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No SNARC Effect Among Left-to-Right Readers: Evidence From a Turkish Sample

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ABSTRACT

The spatial-numerical association of response codes (SNARC) refers to the faster left-hand responses to smaller numbers and faster right-hand responses to larger numbers. Although easily replicable in Western cultures, the prevalence of the SNARC effect in other cultures has long been an issue. In the current study, we aimed to replicate the SNARC effect in a parity judgement task with Turkish participants ($N = 66$) whose reading habits are entirely left-to-right. The results revealed no SNARC effect. To the best of our knowledge, this is the first finding indicating the absence of regular SNARC effect among left-to-right readers in a classical parity judgement task. Based on these findings, we suggest that investigations of cultural influences on spatial-numerical associations should take a broader perspective rather than only focusing on reading habits.

KEYWORDS

SNARC
reading habits
mental number line
parity judgement
SNA

INTRODUCTION

The cognitive representation of numbers is typically associated with space. The spatial-numerical associations (SNAs) have been demonstrated through various behavioral tasks (see Toomarian & Hubbard, 2018, for a recent review). For instance, Fischer (2001) reported that participants showed a leftward bias when bisecting strings consisted of small digits (i.e., 1 and 2) and a rightward bias when the strings consisted of large digits (i.e., 8 and 9; see also Calabria & Rosetti, 2005). Furthermore, Fischer et al. (2003) found that passive exposure to small and large numbers in a simple detection task might lead participants' attention to the left and right visual field, respectively (but see also Pellegrino et al., 2019). A similar bias was observed in a random number generation task by Loetscher et al. (2008). Participants generated smaller numbers when turning their heads to the left and larger numbers when turning to the right.

One of the most extensively investigated SNA is the spatial-numerical association of response codes (SNARC) effect, which is often evidenced by, respectively, faster left/right responses to smaller/larger digits in a binary classification task on the parity status of a centrally presented number (Dehaene et al., 1993). The magnitude in a parity judgement task seems irrelevant, but it interferes with the responses, presumably due to automatic magnitude processing. Dehaene et al. (1993) suggested that the SNARC effect could result from the left-to-right direction of the mental number line (MNL; Restle, 1970), in which the semantic memory of numbers is mapped on a spatial continuum. The SNARC effect has been well-established in a wide range of tasks (e.g., magnitude classification, Dehaene et al., 1990; phoneme detection, Fias et al., 1996; font detection, Notebaert et al., 2006), experimental settings (e.g., feet responses, Schwarz & Müller, 2006; oculomotor responses, Fischer et al., 2004; pointing responses, Fischer, 2003), and numerical modalities (e.g., number words, Fias, 2001; auditory number words and dot patterns, Nuerk et al., 2005; sign language numbers in deaf signers, Chinello et al., 2012).

Perhaps the most remarkable characteristic of the SNARC effect is its situational nature (for a review, see Cipora et al. 2018). In line with this, Fias et al. (1996) demonstrated that faster right-hand responses were associated with digits 4 and 5 placed in the numerical range of 0-5, but in the range of 4-9, the same digits elicited faster left-hand responses. Also, when Bächtold et al. (1998) asked participants to imagine the digits on a clock face (with smaller numbers on the right and larger numbers on the left), they observed a reversed SNARC effect (faster left-hand responses for large and faster right-hand responses for small numbers). Furthermore, different tasks induce different patterns of the SNARC effect. More specifically, although a linear pattern of the SNARC effect is observed during parity judgement tasks, the magnitude classification task elicits a categorical shape, possibly due to direct (during magnitude classification) and indirect (during parity judgement) activation of the MNL based on task requirements (Gevers et al., 2006; Wood et al., 2008). In fact, the situational dependency of the SNARC effect can further interact with the task demands, and therefore, yield different results for parity judgement and magnitude classification tasks (e.g., Mingolo et al., 2021). In line with this, the SNARC effect in parity judgement disappears under verbal working memory load,

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whereas the SNARC effect in magnitude comparison disappears under spatial working memory load (van Dijck et al., 2009; see also Deng et al., 2017), suggesting that different types of working memory resources are employed during parity judgement and magnitude classification tasks. These findings provide convincing evidence that, rather than being fixed or automatic, the SNARC effect is a flexible phenomenon that can readily change or disappear under certain conditions.

