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It Does Exist! A Left-to-Right Spatial–Numerical Association of Response Codes (SNARC) Effect Among Native Hebrew Speakers

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Several studies, starting with Dehaene, Bossini, and Giraux (1993), have reported that, in parity-judgment tasks, the difference in response latencies generated by the right and left hand are negatively correlated with number magnitudes. This SNARC (spatial–numerical association of response codes) effect is in line with the notion that the "mental number line" extends from left to right. The SNARC effect has been found mainly in native speakers of Germanic/Romanic languages; it has been suggested that the SNARC effect may derive from the experience of reading from left to right. To date, there is no evidence that the SNARC (or reverse SNARC) effect exists in parity judgments in native speakers of Hebrew readers. Here we provide the first demonstration of a horizontal, left-to-right SNARC effect in native speakers of Hebrew performing the parity task. Although we found no SNARC effect using the standard parity task, a reliable SNARC effect was found when we succeeded in reducing the MARC (markedness association of response codes) effect. We succeeded in reducing the MARC effect by implementing the parity task in 2 sessions, on 2 different days, each time using a different mapping of the parity-to-response side.

Public Significance Statement
Several studies starting with Dehaene et al. (1993) reported that latencies of difference between right- and left-hand responses in parity decision tasks are negatively correlated with number magnitudes. This spatial-numerical association of response codes (SNARC) effect supports the assumption that the mental number line spreads from left to right. The SNARC effect has been found mainly in native speakers of Germanic/Romanic languages. This study provides the first demonstration of a horizontal, left-to-right SNARC effect in native speakers of Hebrew performing the parity task. While we found no SNARC effect using the standard parity task, a reliable SNARC effect was found when we succeeded in reducing the markedness association of response code (MARC) effect. We succeeded to reduce the MARC effect by implementing the parity task in two sessions, on two different days, each time using a different mapping of parity-to-response side.

Keywords: SNARC effect, Hebrew, reading direction, MARC effect, mental number line

The Influence of the Writing System on the SNARC Effect

In the past it was proposed that numbers are represented mentally along a "mental number line" (MNL), on which numbers are mapped in accordance with their increasing magnitude (Moyer & Landauer, 1967; Restle, 1970). Consistent with this idea, Dehaene, Bossini, and Giraux (1993) showed that numerical information is spatially coded in a specific direction, as if the numbers were located on a horizontal MNL extending from left-to-right. In their study, the participants classified numbers as odd or even using two different mappings of the parity-to-response side (even-left/odd-right vs. even-right/odd-left, i.e., bimanual parity-judgment task). Dehaene et al. found that responses to larger numbers were faster with a right-hand key press, whereas responses to smaller numbers

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were faster with a left-hand key press. The authors termed this effect the *spatial–numerical association of response codes* (SNARC) effect. A mathematical estimate of the SNARC effect was obtained by the correlation between dRT (the difference in response latency to the same number between the right- and the left-hand key presses, i.e., right-hand minus left-hand reaction times [RTs]) and number magnitude.

The negative correlation between the dRT and numerical values reported in early studies of the SNARC effect is consistent with the assumption that the MNL spreads from left to right. These studies were performed on readers of languages read from left to right, which led to the common view that the SNARC effect results from the direction of the writing system (i.e., reading and writing direction), that is, from directional scanning habits (Dehaene et al., 1993). In that seminal study, Dehaene et al. reported that Iranian participants who immigrated to France (whose first language was read from right to left) showed little signs of the SNARC effect. Among native Arabic speaking participants, who also use a right-to-left writing system, a reversed SNARC effect was found (Shaki, Fischer, & Petrusic, 2009; Zebian, 2005). These findings strengthen the assumption that reading direction affects the way people perceive and process numbers.

Hung, Hung, Tzeng, and Wu (2008) proposed that the direction of the writing system and the specific context in which numbers are encountered determine the direction of the MNL. In their study, Chinese readers showed the regular horizontal SNARC effect when the stimuli were Arabic digits, whereas a vertical SNARC effect was found when the stimuli were Chinese number words (which typically appear in a top-to-bottom aligned vertical text). The direction of the vertical SNARC effect was consistent with the Chinese writing system: Responses to smaller numbers were faster with a top-key press, whereas responses to larger numbers were faster with a bottom-key press. However, Japanese participants who read and write from top to bottom showed that the orientation of the vertical number line was opposite (i.e., bottom-to-top) to the dominant writing direction, suggesting that the direction of the writing system is not the key factor that determines the direction of the SNARC effect (Ito & Hatta, 2004; see also Schwarz & Keus, 2004).

Many studies have shown that the number–space association is sensitive to influences of the direction of the writing system and to recent spatial experience (i.e., Fischer, Mills, & Shaki, 2010; Fischer, Shaki, & Cruise, 2009; Shaki & Fischer, 2008). It should also be remembered that many more experimental conditions—number range (e.g., Dehaene et al., 1993, Experiment 3), instruction (e.g., Bächtold, Baumüller, & Brugger, 1998; Müller & Schwarz, 2007, Experiments 1 and 2; Shaki, Petrusic, & Leth-Steensen, 2012), or memory requirements (e.g., Lindemann, Abolafia, Pratt, & Bekkering, 2008; van Dijck & Fias, 2011)—can influence the direction of the association between numbers and space as it is reflected in the SNARC effect. These findings support the idea that the SNARC effect does not reflect only long-standing directional habits, but also episodic factors that mirror the specific characteristics of the task at hand. Shaki, Fischer, and Petrusic (2009).

