

Journal of Experimental Psychology: Learning, Memory, and Cognition

SNARC Struggles: Instant Control Over Spatial-Numerical Associations

Roland Pfister, Philipp A. Schroeder, and Wilfried Kunde

Online First Publication, May 6, 2013. doi: 10.1037/a0032991

CITATION

Pfister, R., Schroeder, P. A., & Kunde, W. (2013, May 6). SNARC Struggles: Instant Control Over Spatial-Numerical Associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. Advance online publication. doi: 10.1037/a0032991

RESEARCH REPORT

SNARC Struggles: Instant Control Over Spatial–Numerical Associations

Roland Pfister, Philipp A. Schroeder, and Wilfried Kunde
Julius-Maximilians-University of Würzburg

Numbers and space are tightly linked—a phenomenon that is referred to as the spatial–numerical association of response codes (SNARC) effect (Dehaene, Bossini, & Giraux, 1993). The present study investigates how quickly and flexibly the behavioral impact of such spatial–numerical associations can be controlled. Participants performed a parity judgment task, and we examined how the SNARC effect is influenced by the preceding congruency between the required response and the target number’s spatial association. Results indicate that the SNARC effect is reduced instantly after having experienced a number’s spatial association to interfere with responding. This sequential modulation indicates a pronounced flexibility of spatial–numerical associations driven by cognitive control mechanisms.

Keywords: numerical cognition, cognitive control, SNARC effect, Gratton effect

How “left” is a 1 compared to a 9? Research on numerical cognition suggests that this question can be answered quite definitively with “rather left.” This answer is based on numerous studies on the spatial–numerical association of response codes (SNARC) effect (Dehaene, Bossini, & Giraux, 1993). More precisely, small numbers were found to facilitate left responses in various judgment tasks, whereas large numbers were found to facilitate right responses (e.g., Fias, Lauwereyns, & Lammertyn, 2001; Gevers & Lammertyn, 2005; Müller & Schwarz, 2008; for a meta-analysis, see Wood, Willmes, Nuerk, & Fischer, 2008).

The SNARC effect has long been ascribed to a mental number line even though recent accounts suggest that number–space interactions might be explained more parsimoniously in different integrative frameworks (e.g., spatial–quantity associations: Buetti & Walsh, 2009; polarity correspondence: Proctor & Cho, 2006). In any case, converging evidence suggests spatial–numerical associations are relatively flexible (cf. van Dijck & Fias, 2011). For instance, a given number can be associated with the right-hand side if it is large compared to the current context—for example, the digit 5 if the stimulus set comprises the digits 1–5—whereas it can be associated with the left-hand side in a different context—for example, the digit 5 if the stimulus set comprises the digits 5–9 (Dehaene et al., 1993; Fias, Brysbaert, Geypens, & d’Ydewalle, 1996). Additionally, the SNARC effect decreases after exposure to SNARC-incongruent mapping rules (Fischer, Mills, & Shaki, 2010; Notebaert, Gevers, Verguts, & Fias, 2006), and it even

reverses if participants are instructed to imagine numbers on a clock face (Bächtold, Baumüller, & Brugger, 1998; Ristic, Wright, & Kingstone, 2006).

These findings indicate that spatial–numerical associations are not only affected by long-term effects such as the reading habits of a given culture (Shaki, Fischer, & Petrusic, 2009) but also by different transient factors. Yet, the studies mentioned above do not address the question of how flexibly the spatial association of numbers can be controlled, because the described variables were manipulated between entire sessions or at least for extended blocks of trials. In contrast, the present study addresses this question by investigating instant adjustments on a trial-to-trial basis. More precisely, we investigated whether the SNARC effect is reduced after participants have just experienced a number’s spatial association to conflict with the current task (e.g., when responding to a large number with the left hand).

