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The role of parity, physical size, and magnitude in numerical cognition: The SNARC effect revisited

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People indicate the physical size or the parity status of small numbers faster by a left-hand key and those of larger numbers by a right-hand key. Because magnitude information is not required for successful performance in these tasks, the presence of a number–space association (the SNARC effect) has been taken to indicate the automatic activation of numerical magnitude in all tasks with numerals. In order to test this account, in a series of five experiments, we derived two consensual markers of automatic activation of irrelevant numerical magnitude, the size congruity effect (for judgments of physical size), and the Garner effect (for judgments of parity). Both markers were found independent of the SNARC effect. Consequently, we question the traditional explanation of the SNARC effect and offer an alternative account in terms of a highly overlearned stimulus–response loop.

Is 3 an odd or even number? The time it takes one to record a response for this simple question is affected by the relative position of the response key used to indicate parity. People respond to 3 (and to other small numbers) faster with a left-hand key, and they respond to 8 (and to other larger numbers) faster with a right-hand key, regardless of the odd–even assignment of the response keys. This spatial–numerical association of response codes (SNARC; Dehaene, Bossini, & Giraux, 1993) is notable because magnitude information is not strictly needed for deciding parity. Consequently, the presence of the SNARC effect has been taken to support the idea that the meaning of numerals (i.e., numerical magnitude) is activated in an automatic fashion when numerals are presented for view for any purpose. It is this explanation of the SNARC effect that we challenge in the present study.

We employed two separate tools to test the traditional explanation of the SNARC effect. The first was the size congruity effect (SCE), a potent marker of automatic activation of semantic information with numerals. The SCE documents the influence of numerical magnitude on judgments of physical size of numerals. When the relative physical sizes of numerals in a pair are compared, people respond faster for congruent pairs (e.g., 8 2) than for incongruent pairs (e.g., 8 2; Fitousi & Algom, 2006). For singly presented numerals, people react to the large physical format of 8 faster than they do to that of 2, but the reverse holds true for 8 versus 2 (Algom, Dekel, & Pansky, 1996; Choplin & Logan, 2005). The task in studies of the SCE entails a nonsemantic attribute of digits, yet irrelevant numerical value cannot be ignored and affects task performance. Do the SCE and the SNARC effect interact in processing?

In order to test the relationship between the two markers of automatic activation, in the first experiment we derived the SCE and the SNARC effect on a common set of numerals for the same group of observers. The task comprised judgments of the physical size (large, small) of numerals conveyed via alternative response key assignments (large size by the left-hand key and small size by the right-hand key, or large size by the right-hand key and small size by the left-hand key). If the SNARC effect taps activation of magnitude information, it should interact with the SCE, which registers the inadvertent involvement of numerical magnitude in tasks of physical size. In particular, a larger SNARC effect is expected for congruent (large numbers in large physical formats and small numbers in small physical formats) than for incongruent (numerical and physical size conflict) number stimuli. If the SCE and the SNARC effect are found to be independent of each other, a revision

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of the traditional interpretation of the latter as a marker of automatic activation is invited.

Our second theoretical device was the Garner effect, psychology's classic vehicle for deciding the separability or integrality of stimulus dimensions in perceptual processing (Garner, 1974; Melara & Algom, 2003; Melara & Mounts, 1993; Pansky & Algom, 1999, 2002). The logic of our Garner test is simple. People classify numbers on the target dimension of parity under two conditions. In one condition, the task-irrelevant dimension of numerical magnitude is permitted to vary within a narrow window of values. In another condition, the values of the task-irrelevant dimension are not constrained, so that they vary considerably from trial to trial. The question of interest is this: Is parity performance comparable under the two conditions? If the large amount of irrelevant variation in the second condition exacts a toll on parity performance, then performance is not comparable, and the dimensions are integral in processing (i.e., full selective attention to parity is compromised). If, on the other hand, parity performance is comparable under the two conditions, then the dimensions are separable, revealing good selective attention to parity. The difference in performance between the two conditions is called *Garner interference*. The presence of Garner interference is the hallmark of integral dimensions, whereas its absence defines separable dimensions. Are parity and magnitude integral or separable dimensions?

In order to examine the mode of processing, in Experiments 2–5 we derived Garner interference and the SNARC effect from the same set of data collected from the same group of observers. According to the traditional explanation, parity and magnitude are integral dimensions because magnitude is activated in an obligatory fashion in judgments of parity (as well as in any other judgment made with respect to numerals). An appreciable amount of Garner interference is therefore expected to plague the judgments of parity. If, on the other hand, magnitude information is not activated in judgments of parity, people are better able to withstand the influence of variation in irrelevant magnitude. In this case, good selective attention to parity would be indexed by the absence of Garner interference. If the data reveal the latter pattern, and parity and magnitude are found to be separable, the construal of the SNARC effect as a magnitude-induced phenomenon would be cast in doubt.

Vicissitudes of the SNARC Effect

The antecedent condition for assaying the SNARC effect entails manual performance of a nonsemantic task with numerals under alternative key assignments. A SNARC effect commonly appears in such setups, although quite often it is absent. Apart from parity, the effect has been reported in the gamut of tasks from color naming (Keus & Schwarz, 2005), to detecting the presence of a phoneme in the digit's name (Fias, Brysbaert, Geypens, & d'Ydewalle, 1996), to bisection lines made of digits (Fischer, 2001), to fingerpointing to the digit's location (Fischer, 2003), to judgments of numerical magnitude themselves (Gevers, Verguts, Reynvoet, Caessens, & Fias, 2006). What is remarkable about these tasks (apart from that of magnitude) is that none requires magnitude information for successful performance. It is precisely the presence of the SNARC effect that has given currency to the inchoate idea of the ubiquitous involvement of magnitude.

Nevertheless, as we have alluded, the SNARC effect is not as robust as sometimes thought. On the background of the positive findings, Lammertyn, Fias, and Lauwereyns (2002) failed to obtain the effect in a color judgment task, and Fias (2001) failed to obtain one in a phoneme decision task. Brysbaert (1995) and Dehaene et al. (1993) did not find the standard SNARC effect with two-digit numbers (but see Dehaene, 1997; Dehaene, Dupoux, & Mehler, 1990). We find it notable that Ito and Hatta (2004) did not find a SNARC effect for judgments of numerical magnitude.

The direction of the SNARC effect is easily reversed, too. The pliability might be taken to challenge the idea of a mandatory association between magnitude and position on a number line laid out from left to right. Consider the typical clock or wristwatch with a numbered dial and moving hands or pointers. On such displays, small numbers (e.g., 1, 2, 3) appear on the right, and large numbers (9, 10, 11) appear on the left. In an associated time-of-the-day decision (earlier or later than 6 o'clock), people responded faster to smaller numbers with a right-hand key and to larger numbers with a left-hand key (Bächtold, Baumüller, & Brugger, 1998). Number and side of response were associated, but the pattern was opposite that observed with the standard SNARC effect.

It is moot whether the SNARC effect is uniquely associated with a left–right axis. Recently, Schwarz and Keus (2004) reported an association between numerals and vertical position in space. Ito and Hatta (2004) have similarly found a vertical SNARC effect with Japanese participants, noting that the pattern of the vertical effect was opposite that expected on the basis of the Japanese writing habit. The SNARC effect is not limited to numbers. In a consonant versus vowel decision task (Gevers, Reynvoet, & Fias, 2003), letters that come early in the alphabet were responded to faster with a left-hand key, and those appearing later with a right-hand key (but see Dehaene et al., 1993). In another experiment (Gevers, Reynvoet, & Fias, 2004), the participants judged names of months for a before-or-after-July decision. People responded to earlier months faster with a left-hand key but responded to later months faster with a right-hand key. Given these data, we asked whether the SNARC effect could reflect a long-term, highly overlearned association between certain stimulus attributes and left–right position in space. In light of the frequent failures to produce the effect, we further asked whether the effect could be the result of strategic rather than automatic response tendencies (see Fischer, 2006).