As for Hebrew speakers, who read and write words from right to left but numbers from left to right, no SNARC effect or reversed SNARC effect was reported under the parity task. In 2009, Shaki et al. argued that the absence of the horizontal SNARC (or reversed SNARC) effect among Hebrew participants might be ascribed to the inconsistency between the alphabetic and the number-writing systems. Their argument is strengthened by the findings that indicate that no spatial–numerical association exists among Farsi readers who also read words from right to left but numbers from left to right (Rashidi-Ranjbar, Goudarzvand, Jahangiri, Brugger, & Loetscher, 2014). However, Shaki and Fischer (2012) argued that despite the inconsistency of the two directional writing systems, a SNARC effect is present "when the response dimension is spatially orthogonal to the conflicting processing dimension" (i.e., with vertical responses, p. 804). Recently, Shaki and Fischer (2014) argued that, to assess whether there is horizontal spatial–numerical mapping in readers from cultures with mixed reading habits, it is essential to remove the spatial features from both the stimulus and the response (for further details, see Fischer & Shaki, 2016). It is important to note that Fischer and Shaki (2016) found a left-to-right SNARC effect among Hebrew speakers while using a number-comparison task (i.e., when asking participants to judge whether the presented number was smaller or larger than 5). It raises the question why the horizontal SNARC effect was never found among Hebrew speakers using the parity task though it was found using the comparison task. One of the salient differences between the parity and comparison tasks is the relevance of the parity status of numbers to the task performed.

The Parity Task: SNARC and MARC Effects

Since the seminal study of Dehaene et al. (1993), the parity task has become the most frequently used task to investigate the SNARC effect (Wood, Nuerk, Willmes, & Fischer, 2008). Commonly, responses to even numbers are faster than responses to odd numbers in the parity task (i.e., the odd effect; see Hines, 1990). Furthermore, right-hand responses are faster than left-hand responses (e.g., Dehaene et al., 1993). These results show the basic asymmetries in the way dimensions are processed and are consistent with the principle of lexical marking. By this principle, "positive" adjectives are stored in memory in a less complex and more accessible form than their opposites (Clark, 1969). This leads to faster categorization of the "plus" polar endpoints (e.g., right/even) than the "minus" polar endpoints (e.g., left/odd) of dimensions.

When the parity task is used to estimate the SNARC effect, participants are asked to indicate the parity status of numbers with bimanual responses twice, once with the even response assigned to the right side and the odd response to the left side, and once with the opposite mapping. Under such conditions, another phenomenon can emerge in addition to the SNARC effect: Odd numbers are responded to faster with a left-hand key press and even numbers are responded to faster with a right-hand key press (Willmes & Iversen, 1995; see also Reynvoet & Brysbaert, 1999). Berch, Foley, Hill, and Ryan (1999) argued that this interaction between number parity and response side results from "association between the unmarked adjectives 'even' and 'right' and between the marked adjectives 'odd' and 'left' (p. 287). This effect was coined the linguistic *markedness association of response codes* (MARC) effect (Nuerk, Iversen, & Willmes, 2004). Nuerk et al. found a larger MARC effect for number words than numerals, and as a result, they concluded that the MARC effect results from lexical marking and reflects the correspondence in linguistic markedness. Alternatively, Cho and Proctor (2007) proposed that the MARC effect reflects polarity correspondence based on the primary structural property of the categorical codes of the stimulus and response. The markedness and polarity accounts agree that one of the two bipolar endpoints of a given dimension is the default "unmarked" (+ polar) endpoint (even for parity, right for hand key-press response), and one is the opposite "marked" (– polar) endpoint (odd for parity, left for hand key-press response). By both accounts, in binary categorization tasks (like the parity task), responses are faster when there is correspondence in markedness/polarity (i.e., when even/odd numbers are responded to with right/left-hand key presses). This markedness/polarity correspondence principle indicates a processing benefit in addition to the one due to the basic asymmetries in the way the positive and negative polarities of parity and response-side dimensions are processed (see Lakens, 2012; Proctor & Cho, 2006).

The MARC effect makes the SNARC effect difficult to detect (Berch et al., 1999). To clarify this point, let us consider an example in which participants perform the parity task under the standard instructions used in SNARC research, and only four numbers—1, 2, 8, and 9—are included. The SNARC effect means that large numbers (8 and 9) are responded to faster with the right hand and small numbers (1 and 2) are responded to faster with the left hand, than with the opposite mapping. By contrast, the MARC effect results in faster latencies when even numbers (2 and 8) are responded to with the right hand and odd numbers (1 and 9) are responded to with the left hand, than with the opposite mapping. Berch et al. explained this by saying that the MARC effect "segregates the odd and even subsets so that it counteracts the downward trend of the right-key minus left-key differences as a function of target magnitude by depressing the differences among the numbers within the odd and even subsets" (p. 305). Dehaene et al. (1993) were aware of that and in their analysis of variance (ANOVA) of the SNARC effect, they reduced the 10 numbers (that were used as the number set) to five bins of increasing magnitude, because in this way, within any given bin, left-and right-side responses were based on responses to both numbers of that bin and from both parity-to-response-side mappings. In other words, Dehaene et al. manipulated parity and number magnitude orthogonally to reduce the effect of the parity-to-response-side association, that is, the MARC effect (Schwarz & Keus, 2004). Tzelgov, Zohar-Shai, and Nuerk (2013) provided a formal analysis showing how the interaction between parity and response side reduces the quantitative estimate of the SNARC effect and how estimating the SNARC effect using number magnitudes rather than numbers per se (as originally suggested by Dehaene et al., 1993) improves the estimate of the SNARC effect. The impact of the MARC effect on the SNARC effect was further examined in this study.