Such a reduced impact of irrelevant stimulus features following conflict is a common finding in the domain of cognitive control that has been reported for various tasks (e.g., Gratton, Coles, & Donchin, 1992; see also Botvinick, Braver, Barch, Carter, & Cohen, 2001; Kunde & Wühr, 2006; Notebaert, Gevers, Verbruggen, & Liefoghe, 2006). A first investigation of such sequential modulations for the SNARC effect was reported by Notebaert and Verguts (2008), who employed a task-switching design in which the participants performed a Simon task and a SNARC task in different trials. In the Simon task, participants responded to a feature of a laterally presented *X* (color or format), whereas in the SNARC task, they responded to the format of a centrally presented number (normal font vs. italic). The stimulus set comprised the numbers 1, 2, 8, and 9 to create distinct SNARC-congruent and SNARC-incongruent trials. Most relevant for the present study are task repetitions, that is, SNARC trials that are followed by another SNARC trial. Here, the SNARC effect seemed to disappear after incongruent trials, which can be taken as preliminary evidence for instant control over a number’s spatial association.

Roland Pfister, Philipp A. Schroeder, and Wilfried Kunde, Department of Psychology, Julius-Maximilians-University of Würzburg, Würzburg, Germany.

Correspondence concerning this article should be addressed to Roland Pfister, Julius-Maximilians-University of Würzburg, Department of Psychology III, Röntgenring 11, 97070 Würzburg, Germany. E-mail: roland.pfister@psychologie.uni-wuerzburg.de

The described experimental setup, however, does not allow for firm conclusions regarding this point. Most importantly, SNARC and Simon trials appeared intermixed in the design so that spatial information was continuously present (in terms of the laterally presented Simon stimuli) and had to be suppressed to allow for correct performance in incompatible Simon trials. Arguably, this setup might have influenced spatial coding in the SNARC task (cf. Keus & Schwarzer, 2005). Additionally, the limited stimulus set does not rule out alternative explanations such as feature repetition and integration effects that could readily account for the observed sequential effects within each task (for recent evidence, see Puccioni & Vallesi, 2012; Schmidt & De Houwer, 2011).

The present study thus provides a more direct test of trial-to-trial control over spatial-numerical associations. Participants performed a parity judgment task on centrally presented numbers, and we expected to observe a reduced SNARC effect after incongruent trials compared to congruent trials. In addition to typical sequence analyses in terms of an interaction of preceding and current congruency, we also report a more detailed analysis of the SNARC effect in terms of individual regression slopes (regression coefficient analysis; Lorch & Myers, 1990; cf. Fias et al., 1996; Pfister, Schwarz, Carson, & Janczyk, in press). Here, we expected decreased regression slopes following incongruent trials compared to congruent trials.

The additional regression coefficient analysis comes with several advantages. For one, it allows a precise quantification of the SNARC effect, yielding more information than the qualitative present versus absent result of typical sequence analyses (Fias et al., 1996). In addition to assessing the slope coefficient, regression coefficient analysis also allows quantifying which proportion of the variance can be explained by linear regressions in each condition (in terms of R^2). This additional measure allows for a direct test of two possible mechanisms. If, for one, the spatial-numerical associations themselves change after having experienced an association to conflict with current behavior, the slope coefficient should change (possibly even reverse), whereas R^2 should not be affected notably. In turn, observed changes only in slopes with unchanged R^2 would indicate that spatial-numerical associations continue to influence behavior even though the associations themselves were changed. By contrast, changes in R^2 do not allow for precise conclusions about the underlying associations but indicate that these associations have a less direct impact on action control.

Method

Participants, Apparatus, and Stimuli

Twenty-four native German speakers took part in the experiment (18 females; mean age = 21.4 years; range = 18–39 years). The experiment lasted about 45 min, and participants received 6 € for compensation.

Stimuli were presented centrally on a 17-in. (43.18-cm) monitor in 32-point Arial font. The stimulus pool comprised four even and four odd digits (2, 3, 4, 5, 6, 7, 8, 9) and a plus-symbol (+) that served as fixation. Parity judgments were given with the left and right index finger on two external keys, and parity-response mapping was counterbalanced across participants.

Procedure

Each trial started with a fixation cross (300 ms) followed by the target digit. Responses were registered for up to 2,000 ms; wrong responses and response omissions were immediately followed by error feedback (German “*Fehler!*” for errors, and “*Zu langsam!*” for slow responses). The next trial started after an additional 300-ms intertrial interval.

Participants completed a training block of 20 trials and 10 experimental blocks of 140 trials each. They received a short framing instruction telling the story of a student, “Kalle,” who needed their help to sort the pages of his bachelor’s thesis to odd and even page numbers. Instructions were presented at the beginning and in the middle of the experiment to maintain motivation during the session. In addition, the spatial connotation of this instruction might have increased the overall SNARC effect (Bächtold et al., 1998; Wood et al., 2008), but we consider it unlikely to have affected possible sequential modulations that were of main interest for the present experiment.

