity and plural nouns refer to multiple entities. Although the plural does not represent a specific quantity, we assumed it to represent a quantity which is – on a (Western) mental number line – localized more towards the right relative to a singular quantity (= 1), thus leading to a SNARC-like effect. In other words, singular forms should be responded to faster with the left hand whereas plurals should be responded to faster with the right hand.

This prediction goes against the predictions based on the MARC effect: In linguistic theory, singular is thought to be unmarked, and plural is thought to be marked (cf., Greenberg, 1966). For example, within a language, singulars are used more frequently than plurals. And, if a language has a morphological coding of number (such as an affix), then the plural is typically overtly coded, thus formally more complex, whereas singulars often lack an overt coding, as in the German example (1) above. The MARC effect 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. Hence, singular forms should be responded to faster with the right hand (unmarked) whereas plurals should be responded to faster with the left hand (marked).

Apparently, grammatical number poses a problem to polarity accounts. Two conflicting polarity alignments are potentially at work operating on the same stimulus dimension: one alignment coding singulars as [+] polarity due to its linguistically unmarked status, and one coding singulars as [–] polarity due to the conceptual quantity representations. Typically, however, polarity alignment accounts do not deal with conflicting polarity associations and therefore they make no prediction about which polarity association should occur in a given setting. Moreover, if competing associations interfere with each other the model does not predict how interference affects behavior.

One level of dissociation of those effects might operate on processing depth: the SNARC effect may become stronger when magnitude processing is activated more intensively (Gevers, Verguts, Reynvoet, Caessens, & Fias, 2006), i.e. the size of the SNARC effect depends on response latencies and the amount of semantic number processing required. In their meta-analysis, Wood, Willmes, Nuerk, & Fischer (2008) found a positive correlation of the SNARC effect size and response latencies across studies. Moreover, they found SNARC effects to be more pronounced in studies in which the task required the active processing of numerical magnitude (see also De Brauwer & Duyck, 2008; Fias, 2001). Because the SNARC effect requires a certain amount of semantic magnitude processing, we expect it to occur only in semantic tasks. The MARC effect on the other hand, could already occur in an asemantic task, since no semantic information is necessarily required to encode a plural inflection, which is a surface characteristic of a word. Thus, one might hypothesize that those two effects are potentially dissociated in respect to task requirements. To explore this possibility and to investigate a potential dissociation of SNARC and MARC, we introduced tasks requiring different processing depths.

Method

We designed four different tasks corresponding to different stages of processing depth. In the first task, participants had to decide whether the presented 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 the third task, participants had to make animacy judgments, where they had to decide whether the nouns denoted creatures (animate) or objects (inanimate) (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).

Because quantity information is assumed to be represented at a conceptual level of processing and the SURF and LEX conditions do not require conceptual access, we expected no SNARC effect to occur at SURF and LEX. On the other hand, both decisions in SEM and QUANT required access to conceptual representations, thus a SNARC effect is expected to occur at SEM and QUANT. A MARC effect, however, could already occur in asemantic tasks, thus we do not predict any task dependency of a potential MARC effect. In their interaction, with increasing processing depth the impact of the MARC effect should be increasingly attenuated by the impact of the SNARC effect.

Participants

Fifty-two native speakers of German (33 female, 19 male), with an average age of 26.9 years (SD = 7.0) volunteered to participate for payment. All of them had normal or corrected-to-normal vision.

Stimuli

The stimuli consisted of four German nouns in both their singular and plural form, respectively (*Kuh/Kühe* 'cow(s)', *Löwe/Löwen* 'lion(s)', *Münze/Münzen* 'coin(s)', and *Stuhl/Stühle* 'chair(s)'). We applied the following selection criteria to fit the stimuli to the experimental design: 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*). 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. This was done to ensure that participants access lexical knowledge rather than focus their attention just to one particular orthographic cue.

Procedure

All subjects participated in eight blocks of trials, i.e. two blocks per processing depth (SURF, LEX, SEM, and QUANT). After the first block of each processing depth, 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 counter-balanced across participants. Each block started with a training session in which all words were presented once. In the test blocks, each word was presented ten times in randomized order.