The Present Study

The SNARC effect was found among Hebrew speakers when magnitude information was relevant to the task, that is, when asking participants to judge whether the presented number was smaller or larger than 5 (i.e., number comparison task) (Fischer & Shaki, 2016), but it was never found under automatic processing using the parity task. When numerical magnitude is part of the task requirement (e.g., as in numerical comparison tasks), numerical magnitudes are processed intentionally. Compared with automatic processing, intentional processing is much more affected by the specific task demands and by specific strategies implemented (by participants) to meet these demands (Tzelgov, Ganor-Stern, & Maymon-Schreiber, 2009). In such a case, the use of the MNL metaphor is controversial because the resulting representation might be the one generated by intentionally applied strategies that are created (if indeed they are) to meet the specific task requirements (e.g., Shaki & Petrusic, 2005; Tzelgov et al., 2009).

As Dehaene et al. (1993) pointed out, magnitude information in the parity task is not part of the task requirement and is irrelevant for performing the task. Accordingly, following the minimalistic approach to automatic processing (i.e., a process is automatic if it runs without monitoring; Bargh, 1989, 1992; Tzelgov, 1997), the SNARC effect may be considered to reflect automatic activation of stored numerical representations. This assumption is in line with theories that define automaticity as a process of retrieval from memory (e.g., Logan, 1988; Perruchet & Vinter, 2002) and as such, task requirements have little effect on automatic processing (Tzelgov, 1997). Thus, the parity task is an efficient way to learn about the order of the MNL in memory being minimally affected by task requirements. (Tzelgov et al., 2009). The main interest of the present study was to explore the SNARC effect, which is considered to be a marker of the direction of the MNL, among native Hebrew speakers under automatic processing via the use of a parity task.

We believe that when the parity task is used to examine the SNARC effect among Hebrew speakers, language-specific features (morphology) of the terms "even" and "odd" (i.e., not even) work against the SNARC effect. In Hebrew, even is *zugi* and odd is *e-zugi* (i.e., "not even"), meaning that a prefix negates the unmarked word root. Accordingly, the markedness becomes more salient (Clark, 1969; Zimmer, 1964). Zimmer (1964) claimed that congruency effects tend to be enlarged in languages in which morphology contributes to markedness). Following such reasoning, we believe that this formal morphological factor enlarges the MARC effect in Hebrew. Shaki et al.'s (2009) study showed some direct support for this claim: In their study, the MARC effect was larger (although not significant) for the Israeli (i.e., Hebrew-speaking) than for the Canadian (i.e., English-speaking) participants. Thus, we expected an enlarged MARC effect among Hebrew participants using the standard design of the parity task. Consequently, the SNARC effect should be reduced or absent. It follows that if we are right, one way to show the SNARC effect in Hebrew-speaking participants would be by weakening the MARC effect.

With regard to the direction of the MNL among Hebrew participants, our working assumption was that a SNARC effect consistent with a spreading of a left-to-right MNL was to be expected among native Hebrew speakers, independent of the direction of the Hebrew alphabetic writing system (from right to left), for several reasons. First, consistent with the findings of Hung et al. (2008), the arrangement of the symbolic Arabic numbers on the MNL should mirror the left-to-right direction of the Hebrew number writing system. Second, it is usually assumed that the left-to-right representation of the number line is more natural (e.g., Bächtold et al., 1998; Kugelmass & Lieblich, 1970; Müller & Schwarz, 2007), even among Hebrew-speaking participants (Schwalm, Eviatar, Golan, & Blumenfeld, 2003). Third, the left-to-right direction of the MNL seems to reflect a nativistic foundation of such an orientation that is independent of cultural factors (de Hevia, Girelli, Addabbo, & Macchi Cassia, 2014; Rugani, Vallortigara, Priftis, & Regolin, 2015). Therefore, it is reasonable to assume that among adult Hebrew speakers, a left-to-right SNARC effect should be found.

Experiment 1

This experiment was another attempt to obtain the SNARC effect among native Hebrew speakers using the standard parity-judgment task. Namely, each participant performed the parity task twice (each time using a different mapping of parity-to-response sides) in a single session.

Method

Participants. Thirty-two students (17 men, 15 women), either from Ben-Gurion University of the Negev or Achva Academic College, ages 20–29 years, participated in this study for course credit or in return for monetary compensation. All participants were native Hebrew speakers and all were born, raised, and educated in Israel. They were all right-handed, as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971), with no reported history of learning disabilities, or attention deficit/hyperactive disorder (ADHD). All participants were screened with the *Diagnostic and Statistical Manual of Mental Disorders*, 4th ed. (*DSM–IV*; American Psychiatric Association, 1994) for attentiveness, hyperactivity and spontaneity, to assess ADHD (18 relevant symptoms). Participants had normal or corrected-to-normal vision and they reported no chronic use of medication, and had no significant medical, neurological, psychiatric, or orthopedic (i.e., related to arm movement) disorders. Participants gave their informed consent before the beginning of the experiment and they all were naïve as to the purpose of the experiment.