Data Treatment

For the following analyses, we excluded stimulus repetitions (cf. Tan & Dixon, 2011), trials with errors (6.1%), and trials following errors. Additionally, trials were counted as outliers when the response time (RT) deviated from the corresponding cell mean by more than 2.5 standard deviations (2.5%), calculated separately for each participant, trial type (response repetition vs. response alternation compared to the preceding trial), congruency condition (SNARC-congruent vs. SNARC-incongruent), and preceding congruency condition. As concerns the latter two factors, we consider the target numbers 2–5 to be congruent for left responses and the target numbers 6–9 to be congruent for right responses.

Sequential modulations of the SNARC-effect were analyzed in two distinct ways: (1) via congruency-dependent means and (2) via regression coefficient analysis. With *congruency-dependent means*, we refer to the approach to sequential analyses that is used for most conflict paradigms (e.g., Egner, 2007): RTs were aggregated to individual means for each orthogonal combination of the factors trial type (response repetition vs. response alternation), congruency (SNARC-congruent vs. SNARC-incongruent), and preceding congruency (see Figure 1), and the resulting data were analyzed by means of a $2 \times 2 \times 2$ repeated-measures analysis of variance (ANOVA). Because stimulus repetitions were removed anyway, all trials with response repetitions are partial repetitions (repeating the response but not stimulus), whereas all trials with response alternations are complete alternations (of responses and stimuli). Consequently, an unbalanced proportion of partial versus full repetitions in the congruency sequence conditions cannot account for sequential modulations of the SNARC effect neither with response repetitions nor response alternations (cf. Hommel, Proctor, & Vu, 2004, for such an account).

For the *regression coefficient analysis*, we first calculated the mean SNARC effect as $RT_{\text{right}} - RT_{\text{left}}$ for each participant and each magnitude bin (2/3, 4/5, 6/7, and 8/9) as a function of trial type (response repetition vs. response alternation) and preceding congruency (SNARC-congruent vs. SNARC-incongruent; see Figure 2). We then extracted individual slope coefficients of the regression of the SNARC effect on magnitude bin, separately for each trial type and preceding congruency condition (using the

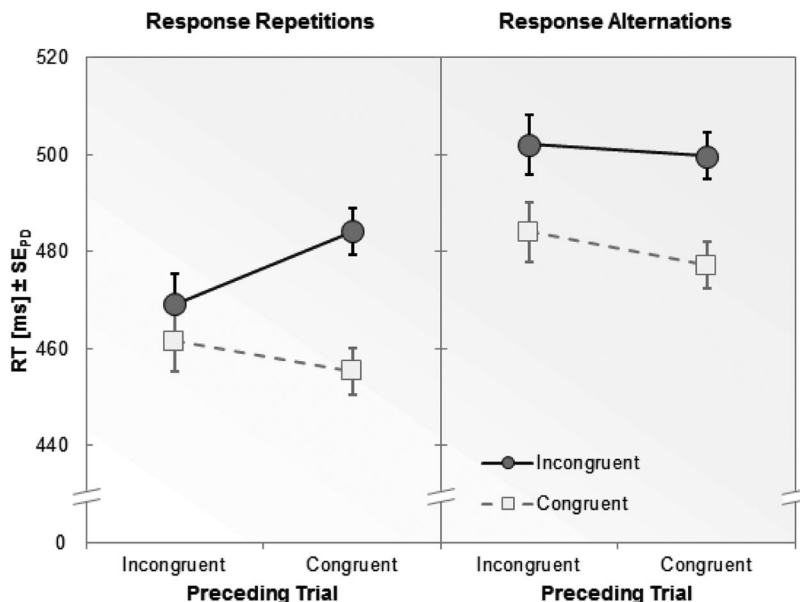


Figure 1. Mean response times (RTs) and their sequential modulation in spatial-numerical association of response codes (SNARC)-congruent and SNARC-incongruent trials. Pronounced sequential modulation was only present for response repetitions (left panel). For response alternations (right panel), sequential modulation was considerably weaker and was only marginally significant. Error bars represent standard errors (SEs) of paired differences (PD), computed separately for each pairwise comparison of congruent and incongruent trials (cf. Pfister & Janczyk, 2013).

algorithm for SPSS as described in Pfister et al., in press). The extracted slopes were then analyzed by means of a 2×2 ANOVA. Additionally, we computed the correlations of SNARC effect and magnitude bin for each trial type and preceding congruency condition. To arrive at an estimate of how much variance was accounted for by the regression analyses, we submitted these correlations to a Fisher-Z-transformation. The resulting Z-scores were then averaged across participants and re-transformed to correlation coefficients. The squared correlations are reported as (Pseudo)- R^2 .

