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The power of the mental number line: how the magnitude of unattended numbers affects performance in an Eriksen task

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Abstract

Number magnitude is known to be activated even when it is irrelevant. However, little is known about whether and how this automatic number magnitude activation is attentionally used to select relevant information and to inhibit irrelevant information.

In an Eriksen paradigm, we investigated this issue in a magnitude comparison task with the standard 5. First, we replicated the usual attentional congruency effects for numbers. When the distractors would lead to a response which is incongruent with the correct response to the target, participants were slow. Second, we observed the common number magnitude (distance and SNARC) effects for the target number, but generally failed to find such effects for distractors. Finally, we found evidence that participants could not help making a dysfunctional second order magnitude comparison in which they compared the target with the to-be-inhibited distractor.

The results seem to suggest that it is not the magnitude of the distractors themselves which determined performance, but their relation to target magnitude. This relation seems to be used in a functional way to enhance attentional selection and inhibition processes. In line with results from other paradigms (Fischer, Castel, Dodd, & Pratt, 2003) we conclude that the automaticity of number magnitude processing and its influence on attentional selection and inhibition procedures should not be underestimated.

Key words: mental number line, SNARC, MARC, Eriksen, attention, distance effect

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The representation of number magnitude strongly influences performance in everyday numerical tasks. The classical indication of a magnitude representation is the numerical distance effect. The decision whether or not a given number is larger or smaller than another number can be made faster when the distance between the two numbers is large than when it is relatively small (Moyer & Landauer, 1967; Restle, 1970; for two-digit numbers, see Dehaene, Dupoux ,& Mehler, 1990; Nuerk, Weger, & Willmes, 2001). Most models of number processing assume automatic (co-)activation of number magnitude even for non-semantic tasks in which number magnitude is irrelevant. Prominent examples for such automatic co-activation are (i) the SNARC-effect (for a detailed review see Fias & Fischer, 2005; Gevers & Lammertyn, this issue) and (ii) the Number-Stroop effect.

The SNARC (Spatial-Numerical Association of Response Codes)-effect (Dehaene, Bossini, & Giraux, 1993; Fias, Brysbaert, Geypens, & D'Ydewalle,1996) describes an automatic association between the location of the response hand and the abstract semantic magnitude of a given number which is modality-independent (Nuerk, Wood, & Willmes, in press). Even for tasks in which magnitude is irrelevant, like parity judgement or phoneme detection, larger numbers are faster responded to with the right response key while smaller numbers are faster responded to with the left. The explanation given by Dehaene and colleagues is that the magnitude of a number on an oriented mental number line is automatically activated. The mental number line is assumed to be oriented from left to right; thus larger numbers are spatially located on the right mentally. When the response key is also on the right, there is a congruency between the mental spatial location of the number on the number line and the location of the response. In such a congruent condition responses are fast and otherwise slow.

An effect related to the SNARC effect is the linguistic markedness association of response codes (MARC) effect (Nuerk, Iversen, & Willmes, 2004). It describes an association between the linguistic markedness of the stimuli and the markedness of responses. According to linguistic theory, most adjectives can be categorized as either an (unmarked) base form or a (marked) derived form (e.g., "efficient" – unmarked, "inefficient" – marked). The most important expression of the MARC effect is the association between parity and response hand. "Even" and "right" are conceptualized as unmarked base forms while "odd" and "left" are the marked forms. The MARC effect predicts that – especially for verbal notation – responses are fast when they are congruent with regard to markedness: The associations even-right and odd-left are therefore faster responded to than the associations even-left and odd-right. The MARC effect in this study may be important because when markedness association is used as a predictor, it may pick up variability in decision times which may mask the SNARC effect (cf. Nuerk et al., 2004).

Of particular importance for this study are observations that the SNARC effect can be observed even without semantic processing of numbers. Fias, Lauwereyns, and Lammertyn (2001) could show that irrelevant numbers that are superimposed on other stimuli may produce a SNARC effect when the task (e.g. orientation decision) also affects representations that are subserved by parietal circuits. Similarly, attention shifts are influenced by the magnitude of a given number just if this number serves as a fixation point and is irrelevant for the task (Fischer, Castel, Dodd, & Pratt, 2003). Thus, it is not necessary that a task requires semantic processing of numbers and even when the number should be ignored, the SNARC effect can be exhibited.

Another effect of importance for the current study is the so-called number stroop effect (Henik & Tzelgov, 1982). The number stroop effect results from an interference of physical size and numerical size. When two numbers have to be compared, adult participants and also children (Girelli, Lucangeli, & Butterworth, 2000, Rubinsten, Henik, Berger & Shahar-Shalev, 2002) are faster when the physically larger (resp. smaller) number is also numerically larger (resp. smaller) than when physical and numerical size are incongruent. This congruency effect holds for both, physical comparison and numerical comparison. Recent evidence does – additionally – show that the interference is not a digital function of response congruency, but that it is parametrically modulated (Schwarz & Ischebeck, 2003). The larger the distance for the task-irrelevant dimension and the smaller the distance for the task-relevant dimension the stronger the interference. So, for instance, in a physical comparison task, interference would be larger when the physical distance between the two numbers is small (i.e., if they have almost the same physical size) and when the numerical distance is large (e.g., for 1 and 9 as compared to 4 and 5). Thus, numerical magnitude is activated even when it is irrelevant and it can influence performance parametrically and not just categorically even when it is irrelevant (see Dehaene & Akhavein, 1995, for similar data in another task).