Stimuli and apparatus. The stimuli were single Arabic digits ranging from 1 to 9 (5 excluded), presented one at a time at the center of the screen in bold, 32-point Times New Roman font in white on a black background. The "Q" and "P" keys of a standard QWERTY keyboard served for left-hand and right-hand key responses, respectively.

The experiment was conducted on an IBM-PC with stimuli presented on a 17-inch monitor screen, which was viewed from a distance of approximately 50 cm. E-Prime software (Psychology Software Tools, Inc., Pittsburgh, PA) controlled the presentation of stimuli.

Procedure. The participants were asked to classify numbers as even or odd (i.e., parity-judgment task) by pressing the "Q" key or the "P" key. Each trial of the parity task started with a fixation cross that appeared at the center of the screen for 200 ms, followed by a blank screen for 300 ms, and then the number stimulus appeared and remained visible until the participant responded. After response, there was a 1,300 ms interval of a blank screen before the next trial started. The participants had to respond with one key if the target was an even number and with the other key if it was an odd number. No feedback was given. Speed and accuracy of each response were recorded.

Each participant performed the parity task twice; once with the even responses assigned to the right-hand key and the odd responses to the left-hand key and once with the opposite mapping (i.e., within-participants design). Both mappings of parity-to-response side were conducted during the same session, but in separate blocks. Each experimental block was preceded by 10 training trials, which were not analyzed. Within a single block, each number was presented 16 times, resulting in 128 random trials per block and 256 trials in total. The specific instructions for each block were provided orally before each block. The order of the mappings was counterbalanced across participants. Between the two response conditions (even-left/odd-right vs. even-right/odd-left), there was a break of about 10 min.

Results and Discussion

The trials with incorrect responses (2%) and RTs longer than 2 *SD*s from the individual mean (5%) were removed from further analysis. Mean RTs for correct responses were computed for each participant in each experimental condition. In all statistical tests, we used a .05 significance level.

Following Dehaene et al. (1993), we applied a three-way repeated-measures ANOVA with response side, magnitude (4 levels of number magnitude), and parity as the manipulated factors in the various conditions. To control for potential biases of parity status on lateralized RT (i.e., MARC effect), we reduced the eight numbers used as the stimuli in all the experiments into four bins of increasing magnitude, each one containing one odd and one even number. In this way, within any given bin, RTs for left-side responses and right-side responses were based on responses to both digits of this bin and on both mappings of parity-to-response side. Thus, any main effect of mapping and of the individual digits should have been cancelled out (Dehaene et al., 1993). In addition, following Tzelgov et al.'s (2013) suggestion, we estimated the SNARC effect by using number magnitude rather than number (per se) as the predictor variable.

Responses to even numbers were faster (492 ms) than to odd numbers (509 ms), $F(1, 31) = 26.05$, $MSE = 1{,}275$, $\eta_p^2 = .46$. This difference was moderated by magnitude, $F(3, 93) = 9.30$, $MSE = 1{,}412$, $\eta_p^2 = .23$. In particular, as number magnitude increased, the responses to even numbers became faster as the responses to odd numbers became slower. The interaction between response side and parity was significant, $F(1, 31) = 30.73$, $MSE = 5{,}954$, $\eta_p^2 = .50$, showing a clear MARC effect. In particular, right-side responses were faster for even numbers than for odd numbers, and left-side responses were faster for odd numbers than for even numbers.

Finally, the three-way interaction between side of response, magnitude, and parity was also significant, $F(3, 93) = 4.70$, $MSE = 1{,}139$, $\eta_p^2 = .13$, see Figure 1. When participants responded to odd numbers (see left panel), RTs with the left hand were slower when number magnitude increased and were faster with the left-hand key press than with the right-hand key press. In contrast, when participants responded to even numbers (see right panel) reaction with both hands was faster when number magnitude increased and was faster with the right-hand key press than with the left-hand key press.

As can be seen in Figure 1, the MARC effect dominates performance and overshadows a possible SNARC effect. There were no other significant effects. In particular, the interaction between

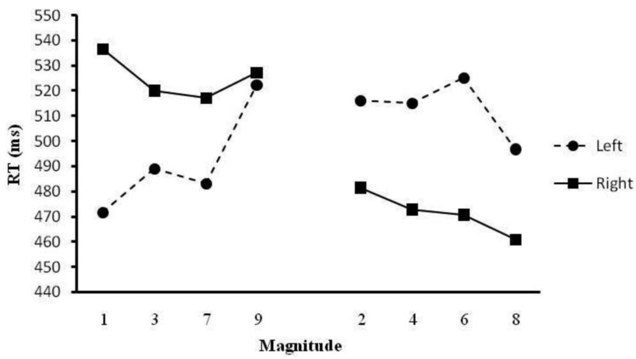

Figure 1. Mean response times in Experiment 1 for left- and right-hand responses as a function of number magnitude for odd and even numbers.

response side and magnitude, which is the signature of the SNARC effect, was absent, $F(3, 93) = 2.07$, $MSE = 2{,}738$, $\eta_p^2 = .06$.