Considering the cumulative results, we subjected the role of magnitude in nonsemantic numerical tasks to fresh scrutiny. Our predictions were straightforward. First, if numerical magnitude is accessed ineluctably in nonsemantic tasks (such as with physical size), it should interact with that potent marker of automatic activation, the SCE. Second, if magnitude information is involved in a parity judgment task, parity and magnitude ought to form integral dimensions in a Garner test.

STUDY 1
The Relationship Between SNARC and Size Congruity Effects

The participants decided the physical size (large, small) of single numerals in two blocks of trials. In one block, they indicated large physical size by pressing a left-hand key and small physical size by pressing a right-hand key. In another block, the participants responded through the reverse key assignment. To derive the SNARC effect, we compared performance for each number under the two response allocations. A SNARC effect was present when the responses to smaller numerical values were faster with the left-hand key and those to larger numerical values were faster with the right-hand key.

The design also permitted the derivation of the SCE. With data pooled across the two blocks, we compared performance for each number in large and small format. An SCE was present when responses were faster to small formats for smaller numerical values but to large formats for large numerical values. Our goal was to examine the two effects jointly. Do they interact in processing? Is the SNARC effect larger for congruent stimuli (small numbers in small physical size and large numbers in large physical size) than for incongruent stimuli?

Experiment 1
Judgments of Physical Size of Numerals By Left- and Right-Hand Response Keys

Method

Participants. Twenty-two Carleton University undergraduates participated in a single experimental session in order to satisfy course requirements. All of the participants reported normal or corrected-to-normal vision.

Stimuli and Apparatus. The stimulus set comprised the digits 1 through 9, except 5. The digits appeared on screen in bold Times New Roman font, in either small or large font size (30 or 40 pixels, respectively). Each of the 16 stimuli (8 digits $\times$ 2 sizes) was presented five times, preceded by 16 practice trials (unbeknownst to the participants). Order of presentation was random and was different for each participant. On a trial, the number appeared at the center of the screen. Stimulus presentation, event sequencing and timing, and recording of the responses were all governed by a Pentium III computer running SuperLab.

Design and Procedure. The participants were tested individually in a dimly lit room. They were seated approximately 60 cm from the center of the screen. The participant's task was to decide whether the font size of the digit was small or large (while ignoring numerical value). The responses were made by pressing one of the marked keys ("A" on the left, "L" on the right). In one block, the participants indicated small font size by pressing the left-hand key and large font size by pressing the right-hand key. In the other block, they responded using the reverse key assignment. Half of the participants first performed in the first block, and the other half first performed in the second block. The stimuli were response terminated, and a new stimulus was presented following a 1,000-msec interval. Participants were encouraged to respond quickly but accurately.

Results

The SCE. In Figure 1, we present the mean latencies of the correct responses given to each digit for the two values of physical size. Salient to the visual inspection is the systematic influence of numerical value (irrelevant to the task at hand) on the judgments of physical size. For smaller numerical values (numbers 1–4), the participants responded faster when the numeral appeared in a small format than when it appeared in a large format. For larger numerical values (numbers 6–9), the responses were faster to the large format than to the small format. The interaction of number and physical size [$F(7,147) = 2.682$, $MS_e = 234{,}439$, $p < .02$] supported the appreciable

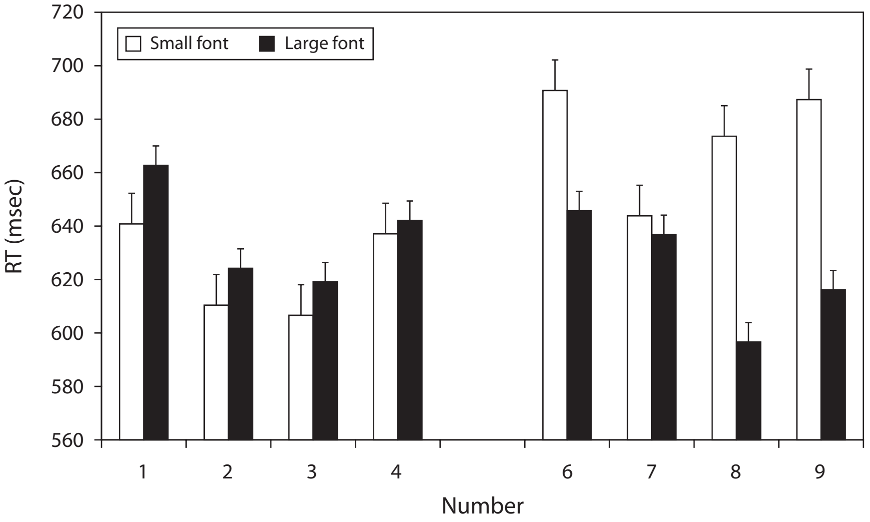

Figure 1. Size congruity effect: Reaction times (RTs, in milliseconds) for judgments of physical size, plotted against number (Experiment 1).

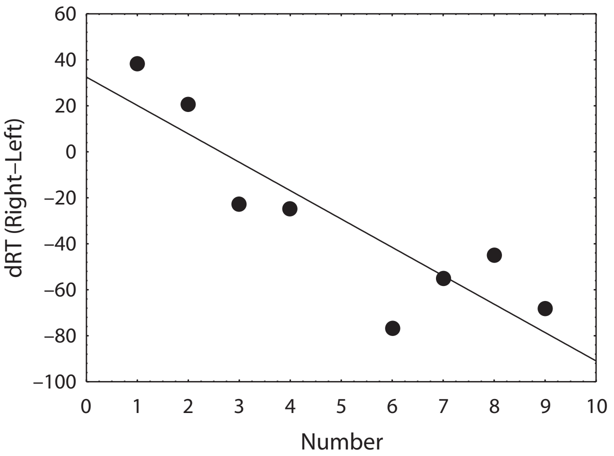

Figure 2. SNARC effect for judgments of physical size: The difference in reaction times (RTs, in milliseconds) between the right- and the left-hand keys (dRT = right − left), plotted against number (Experiment 1).

SCE that characterized our data. In another analysis, we incorporated the variable of congruity (congruent stimuli, for which size and number agree; incongruent stimuli, for which size and number disagree) and found a sizable SCE in this analysis [$F(1,21) = 10.6$, $MS_e = 16{,}808$, $p < .004$]. Notably, the pattern seen in Figure 1 appeared in the data of virtually all of the individual participants.

The SNARC effect. In Figure 2, we present the mean difference in RT between responses made with the right- and left-hand keys (dRT) to each digit. The difference in speed between the two lateralized responses is plotted against numerical magnitude (number). The presence of an appreciable SNARC effect is salient in Figure 2. For small numbers, the left-hand responses were faster than the right-hand responses; for large numbers, the reverse pattern held [$F(7,147) = 3.175$, $MS_e = 22{,}346$, $p < .007$]. In the ANOVA that included congruity as another main factor, the interaction of number and hand was similarly dependable [$F(5,15) = 3.453$, $MS_e = 1{,}094$, $p < .02$]. The presence of the typical SNARC effect is documented by the negative slope [-12.4, $t(7) = -4.08$, $p < .001$] of the best-fitting linear regression line.