However, in the above number stroop task, both numbers have to be processed to a certain extent. We were interested whether number magnitude influenced performance in a similar way as in the number stroop task when processing the interfering number must be inhibited in every respect (and not just with respect to one stimulus attribute). In the number stroop task, one could argue that the numerical magnitude representation is only activated because another (physical) magnitude of the same stimulus must be processed. We were interested if this is also the case when going one step further and using a task in which subjects are asked to inhibit the distractor number in every respect and in which they must do so in 50% of the trials in order to retrieve the correct response. Note that this characteristic is also different from the task employed by Fias et al. (2001) in which they found a SNARC effect for irrelevant (superimposed) numbers in an orientation judgement task. There the number could or could not be ignored; since its perception was not explicitly linked to any response action, there is no direct need to actively inhibit the number representation. We will see that this makes a difference.

In sum, the general question of the study was whether such automatic number magnitude activation is also present for distractors and if so whether this magnitude activation can be attentionally used to select relevant target information and to inhibit irrelevant distractor information. Specifically, we wanted to explore whether only the categorical response association of the distractor influenced responses or whether the relationship between the magnitude of the target and the magnitude of the irrelevant and to-be-inhibited distractor also played a parametric role.

A good way to examine these questions is provided by the classical flanker task, introduced by Eriksen and Eriksen (1974). In this task a target stimulus (a letter chosen from two sets of letters) is presented at a central display location. Simultaneously, to the left and the right of the target, flanking distractor letters (“flankers”) are displayed. In a forced-choice task, participants are required to respond with a button press according to which of the two sets the target was chosen from. Flankers are irrelevant for the task and should be ignored. To be able to respond correctly, observers need to focus on the central target stimulus. The results of Eriksen and Eriksen’s study suggest that the spatial extent of the processing focus, i.e., the area from where information is extracted, cannot be smaller than about 1° of visual angle. Consequently, task performance is affected by irrelevant distractor information if (at least some of) the flanking distractor letters are presented within the minimum spatial extent of the processing focus (i.e., an area subtending 1° of visual angle). The effect of flanker distance could be taken as evidence for a purely perceptual mechanism of letter similarity or, alternatively, lateral inhibition. More importantly in the present context of number processing, performance is also affected by which set of letters the flanking stimuli were chosen from in a given experimental trial: Response times expedited or slowed, dependent on whether the target and the flanking distractors required the same or different responses, respectively. In other words, in the Eriksen and Eriksen flanker task, reaction times are affected by semantic properties of the target and distractor stimuli.

Method

Participants

24 participants (mean age 23.0; 10 female) participated in the experiment. All observers had normal or corrected to normal vision and were paid for participation.

Apparatus

Observers viewed the PC monitor display from a distance of 57 cm, with eye-screen distance held constant through the use of a chin rest. The experiment was conducted in a darkened room with dim background lighting to prevent screen reflections. A Sony Multiscan G420 Trinitron monitor was used (frame rate 100 Hz), controlled by a INTEL Pentium 4 (1600 MHz) computer equipped with an ELSA Gladiac 511 (64 MB) graphics card. Observers responded by pressing a left or right button of a purpose-built keypad with the index finger of the left or right hand, respectively. Left and right buttons of the keypad were placed to the left and right relative to the central location and kept at a fixed horizontal distance of 16 cm. RTs and error rates were recorded by the computer.

Stimuli and design

All participants participated in a magnitude comparison task (with fixed standard 5) and in a parity judgement task. The sequence of the tasks was counterbalanced between participants. Only the magnitude comparison experiment will be reported here.

The display always consisted of seven horizontally aligned number stimuli, one central target and three distractor stimuli to the left and the right of the target, respectively. The size of each stimulus was approximately 0,5° of visual angle in height and 0,25° in width and the display of target and distractors subtended a visual angle of 2,5°. The target was always presented at the middle position, indicated by two vertical bars above and below the number in between 6 distractor numbers (3 on each side). Through presenting the vertical indicator bars, observers were not required to determine the exact position of the target digit. All of the distractor numbers were always identical. Target number and distractors could range from 1 – 4 and 6 –9 resulting in 8 * 8 =64 different target distractor combinations which were manipulated in a fully randomized design. Participants had to decide, by pressing one of the keypad buttons (distance ~25cm), whether the target number was larger or smaller than 5.

After half of the experiment, the association between the correct response (larger/smaller) and the response keys (left/right) was changed. The sequence of response key associations (left/smaller; right/smaller first) was counterbalanced across participants.

Procedure

Observers were familiarized with the task in one practice block of 64 trials. Each of the 64 experimental target-distractor combinations was repeated 20 times (i.e., 10 times in each response key assignment); the experiment consisted of 20 blocks in which each trial was presented once in random order. After 10 blocks the hand-response association was changed. Blocks were separated by a 30 second break with a feedback of how many errors (in percent) had been made in the preceding block.