Although the SNARC effect seems to be easily replicable in Western cultures, nearly 30% of participants do not manifest a typical left-to-right association of numerical magnitudes (Wood et al., 2006), suggesting that various individual characteristics may modulate the emergence of the SNARC effect. For instance, the finger-counting habits of individuals were suggested to influence the SNARC effect (Fischer & Brugger, 2011). Fischer (2008) showed that individuals who counted their fingers from right to left did not show the SNARC effect, although it was present among individuals who counted their fingers from left to right. It is worth noting that the finger-counting effect on the SNARC failed to be replicated in several studies (see Fabbri, 2013; Hohol et al., 2022; Prete & Tommasi, 2020; Wasner et al., 2014) and thus, the results are inconclusive. Other possible factors influencing the SNARC effect are mathematical ability (Cipora et al., 2020; Hoffmann et al., 2014a), spatial ability (Cipora et al., 2020; Viarouge et al., 2014), inhibition capacity (Cipora et al., 2020; Hoffman et al., 2014b; Hohol et al., 2017), and general processing speed (Cipora et al., 2020; Hoffmann et al., 2014a). These individual factors usually have intricate effects on the SNARC. For instance, mathematical ability is found to be significantly influential on the SNARC effect, usually in groups with either very high or very low levels of math skills (Bachot et al., 2005; Cipora et al., 2016; Hoffmann et al., 2014a) rather than those with more typical levels (Cipora & Nuerk, 2013). Furthermore, the direction of the relationship also changes depending on whether the participants are adults or children; better math skills are associated with a stronger SNARC effect in children (Bachot et al., 2005) but a weaker SNARC effect in adults (Hoffmann et al., 2014a; for a review, see Cipora et al., 2020). Therefore, in addition to its situational nature, the SNARC effect involves an inter-individual variance, probably influenced by the interaction of multiple factors.

Since its initial report, the prevalence of the SNARC effect in different cultures has been an object of issue. Dehaene et al. (1993) suggested that individuals' reading habits might influence the direction of the MNL. Conceivably, they would have found a reversed SNARC effect in a sample whose reading/writing direction is from right to left. Instead, they observed no SNARC effect with Persian speakers (i.e., right-to-left reading habit). Shaki et al. (2009) also found that, with right-to-left reading cultures, the SNARC effect either disappeared (with Hebrew speakers) or was reversed (with Arabic speakers; see also Zebian, 2005 for SNARC-like effects). Also, some studies with bilingual individuals with both left-to-right (Russian) and right-to-left (Hebrew) reading habits showed that the SNARC effect could be influenced simply as a result of reading a paragraph in Russian (regular SNARC) or Hebrew (no SNARC; Shaki & Fischer, 2008), or a number word (Fischer et al., 2009). Furthermore, Fischer et al. (2010) showed that reading a text which includes small and large numbers at the left and right ends of the lines induced SNARC-congruent and SNARC-incongruent conditions and led to changes in the SNARC effect. Participants who read the incongruent text before the task showed either reduced (English speakers) or reversed (Hebrew speakers) SNARC effect. Thus, rather than being direct and permanent, the influence of reading habits on SNAs might be continually reshaped in the given context.