Results

Congruency-Dependent Means

The $2 \times 2 \times 2$ ANOVA showed response repetitions to be considerably faster than response alternations (see Figure 1), $F(1, 23) = 19.28, p < .001, \eta_p^2 = .46$. A pronounced SNARC effect was present as indicated by a significant main effect of congruency, $F(1, 23) = 16.48, p < .001, \eta_p^2 = .42$, whereas the main effect of preceding congruency did not approach significance ($F < 1$). Furthermore, the factor trial type interacted with preceding congruency, $F(1, 23) = 6.20, p = .020, \eta_p^2 = .21$, but not with current congruency ($F < 1$). Most importantly for the present experiment, however, the SNARC effect differed after congruent and incongruent trials as indicated by an interaction of congruency and preceding congruency, $F(1, 23) = 18.02, p < .001, \eta_p^2 = .44$. The three-way interaction was also significant, $F(1, 23) = 8.79, p = .007, \eta_p^2 = .28$, and we followed up on this interaction by performing 2×2 ANOVAs with the factors preceding congruency

and current congruency separately for both, response repetitions and alternations.

The analysis of response repetitions (see Figure 1, left panel) yielded a significant main effect of current congruency, $F(1, 23) = 14.27, p < .001, \eta_p^2 = .38$, whereas the main effect of preceding congruency was not significant, $F(1, 23) = 2.45, p = .131, \eta_p^2 = .10$. These main effects were qualified by a significant interaction of preceding congruency and current congruency, $F(1, 23) = 15.58, p < .001, \eta_p^2 = .40$, which was driven by a smaller congruency effect after incongruent trials, $t(23) = 1.23, p = .231, d = 0.25$, than after congruent trials, $t(23) = 6.03, p < .001, d = 1.23$.

The corresponding analysis of response alternations (see Figure 1, right panel) yielded significant main effects of current congruency, $F(1, 23) = 16.25, p < .001, \eta_p^2 = .41$, and preceding congruency, $F(1, 23) = 4.99, p = .036, \eta_p^2 = .18$. In contrast to the analysis of response repetitions, the interaction only approached significance, $F(1, 23) = 3.78, p = .064, \eta_p^2 = .14$, again driven by a slightly smaller congruency effect after incongruent trials, $t(23) = 3.51, p = .002, d = 0.72$, than after congruent trials, $t(23) = 4.34, p < .001, d = 0.89$.

Regression Coefficient Analysis

For response repetitions, mean regression lines equated to $\hat{y} = -8.76 \times \text{bin} + 8.04$ for the SNARC effect following incongruent trials and to $\hat{y} = -26.48 \times \text{bin} + 78.03$ for the SNARC effect following congruent trials (see Figure 2, left panel). For response alternations, the corresponding regression lines equated to $\hat{y} = -15.92 \times \text{bin} + 51.30$ for the SNARC effect following incon-