Observers were instructed to respond as quickly and as accurately as possible. A trial started with the simultaneous onset of all seven numbers which were all green against a black screen background. This display remained on the screen until the observer responded (or until the error feedback sign was given). The inter-trial interval was 1400 ms as in the original experiment of Eriksen and Eriksen (1974).

Results

Only correct trials were analyzed for the RT data. In the subsequent cleaning procedure, trials outside the interval [200, 1500] ms and – in a second step – trials outside +/- 3 SD around the individual mean were eliminated. The RT analyses were conducted on the means of the remaining data for the 64 conditions.

The 128 conditions (64 target-distractor conditions x 2 response hand associations) can be analyzed in multiple ways. To restrict the complexity of the results in some way, we organized the data analyses into four subsections

(i) We explored common attentional (response-) congruency effects for numbers which are typically observed for letters in the Eriksen paradigm. When target and distractors lead to the same response, RT is usually fast and otherwise slow. The replication of previous results would be an indication that attentional processes in this number processing task are similar as for other stimuli and tasks.

(ii) We analyzed the common number magnitude effects for the target, such as the numerical distance effect and the SNARC effect. The replication of number processing effects is important because it may indicate that the mental number line is accessed in a similar way for targets surrounded by distractors in our task as is usually the case for single numbers.

The other two analyses do explore the role of the to-be-inhibited distractor numbers.

(iii) We examined the same common magnitude effects (distance, SNARC) also for the distractors. A common response-congruity effect in (i) would only show that the response-tendency of the distractors is processed. This analysis examines whether distractors are processed in a similar way as for targets although they must be inhibited.

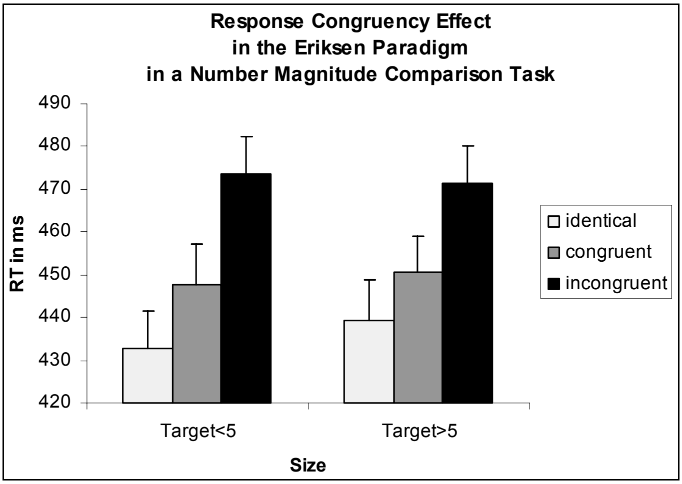
(iv) We explored the interaction between attentional effects and the magnitude relation between attended target and unattended distractor. This analysis may corroborate previous data (Fischer et al., 2003) which suggest a close relationship between numerical magnitude and attentional processes.

For the sake of brevity, error data were not analyzed.

(i) Attentional congruency effects:

For an investigation of attentional congruency effects and its possible interaction with size, we performed a 2 x 2 ANOVA with the factors distractor congruency (same or different response) and target size (larger or smaller than 5). Attentional-congruent (or response-congruent) conditions in which target and distractor number share the same response category (i.e., both larger or smaller than 5) were consistently faster than incongruent trials (F(1,23) = 226.82; p < .001). This congruency effect prevailed when identical trials (e.g. 222222) were not included as congruent trials (F(1,23) = 154.07; p < .001). There was no main effect of target size, but an interaction with congruency when identical trials were included (F(1,23) = 4.30; p = .05). The congruency effect was larger for targets smaller than 5. An additional analysis revealed that there was a size effect for identical trials (t(23) = 2.25; p < .05) in that trials smaller than 5 were faster. No size effect was found when identical trials were not included (all p > .25 two-sided; see Figure 1 for results).

Figure 1:
RT data for response-congruent (3331333), response-incongruent (3337333), and identical (3333333) trials for two different sizes (smaller/larger than 5) in a magnitude comparison task in an Eriksen paradigm. Incongruent trials are slower responded to than congruent trials.



(ii) Target magnitude effects

For the analysis of the target magnitude effects, we collapsed the data acquired for each target number over all distractors. We explored the *distance effect* by computing a linear trend over the splits (i.e., the absolute distances between the target number and the standard 5) and its interaction with size (larger/smaller than 5) by computing a linear-by-linear trend with both factors.[4] We observed a highly significant linear trend: larger distances produced faster responses than smaller distances (F(1, 23)= 300.12, p < .001). We obtained no main size effect (F< 1), however, the linear-by-linear trend revealed an alteration of the distance effect by size (F(1, 23)= 45.43, p < .001). The distance effect was larger for numbers smaller than 5 (see Figure 2a).