In order to further assay the SNARC effect, we used Lorch and Myers's (1990) repeated measures regression analyses. For each participant, we derived the standardized beta regression coefficients with dRT [RT(right) − RT(left)] as the dependent variable and numerical magnitude as the predictor. These weights ($M = -0.278$, $SD = 0.424$) differed significantly from zero [$t(21) = -2.93$, $p < .008$]. The data of 16 of the 22 participants displayed the typical negative slope. The pattern of Figure 2 thus documents the presence of a reliable SNARC effect in the present data.

The relationship between the SCE and the SNARC effect. Clearly, both the SCE and the SNARC effect are prominent features of the present data. Are they associated? In order to address this critical issue, we calculated the SNARC effect separately for congruent (numerical and physical size match) and incongruent (numerical and physical size conflict) stimuli. The two SNARC effects are shown jointly in Figure 3. The slopes are −12.05 and −12.65, respectively, for the congruent and incongruent number stimuli. Neither slope differed from that of the overall SNARC effect (Figure 1), nor did they differ from each other ($F < 1$ in both instances). The two SNARC functions are remarkably similar; their average vertical difference reproduces the SCE. These results show that the SCE and the SNARC effect are unrelated.

The conclusion that the effects are separate is further corroborated by the lack of the three-way number × size × hand interaction ($F < 1$) in the omnibus ANOVA. The absence of this interaction is interpretative (i.e., does not result from lack of power), because the same analysis yielded reliable number × size (the SCE) and number × hand (the SNARC effect) interactions. We recorded the same outcome with the ANOVA that entailed the main variable of congruity. Although both the SCE and the SNARC effect were reliable, their association—the congruity × number × hand interaction—was not ($F < 1$). We further tested the relationship of the two effects at the level of each of the eight individual numbers used. In none of the individual ANOVAs did we record a reliable interaction of congruity and hand. The SNARC effect was roughly the same for congruent and incongruent stimuli.

Discussion

The present dissociation of the effects of SNARC and size congruity suggests that the traditional explanation of the former in terms of automatic activation of numerical value cannot be a fully valid or exclusive account. The SCE is known to tap the activation of numerical magnitude, even in cases in which this information is irrelevant to the task at hand and can hurt performance. If the

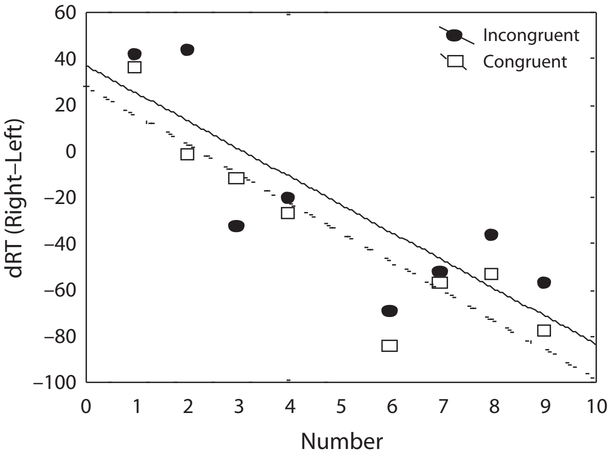

Figure 3. Joint SNARC and size congruity effects: SNARC functions (dRT, plotted against number) for size-congruent and size-incongruent stimuli. The parallelism implies the lack of an interaction between the two effects, with the vertical separation of the functions reproducing the (average) SCE (Experiment 1).

SNARC effect similarly taps into the same magnitude information, a larger SNARC is expected to emerge for congruent than for incongruent stimuli. For the former stimuli, the SCE enhances magnitude processing, which, in turn, should magnify the left–right asymmetry. The data showed instead that SCE-induced magnitude processing left the SNARC effect invariant. Inevitably, the SNARC effect is not associated with the same process of numerical magnitude that is tapped by the SCE.

The present results invite an alternative explanation of the SNARC effect that does not appeal to the notion of automatic activation of magnitude. We submit that the SNARC effect reflects a heavily overlearned stimulus–response mapping. People's responses reflect the real-world arrangement by which the numbers 1–4 are typically located at the left and larger numbers are typically located further to the right. An even more generic learning principle could be involved. When people arrange things by size, they typically put smaller stimuli at the left end and larger stimuli further to the right. The numerals 1 through 4, appearing at the left in many real-word arrangements, would be associated with smallness by this pervasive spatial–motor principle.

STUDY 2
The Relationship Between the SNARC and Garner Effects

In the second study, the task for the participants was decision of parity. They were presented with single digits and decided, while timed, whether the digit was odd or even. In order to test for the presence of the SNARC effect, a given parity task was always performed twice under alternative key assignments. In each task, we compared parity performance for the same digits under the two assignments. Number-dependent differences in left–right responding document the SNARC effect. In order to test for the presence of Garner interference, we had the participants decide parity in two tasks that differed in the amount of task-irrelevant variation in numerical magnitude. In the first task—the baseline condition—magnitude was limited to either small or large values. Thus, in one baseline task, all of the numbers presented for judgment were small (1–4); in the other baseline task, all of the numbers were large (6–9). In the second task—the filtering condition—numerical magnitude varied along the full range (1–9). We compared parity performance between the baseline and the filtering tasks. A deficit in parity performance in the filtering task—a Garner interference—documents the breakdown of full selective attention to the target dimension of parity under large irrelevant variation.

Our goal was to examine the SNARC and Garner effects jointly. Both effects were expected to appear in the data. The former is produced by the alternative response options used, a setup that permits the processing of irrelevant magnitude to express itself as a SNARC effect. The Garner effect is similarly produced by the intrusion of magnitude on parity. Because magnitude is always activated, parity cannot be processed independently of magnitude, although parity does not similarly intrude on judgments of magnitude. The presence of Garner interference supports the prediction that parity and magnitude are integral dimensions, with parity as the relevant dimension.

The results obtained in a pair of experiments by Sudevan and his colleagues (Otten, Sudevan, Logan, & Coles, 1996; Sudevan & Taylor, 1987) seem to support this prediction. In their experiments, the same pair of response keys served to indicate parity (odd or even) and magnitude (smaller or greater than 5), with judgments of the two attributes alternating across trials in a random fashion. When numbers smaller than 5 were indicated by the left key and numbers larger than 5 were indicated by the right key (a key assignment corresponding to the direction of the hypothetical number line), parity judgments were affected by magnitude, but the reverse interference was not found (Sudevan & Taylor, 1987). With the reverse key assignment (one opposite to the direction of the mental number line), magnitude and parity affected each other (Otten et al., 1996).

Nevertheless, these experiments are not conclusive, because a Stroop-like congruity was imposed through the peculiar key assignments used. Parity and magnitude are not genuine Stroop dimensions (unlike the dimensions of color word and print color). A large even number is neither more nor less congruent than a small odd number. The quality of congruity does not apply to the dimensions of numerical magnitude and parity. The values along the two dimensions are zero correlated.

Therefore, in this study, we tested selective attention to each attribute through the Garner paradigm. The Garner paradigm is well suited to test selectivity with any pair of dimensions, Stroop and non-Stroop alike.

Experiment 2A
SNARC Effects in Judgments of Parity

Method

Participants. Sixteen young men and women, paid volunteers from the Tel-Aviv University community, took part in Experiment 2A. All were native speakers of English whose stay in Israel did not exceed 1 year.