The experiment was controlled using Superlab 2.04 software (Abboud, 1991) 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. Stimuli 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, centered in egocentric space and separated 10 cm from each other. At the beginning of each trial, a fixation stimulus consisting of five asterisks (*****) was presented in the center of the screen for 300 ms. Then, the target appeared and remained for 1300 ms, during which response time was measured. The inter-trial-interval was 1500 ms (blank screen). The instructions given to participants stressed both speed and accuracy.

Analysis

Six participants were excluded from analyses because they showed difficulties in changing the response assignment in at least one task. In the remaining data set, 5.8% of the trials had to be excluded due to wrong responses (3.45%), anticipations (RT faster than 200 ms) (0.05%), or RTs outside ±3 standard deviations from the individual mean of each task per hand association per speaker (2.31%). There was no trade-off between mean RT and error rate (r =-.182; p>.05).

Reaction times were analyzed using a series of generalized linear mixed effects models implemented in the R software (R Core Team, 2012) and the package *lme4* (Bates, Maechler, & Bolker, 2012). We used a Gaussian error distribution and identity link function. Both *subjects* and *items* were used as crossed random intercept effects. Since we are interested in the interaction of stimulus and response, we included the factor *Number* (singular, plural) interacting with the factor responding *Hand* (right, left) as a fixed effect in the models.

In a first step, we tested if this interaction is dependent on task requirements, thus we included a three-way interaction of *Hand* × *Number* × *Task* (SURF, LEX, SEM, QUANT) as a fixed effect. In subsequent analyses we tested the *Hand* × *Number* interaction for each task separately.

We computed p-values comparing the models with the interactions in question to the models with only the non-interacting fixed effects via Likelihood ratio tests (LRTs).

Results

Overall, responses to tasks differed substantially in terms of response latency, such that SURF was responded to fastest (513 ms) followed by SEM (548 ms), LEX (579 ms), and QUANT (631 ms). Crucially, the *Hand* × *Number* × *Task* interaction was significant ($\chi(9)=81.514$, p<0.0001), indicating that there was a stimulus-response interaction modulated by task specific effects (cf. Figure 1).

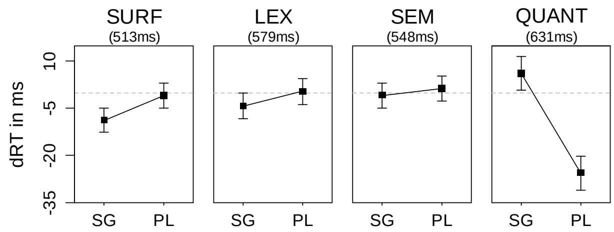

Figure 1**:** Estimated RT differences (dRT) and standard errors between right hand and left hand responses as a function of grammatical number (SG = singular; PL = plural). Negative slopes indicate SNARC-like effects; positive slopes indicate MARC-like effects. Mean RT of each depth is given in brackets.

Subset analyses of each processing depth separately revealed that SURF showed a significant *Hand* × *Number* interaction (χ(1)= 4.096, p=0.043), such that the model estimated a greater right hand advantage for singular forms (9 ms) than for plural forms (1 ms) (SE=3.88 ms), as predicted by a MARC-based account. The two-way interaction *Hand* × *Number* did not reach significance in the LEX or SEM condition (χ(1)=1.226, p=0.27 and χ(1)= 0.303, p=0.58, respectively). For the QUANT processing depth, there was a significant interaction of *Hand* × *Number* (χ(1)=35.11, p<0.0001) such that the model estimated a left hand advantage for singular forms (6 ms) and a right hand advantage for plural forms (26 ms) (SE=5.36ms), as predicted by a SNARC-based account.

Table 1: Overview of stimulus-to-response mappings as a function of task and RT bin.

Task	Bin	dRT SG	dRT PL	Slope	SE
SURF	1	-3,71	-1,31	**-2,40**	2,18
	2	-1,28	0,09	**-1,37**	1,22
	3	-0,23	-1,16	**0,94**	1,67
	4	-0,53	-3,21	**2,68**	6,12
LEX	1	-2,04	2,46	**-4,50**	2,59
	2	-0,33	-1,59	**1,26**	1,34
	3	1,69	1,21	**0,47**	1,80
	4	-4,52	-7,16	**2,64**	6,04
SEM	1	-1,56	3,42	**-4,99**	2,55
	2	-1,83	0,47	**-2,30**	1,41
	3	1,37	1,48	**-0,11**	1,53
	4	7,39	-0,99	**8,38**	6,22
QUANT	1	-3,33	-3,40	**0,07**	3,19
	2	2,09	1,73	**0,36**	1,97
	3	1,96	-3,14	**5,10**	2,56
	4	3,65	-16,95	**20,60**	8,57