For the *SNARC effect*, we computed the individual slopes as introduced by Fias and colleagues (1996; see Lorch & Myers, 1990). Although the SNARC effect seemed highly reliable in the fixed regression analysis (r = -.82, Figure 2b), we did not obtain a linear SNARC effect with the Lorch & Myers method, because participants were too variable (t(23) = -.89, p = .19, one-sided). When we looked for a MARC effect in addition to the SNARC effect by introducing both predictors into the individual regression analyses (cf. Nuerk et al., 2004), we made an interesting observation. We did not observe a significant MARC effect (t(23)= -.69, p =.27), however, now the SNARC effect became significant (t(23) = -1.94, p <.05). It seemed that at least in some participants the MARC predictors eliminated irrelevant error variance, so that the SNARC effect became more stable across participants.

Nevertheless, inspection of the data revealed (see Figure 2b) that the SNARC effect was rather categorical than continuous in nature. Therefore, we analyzed the SNARC effect with a categorical predictor (rather than a continuous one). The categorical SNARC effect became always significant with and without additional MARC predictors (both t(23) >= 1.84, both p <.05). To examine whether a continuous or a categorical SNARC effect could better predict performance, we used the Lorch & Myers method with a continuous SNARC predictor (i.e., the number magnitude) and a categorical SNARC predictor (i.e. smaller/larger than 5) as above. The categorical SNARC predictor was significant across participants (t(23) = -2.02, p <.05) while there was no indication of a continuous SNARC effect when the categorical effect had been partialled out (t(23) = -0.10, p = .46). Thus, numbers larger than 5 were faster responded to with the right hand and numbers smaller than 5 with the left hand.

In sum, the data show a divergence between the distance and the SNARC effect already for the target data. While the distance effect reveals continuous magnitude related performance differences, the SNARC effect is better explained by the response category (smaller, larger) than by the numerical value of the target number.

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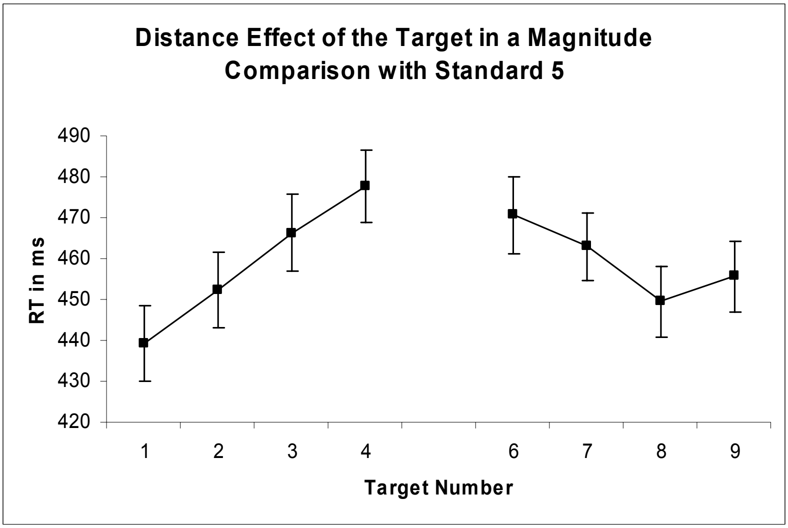
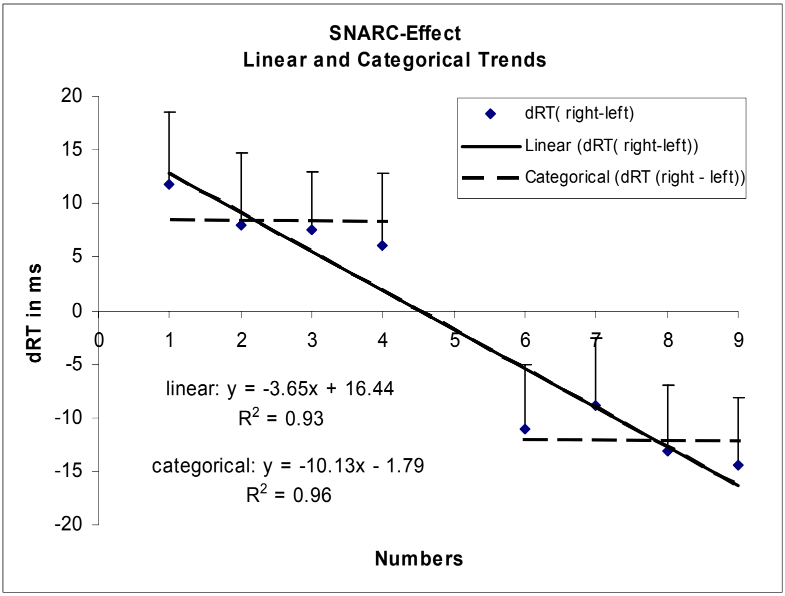
[4] Note that an ANOVA with a four-level split factor is not appropriate because it just tests the global null hypothesis. However, the hypotheses about the distance effect are more specific and should be tested accordingly (e.g. with linear trend test or t-tests of individually computed slopes; cf. Hager, 2002; see also Lorch & Myers, 1990).