The results of Experiment 1 are consistent with previous failures, in our and other labs, to obtain the SNARC effect in Hebrew-speaking participants. It is worth noticing that the highest R^2-alerting value of the MARC effect was 63.[1] In addition, the sum of squares due to the interaction of response side with parity, the interaction of magnitude with parity, and the triple interaction (Response Side × Magnitude × Parity) explained about 82% of the variability between the various experimental conditions (see Table 1). Thus, parity dominated performance via the MARC effect and by additional interactions. These effects masked any possible effects of other factors and in particular, the Response Side × Magnitude (i.e., SNARC effect) interaction.

The interaction between parity and side of response (i.e., MARC effect) was not eliminated, although we reduced the eight numbers into four bins of increasing magnitude (Dehaene et al., 1993; Schwarz & Keus, 2004) and also quantified the SNARC effect as the correlation between latency of hand difference (i.e., dRT) and magnitude (Tzelgov et al., 2013). Among Hebrew participants, it seems that association between the parity attribute (odd vs. even) and the side of response (left vs. right, respectively) is very strong, apparently because of the contribution of morphology to markedness. This MARC effect seems to reflect a powerful psychological process that masks the association between irrelevant number magnitude and space.

It follows that to obtain a SNARC effect in Hebrew readers under conditions of automatic processing of magnitude (i.e., in the parity task), one has to make an attempt to minimize the MARC effect. In Experiment 2, we assumed that one way to minimize the MARC effect would be by allowing the activation of a specific mapping to decay before participants encountered an alternative mapping.

Experiment 2

Lakens, Semin, and Foroni (2012) proposed that "the presence of shared relational structures in the bipolar stimulus and response dimensions might increase the salience of the structural overlap between the two dimensions" (p. 586). In analogy to their proposal, we assumed that the coactivation of the two mappings creates associations and highlights the correspondence in linguistic markedness, consequently increasing the MARC effect. We believe that participants become more aware of the convenience (even-right/odd-left) or inconvenience (even-left/odd-right) of the mapping they encounter, only when they shift to the second mapping. Consequently, when the two mappings of parity-to-response side are coactivated, participants focus on the relevant stimulus information (parity status of the number) and the task demands (i.e., the relevant mapping). As a result, the MARC effect dominates performance and overrides the SNARC effect. To avoid such coactivation, we decided to run the two blocks of the parity task, differing in parity-to-response-side mapping, on different days (for similar manipulations see Müller & Schwarz, 2007; Schwarz & Keus, 2004; Schwarz & Müller, 2006). We reasoned that the activation of the first mapping of parity-to-response would decay with time and as a result, the MARC effect would be cancelled or at least be reduced, thereby allowing the SNARC effect to appear. In all other aspects, Experiment 2 was similar to the previous experiment.

Method

Experiment 2 was similar to the previous experiment except that participants performed two sessions on two different days with a 1-week interval between them. In each session, one of the two response rules was implemented: Right versus left responses to even numbers and left versus right responses to odd numbers.

Participants were 19 students (15 women, 4 men) between 21 and 25 years old who did not participate in the previous experiment and took part in this study in return for monetary compensation. All other characteristics of the participants were similar to those of Experiment 1.

Results and Discussion

The trials with incorrect responses (3%) and RTs longer than 2 *SD*s from the mean (5%) were removed from further analysis. Mean RTs for correct responses were computed for each target, each response side, and each participant.

The statistical analysis was identical to that of Experiment 1. Responses to even numbers were faster (488 ms) than to odd numbers (510 ms), $F(1, 18) = 18.96$, $MSE = 1{,}888$, $\eta_p^2 = .51$. The MARC effect was insignificant, $F(1, 18) = 3.42$, $MSE = 10{,}372$, $\eta_p^2 = .15$. Most important to note, the interaction between response side and number magnitude was significant, $F(3, 54) = 3.68$, $MSE = 2{,}405$, $\eta_p^2 = .17$, indicating that, as number magnitude increased, responses on the right side became faster, while responses on the left side became slower, providing the typical signature of the SNARC effect (see Figure 2). Furthermore, the linear contrast of this interaction was also significant, $F(1, 18) = 4.83$, $MSE = 5{,}105$, $\eta_p^2 = .21$. The linear regression slope in terms

[1] R^2 alerting is the correlation between the means and their contrasts weights (Rosnow & Rosenthal, 2003). In the specific case of the MARC effect this is equivalent to the proportion of the sum of squares of the interaction of hand by parity (i.e., which reflects the MARC effect) out of the sum of squares of all effects in a given experiment.

Table 1
R^2 Alerting of the MARC Effect and Value of the Parity Influence for Each Experiment

Experiment	R^2-alerting of the MARC effect	Parity influence: Magnitude × Parity + Hand × Parity + Hand × Magnitude × Parity
1. Standard design	.63	.82
2. A week interval between the two mappings	.33	.41
3. One-day interval between the two mappings	.46	.55

Note. MARC = markedness association of response codes; the parity influence was calculated as the sum of squares of the interaction of Hand × Parity, Magnitude × Parity, and Hand × Magnitude × Parity out of the sum of squares of all effects in the given experiment.

of ms/magnitude[2] was −6.69 and the correlation between response side and magnitude was $r = -.96$ (for further discussion, see Pinhas, Tzelgov, & Ganor-Stern, 2012). To the best of our knowledge, using the parity-judgment task, we report for the first time a left-to-right SNARC effect among native Hebrew speakers. There were no other significant effects. In particular, in contrast to Experiment 1, the three-way interaction between side of response, magnitude, and parity was insignificant (see Figure 3). It should also be noted that, as opposed to Experiment 1, for odd numbers as for even numbers, the right- and the left-hand patterns were consistent with the SNARC effect.