In addition, studies with preschool children (see Ebersbach et al., 2014; Hoffmann et al., 2013; Patro & Haman, 2012) have challenged the reading direction account, showing that SNAs could emerge before reading habits are consolidated. According to Patro et al. (2015), the SNAs observed among preliterate children result from implicit learning of the directional behaviors of their social-cultural environment. To support their hypothesis, they trained 3-to-4-year-old children in a task in which the children moved a frog across the water with finger movements (left-to-right or right-to-left) on a touchpad. The children who received left-to-right training showed a SNARC-like effect, and those who received the right-to-left training showed a reversed SNARC-like effect in a numerosity comparison task, suggesting that directional behaviors can be influential in SNA construction. Nuerk et al. (2015) proposed several possible mechanisms for the cultural transmission of SNAs to the child from their parents via the penetrating effects of the embodied social-cultural constructs. Children could construct SNAs by pretending to be adults reading and writing. Also, these children were continually exposed to a range of socially dominant attentional-directional habits not necessarily related to the reading direction, such as drawing lines, counting objects, arranging toys, and representing events in time (i.e., future is conceptualized as heading right in Western cultures; see also Patro et al., 2016). These studies clearly suggest that cultural influences on the MNL require a much broader perspective than reading-direction-based views.

The Current Study

In the current study, we propose that examining the spatial numerical associations in different cultures by only focusing on reading direction may not be sufficient to reveal the potentially complex underlying mechanisms involved. For instance, some previous works have already shown that the SNARC effect could be mediated by language (e.g., De Brauwer et al., 2008; Dowker & Nuerk, 2016; Duyck & Brysbaert, 2008; Fias, 2001). Therefore, we would expect variabilities in the SNARC effect in languages with certain differences from the Western ones.

In line with this prediction, although the Turkish language is read from left to right like Western languages, it differs from them in terms of its syntactic and semantic features, which may affect the findings on the SNARC effect. Syntactically, the grammatical number (i.e., using plural words to refer to more than one thing) is less prominent in Turkish compared to many Western languages. For instance, in Turkish, instead of saying "two apples," people would say "two apple." The syntactic structure of a language can be influential on the development of the numerical concept and spatial mapping of numbers (Dowker & Nuerk, 2016; Sarnecka, 2014).

Also, semantically, “odd” and “even” have connotations with culturally loaded meanings, thus may disrupt the SNARC effect. In Turkish, “tek” (“odd”) means “single,” “one,” or “only.” It can be used to describe something or someone who is alone or the only kind. “Çift” (“even”) means “couple” or “pair” in Turkish. It can refer to a romantic couple or a pair of something (such as a pair of shoes), or “double” as in twice the amount or twice as many. Depending on the context and how the words are used, these words are considered “good” or “bad.” For instance, “tek” can mean “cool” or “awesome” but also “solitary” or “alone.” Similarly, “çift” can mean “couple” or “pair” and can be seen as good in the context of a romantic relationship or a matched set of objects. However, it can also describe something as “double” or “twofold,” which may be seen as unfavorable if the person or object is considered excessive or unnecessary. Presumably, the context-dependent nature of the words causes a wide range of semantic ambiguity. Thus, the “odd or even” instruction used in a typical parity judgement task may produce an increased working memory load, interfering with the SNARC effect (e.g., van Dijck et al., 2014).

It is important to note that the direction of the Turkish script was changed from right-to-left to left-to-right in 1928, which is a relatively recent change (Yılmaz, 2011). This was only three generations ago, presumably not enough to change deep-rooted habits largely embodied by the script direction. Therefore, while the reading/writing direction is from left to right currently, some directional behaviors from the past (in this case, the right-to-left system) might be prevalent in the cultural habits (i.e., right-to-left; Maass & Russo, 2003; Tversky et al., 1991; Vaid, 1995), which would result in more flexible SNAs compared to a typical Western sample, and induce variations in the SNARC effect.

In this sense, we believe it might be interesting to study the SNARC effect with Turkish speakers, considering that the Turkish language differs from Western languages in terms of many linguistic features, yet it is also a culture that reads from left to right like its Western counterparts. Therefore, we aimed to examine the replicability of the SNARC effect in a typical parity judgement task with a sample of Turkish native speakers. Some studies examined the space-magnitude associations among Turkish speakers (e.g., Dural et al., 2017, 2018; Gurbuz & Gokce, 2021) yet they used non-numerical stimuli, and thus, their findings are not directly applicable to SNAs. Therefore, to our knowledge, this is the first study that examined the SNARC effect with Turkish speakers.