Figure 2:
Standard magnitude effects for target trials: Figure 2a: (top) distance effect: Performance becomes faster with increasing numerical distance from the standard. Figure 2b (bottom) SNARC effect: dRT depicts the difference in RT between right hand and left hand responses (RT(right) – RT(left)). Thus, positive values indicate that the right hand responses are slower. It can be seen that larger numbers are relatively faster responded to with the right hand and smaller numbers with the left hand. Note that the SNARC effect is rather categorical in these data.





(iii) Distractor magnitude effects

For the distractor effects we carried out the equivalent analysis as for the targets, the difference being that now the data were collapsed over targets rather than over distractors. The results were straightforward. With regard to the distance effect, we did not observe any linear trend (F(1, 23) < 1). However, we observed a small size effect of 3 ms for the distractors (F(1, 23)= 4.29, p = .05) with faster responses for smaller distractors. The linear-by-linear trend analysis revealed no linear alteration of the distance effect by size (F(1, 23) < 1).[5]

There was also no linear SNARC effect with the Lorch & Myers method (t(23) = -.56, p = .29, one-sided). However, there tended to be a categorical SNARC effect when the MARC effect was partialled out (t(23) = -1.84, p < .05). Trials with smaller distractor numbers tended to be responded to more quickly with the left hand side, when the parity x hand association was partialled out individually. However, in the absence of a main categorical SNARC effect (t(23) = .20, p = .84, two-sided), this effect should be interpreted with great care until it is replicated. No other effect reached significance.

In sum, there are no reliable or consistent main distractor magnitude effects in the above analyses except for the small size effect. Thus, taken together with the highly significant congruency effects, these results may indicate that it is not the distractor magnitude per se which is important, but its relation to the target magnitude. In the following section, we will explore this hypothesis in greater detail.

(iv) The interaction between attentional effects and the target-distractor magnitude relation:

The influence of the target magnitude relation can be studied in three ways: First, one could ask whether the attentional congruency effects are altered in some way by the difference between target and distractor. Second, one could ask whether the main target magnitude effects observed above are influenced by the distractor attributes in some way. The way these interactions can be analyzed is quite complex: Therefore, the derivation of the test statistics is shortly elaborated on in the following paragraphs.

(a) Modulation of attentional congruency effects by target-distractor difference. A possible hypothesis can be derived from the number stroop task (see introduction). In this task the congruency effects can be observed for different types of magnitudes, namely physical and numerical magnitude. When a smaller number is physically larger in a numerical comparison task, responses are slow. Similarly, in our Eriksen task, there are two types of magnitude relations. The first relation is the common target-standard difference (short: TS difference = target – standard). We use the term difference to indicate that the relative direction rather than the absolute distance or the absolute split is important. E.g., for the trial 2223222, the TS difference is 3 – 5 = -2, with the minus sign indicating that the target is *smaller* than the standard. The second relation is the target-distractor difference (short: TD difference = target – distractor). E.g., for the trial 2223222, the TS difference is 3 – 2 = +1 with the plus sign indicating that the target is *larger* than the distractor. TS difference and TD difference can be

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[5] Note, however, that the interaction between size and split in the ANOVA was significant (F(1, 23) = 15.03, p < .001). This was not due to a systematic (linear) modulation of the distance effect, but to a significant linear by quadratic trend interaction (F(1, 23) = 25.78, p < .001). Inspection of the data revealed that for the small numbers the middle splits (i.e., digits 2 and 3) were slower than the outer splits (i.e., 1 and 4) while for large numbers this effect was reversed (i.e., 6 and 9 were slower than 7 and 8).

congruent in that the target is both smaller (larger) than the standard and smaller (larger) than the distractor (e.g., 4443444 or 6668666). TS difference and TD difference can also be incongruent in that the target is smaller (larger) than the standard but larger (smaller) than the distractor (e.g., 2223222 or 999899). We like to term this type of congruency **second order congruency (or incongruency)** to distinguish it from the attentional congruency effects we have examined above. Second order incongruency implies that a number that is smaller (larger) than the standard is nevertheless the largest (smallest) in the display. For instance, in the trial 2223222, the target 3 is numerically smaller than the standard 5, but nevertheless the largest number in the display. In contrast, in the trial 4443444, the target 3 is not only smaller than the target 5, but also smaller than all other numbers in the display. Second order congruency can only be examined and manipulated for attentionally congruent trials in which target and distractor lead to the same response. All attention-incongruent trials like 3337333 in which target and distractor lead to different responses are always second order congruent, because the target 7 is larger than 5 and is always the largest number in the display (and vice versa).