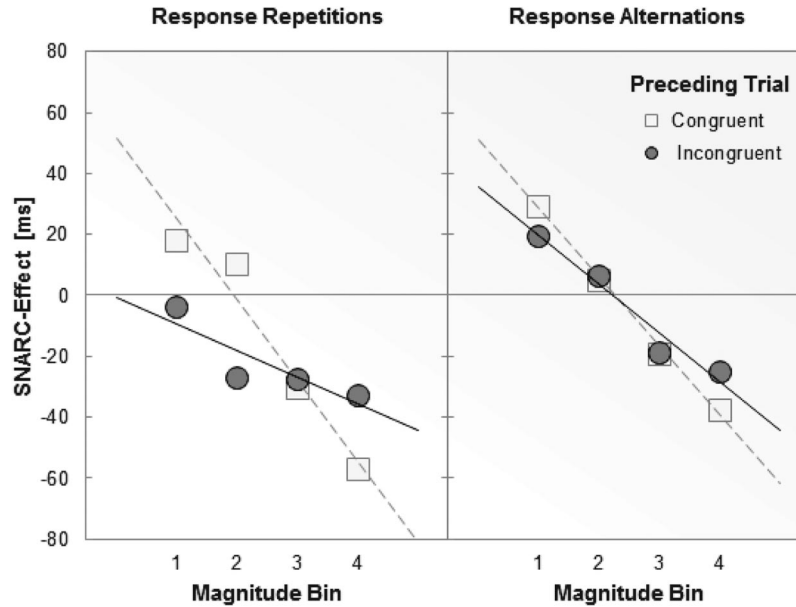


Figure 2. Mean spatial–numerical association of response codes (SNARC) effects, computed as response time $(RT)_{\text{right}} - RT_{\text{left}}$, as a function of magnitude bin and preceding congruency. Mean regression lines were computed by averaging individual slopes and intercepts. Regression lines were significantly shallower after incongruent than after congruent trials for both response repetitions and response alternations.

gruent trials and to $\hat{y} = -22.52 \times \text{bin} + 73.41$ for the SNARC effect following congruent trials (see Figure 2, right panel).¹

The consistently shallower slopes following incongruent trials gave rise to a highly significant main effect of preceding congruency, $F(1, 23) = 19.14$, $p < .001$, $\eta_p^2 = .45$, whereas the main effect of trial type did not approach significance, $F(1, 23) = 0.39$, $p = .537$, $\eta_p^2 = .02$. A marginally significant interaction, $F(1, 23) = 4.15$, $p = .053$, $\eta_p^2 = .15$, was driven by a more pronounced impact of preceding congruency for response repetitions, $t(23) = 3.5$, $p = .002$, $d = 0.72$, than for response alternations, $t(23) = 3.03$, $p = .006$, $d = 0.62$.

A similar pattern emerged for the proportion of variance accounted for by the individual regression analyses. For response repetitions, $R^2 = 59\%$ of the variance were explained for the SNARC effect following congruent trials, and the mean correlation coefficient was significantly different from zero, $r = -.77$, $t(23) = -5.64$, $p < .001$. In contrast, only $R^2 = 7\%$ of the variance were explained for the SNARC effect following incongruent trials, and the corresponding mean correlation coefficient was not significant, $r = -.27$, $t(23) = -1.29$, $p = .209$. A paired-samples t -test on the Z -scores also confirmed a significant difference between both correlations, $t(23) = -3.52$, $p = .002$, $d = -0.72$. For response alternations, R^2 amounted to 59% for the SNARC effect following congruent trials, $r = -.77$, $t(23) = -5.59$, $p < .001$, and to 21% for the SNARC effect following incongruent trials, $r = -.45$, $t(23) = -2.39$, $p = .026$. Both correlations differed significantly from each other, $t(23) = -4.19$, $p < .001$, $d = -0.85$.

Exploratory Analysis: Stimulus Repetitions

To validate the present results against a recent demonstration of an absent SNARC effect for stimulus repetitions (Tan & Dixon,

2011), we also extracted regression slopes for this situation. The resulting mean slope was indeed relatively small (-11.14 ms/bin) but it differed significantly from zero, $t(23) = 3.42$, $p = .002$, $d = 0.70$. When compared to the results of the above analysis of response repetitions, the mean slope for stimulus repetitions was significantly shallower than the slope for response repetitions following congruent trials, $t(23) = -3.73$, $p = .001$, $d = -0.76$, whereas it did not differ significantly from the slope for response repetitions following incongruent trials, $t(23) = 0.46$, $p = .649$, $d = 0.09$.

Discussion

The present experiment probed for flexible control over spatial–numerical associations. Participants performed a parity judgment task and we examined the SNARC effect (Dehaene et al., 1993) as a function of preceding congruency between the required response and the spatial association of the target number. As predicted, the SNARC effect was reduced instantly after having experienced the spatial–numerical association to interfere with responding correctly.