METHOD

Participants

Sixty-six native Turkish-speaking volunteers who lived in Turkey served as participants in the study (38 females, M_{age} = 24.49 years, range = 18 - 36 years, SD_{age} = 5.66). A sample of 66 participants ensures .80 power to detect the group level SNARC effect at Cohen’s d = 0.35 at the α level of .05. Four participants were left-handed and four were ambidextrous, based on the Edinburgh Handedness Inventory (Oldfield, 1971). None of the participants reported speaking a language or having a reading/writing habit with a right-to-left direction. All provided written informed consent and had normal or corrected-to-normal vision. The present research was approved by the Ethics Committee of the Izmir University of Economics.

Stimuli and Apparatus

Arabic digits from 1 to 9, except 5, were used as stimuli and centrally presented individually in black on a white background (Courier New, 55 pt. font). Stimuli were presented using SuperLab 4.0 (Cedrus Corp.) on a 20 in. LCD monitor with a 1600 × 900 resolution and 60 Hz refresh rate. Responses were recorded via a Turkish QWERTY keyboard (see the Appendix, Figure A1).

Procedure

During the parity judgement task, participants sat approximately 65 centimeters from the monitor in a sound-isolated and dimmed experimental chamber and maintained the same position. They indicated whether a digit appearing on the center of the screen was odd or even using their left or right index fingers to press the “A” or “İ” keys (“İ” is the rightmost letter on the Turkish QWERTY keyboard), respectively. The task consisted of two blocks with reversed response key assignments and a 30-second rest in between, and the order of the blocks was counterbalanced across participants. Each trial began with a 300 ms white fixation rectangle with a black outline (22 mm × 32 mm), followed by a digit that remained on the screen until a response on the “A” or “İ” key, or for 1300 ms if no response was given. The trial ended with a 1500 ms blank screen. Participants had a total time window of 2800 ms per digit to respond. To avoid successive repetition, we randomized the presentations of the digits within 8-digit sets consisting of numbers between 1 and 9, except 5. Each digit was presented 11 times in each experimental block. Thus, the task consisted of 176 trials (i.e., 8 digits × 11 presentations × 2 experimental blocks). An 8-trial practice session preceded each experimental block. Participants were instructed to respond as quickly and as accurately as possible. The experiment took approximately 10 minutes.

Data Preparation and Analyses

Practice trials were not analyzed. Incorrect responses (3.00%) were removed. Furthermore, trials that were preceded by the same number (1.40%) were removed because the SNARC effect is eliminated on these trials (Tan & Dixon, 2011). None of the reaction times (RTs) were less than 200 ms in the correct trials. The RTs outside ±2.5 *SD*s from the individual mean RT were excluded (2.93%; see the Appendix, Table A1 and Figures A2-A5 for findings based on ± 3 *SD* sequential filtering, Cipora & Nuerk 2013). Thus, 92.67% (ranging between 78.98% and 97.16%) of the data was valid and analyzed further.

In the analysis, we reported the SNARC effect with the linear regression approach (see Fias et al., 1996). In a parity judgement task, the linguistic markedness of response codes (MARC) effect (Nuerk et al., 2004) can emerge, characterized by faster left-hand responses to odd digits and faster right-hand responses to even digits. Therefore, we included the parity status of the digits along with the magnitude in a multiple regression model to examine a possible MARC effect (see Nuerk et al., 2004; Nuerk et al., 2005). Furthermore, both unstandardized and standardized slopes of the SNARC and MARC effects were reported. Standardized slopes are the effect sizes for the SNARC and MARC effects and they are influenced neither by individual RT nor the individual variance within RTs (see Cipora et al., 2019; Hoffmann et al., 2014a). Negative slopes for both unstandardized and standardized values indicate the typical SNARC (faster left-sided RTs for small digits and faster right-sided RTs for large digits) and MARC (faster left-sided RTs for odd digits and faster right-sided RTs for even digits) effects. To determine the presence of a significant SNARC or MARC effect at the sample level, we tested slopes against 0 using a one-sample *t* test.