We explored whether performance in response-congruent trials was influenced by second order congruency. As can be seen in Figure 3, this was clearly the case. When we computed a 2 x 2 ANOVA with the factors second order congruency and size for the response-congruent trials only, we observed a main effect of second order-congruency ($F(1, 23) = 75.22$, $p < .001$): For instance, trials like 3332333 in which a number *smaller* than 5 is also *smaller* than all the distractors in the display were faster than trials like 2223222 in which the target number is *smaller* than 5 but *larger* than the rest of the display. There was no main effect of size in this analysis ($F(1, 23) < 1$) but a significant interaction ($F(1, 23) = 20.41$, $p < .001$): The second-order congruency effect was larger for smaller-than-5 trials.[6]

The reader may have noticed that the second order congruency effect is inevitably confounded with target distance in this analysis. To examine whether target distance can explain the second order congruency effect, we eliminated the effect of target distance as estimated by identical (222222) trials (see Footnote 3 for a detailed exploration of the procedure). However, the second order congruency effect prevailed ($t(23) = 1.95$, $p < .05$, one-sided), but the interaction with size disappeared ($F(1, 23) < 1$). Thus, participants seemed to be influenced by the result of a second-order magnitude comparison between target and irrelevant distractor and this influence cannot be fully explained by a confusion with distance.

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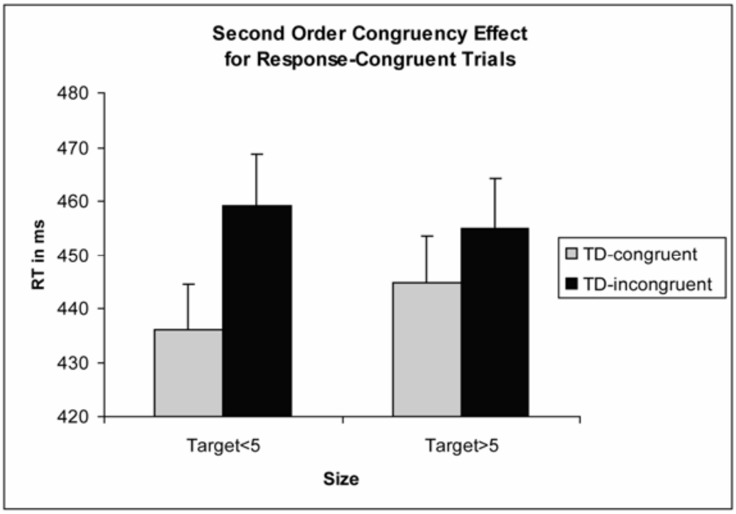
[6] Identical trials (like 333333) were not considered in this analysis of second order congruency. The elimination of the distance effect in this and all further analyses was computed as elaborated in the following example. For the 6 second order congruent trials smaller than 5 (i.e., 4441444, 3331333, 2221222, 4442444, 3332333, 4443444), we computed the weighted mean over the identical trials with exactly the same targets as the analyzed trials (i.e. (3 * RT(1111111) + 2*RT(2222222) + 1 * RT(3333333))/6). In order to obtain the residuals, this mean was subtracted from the mean over the above 4 second order congruent trials. ANOVAs were then computed over these residuals. This procedure has the advantage that we have an exact estimation of the RT produced by the distance effect. If we had used the distance slope as a covariate, we would have added additional noise because the distance effect is not linear for all target numbers (e.g. number 9, see Figure 2).

Figure 3:
Second order congruency effect in response-congruent trials: Target-distractor congruent (TD-congruent) targets which are *smaller* (larger) than the standard and also *smaller* (larger) than all other distractor numbers in the display (e.g. 4442444) lead to faster responses than target-distractor incongruent (TD-incongruent) targets which are *smaller* (larger) than the standard, but *larger* (smaller) than all other distractors (e.g. 2224222). This effect prevails when the confounded distance effect as estimated from identical trials is eliminated.