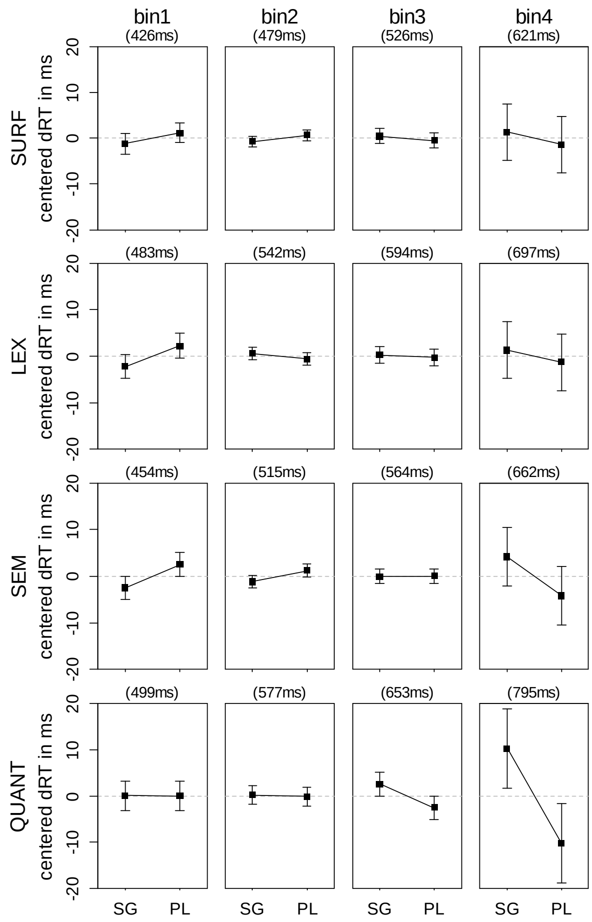

Figure 2**:** Estimated RT differences (dRT) and standard errors between right hand and left hand responses as a function of grammatical number for RT bins (centered around zero). Negative slopes indicate SNARC-like effects; positive slopes indicate MARC-like effects. Mean RT of each bin is given in brackets.

Since the mean response latencies of the tasks differed substantially, the observed dissociation between SNARC and MARC might be due to overall processing time rather than required magnitude processing. To obtain a view of the time course, we rank ordered RTs for each subject and processing depth and divided them into four equal bins (Ratcliff, 1979). We tested if the *Hand* × *Number* interaction was dependent on the factor *RT bin* (bin 1-4) for each task separately. This was not the case for SURF, LEX or SEM (χ(9)≤12.75, p≥0.17). It was, however, for QUANT as indicated by a significant interaction of *Hand* × *Number* × *RT bin* (χ(9)=20.77, p=0.014). In this condition, there was a significant SNARC-like effect in late responses (bin 3 and 4) (χ(1)≥3.94, p≤0.047), but not for early responses in bin 1 and 2 (χ(1)≤0.035, p≥0.85) (cf. Table 1, Figure 2).

Numerical trends further indicate that SNARC-like effects are found in all tasks depending on overall processing time. This pattern of evidence suggests that these SNARC effects could be accounted for by processing time only rather than processing depth. Visual inspection of the slopes over time yielded a similar pattern: Early responses exhibit positive or flat slopes indicating MARC-like patterns and/or the absence of SNARC-like effects, while late responses exhibit negative slopes indicating SNARC-like patterns. Moreover, the change of slope over the time course appears to be roughly linear.

Discussion

The present study investigated stimulus-to-response mappings when processing grammatical number in binary tasks. We demonstrated that grammatical number markers elicit a SNARC-like effect, i.e. German words inflected for singular had a relative left hand advantage; plurals had a relative right hand advantage. At the same time, we demonstrated a MARC effect that showed the opposite pattern. There was a reliable MARC effect in a font classification task (SURF) and a reliable SNARC effect in a magnitude classification task (QUANT). 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 RTs obtained reveals that QUANT indeed required the longest processing time. A significant interaction of reaction times and stimulus-to-response mapping in the magnitude classification task as well as numerical trends in all tasks (cf. Table 1, Figure 2) underpin 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 effect already appears in early responses while a SNARC effect only appears in late responses"). 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).