Before regression analyses, a difference score (dRT) was obtained by subtracting left-hand RTs from right-hand RTs for each digit and participant. The unstandardized SNARC slopes were calculated based on these dRTs using individual regression analyses where the digits served as the predictor variables. To calculate the standardized SNARC slopes, we conducted Pearson correlation analyses between dRT and digit magnitude. Then, Fisher's z transformation was applied to correlation coefficients to approximate a normal distribution. In line with this, the unstandardized MARC slopes were calculated by regressing dRTs on the digit magnitude and parity (contrast coded as -.5 and .5 for odd and even digits, respectively). Finally, Fisher's *z*-transformed correlation coefficients of dRT and parity were calculated for the standardized MARC slopes.

RESULTS

Findings revealed that neither unstandardized nor standardized SNARC and MARC slopes significantly differed from 0 (see Table 1), indicating the absence of the SNARC (see Figure 1) and MARC effects. The distribution of individual unstandardized SNARC slopes is shown in Figure 2 (see the Appendix, Figures A6-A8 for the distributions of other individual SNARC and MARC slopes).

We also performed a Bayesian one-sample *t* test using JASP (JASP Team, 2022) to obtain evidence for the absence of the SNARC effect. We reported BF_{0-} values by setting the Cauchy prior width to its JASP default of r = .707 to demonstrate how much the null hypothesis was favored over the alternative hypothesis. Because our directional prediction indicated that the unstandardized SNARC slopes would have been significantly lower than 0, implying the presence of the SNARC effect, we chose "< test value" for the alternative hypothesis. To interpret the Bayes factors, we considered the guidelines proposed by Jeffreys (1961). The Bayesian one-sample *t* test for the unstandardized SNARC slopes produced a BF_{0-} of 15.34 (see Figure 3, Panel A), which revealed that the null hypothesis was approximately 15 times more likely than the alternative hypothesis. As seen in Figure 3, Panel B, the data provided strong evidence for the null hypothesis through different Cauchy prior widths (default, wide, and ultrawide).

TABLE 1.
SNARC and MARC Effects

Slope	*M* (*SD*)	*t* (*df* = 65)	*p*
Unstandardized SNARC	0.97 (6.52)	1.20	.23
Standardized SNARC	0.07 (0.38)	1.42	.16
Unstandardized MARC	13.50 (114.32)	0.96	.34
Standardized MARC	0.12 (1.04)	0.93	.35

DISCUSSION

The results of the current study provided evidence for the absence of the SNARC effect (Dehaene et al., 1993) with Turkish participants in a parity judgement task. The absence of the regular SNARC effect was previously reported in some non-Western cultures (see Dehaene et al., 1993; Shaki et al., 2009). However, these findings are usually attributed to these cultures' right-to-left reading direction. Bearing in mind the need for empirical support from future studies, the evidence provided by the current study is significant, as it may be the first instance of observing the absence of the regular SNARC effect in a non-Western culture with left-to-right reading habits. Therefore, we believe that the current findings bring new insight to the literature by suggesting that rather than a reading-directed-focus, a broader perspective should be taken when examining the cultural influences on the SNARC effect.

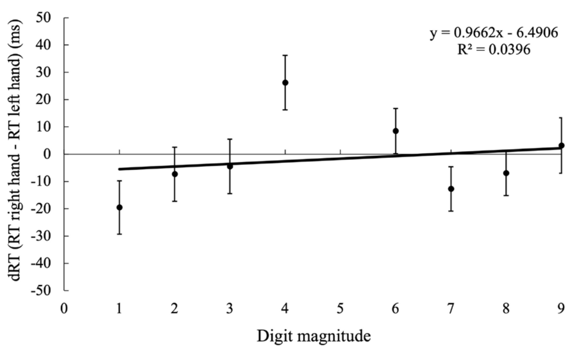

FIGURE 1.
SNARC Slope (Error bars represent *SE*)