These findings indicate that a number’s spatial association can be accessed very flexibly depending on current task demands; the corresponding adjustments obviously can take place on a timescale of milliseconds and do not need prolonged exposure or training (Bae, Choi, Cho, & Proctor, 2009; Fischer et al., 2010; Notebaert, Gevers, Verguts, & Fias, 2006). Furthermore, this observation extends previous findings of sequential modulations for different

¹ Measurement units—[ms/bin] for the slope coefficient and [ms] for the intercept—were omitted from the equations for readability.

conflict paradigms (e.g., Cohen Kadosh, Gevers, & Notebaert, 2011; Egner, 2007) to the field of numerical cognition (cf. also Nuerk, Bauer, Krummenacher, Heller, & Willmes, 2005; Ristic et al., 2006). Current models assume two different mechanisms to enable such conflict adaptation: inhibition of irrelevant information on the one hand, and amplification of relevant information on the other hand (Ridderinkhof, 2002; see also Egner & Hirsch, 2005; Scherbaum, Fischer, Dshemuchadse, & Goschke, 2011). The present reduction of the SNARC effect after incongruent trials is likely to represent a pure behavioral measure of the former (inhibitive) mechanism and might thus be an interesting approach for studies that try to isolate the neural substrate of these processes.

It should be noted, however, that we found the SNARC effect after incongruent trials to be reduced but still significant. Experiencing a number's spatial association to conflict with the current response thus seems to weaken the corresponding spatial associations, but it does not seem to change the SNARC effect qualitatively as is observed for more prolonged manipulations, ranging from particular instructions (Bächtold et al., 1998) to cultural factors (Shaki et al., 2009). The notion of a reduced but still reliable SNARC effect after incongruent trials is also in line with previous reports on automatic feature binding across perception and action. According to the framework of the Theory of Event Coding (Hommel, Müssele, Aschersleben, & Prinz, 2001), an action is represented by codes of its features—and in case of a parity judgment task, these features likely entail the number's spatial association (Caessens, Hommel, Reynvoet, & van der Goten, 2004). Thus, the spatial–numerical association is inherently part of the corresponding action representation, even though converging evidence suggests that the weight of particular features might be adjusted intentionally (e.g., Memelink & Hommel, 2013). Such a reduced weight might, in turn, account for the observed sequential modulations and could represent the inhibitive mechanism discussed above.

Moreover, the notion of *inhibited* rather than changed spatial associations is also supported by the analysis of explained variance (R^2). As outlined above, the observed reduction of both, slopes and R^2 , does not allow for any firm conclusions regarding the underlying spatial associations themselves. Rather, we prefer a more conservative interpretation in terms of an inhibitive mechanism that does not necessarily reflect qualitative changes in spatial–numerical associations that can be achieved by more sustained manipulations (e.g., Bächtold et al., 1998). Several speculations are possible regarding the exact nature of this mechanism, such as inhibited extraction of a number's magnitude, an inhibited link between magnitude and space, or simply higher fluctuations of whether or not magnitude is extracted at all in a given trial. These accounts offer different interesting views on the findings observed here, but the present experimental design does not seem to be suited for disentangling the different alternatives.

In any case, we analyzed the sequential modulations of the SNARC effect separately for response repetitions and alternations and with stimulus repetitions removed. The reason for doing so was a methodological one, because this is a simple way to control for an unequal proportion of full versus partial repetitions of S–R episodes that has been considered to account for sequential congruency effects (Hommel et al., 2004). Thus, even though neither sequential effects for response repetitions nor response alternations can be explained this way, the effect was somewhat larger for

response repetitions compared to response alternations. At present we can only speculate about the reasons for this finding. Perhaps response alternations represent a kind of “mini task switch,” which is known to reduce sequential effects (Kiesel, Kunde, Hoffmann, 2006). It might also be that changing responses (from left to right or right to left) generally amplifies the spatial representation of the responses, which are then more easily activated by numerical size. In other words, emphasizing the spatial nature of a response (by response alternation or any other appropriate manipulation) may render the impact of irrelevant numerical size less prone to contextual modulations such as preceding congruency.

Another noteworthy observation of the present experiment is the reduced but significant SNARC effect for stimulus repetitions. For these situations, a previous study has found the SNARC effect to disappear (Tan & Dixon, 2011). This finding was taken to suggest that spatial information is extracted during response selection—a process that can be by-passed if the same stimulus is encountered twice in a row (see also Pashler & Baylis, 1991). The present results agree with this conclusion, but the residual SNARC effect also indicates that the assumed shortcut is either no all-or-none process or, alternatively, that the shortcut is not used in all trials with stimulus repetitions.