Polarity alignment accounts (Landy et al., 2008; Proctor & Cho, 2006; Santens & Gevers, 2008) explain both the SNARC and the MARC effect within the same framework. According to this account, congruent polarities lead to faster response selection than incongruent polarities. However, this account makes contradicting predictions regarding the response association for grammatical number: Based on the linguistic markedness dimension, singulars should be coded as [+] polarity and plurals as [–] polarity, thus leading to a facilation of right hand responses for singular forms. A quantity-based account makes the opposite prediction, which assumes that singulars are coded as [–] polarity and plurals as [+] polarity (in analogy to numerals). Interestingly, the present study found both patterns, thus two conflicting polarity alignments have been shown to operate on the same stimulus dimension. Polarity alignment accounts in their present state, however, do not predict which polarity associations occur in a given setting and – if competing associations interfere with each other – how their interaction affects behavior. The present data indicate a temporal dissociation of these stimulus-to-response associations with MARC 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 (SNARC) increases. Due to the lack of statistically significant results for some conditions, this remains, however, speculative.

Generally, the presence of a SNARC effect in the quantity task 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. One might argue, that the present data are ambivalent with respect to the question whether this quantity representation of grammatical number can be conceived as organised in a left-to-right oriented mental number line or not. One could, of course, doubt the relevance of the quantity-to-space nature of the response-to-stimulus mapping and stick with a more neutral 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, and consequently our data would say nothing about the association between conceptual number and grammatical number. However, one would have to explain why singular is associated with [–] polarity and plural with a [+] polarity. To us, one possible interpretation is grounded in the spatial nature of the conceptual quantity representation.

Future research might shed light on these issues. An excellent testing ground are languages which have more complex morphological number systems: In addition to singular and plural, some number systems also have an additional grammatical category that is called "dual", which serves to refer to two distinct real-world entities (cf., Corbett, 2000). Other, more rarely occurring grammatical systems also contain a so-called "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 interaction of different stimulus-to-response associations in general and the interrelationship of linguistic and conceptual number in particular.

Conclusion

To conclude, grammatical number elicits two contradicting stimulus-to-response mappings. A MARC effect based on the linguistic markedness of the grammatical categories singular and plural; and a SNARC-like effect based on its semantic reference to magnitudes. Similar to Arabic numbers and number words, this quantity representation seems to be organised in a rightward direction for increasing quantities. This SNARC-like effect, however, only appears in relatively late responses, while the MARC effect appears to be restricted to relatively early responses. Linear trends in slope changes over time indicate that both effects interfere with each other.

In general, the use of linguistic categories beyond number words appears to be an interesting and promising avenue to investigate the relationship of different stimulus-to-response mappings.

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References

Abboud, H. (1991). *SuperLab.* Wheaton, MD: Cedrus.

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.

Bates, D., Maechler, M., & Bolker, B. (2012). lme4: Linear mixed-effects models using S4 classes. R package version 0.999999-0. http://CRAN.R-project.org/package=lme4

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.

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

De Brauwer & Duyck, W. (2008). The SNARC effect in the processing of second-language number words: Further evidence for strong lexico-semantic connections. *The Quarterly 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.

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

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.

Gevers, W., Verguts, T., Reynvoet, B., Caessens, B., & Fias, W. (2006). Numbers and space: a computational model of the SNARC effect. *Journal of Experimental Psychology: Human Perception and Performance*, *32*(1), 32–44.

Greenberg, J. (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.

Landy, D. H., Jones, E. L., & Hummel, J. E. (2008). Why spatial-numeric associations aren't evidence for a mental number line. *Proc. 30th Ann. Conf. Cogn. Sci. Soc.*, 357–362.

Loetscher, T., Schwarz, U., Schubiger, M., & Brugger, P. (2008). Head turns bias the brain's internal random generator. *Current Biology*, *18*(2), 60–62.

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*, *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.

R Core Team (2012). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.ISBN 3-900051-07-0, URL http://www.R-project.org/.

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.

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.

Wood, G., Willmes, K., Nuerk, H.-C., & Fischer, M. (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.