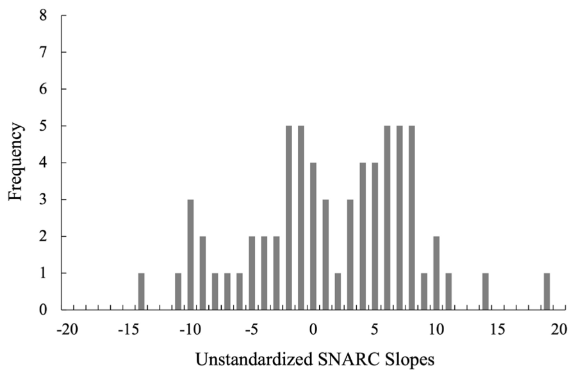

FIGURE 2.
Distribution of Individual Unstandardised SNARC Slopes

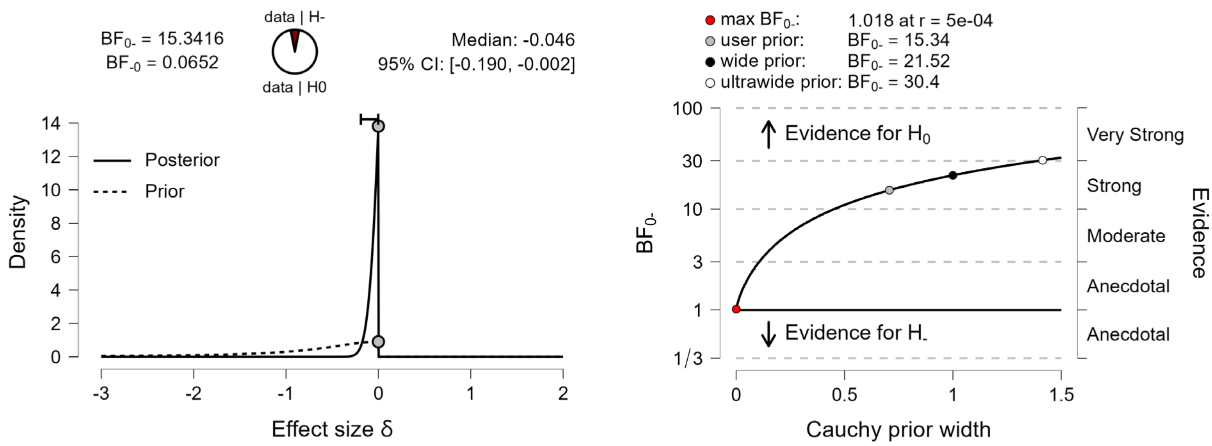

FIGURE 3.

Bayesian Hypothesis Testing. Left Panel: The Prior and Posterior Distribution Plot for a Directional Analysis of Unstandardized SNARC Slopes. Right Panel: Robustness Check Illustrating the Effects of Assigning Wide (*r* = 1) and Ultrawide (*r* = 1.41) Cauchy prior Widths on Bayes Factor Values in addition to Cauchy prior width of *r* = .707 used in the analysis.
In a Bayesian context, a prior distribution of effect sizes expected under an alternative hypothesis must be specified (Brennan et al., 2021). This prior scale parameter means that before observing any data, we expect with 50% confidence that the true effect size lies between 0 and 1.41 (see Figure 3, Right Panel)

When a study produces a null effect, it is usually necessary to examine the methodology and confirm that the study was conducted similarly to previous studies. This is also applicable to the current study. The statistical power of the study (.80) was enough to detect a potentially statistically significant SNARC effect. Furthermore, our methodology was consistent with typical SNARC studies. For example, we used digits from 1 to 9 except 5 as stimuli. Nuerk et al. (2004) suggested that 0 has a special parity status and should not be included in MNL experiments since it slows the mean RT of even numbers. We also excluded 5 to balance the number of odd and even digits in the stimulus list. Five is also considered the midline of the MNL and thus excluded from the stimuli list in most studies (e.g., Cipora et al., 2019; Shaki et al., 2009). Furthermore, we followed the exact stimulus presentation procedure in Dehaene et al. (1993)'s original study (Experiment 1). Cipora and Wood (2017) pointed out the need for a sufficient number of trials in each block to detect a SNARC effect. In several studies (Dehaene et al., 1993; Nuerk et al., 2004; Nuerk et al., 2005; Shaki et al., 2009; Wood et al., 2006; for a large sample online replication, see Cipora et al., 2019), 10 to 11 repetitions of each number in a block served well for the purpose. Accordingly, we presented each digit 11 times in a block, following the classical parity judgement procedures used in previous studies on the SNARC effect. Thus, the absence of the SNARC effect is unlikely to be attributable to methodological issues.