Stimuli and Apparatus. Digits 0–9 were generated by an IBM-compatible microcomputer (PC 486) and displayed on a VGA color monitor set at a resolution of 600 × 800 pixels. The digit (Arial font, 48 pixels) appeared in black on a white background near the center of the screen. To avoid adaptation or fixating at a small portion of the stimulus, we introduced a trial-to-trial spatial uncertainty of up to 15 pixels around the center location. The viewing distance was 60 cm. Each of the 10 digits was presented nine times in a block, resulting in two blocks of 90 stimuli. The stimuli were response terminated. A new stimulus was presented following a 500-msec interval. Trials in which the participant's RT was either greater than 1,200 msec or smaller than 100 msec were excluded from the analysis.

Procedure. The participants were tested individually in a dimly lit room. They performed in two blocks. In one block, the participants indicated odd numbers by pressing a left-hand key and indicated even numbers by pressing a right-hand key. In another block, they responded using the reverse key assignment. Half of the participants first performed in the first block, and half first performed in the second block. Unbeknownst to the participants, 20 practice trials preceded the experimental trials in each block.

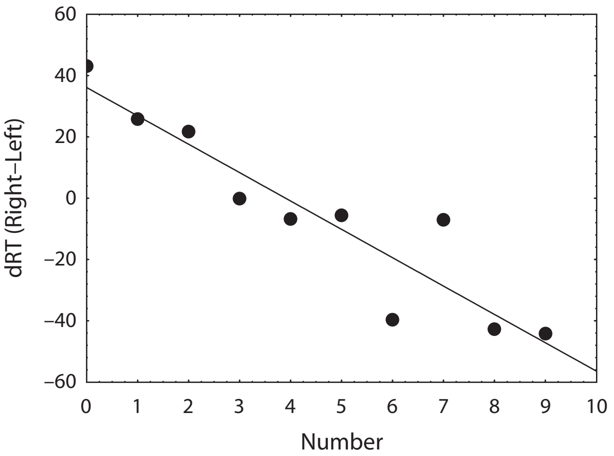

Figure 4. SNARC effect for judgments of parity: The difference in reaction times (RTs, in milliseconds) between the right- and the left-hand keys (dRT = right − left), plotted against number (Experiment 2A).

Results

For each digit, we calculated the mean difference in RT between the responses with the right- and the left-hand keys (dRT). This difference is plotted in Figure 4, against number (i.e., numerical magnitude). For smaller numbers, the left-hand responses were faster than the right-hand responses, but the reverse pattern held true for larger numbers. The presence of the SNARC effect is documented by the negative slope (−9.25) of the regression line (intercept = 36.13) [$r^2 = .865$; $t(8) = 5.23$, $p < .002$].

We used Lorch and Myers's (1990) repeated measures regression analyses to further test for the SNARC effect. For each participant, we derived the standardized beta regression coefficients for the individual SNARC function. These weights ($M = -0.400$, $SD = 0.267$) differed significantly from zero [$t(15) = -6.03$, $p < .00001$].

Discussion

In Experiment 2A, we replicated the results of the original Dehaene et al. (1993) study, producing the standard SNARC effect. Parity judgments depended on magnitude, despite the fact that magnitude was irrelevant to the task at hand. Does the presence of the SNARC effect imply the activation of irrelevant magnitude? To answer this question, in the following experiment we applied Garner's speeded classification paradigm. In Experiment 2B, irrelevant magnitude was varied twice as much in one condition (filtering) than in the other condition (baseline). Consequently, the involvement of magnitude is expected to be larger in the former than in the latter condition.

Experiment 2B
Garner Interference in Judgments of Parity

Method

Participants. The same 16 young men and women as those from Experiment 2A participated in this experiment.

Stimuli and Apparatus. The same numerical stimuli as those from Experiment 2A were used in Experiment 2B. The participants performed in three different blocks of trials: a baseline block, in which magnitude was limited to small digits (1–4); another baseline block, in which magnitude was limited to large digits (6–9); and a filtering block that included all the digits (1–9). Each digit in the baseline conditions appeared seven times in a random fashion, making for a block of 28 trials. Each digit in the filtering condition appeared seven times in a random fashion, making for a block of 56 trials. Order of blocks was randomized across participants, with the constraint that the baseline blocks were performed successively, but with breaks separating successive blocks. The stimuli were response terminated. A new stimulus was presented following a 500-msec interval. Trials in which the participant's RT was either greater than 1,200 msec or smaller than 100 msec were excluded from the analyses.

Procedure. The participants were tested individually in a dimly lit room. They performed in three blocks. In all blocks, and unbeknownst to the participant, 20 practice trials preceded the experimental trials. The participants had a 1-min break after performing in each block. Half of the participants indicated even numbers by pressing a right-hand key and indicated odd numbers by pressing a left-hand key. The other half of the participants performed with the opposite key assignment.

Results

Despite the substantial difference in trial-to-trial variation of irrelevant magnitude between the baseline and the filtering blocks, parity performance was on par in the two conditions ($M = 471$ msec in the baseline block; $M = 472$ msec in the filtering block). For errors, too, the rate in the baseline condition (3.6%) was comparable to that in the filtering condition (3.9%) [$t(15) = 0.52$, $p > .05$]. There was not a reliable difference in parity performance between the two baseline tasks [$M = 478$ msec for small numbers; $M = 463$ msec for large numbers) [$t(15) = 1.3$, $p = .19$]. Notably, too, neither block differed reliably from filtering [$t(15) = 0.7$, $p > .05$; $t(15) = 0.52$, $p > .05$, respectively, for the two baseline blocks].

Discussion

The lack of Garner interference for parity is remarkable. The same participants who exhibited an appreciable SNARC effect—a putative marker of the automatic influence of number—were immune to great changes in variation of those numbers. The absence of Garner interference shows that the participants filtered out magnitude successfully when judging parity, so that selective attention to parity was good. This conclusion, in turn, casts doubt on the explanation of the SNARC effect as a marker reflecting the activation of irrelevant magnitude.

These results invite replication and extension. Before accepting that invitation, however, we report the results with respect to judgments of numerical magnitude (rather than parity) made by the same participants. In Experiment 3, we made magnitude the task-relevant dimension and parity the irrelevant one. The Garner design was used. Random halves of the participants judged magnitude (whether the digit was greater or smaller than 5) under two conditions: in a block in which only even (odd) digits were presented, and in a block in which the numbers varied across even and odd digits. Because different participants performed with the different key assignments, we did not derive the SNARC effect for the present magnitude judgments (but see Experiment 5).

We did not expect irrelevant parity to interfere with the judgments of magnitude. Unlike for the case of magnitude, automatic activation is not generally presumed for parity, despite the fact that parity is also a semantic property of numbers, albeit not a central one.

Experiment 3
Garner Interference in Judgments of Numerical Magnitude

Method

Participants. The same 16 young men and women from Experiment 2 participated.

Stimuli and Apparatus. The same stimuli and apparatus as those from Experiment 2 were used in Experiment 3. The participants judged magnitude in three different blocks of trials: (1) a baseline block limited to the even numbers 2, 4, 6, 8; (2) a baseline block limited to the odd numbers 1, 3, 7, 9; and (3) a filtering block that contained all of those odd and even numerals. Each digit in the baseline conditions appeared seven times in a random fashion, making for blocks of 28 trials. Each digit in the filtering condition appeared seven times in random fashion, making for a block of 56 trials. The order of blocks was randomized across participants, with the constraint that the baseline blocks were performed successively.