In the present study, we examined whether a time interval between the implementation of the two mappings would cancel, or at least reduce, the MARC effect, thereby allowing the SNARC effect to appear. While in Experiment 1 the partial η^2 of the MARC effect was .50, in this experiment the partial η^2 value was .16. Thus, these results provide evidence in favor of the hypothesis that decay of activation of the first mapping over a week's time is needed to reduce the MARC effect. Consequently, it allowed the SNARC effect to be obtained among native Hebrew speakers. These findings confirm that a left-to-right SNARC effect can be obtained among native Hebrew speakers when it is not masked by the MARC effect.

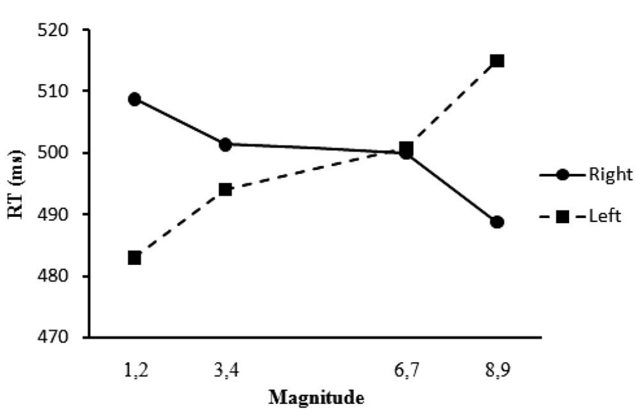

Figure 2. Mean response times in Experiment 2 for left- and right-hand responses as a function of number magnitude.

Experiment 3

In Experiment 3 we tried once again to obtain the SNARC effect in native Hebrew speakers, using the same paradigm in which the participants performed the parity task twice (each time using a different mapping of parity-to-response side) in two sessions on two different days. The only difference between Experiments 2 and 3 is that in the present experiment, we used a 1-day interval (instead of 1 week) between the two sessions.

Method

Participants were 24 students (11 female, 5 male) between 21 and 27 years old who didn't participate in the two previous experiments and took part in this study in return for monetary compensation. All other characteristics of the participants were similar to those in the two previous experiments.

Results and Discussion

The trials with incorrect responses (3%) and RTs longer than 2 *SD*s from the mean (5%) were removed from further analysis. Mean RTs for correct responses were computed for each target, each response side, and each participant.

The statistical analysis was identical to that of Experiment 1. Responses with the right-hand key were faster (518 ms) than those with the left-hand key (526 ms), $F(1, 23) = 4.94$, $MSE = 986$, $\eta_p^2 = .18$. Responses to even numbers were faster (516 ms) than to odd numbers (528 ms), $F(1, 23) = 14.83$, $MSE = 897$, $\eta_p^2 = .39$. The MARC effect was insignificant, $F(1, 23) = 3.77$, $MSE = 14{,}112$, $\eta_p^2 = .14$. Most important, the interaction between response side and number magnitude was significant, $F(3, 69) = 6.00$ $MSE = 1{,}551$, $\eta_p^2 = .21$, indicating that as number magnitude increased, responses on the right side became faster, and responses on the left side became slower (i.e., SNARC effect, see Figure 4). Furthermore, the linear contrast of this interaction was also significant, $F(1, 23) = 10.42$, $MSE = 2{,}348$, $\eta_p^2 = .31$. The linear regression slope in terms of ms/magnitude[2] was −5.93 and the correlation between response side and magnitude was $r = -0.94$. There were no other significant effects. In particular, in contrast to Experiment 1, the three-way interaction between side of response, magnitude, and parity was insignificant (see Figure 5). Note that similar to Experiment 2, the right- and the left-hand patterns were

[2] Following Tzelgov, Zohar-Shai, and Nuerk's (2013) suggestion, we analyzed the data in terms of the relation of number magnitude and dRT rather than to numbers (per se) and dRT. This analysis was performed using units of magnitude defined as the means of two adjacent numbers (for details, see Tzelgov et al., 2013).

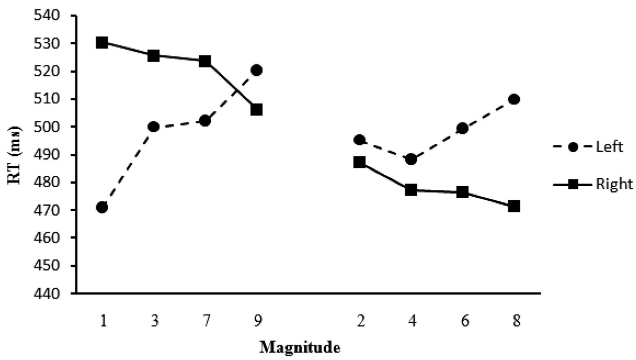

Figure 3. Mean response times in Experiment 2 for left- and right-hand responses as a function of number magnitude for odd and even numbers.

consistent with the SNARC effect for odd numbers as for even numbers.