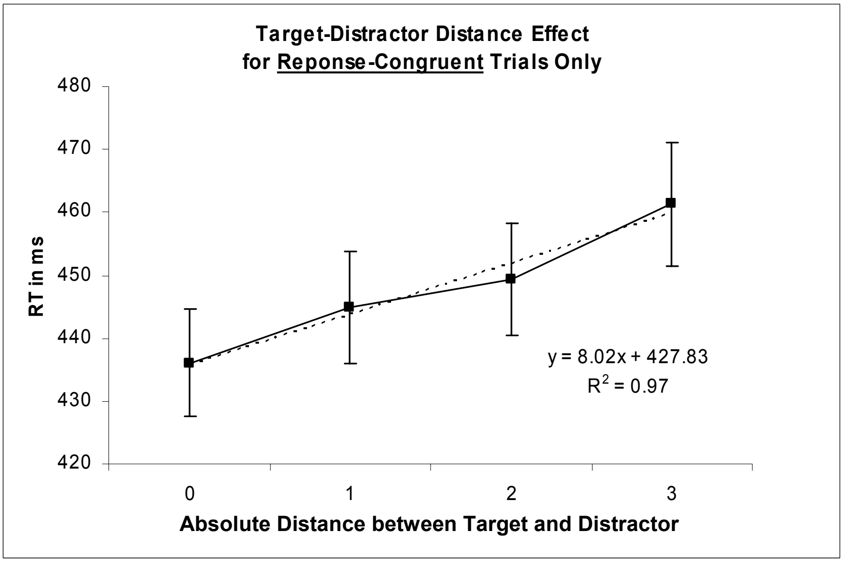


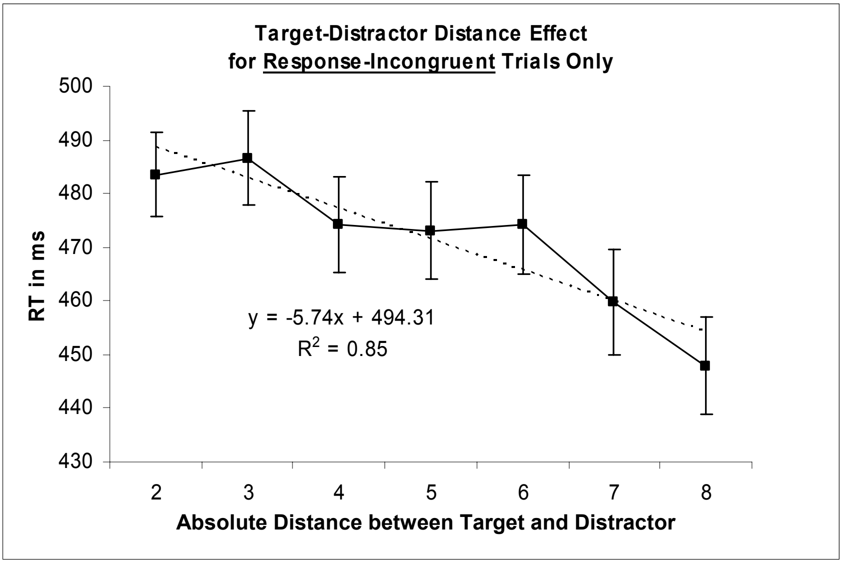
Another way to investigate whether the attentional congruency effects are parametrically affected by the target-distractor relation is to examine performance as a function of absolute distance between target and distractor. When this is done separately for congruent and incongruent trials, the results were surprisingly straightforward.

For *response-congruent* trials, performance became better as distance between target and distractor decreased (see Figure 4a; linear trend F(1, 23) = 91.21, p < .001, with identical trials – i.e. distance 0 - included, and F(1, 23) = 28.89, p < .001, without identical trials). When the individual slopes were computed with the Lorch & Myers method, performance decreased with increasing distance by about 7.4ms without and 7.5ms with identical trials (t(23) = 5.29; p < .001 without identical trials, t(23) = 9.33, p < .001 with identical trials). In sum, for attentional-congruent trials where target and distractor led to the same response the same results were found as in priming studies: The smaller the numerical distance, the better was performance. Note that for congruent trials, the average target distance from the standard 5 is always 2.5 for all target-distractor distances. So, there is no confusion in this analysis.

For response-incongruent trials, the pattern was just reversed. The larger the numerical distance between target and distractor, the better was performance (see Figure 4b; linear trend F(1, 23) = 26.67, p < .001). In this analysis, target-distractor distance is confounded with distance of the target from the standard. For instance, a target distractor distance of 2 in

Figure 4:
Target-distractor distance effect for response-congruent and response-incongruent trials. For response-congruent trials (Figure 4a, top), performance is facilitated when the distance between target and distractor is small. In contrast, for response-incongruent trials (Figure 4b, bottom), responses became faster as the distance between target and to-be-inhibited distractor increased. These effects prevail when the confounded distance effect as estimated by identical trials is eliminated.





incongruent trials can only occur in the trials 4446444 and 6664666. These small target-distractor distance trials also have a very small target distance to the standard. Therefore, we repeated the analysis after the normal target distance effect as estimated by the identical trials was eliminated: Still, the target-distractor distance effect remained significant (linear trend $F(1, 23) = 20.60$, $p < .001$). When the individual slopes were computed as above, performance became 3.2 ms faster (2.4 ms after distance being partialled out) as target-distractor distance became larger. In sum, the farther the distractor was away from the target, the faster was the response. It seemed that inhibition of the wrong response triggered by an incongruent distractor was easier when the distractor was well separated from the target on the mental number line.

(b) Modulation of target and distractor magnitude effects by target-distractor relationship. In contrast to the modulation of the attentional congruency effects, we did not find any significant alteration of any target or distractor magnitude effect (distance, SNARC; MARC) by target-distractor congruency in any analyses ($p >= .15$, two-sided).

In sum, the influence of attentional congruency and target-distractor magnitude relation on one another is not reciprocal, but asymmetrical. The relationship between target and distractor magnitude influenced attentional congruency effects in a quite systematic way. Inhibition of incongruent numbers became easier as the distractor was farther away on the number line. Vice versa, for congruent trials, responses were facilitated as the distractor got closer on the number line. In contrast, distance and SNARC effects of target and distractor were not influenced by attentional congruency in any way.

Discussion

The goal of the current study was to explore if and how the magnitude of to-be-inhibited distractors is processed in a magnitude comparison task in a standard attention paradigm. In particular, we wanted to investigate whether only the magnitude of the distractor influenced responses or whether the relationship between target and distractor was more important.