Procedure. The procedure was similar to that in Experiment 2B. Half of the participants indicated larger numbers (greater than 5) by pressing a right-hand key and indicated smaller numbers (less than 5) by pressing a left-hand key. The other half performed the procedure with the opposite key assignment.

Results

Mean magnitude decisions (greater or less than 5) in the baseline (457 msec) and filtering (463 msec) conditions were comparable [$t(15) = 0.57, p > .05$]. For accuracy, there were more errors in the baseline conditions (3.9%) than in the filtering conditions (2.8%), although the difference was not reliable [$t(15) = -1.97, p > .05$]. Clearly, Garner interference was absent from the judgments of magnitude. There was not a reliable difference in magnitude performance between the two baseline conditions ($M = 462$ msec for the even blocks; $M = 451$ msec for the blocks) [$t(15) = 0.978, p = .341$]. Of more importance, performance for neither baseline block differed reliably from that of the filtering block [$t(15) = 0.03, p > .05$; $t(15) = 0.878, p > .05$, respectively, for the even-number and odd-number baseline blocks].

Discussion

Our participants decided magnitude as speedily and accurately when all the numbers were odd or when all were even as they did when irrelevant parity changed in a random fashion from trial to trial. The lack of Garner interference for magnitude is not really surprising. What is revealing about the results of Experiment 2B and Experiment 3 is their symmetry. Magnitude did not intrude on parity (Experiment 2B), and, conversely, parity did not interfere with judgments of magnitude (Experiment 3).

Asymmetry in the processing of various stimulus dimensions is the hallmark of the automaticity approach. The results of our second study, taken as a whole, are inconsistent with this view. Their signature is the symmetry in magnitude and parity processing despite the fact that magnitude is considered to be an automatically retrieved attribute of number.

Given the collective results of Experiments 2 and 3, in Experiment 4 we derived the SNARC and the Garner effects from the same set of data. The participants performed twice in the Garner design, each time with a different key assignment.

Experiment 4
Joint Derivation of SNARC and Garner Effects for Parity

Method

Participants. Sixteen young men and women, paid volunteers from the Tel-Aviv University community who did not participate in the previous experiments, took part in Experiment 3. All were native speakers of English whose stay in Israel did not exceed 1 year.

Stimuli and Apparatus. The same numerical stimuli from Experiment 2B were used in Experiment 4. Participants judged parity in the following three blocks: (1) a baseline block, in which magnitude was limited to smaller digits (1–4); (2) another baseline block, in which magnitude was limited to larger digits (6–9); and (3) a filtering block that included all the digits. Each digit in the baseline conditions appeared seven times in a random fashion, making for a block of 28 trials. Each digit in the filtering condition appeared seven times in a random fashion, making for a block of 56 trials.

The participants performed in the three blocks twice, each time with a different response key assignment. Half of the participants first performed in the three blocks, indicating even numbers with the right-hand key, and the other half first performed in the same blocks, indicating even number with the left-hand key. Each group then performed with the reverse key assignment. Order of key assignment and order of blocks within a given assignment were randomized across participants (with the constraint that the baseline blocks were performed successively). The stimuli were response terminated. A new stimulus was presented following a 500-msec interval. Trials in which the participant's RT was either greater than 1,200 msec or less than 100 msec were excluded from the analyses.

Procedure. The participants were tested individually in a dimly lit room. In all blocks, and unbeknownst to the participants, 20 practice trials preceded the experimental trials. The participants had a 1-min break after performing in each block.

Results

The SNARC effect. For each of the eight digits in the filtering condition, we calculated the mean RTs that were needed to decide parity with the left- and right-hand keys. The effects for digit (i.e., numerical magnitude) [$F(7,105) = 1.323, MS_e = 3,665, p = .246$] and for hand ($F < 1$) were not reliable. However, the number × hand interaction [$F(7,105) = 2.672, MS_e = 7,334, p < .05$] documented the presence of an appreciable SNARC effect in the filtering condition.[1] In Figure 5, we present the SNARC effect attained. The negative slope (−9.815) of the regression line depicts the presence of the SNARC effect (intercept = 42.618) [$r^2 = .7431$; $t(6) = 17.362$, $p < .05$].

To further test the SNARC effect, we again used Lorch and Myers's (1990) repeated measures regression analysis with each participant. The individual standardized weights ($M = -0.350, SD = 0.289$) differed significantly

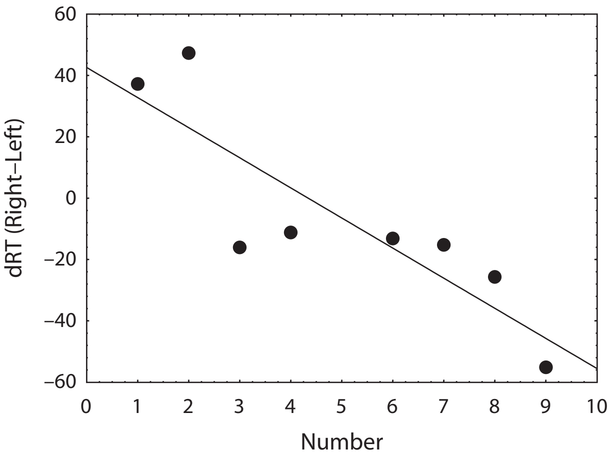

Figure 5. SNARC effect for judgments of parity: The difference in reaction times (RTs, in milliseconds) between the right- and the left-hand keys (dRT = right − left), plotted against number (Experiment 4).

from zero [$t(15) = -4.842$, $p < .005$], documenting the SNARC effect in yet another analysis.

The SNARC effect was absent from the baseline conditions. In the baseline condition that was limited to large numbers, the effect for number [$F(3,45) = 2.466$, MS_e = 3,743, $p < .05$] was statistically dependable, but that for hand ($F < 1$) was not. Their interaction was not reliable [$F(3,45) = 1.115$, MS_e = 5,936, $p = .35$], thereby documenting the absence of the SNARC effect in these data. Nevertheless, we attempted to recover the effect (if there was one) by deriving the dRT–number regression slopes for each of the individual participants. The data of only 10 of the 16 individuals exhibited the expected negative slope, a result that does not differ from chance ($p = .227$). By way of contrast, 15 of the 16 participants had data with a negative slope in the filtering condition. In the second baseline condition, with numbers limited to smaller values, the data showed main effects for number [$F(3,45)$ = 5.983, MS_e = 2,907, $p < .05$] and for hand [$F(1,15)$ = 10.380, MS_e = 1,994, $p < .05$], but not for their interaction [$F(3,45) = 1.35$, MS_e = 5,728, $p = .269$]. A SNARC effect was absent from this condition, too.

Garner interference. Despite the substantial difference in the variation of number, performance was on par across the baseline and filtering conditions (M = 508 msec for both). For errors, too, the baseline-filtering difference was not reliable [5.0% and 4.3%, respectively; $t(15) = 1.208$, $p = .245$]. Parity performance did not differ between the two baseline conditions (M = 510 msec for small numbers; M = 506 msec for large numbers) [$t(15) = 0.241$, $p = .812$]. Even more notable, performance in neither block differed from that in filtering [for the small-number block, $t(15) = 0.184$, $p = .855$; for the large-number block, $t(15) = -0.138$, $p = .891$].

For another check of the absence of any influence of irrelevant variation, for each of the individual numbers presented, we calculated the mean RTs of the pertinent responses in the baseline and filtering conditions. None of the pairs of means entailed a reliable difference [$t(15) \leq 1.62$, $p \leq .25$], nor was there a number × condition (baseline, filtering) interaction.