General Discussion

Earlier studies conducted on adult Hebrew speakers have shown indicators (e.g., the distance effect: The larger the difference between the compared stimuli, the shorter the RT; Moyer & Landauer, 1967) for the representation of numbers along an MNL (e.g., Ganor-Stern, 2012; Rubinsten, Henik, Berger, & Shahar-Shalev, 2002). If this is so, it requires that this MNL has a vector on which the numbers are spatially oriented. The SNARC effect obtained using the parity task indicated that at least readers of Germanic and Romanic languages represent magnitude information in the form of a left-to-right oriented MNL, and that this information is accessed even when irrelevant. Spatial mapping of numbers seems to be a universal cognitive strategy (Göbel, Shaki, & Fischer, 2011). However, the SNARC effect, as measured under automatic processing, was never reported among Hebrew speakers. The purpose of the present work was to investigate the MNL among native Hebrew speakers. Specifically, we were interested in the SNARC effect in the parity task, which is considered to be a signature of the MNL and also allows inferring its direction. To accomplish this, we ran the parity task using the standard single session, and then performed two experiments over two sessions,

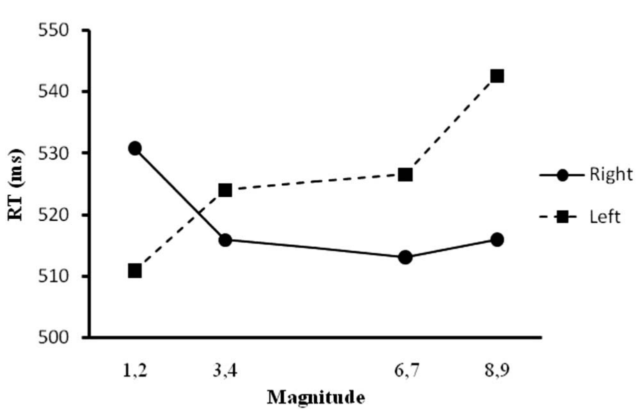

Figure 4. Mean response times in Experiment 3 for left- and right-hand responses as a function of number magnitude.

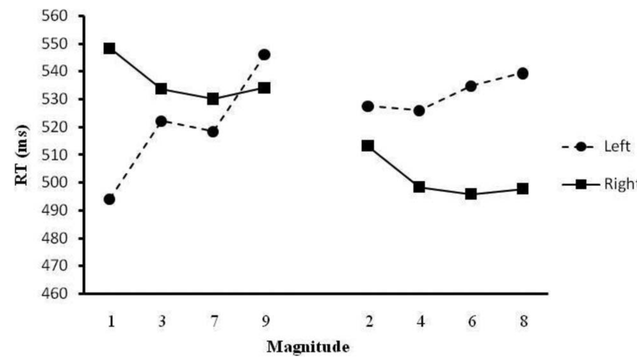

Figure 5. Mean response times in Experiment 3 for left- and right-hand responses as a function of number magnitude for odd and even numbers.

the second one after a time interval, with each session differing in the parity-to-response side mapping. No SNARC effect was found in Experiment 1, in which we used the standard parity task. However, a left-to-right SNARC effect was found in Experiments 2 and 3, each of which added a time interval between the two sessions. Thus, the findings of the three experiments taken together lead to the conclusion that Hebrew speakers show a left-to-right SNARC effect—an effect not easy to obtain. These findings raise two questions: What enabled the SNARC effect to emerge in Hebrew speakers in this study, and what explains the left-to-right direction of the MNL among the native Hebrew speakers who participated in this study?

The Parity Task: SNARC and MARC Effects

To answer the first question, let us take a comparative look at the MARC effect in the three experiments. Experiments 2 and 3 examined whether a time interval between the implementation of the two mappings would cancel or at least reduce the MARC effect and thereby allow the SNARC effect to appear. Whereas in Experiment 1, in which the two mappings were applied in the same session, the partial η^2 of the MARC effect was .50, in Experiment 2, the partial η^2 value was .16 and in Experiment 3, it was .14. From the perspective of this question, the comparisons of the MARC effect in the three experiments, in Bayesian terms, is even more impressive. Specifically, we performed Bayesian *t* tests (Rouder, Speckman, Sun, Morey, & Iverson, 2009) of the MARC effect in each of the experiments. For the convenience of the readers unfamiliar with the Bayesian *t* test, such a test results in the Bayes Factor (BF_{10}), which in plain words means the odds of the data obtained given that H_1 is true against the same data obtained given that H_0 is true, where H_1 and H_0 refer respectively to the existence or nonexistence of a MARC effect. In Experiment 1, BF_{10} was 4302 while it was 1.03 and 1.06 in Experiments 2 and 3, respectively. Thus, these results provide evidence in favor of the hypothesis that decay of activation of the first mapping over time is needed to reduce the MARC effect. Consequently, it allows the SNARC effect to be obtained among native Hebrew speakers. Thus, these results support our assumption that, in Hebrew-speaking participants, at least to some extent, the magnitude of the MARC effect masks the SNARC effect. This finding in itself is not surprising because, for half of the stimuli, the two effects act in opposite directions.