First, we replicated the attentional congruency effects typically observed in the Eriksen task with letters when using digits as stimuli in the magnitude comparison task. When distractors led to the same response as the target, responses were faster than when they were associated with a different response. Second, we observed the standard magnitude effects like the distance effect and the SNARC effect for targets although these targets were surrounded by attentional distractors. Responses became faster as the numerical distance between target and the standard 5 (to which the target had to be compared) increased. Moreover, larger target numbers were faster responded to with the right hand and smaller target numbers with the left hand. However, in this magnitude comparison task, the SNARC effects appeared to be categorical rather than continuous in nature. Thirdly, distractor magnitude effects were analyzed. As shown by the above attentional congruency effects, the distractors (and their magnitude) are indeed processed in this task. Nevertheless, we did neither observe any distance main effect nor any indication of a systematic SNARC effect for the distractors themselves.

This apparent contradiction between distractor magnitude activation - as indicated by the response congruency analyses - and no magnitude activation - as indicated by the distractor magnitude null effects - is resolved by the fourth analysis: We examined how the target-distractor magnitude relationship influenced the effects (or null effects) found in the above three analyses. We wish to focus on two findings.

First, the absolute target-distractor distance modulated performance for both response-congruent and response-incongruent trials, but in opposite directions. For *response-incongruent* trials, in which the distractor had to be inhibited, this inhibition became easier when the distractor was far away from the target. One could conceptualize this finding such that the magnitude representations of target and distractor on the mental number line were used to enhance attentional selection and inhibition processes. When there was no or little overlap between the two magnitude representations, it seemed to become easier to inhibit the distractor representation while this turned out to be much more difficult when target and distractor representations were close together on the mental number line. Please note that the absolute distance of the distractor alone (to the standard 5) did not influence responses in this study. Thus, it is not the magnitude of the distractors itself that seemed to be important, but it is their relation (i.e., the numerical distance) to the target that determined performance.

For *response-congruent* trials, the absolute distance between target and distractors also influenced responses, but in the opposite direction. Responses became facilitated as distractors were closer on the mental number line; i.e., as target-distractor distance decreased. A possible interpretation of this effect may rest on findings of number priming studies (e.g., Brysbaert, 1995; Reynvoet & Brysbaert, 1999). When the prime is close to the probe, responses are relatively fast. The distractor which is close to the target on the mental number line may – in a similar way as primes do – enhance activation of the relevant target number. In contrast, the magnitude activation of a distractor which is farther away on the mental number line may overlap less on the mental number line and therefore facilitate responses to the target to a lesser degree. Thus, it is basically the same notion about the (distributed) magnitude activation of target and distractor on the mental number line (see Dehaene, 2001) helps facilitating relevant activation and inhibiting irrelevant activation that can account for both results.[7]

This interpretation may already imply that the mental number line is used in a functional way for attentional selection and inhibition procedures. However, the second target-distractor magnitude relationship we discuss was dysfunctional in this study. For *response-congruent* trials (in which targets and distractors led to the same results) we obtained an effect, which we would like to term **second order congruency effect**. Trials were defined as second order congruent when target-standard (TS) difference (= target – standard) and target-distractor (TD) difference (= target – distractor) were either both positive or both negative. Otherwise a trial was defined second order incongruent. Second order congruent trials were faster: When the target was smaller (larger) than the standard 5 and also smaller (larger) than all distractors (e.g., 4442444 or 6668666), responses were faster than second order incongruent trials in which the target was smaller (larger) than the standard 5, but larger (smaller) than all other numbers in the display (e.g. 1113111; 9998999). This second order congruency effect also prevailed when we eliminated the confusion with distance. It can be

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[7] Note that in these target-distractor distance analyses, the average target distance to the standard is always identical. So the results cannot be accounted for by a confusion with the common distance effect.

interpreted as interference from an additional automatic magnitude comparison between target and distractor. Since this automatic comparison has just a 50% chance of being second order congruent with the correct response, it is dysfunctional to compute it. Nevertheless, the effect indicates that this second automatic magnitude comparison is carried out. At least when participants are involved in a magnitude comparison task, they cannot help comparing the target with the irrelevant distractor.

Conclusions

The current study underlines the importance of the mental number line. It seems to be used to help to inhibit interfering distractors and to facilitate correct responses when distractors were congruent. So, in this visual attention task, not only the visual attributes of the experimental setting and the response attributes of the stimuli, but also the mental location of the target and distractor on the mental number line determine the selection and inhibition of numbers as stimuli. Hence, distractors which are irrelevant in 100% of the trials and have to be inhibited are nevertheless processed with respect to their magnitude. In this way, this study corroborates earlier findings of Fischer and colleagues (2003) which seem to suggest that the relation between numerical representations and attentional selection is a two-way street. Fischer and colleagues found that the pure fixation of a number leads to spatial shifts of attention. This study extends Fischer's findings in that not only spatial shifts of attention can be induced by numerical magnitude, but that numerical magnitude seems to be used automatically to enhance attentional selection and inhibition in a common attentional paradigm.

This seems to be an automatic process, however. Participants cannot help computing an irrelevant magnitude comparison of the target number with the irrelevant distractor number (similarly as for two-digit numbers; see Wood, Mahr, & Nuerk, this issue), although this computation is dysfunctional in our experimental setting.

In sum, this study seems to suggest that the magnitude relations between target and distractor numbers in one display are not only automatically computed on the mental number line, but that these relations are automatically used to support attentional selection and inhibition processes.

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