SNARC and Garner effects. In these analyses, we split the data across left- and right-hand responses and derived SNARC and Garner effects for each hand separately. For data separated by hand, one can still determine the presence of the SNARC effect by testing the interaction of the effects for hand (left, right) and number magnitude at baseline (small, large). The interaction [$F(1,15)$ = 4.658, MS_e = 403, $p < .05$] documented the presence of the SNARC effect in these sets of data. The main effects for number ($F < 1$) and for hand [$F(1,15) = 3.774$, MS_e = 3,770, $p = .071$] were not reliable.

We next tested for Garner interference with each hand separately. For right-hand responses, performance in the baseline (M = 516 msec) and the filtering (M = 506 msec) conditions was similar [$t(15) = -1.08$, $p = .295$]. Responses in the large-number baseline (M = 512 msec) were a bit faster than responses in the small-number baseline (M = 520 msec), but the difference was not dependable ($t < 1$, an outcome compatible with the lack of effect for number in the main ANOVA). Performance in the large-number baseline block [$t(15) = -1.123$, $p = .278$] and small-number block ($t < 1$) did not differ from that in the filtering condition.

For left-hand responses, too, performance in the baseline (M = 501 msec) and in the filtering (M = 509 msec) conditions was on par ($t < 1$). Although responses in the baseline conditions with small numbers (M = 498 msec) were faster than those in the baseline condition with large numbers (M = 508 msec), the difference was not reliable ($t < 1$, the outcome compatible with the lack of a main effect for hand in the ANOVA). Performance in those conditions did not differ from that in the filtering condition [$t(15) = -1.380$, $p = .187$, and $t < 1$, respectively, for the two baseline blocks]. Therefore, we did not detect Garner interference in data generated by each hand separately, despite an overall SNARC effect, by which hand interacted with numerical magnitude.

Discussion

In Experiment 4, we detected the presence of an appreciable SNARC effect in tandem with the absence of Garner interference. The dissociation is particularly notable because it was obtained in the same set of data by the same group of participants. This striking result replicates and extends those observed in Experiments 2A and 2B. The presence of the SNARC effect is the outcome of putatively automatic activation of numerical magnitude. The absence of the Garner effects documents the lack of such activation. How can these two facets of the data be reconciled?

A possible resolution of the paradox comes by modifying the traditional account of the SNARC effect. The SNARC effect might not reflect the mandatory activation of magnitude but, rather, might reflect that of a heavily overlearned stimulus–response mapping. People are faster to associate 1, 2, or 3 with the left-hand side of space and 6, 7, or 8 with the right-hand side of space not because they analyze the numbers semantically (i.e., recover their magnitude), but simply because they have enormous experience with this form of number–space association. What is recovered automatically is this learned association, not the meaning of the presented numerals.

An explanation of the SNARC effect along these lines was suggested by Schwarz and Keus (2004). According to them,

> the SNARC effect might not so much reflect the nature of our internal representation of numerical magnitude per se (perception) but, rather, result from a highly overlearned motor association between particular numbers and particular manual responses (action)—largely independently of how these numbers are internally represented. (p. 652)

Schwarz and Keus mention the example of the strong association in Western etiquette of forks with the left hand and knives the right hands. It is unlikely that this association results from space-related internal representation of cutlery. In their study, Schwarz and Keus found a SNARC effect for saccades, mimicking the SNARC effect routinely found for hands. A saccadic SNARC effect supports the experience-based explanation of the effect, because a highly overlearned stimulus–motor association applies to hand and eye with equal force.[2]

In Experiment 4, we found the SNARC effect with the full range of numbers, but not with a truncated range. We note that Dehaene et al. (1993) and Fias et al. (1996) reported the SNARC effect in blocks of stimuli with only a small range of numbers. According to their account, the direction of the association between number and space depends on ordinal position within a given range. For example, in the range 0–5, the number 5 is large, but in the range 5–9, it is small. Hence, people should be faster to associate 5 with the right-hand side of space in the former condition, but with the left-hand side of space in the latter condition (Dehaene et al., 1993). The present data do not support the relational account. The numerals 1–4 are small in virtually all natural and experimental contexts, regardless of the overall range. Choplin and Logan (2005) suggested that "the smallest digits are most strongly associated with the attribute 'small' and most weakly associated with the attribute 'large'"(p. 27). Choplin and Logan's data suggest that people retrieve instances of number–space and number–magnitude associations from past experience, commensurate with a learning account of stimulus–response mapping.

Experiment 5
SNARC and Garner Effects in Judgments of Magnitude

In Experiment 5, the same participants from Experiment 4 judged magnitude (rather than parity) in the Garner design. They performed magnitude judgments twice, each time with a different response key assignment. Are judgments of magnitude (comparisons with 5) faster in a condition in which only even (odd) numbers are presented than in a condition in which both odd and even numbers are presented? Can people focus their attention on magnitude and ignore trial-to-trial variation in parity? The question addressed in Experiment 5 was about the perceptual independence of magnitude and parity, this time with magnitude as the target dimension. Considering the SNARC effect, we asked whether it would be present in magnitude judgments themselves.

Method

Participants. The same 16 young men and women from Experiment 4 took part in Experiment 5.

Stimuli and Apparatus. The same numerical stimuli as those from Experiment 3 were used in Experiment 5. Participants judged magnitude in three blocks twice, each time with a different response key assignment: (1) a baseline block limited to the even numbers 2, 4, 6, 8; (2) another baseline block limited to the odd numbers 1, 3, 7, 9, and (3) a filtering block that contained all of these numbers. Each digit in the baseline conditions appeared seven times in a random fashion, making for blocks of 28 trials. Each digit in the filtering condition appeared seven times in a random fashion, making for a block of 56 trials. The order of blocks was randomized across participants, with the constraint that the baseline blocks were always performed one after the other.

The procedure was similar to that in Experiment 3. There were two response key assignments. In the first, participants indicated small numbers (smaller than 5) by pressing a right-hand key. In the second, the participants indicated small numbers by pressing a left-hand key. Half of the participants first performed under the former assignment, whereas the other half first performed under the latter assignment.

Procedure. The participants were tested individually in a dimly lit room. In all blocks, unbeknownst to the participant, 20 practice trials preceded the experimental trials. Participants had a 1-min break after performing in each block.

Results

The SNARC effect. For each of the eight numbers in the filtering condition, we calculated the mean RTs needed to decide magnitude (smaller or larger than 5) with the left- and right-hand keys. The effect for digit (i.e., numerical magnitude) was reliable [$F(7,105) = 5.856$, $MS_e = 12{,}088$, $p < .0000$], whereas that for hand was not ($F < 1$). The number × hand interaction [$F(7,105) = 6.692$, $MS_e = 13{,}276$, $p < .01$] documented the presence of the SNARC effect for magnitude.

In a further test of the SNARC effect, we used Lorch and Myers's (1990) repeated measures regression analysis with the data of each participant. The individual weights ($M = -0.502$, $SD = 0.290$) differed from zero [$t(15) = -6.295$, $p < .01$], documenting once again the presence of the SNARC effect in the magnitude data.

Figure 6 shows the difference in RT between the right- and the left-hand responses dRT [RT(right) − RT (left)], plotted against numerical magnitude. The negative slope (−11.652) of the regression line depicts the presence of the SNARC effect (intercept = 55.506) [$r^2 = .775$; $F(1,6) = 20.673$, $p < .01$].