Several findings support the dissociative relations between the SNARC and the MARC effects. A left-to-right SNARC effect was obtained among Hebrew speakers using a magnitude comparison task in which there was no intentional processing of parity; therefore, it was presumed that no MARC effect existed (Fischer & Shaki, 2016; Shaki & Gevers, 2011). Using the parity task, Shaki and Fischer (2012) found a SNARC effect among Hebrew readers by applying a vertical arrangement of responses. On the basis of the marginally significant Response Side × Parity interaction of their results, we estimated B_{10} as 1.00. This means that there is no indication of a MARC effect in this spatial alignment of response keys. Santiago and Lakens (2015) showed that manipulating keyboard eccentricity left the SNARC effect unaffected and led to the absence of the MARC effect. Berch et al. (1999) found that the SNARC effect that appeared in third-grade participants was attenuated by the emergence of the MARC effect in pupils in sixth and eighth grades. Noteworthy is that the MARC effect stemmed mostly from the dominant right hand of our participants (see Table 2), whereas the SNARC effect resulted mainly from the nondominant left hand (see Table 3[3]). These findings revealed that right- compared with left-hand responses were sensitive to different number-related dimensions (parity vs. magnitude, respectively). Essentially, it seems that the MARC effect counteracts the SNARC effect at the level of the hand. Shaki and Fischer (2012, Experiment 1) reported a similar pattern. All these findings are consistent with the assumption that the SNARC and MARC effects originate from different sources. The recent study of Santiago and Lakens (2015) is consistent with this interpretation.

Table 3
SNARC Effect: Partial η² of the Linear Trend of the Left and Right Hand for Each Experiment

Experiment	Linear trend of the left hand	Linear trend of the right hand
1. Standard design	2E-06	.02
2. One-week interval between the two mappings	**.27**	.11
3. One-day interval between the two mappings	**.33**	**.18**

Note. SNARC = spatial–numerical association of response codes; bold indicates a significant effect.

The Direction of the SNARC Effect Among Native Hebrew Speakers

Surprisingly, the results of this study show that among native Hebrew-speaking participants, a left-to-right SNARC effect was found under the parity task in spite of their right-to-left-directed alphabetic writing system or their mixed reading habits.

The dominant view in the literature, starting with Dehaene et al. (1993), assumes that the SNARC effect results from the directional scanning habit. Thus, it could be that the left-to-right spatial association for numbers in this study stems from the left-to-right direction of the number system used by Hebrew readers. This is consistent with the idea that when there are different systems for representing numerical information, the configuration in which the numerical information is presented has an impact on how this information is processed (Hung et al., 2008). In fact, Schwalm et al. (2003) showed that Hebrew participants found it more difficult to process number information when it was presented from right to left (e.g., 7–1) as opposed to the left-to-right direction of their number system. Also, in their review of "the cultural number line," Göbel et al. (2011) argued that spatial experience with one dominant reading direction habit "shapes the spatial orientation within the selected mapping dimension" (p. 560). Consistent with the findings of the current study, this argument implies that the arrangement of the symbolic Arabic numbers on the MNL should mirror the left-to-right direction of the Hebrew number writhing system. The findings of the current study are also in line with Shaki and Fischer's (2014) suggestion that "directional reading habits . . . lead to the positioning of numbers on an MNL, thus imbuing it with its spatial orientation" (p. 1). In sum, if one constrains the notion of reading habits to the reading of numbers, our findings may still be interpreted as being consistent with the dominant view in the literature, according to which reading habits activate a powerful cultural effect on numerical cognition (for recent review, see Göbel et al., 2011).

Table 2
MARC Effect: Partial η² of the Main Effect of Number Parity of the Left and Right Hand for Each Experiment

Experiment	Main effect of number parity of the left hand	Main effect of number parity of the right hand
1. Standard design	**.27**	**.67**
2. One-week interval between the two mappings	3E-06	**.46**
3. One-day interval between the two mappings	.03	**.33**

Note. MARC = markedness association of response codes; bold indicates a significant effect.

Another cultural factor that could have contributed to the direction of the SNARC effect in the present study is that our participants were to some extent bilingual. The experiments of this study were conducted on Israeli students who were well experienced with reading English. Thus, we cannot rule out the possibility that the direction of the MNL reflects their left-to-right experience with the English writing system. Support for this idea comes from Dehaene et al.'s (1993) study, who showed that the SNARC effect among Iranian participants was stronger the longer they were exposed to the second (Western) language (on the impact of a second language, see also Fischer et al., 2009, and Shaki & Fischer, 2008). In addition, Kugelmass and Lieblich (1970) found a left-to-right scanning-preference tendency among Hebrew speakers—a tendency that increased with age.

Furthermore, the left-to-right direction of the MNL might reflect a nativistic foundation of such orientation that is independent of cultural factors. Such an interpretation is supported by the findings that indicate a predisposition to represent numerical magnitudes in a left-to-right direction in newborn human babies and animals. For

[3] Note that the SNARC effect is measured by the correlation between dRT and number magnitude. Therefore, the SNARC effect was present, although the right-hand advantage was not significantly modulated by number magnitude because left-hand responses became significantly slower with increasing magnitude.

example, 7-month-old infants prefer an increasing left-to-right display of magnitude (de Hevia et al., 2014). Moreover, similarly to humans, chicks associate smaller magnitudes with the left space and larger magnitudes with the right space (Rugani et al., 2015). These findings show that spatial–numerical association is not purely a result of cultural experience and instead may have deep developmental and evolutionary roots. Unfortunately, our study did not differentiate between these possible explanations of the left-to-right SNARC effect in Hebrew readers.

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