In any case, the present results paint a detailed picture of sequential modulations of the SNARC effect. These sequential modulations suggest a high flexibility of spatial–numerical associations that can be accessed quickly and adaptively to allow for optimal performance.

References

- Bächtold, D., Baumüller, M., & Brugger, P. (1998). Stimulus–response compatibility in representational space. *Neuropsychologia*, *36*, 731–735. doi:10.1016/S0028-3932(98)00002-5
- Bae, G. Y., Choi, J. M., Cho, Y. S., & Proctor, R. W. (2009). Transfer of magnitude and spatial mappings to the SNARC effect for parity judgments. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*, 1506–1521. doi:10.1037/a0017257
- Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*, 624–652. doi:10.1037/0033-295X.108.3.624
- Bueti, D., & Walsh, V. (2009). The parietal cortex and the representation of time, space, number, and other magnitudes. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*, 1831–1840. doi:10.1098/rstb.2009.0028
- Caessens, B., Hommel, B., Reynvoet, B., & van der Goten, K. (2004). Backward-compatibility effects with irrelevant stimulus-response overlap: The case of the SNARC effect. *Journal of General Psychology*, *131*, 411–425.
- Cohen Kadosh, R., Gevers, W., & Notebaert, W. (2011). Sequential analysis of the numerical Stroop effect reveals response suppression. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*, 1243–1249. doi:10.1037/a0023550
- Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*, *122*, 371–396. doi:10.1037/0096-3445.122.3.371
- Egner, T. (2007). Congruency sequence effects and cognitive control. *Cognitive, Affective, & Behavioral Neuroscience*, *7*, 380–390. doi:10.3758/CABN.7.4.380
- Egner, T., & Hirsch, J. (2005). Cognitive control mechanisms resolve conflict through cortical amplification of task-relevant information. *Nature Neuroscience*, *8*, 1784–1790. doi:10.1038/nn1594