Visual inspection of Figure 6 reveals two fairly separated groups of points (in the upper left for small numbers and in the lower right for large numbers). To test for the possibility of a step-like SNARC function, we conducted another regression analysis using a categorical predictor instead of the linear predictor. A much larger negative slope (−68.951) of the regression line was supported by a consid-

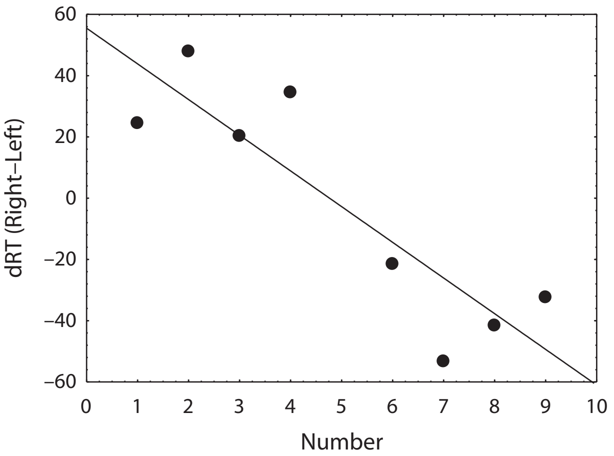

Figure 6. SNARC effect for judgments of magnitude: The difference in reaction times (RTs, in milliseconds) between the right- and the left-hand keys (dRT = right − left), plotted against number (Experiment 5).

erably improved goodness of fit (intercept = 31.722) [r^2 = .904; $F(1,6) = 52.927$]. The SNARC effect likely followed a categorical pattern in the present data. In a recent study, Gevers et al. (2006) also found a step-like SNARC function for magnitude. Our results are consistent with the presence of a categorical SNARC effect for magnitude judgments much like that uncovered by Gevers et al. (2006).

In the baseline condition that was limited to even numbers, we found an effect for number [$F(3,45) = 7.111$, MS_e = 16,498, $p < .005$] but not for hand ($F < 1$). The lack of a number × hand interaction [$F(3,45) = 1.759$, MS_e = 9,882, $p = .168$] indicated the absence of the SNARC effect in these data. We derived the dRT–number regression for each of the individual participants and found the required negative slope with only 10 of the 16 participants ($p = .227$).

In the baseline condition that was limited to odd numbers, neither the effect for digit nor that for hand was reliable [$F(3,45) = 2.072$, MS_e = 6,656, $p = .117$, and $F < 1$, respectively]. The interaction was not reliable [$F(3,45)$ = 2.663, MS_e = 11,193, $p = .059$], although a trend of a number–hand contingency was visually discernible. For the individual data, those of 12 participants showed a negative slope. The corresponding weights ($M = -0.341$, $SD = 0.575$) differed from zero [$t(15) = -2.371$, $p < .05$], supporting the presence of a modicum of a SNARC effect in this condition.

Garner interference. Magnitude performance was comparable in the two baseline conditions (for the even-number condition, M = 482 msec; and for the odd-number condition, M = 489 msec) [$t(15) = 1.158$, $p = .264$]. Garner interference was similarly absent in the accuracy data. In fact, the participants committed more errors in the baseline (5.24%) than in the filtering (3.36%) condition [$t(15) = 2.744$, $p < .05$].

Discussion

People can judge the numerical value of digits while successfully ignoring irrelevant variation in parity. The lack of Garner interference for magnitude is not really surprising because parity, unlike magnitude, is not activated in an obligatory fashion.

Concerning the SNARC effect, some researchers did find the effect for judgments of magnitude (Dehaene et al., 1990; Gevers et al., 2006) and some did not (Ito & Hatta, 2003). We found one in this experiment, but the current SNARC effect for magnitude was different from those typically derived for parity. The SNARC effect did not appear continuous but, rather, appeared discontinuous or categorical (Gevers et al., 2006). Why does the pattern of the SNARC effect differ for parity and magnitude? Possibly, magnitude is first subjected to a gross classification into small or large numbers (Banks, Fujii, & Kayra-Stuart, 1976; Tzelgov, Meyer, & Henik, 1992)—hence, the step-like SNARC function. According to an alternative explanation (Gevers et al., 2006), magnitude judgments (but not parity judgments) are modulated by the distance effect (Moyer & Landauer, 1967). Recall that the magnitude judgments entailed comparisons with 5. As a result, the numbers 3 and 7 were processed faster than 4 and 6. Because the SNARC effect itself depends on generic RT, a step-like function ensues.

GENERAL DISCUSSION

The SNARC effect concerns an innocuous variable: the assignment of response keys to indicate an attribute of a numeral. It thus comes as a surprise to discover that the perfunctory act of allocating response keys influences the outcome. Moreover, the influence is systematic and independent of the tested attribute. Regardless of whether one examines parity, physical size, color, or name, people respond faster to small numbers with a left-hand key and to large numbers with a right-hand key. The pervasive activation of numerical magnitude comes as a natural explanation, given the dependence of the response on numerical value.

Nevertheless, one must be a bit circumspect, because the effect is not reproduced on a permanent basis (Fischer, 2006). If numerical value is automatically activated on the presentation of a numeral for any purpose, why is the effect so often absent? Another reason to exercise caution is the presence of the effect with judgments of numerical magnitude themselves. If the left–right asymmetry is caused by the inadvertent activation of magnitude, it is not immediately clear why the asymmetry should be present when magnitude itself is the target dimension. Reversal of the spatial–numerical association in selected instances also gives one pause, as does the elimination of the effect with crossed hands (Wood, Nuerk, & Willmes, 2006; but see Dehaene et al., 1993). Finally, numerical magnitude is irrelevant with stimuli such as letters, but a SNARC-like effect is often observed with nonnumber stimuli. Collectively, these observations pinpoint a single common source: a deeply entrenched spatial–motor habit.

In this research, we derived two markers of magnitude processing in order to detect the presence of such processing in the SNARC effect itself. Our logic was as follows: The markers of (task-irrelevant) magnitude activation should act in concert with the SNARC effect if, indeed, magnitude information plays a role in its generation. Neither test indicated this to be the case. Both implied that the SNARC effect is generated by processes other than those related to retrieval of the meaning of numerals (i.e., their numerical magnitude).

In the first test, size-congruent stimuli (those for which irrelevant numerical magnitude facilitated responding to physical size) did not produce a larger SNARC effect than did incongruent stimuli (those for which the conflicting dimensions impeded responding). The effects of SNARC and size congruity did not interact, casting doubt on the alleged nature of the former as a semantically induced phenomenon.

The observed independence of the two effects cannot be explained away as a low-power, null result. The pertinent statistical analyses yielded many reliable effects in predictable directions. Moreover, the independence was observed at the level of each of the individual numbers. There were ample opportunities for an interaction to surface, were been an interaction. Again, the results mandate a revision of the traditional explanation of the space–number association in terms of semantic analysis of numerals in all tasks.

In the second test, the participants judged parity, the original dimension studied with the SNARC effect. They did so in a condition in which a narrow window of numerical values was used and in a condition in which the numbers were drawn from a larger range of values. The larger variation of values should be noticed, and it should exact a toll on parity performance if irrelevant magnitude is ineluctably processed in judgments of parity. It did not. The effect of irrelevant variation known as *Garner interference* did not characterize the judgments of parity. The results showed that parity and magnitude are processed in a separate fashion, with parity as the target dimension. Our participants filtered out magnitude successfully when deciding parity, so that their selective attention to the target attribute was good. This in turn calls in question the role of numerical magnitude in generating the SNARC effect with parity.