- Fias, W., Brysbaert, M., Geypens, F., & d'Ydewalle, G. (1996). The importance of magnitude information in numerical processing: Evidence from the SNARC effect. *Mathematical Cognition*, *2*, 95–110. doi:10.1080/135467996387552
- Fias, W., Lauwereyns, J., & Lammertyn, J. (2001). Irrelevant digits affect feature-based attention depending on the overlap of neural circuits. *Cognitive Brain Research*, *12*, 415–423. doi:10.1016/S0926-6410(01)00078-7
- Fischer, M. H., Mills, R. A., & Shaki, S. (2010). How to cook a SNARC: Number placement in text rapidly changes spatial–numerical associations. *Brain and Cognition*, *72*, 333–336. doi:10.1016/j.bandc.2009.10.010
- Gevers, W., & Lammertyn, J. (2005). The hunt for SNARC. *Psychology Science*, *47*, 10–21.
- Gratton, G., Coles, M. G. H., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology: General*, *121*, 480–506. doi:10.1037/0096-3445.121.4.480
- Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences*, *24*, 849–878. doi:10.1017/S0140525X01000103
- Hommel, B., Proctor, R. W., & Vu, K.-P. L. (2004). A feature-integration account of sequential effects in the Simon task. *Psychological Research*, *68*, 1–17. doi:10.1007/s00426-003-0132-y
- Keus, I. M., & Schwarz, W. (2005). Searching for the functional locus of the SNARC effect: Evidence for a response related-origin. *Memory & Cognition*, *33*, 681–695. doi:10.3758/BF03195335
- Kiesel, A., Kunde, W., & Hoffmann, J. (2006). Evidence for task-specific resolution of response conflict. *Psychonomic Bulletin & Review*, *13*, 800–806. doi:10.3758/BF03194000
- Kunde, W., & Wühr, P. (2006). Sequential modulations of correspondence effects across spatial dimensions and tasks. *Memory & Cognition*, *34*, 356–367. doi:10.3758/BF03193413
- Lorch, R. F., & Myers, J. L. (1990). Regression analyses of repeated measures data in cognitive research. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*, 149–157. doi:10.1037/0278-7393.16.1.149
- Memelink, J., & Hommel, B. (2013). Intentional weighting: A basic principle in cognitive control. *Psychological Research*, *77*, 249–259. doi:10.1007/s00426-012-0435-y
- Müller, D., & Schwarz, W. (2008). “1–2–3”: Is there a temporal number line? Evidence from a serial comparison task. *Experimental Psychology*, *55*, 143–150. doi:10.1027/1618-3169.55.3.143
- Notebaert, W., Gevers, W., Verbruggen, F., & Liefvooghe, B. (2006). Top-down and bottom-up sequential modulations of congruency effects. *Psychonomic Bulletin & Review*, *13*, 112–117. doi:10.3758/BF03193821
- Notebaert, W., Gevers, W., Verguts, T., & Fias, W. (2006). Shared spatial representations for numbers and space: The reversal of the SNARC and the Simon effects. *Journal of Experimental Psychology: Human Perception and Performance*, *32*, 1197–1207. doi:10.1037/0096-1523.32.5.1197
- Notebaert, W., & Verguts, T. (2008). Cognitive control acts locally. *Cognition*, *106*, 1071–1080. doi:10.1016/j.cognition.2007.04.011
- Nuerk, H.-C., Bauer, F., Krummenacher, J., Heller, D., & Willmes, K. (2005). The power of the mental number line: How the magnitude of unattended numbers affects performance in an Eriksen task. *Psychology Science*, *47*, 34–50.
- Pashler, H., & Baylis, G. (1991). Procedural learning: II. Intertrial repetition effects in speeded-choice tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*, 33–48. doi:10.1037/0278-7393.17.1.33
- Pfister, R., & Janczyk, M. (2013). Confidence intervals for two sample means: Calculation, interpretation, and a few simple rules. *Advances in Cognitive Psychology*, *9*, 74–80. doi:10.2478/v10053-008-0133-x
- Pfister, R., Schwarz, K. A., Carson, R., & Janczyk, M. (in press). Easy methods for extracting individual regression slopes: Comparing SPSS, R, and Excel. *Tutorials in Quantitative Methods for Psychology*.
- Proctor, R. W., & Cho, Y. S. (2006). Polarity correspondence: A general principle for performance of speeded binary classification tasks. *Psychological Bulletin*, *132*, 416–442. doi:10.1037/0033-2909.132.3.416
- Puccioni, O., & Vallesi, A. (2012). Sequential congruency effects: Distinguishing priming and conflict adaptation. *Psychological Research*, *76*, 591–600. doi:10.1007/s00426-011-0360-5
- Ridderinkhof, K. R. (2002). Micro-and macro-adjustments of task set: Activation and suppression in conflict tasks. *Psychological Research*, *66*, 312–323. doi:10.1007/s00426-002-0104-7
- Ristic, J., Wright, A., & Kingstone, A. (2006). The number line effect reflects top-down control. *Psychonomic Bulletin & Review*, *13*, 862–868. doi:10.3758/BF03194010
- Scherbaum, S., Fischer, R., Dshemuchadse, M., & Goschke, T. (2011). The dynamics of cognitive control: Evidence for within trial conflict adaptation from frequency tagged EEG. *Psychophysiology*, *48*, 591–600. doi:10.1111/j.1469-8986.2010.01137.x
- Schmidt, J. R., & De Houwer, J. (2011). Now you see it, now you don't: Controlling for contingencies and stimulus repetitions eliminates the Gratton effect. *Acta Psychologica*, *138*, 176–186. doi:10.1016/j.actpsy.2011.06.002
- Shaki, S., Fischer, M. H., & Petrusic, W. M. (2009). Reading habits for both words and numbers contribute to the SNARC effect. *Psychonomic Bulletin & Review*, *16*, 328–331. doi:10.3758/PBR.16.2.328
- Tan, S., & Dixon, P. (2011). Repetition and the SNARC effect with one- and two-digit numbers. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale*, *65*, 84–97. doi:10.1037/a0022368
- van Dijck, J.-P., & Fias, W. (2011). A working memory account for spatial–numerical associations. *Cognition*, *119*, 114–119. doi:10.1016/j.cognition.2010.12.013
- 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*, *50*, 489–525.

Received November 20, 2012

Revision received March 14, 2013

Accepted March 18, 2013 ■