A methodological issue concerns the deviation in the present research from the orthodox Garner design. In the orthodox design, a single value of the task-irrelevant dimension is used in the baseline condition. We used a baseline condition in which the task-irrelevant condition was held constant from a semantic point of view (small or large numerical value), but in which several exemplars of each class appeared. We submit that the modification is inconsequential. In fact, the modification has been used in the literature.[3] The present design is powerful enough to have detected integral processing, had such processing been in place. Instead, our data exhibited the dissociation of Garner and SNARC effects at all levels of analysis.

The Neglected Response Codes in the Spatial–Numerical Association of Response Codes Effect

If the traditional account entailing activation of magnitude is suspect, how can the SNARC effect be explained? As we had mentioned, the likely source of the effect is a strong (yet strategically controlled) association of motor responses with habitual locations of stimuli in space. The proliferation of research on the SNARC effect has made it easier to overlook the quintessentially motor nature of the phenomenon. The entire effect is about lateralized response devices in space. The difference between the respective manual responses sustains the effect. Remove the motor or response setup and there is not a SNARC effect to ascertain. (Here it is useful to recall the original terms in the SNARC abbreviation.) The SNARC effect is a response-based phenomenon through and through. No SNARC effect exists with oral reactions *as well as* with other nonmanual, nonlateralized responses.[4]

In contradistinction, several other numerical phenomena (semantic and nonsemantic in nature) are purely perceptual. Effects such as those of Garner, Stroop, or the SCE are independent of motor or manual (left, right) responding. Investigators of these effects often use oral responding. For manual responding, investigators typically counterbalance key allocation or employ a constant regiment (then pool the data across these and other contextual factors). Removed are all effects of side or hand. The upshot is that there is a great divide separating the SNARC effect from the SCE and Garner effect. The former is associated with action in space (reaching for stimuli); the latter two are associated with perception of stimuli in (the visual) space.

The present dissociation could be related to the contrast between action and perception elucidated in much current research. According to a popular conception (Milner & Goodale, 1995), there are two functionally independent systems guiding vision: A dorsal stream is responsible for vision for action, whereas a ventral stream is responsible for vision for perception. The SNARC effect is likely governed by the dorsal stream (see Schwartz & Keus, 2004), whereas the SCE and Garner effect are likely governed by the ventral stream. The former mode of vision reflects ecologically based knowledge akin to the concept of affordances suggested by Gibson (1979). The SCE, Garner, and other effects reflect the operation of the second system concerned with conscious visual experience. The dissociation was recently demonstrated with the Garner effect itself, using purely perceptual and purely motor tasks (Ganel & Goodale, 2003; see also Ganel, Chajut, & Algom, 2008).

Is There an Association Between the Numerals 1–4 (Qua Shapes), Smallness, and Left-Hand Location?

The results of a recent study probing the SCE (Choplin & Logan, 2005) reinforce the idea that numerals are associated instinctively with the left or right side of space. These authors found that people selected the physically larger member of the pair 4 2 faster than they did that of the pair 4 2 (the SCE). Startlingly, they reproduced the same SCE when a letter replaced one of the digits, so that responses to C 2 were faster than those to C 2. Choplin and Logan surmised that people do not make relational, algorithmic comparisons of numerical values in the standard SCE. If they did make such comparisons, an invariant SCE with letter–digit pairs would not be possible. Instead, people's reactions are based on long-term experience with each single numeral in the real world. Most memory instances of the numerals 1–4 come with the attribute "small." Logan's instance theory (1988) can accommodate much SCE research with numerical comparison. We maintain that Choplin and Logan's logic extends naturally to account for the SNARC effect, too. People rely on instances available from memory. Those instances with the numerals 1–4 are associated overwhelmingly with the attribute "left." This is the root cause of the indiscriminate tendency to reach out quickly for those stimuli when they appear on the left.[5]

Concluding Remarks

Is the SNARC effect a magnitude-induced phenomenon or a nonsemantic motor phenomenon? On the basis of the present results, we conclude that the SNARC effect does not emanate from the automatic activation of the meanings of numerals. Rather, it reflects the internalization of the real-world arrangement by which smaller numerals appear on the left and larger ones appear further to the right. Although the empirical association of number and space is well learned, it is nonetheless strategically controlled. People can deploy it or eschew the loop to maximize performance in certain task environments. The loop is somewhat like the movements acquired in learning to ride a bicycle. People can benefit from reenacting those movements in certain bicycle-like tasks, but they do not do so in any obligatory fashion. We endorse Fischer's (2006) recent conclusion that "the presence or absence of an association between numbers and space is the result of a . . . strategic decision, . . . not [of] a reflection of mental representation of numbers" (p. 1067). This optional feature of the SNARC effect explains the frequent inability to reproduce the basic result.

Put succinctly, the SNARC effect is a motor-based stimulus–response habit that dresses up as a congruity effect to beguile the unsuspecting observer.

AUTHOR NOTE

Portions of this research were presented at the 20th and 22nd Annual Meetings of the International Society for Psychophysics held, respectively, in Coimbra, Portugal and St. Albans, U.K. This research is based partly on a doctoral dissertation at the Department of Psychology, Tel Aviv University, by D.F.P. under the supervision of D.A. We thank Mark Ashcraft for his invaluable advice and comments. Thanks also to Robert Melara for helpful comments on an earlier version of the article. We are indebted to Bill Petrusic for his intellectual input and support; portions of the data were collected in his laboratory. Correspondence concerning this article should be addressed to D. Fitousi, Department of Psychology, Pennsylvania State University, University Park, PA 16802 (e-mail: dxf28@psu.edu).

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NOTES

1. We note with respect to this and the previous calculations that there are other (similar) ways to calculate the SNARC effect. We believe that the one reported is the most direct and, hence, the preferable routine. Nevertheless, following Schwarz and Keus (2004), we also calculated the SNARC effect with consecutive pairs of numerals (rather than with single numerals). In this analysis, the number factor has the following values: 1-2, 3-4, 6-7, 8-9. The number $\times$ hand interaction was again dependable [$F(3,45) = 5.192$, $MS_e = 5{,}870$, $p < .01$]. Therefore, the results of this analysis agree with those reported in the main text.

2. Startlingly, Schwarz and Keus (2004) rejected their own learning explanation, based on the finding of the saccadic SNARC effect. To their way of reckoning, those results do not support the unique association of hand and number. We challenge their logic and maintain that their data actually mandate just the opposite conclusion. People look the way that their hands reach!

3. For a recent example, Ganel and Goshen-Gottstein (2002) used the Garner design with multiple values of the irrelevant dimension at baseline (in some conditions, as many as 18 values were used!) and recorded appreciable amounts of Garner interference. For another example, Schweinberger and Soukop (1998) presented multiple exemplars in the baseline condition (four exemplars per value of the irrelevant dimension) and recorded Garner effects in their theoretically prescribed conditions.

4. There are a couple of studies that report SNARC-like effects with attention or other central measures. However, these measures are parasites on the fundamental motor ones derived from the left–right difference in responding. Side-dependent effects are a defining feature of those results, too. Moreover, those few studies would not have been conceived in the absence of the foundational motor phenomenon.

5. In fairness to Choplin and Logan (2005), their general approach entails the assumption of automatic activation of numerical value. However, their novel findings with respect to the SCE, their explanation of those findings, and instance theory (Logan, 1988) can account for the SNARC effect, even when one jettisons this assumption.

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