On the other hand, it is imperative to note that the current study's findings refer to a particular SNA phenomenon, namely, the SNARC effect in a parity judgement task. While parity judgement is a popular way to study SNAs, it is not the only method (for a review, Toomarian & Hubbard, 2018). Furthermore, the parity judgement task may be sensitive to cultural influences since it inevitably involves linguistic codes. For instance, no SNARC effect was found for Hebrew speakers in a typical parity judgement task (e.g., Shaki et al., 2009), yet Zohar-Shai et al. (2017) showed the SNARC effect with Hebrew speakers by reducing the MARC effect. In Zohar-Shai et al. (2017)'s study, participants received two blocks of the parity judgement task on two separate days. Each day, a different parity-to-key arrangement was made.

Considering the semantic ambiguity of "odd" and "even" in Turkish, it would be practical to examine the SNARC effect with Turkish participants by using a magnitude comparison task in which the magnitude of the numbers are directly related to the task requirements, and therefore, not interfered by any linguistic/cultural influences. However, note that the SNARC effects produced from the parity judgement task and magnitude classification task differ in various ways. The shape of the effect is continuous in parity judgement, but categorical in magnitude classification (Wood et al., 2008). Additionally, the tasks use different types of working memory resources, with verbal resources used in parity judgement and spatial resources used in magnitude classification (van Dijck et al., 2009). Furthermore, the two tasks were shaped by different underlying processes, with semantic assessment being used in parity judgement and ordinal assessment being used in magnitude comparison (Prpic et al., 2016).

Furthermore, classification with bilateral responses does not always lead to findings that are consistent with different SNA tasks. For instance, Fischer and Shaki (2016) were able to identify a left-to-right SNA in Hebrew speakers in a go/no-go setup in which neither the stimuli nor the responses were explicitly spatial. Specifically, the participants were presented with right- and left-facing objects and Arabic digits at the center of the screen in a go/no-go task setup. The responses for congruent go trials, such as "press for small digits or left-facing objects." were faster than for the incongruent trials, such as "press for small digits or right-facing objects." Therefore, the validations from other SNA tasks with Turkish speakers are also required before the findings can be clearly attributed to SNAs.

For instance, it might be the case that, among Turkish participants, a conceptual link exists between magnitude and space in a left-to-right fashion, which does not manifest itself behaviorally during a parity judgement task. Conveniently, Dural et al. (2018) have already provided evidence of the size-space compatibility effect with Turkish participants using a false memory paradigm with non-numerical symbols. Participants' memory performance for the previously seen compatible stimulus pairs (small on the left, large on the right) was superior to the incompatible stimulus pairs (small on the right, large on the left). Also, participants committed more false alarms for the compatible novel stimulus pairs. For future empirical efforts, we suggest further investigations to determine whether the bilaterally responded parity task can capture the existing tendencies to associate numerical magnitude with space, regardless of culture/language-specific codes.

Some studies have yet to replicate the SNARC effect in certain cultural groups. For instance, in a cross-cultural study, Shaki et al. (2009) found a regular SNARC in English-speaking participants and a reversed SNARC in Arabic-speaking participants (see also Zebian, 2005, for SNARC-like effects). This finding is consistent with the reading direction hypothesis of the SNARC that a regular SNARC effect should be observed in cultures with a reading direction from left to right, and a reversed SNARC effect should be observed in cultures with a reading direction from right to left. However, neither Shaki et al. (2009) with Hebrew participants nor Dehaene et al. (1993, Experiment 7) with Iranian participants showed a reversed SNARC effect. Although both Iranian and Hebrew participants had a right-to-left reading orientation, the resulting zero SNARC effect was inconsistent with the predictions of the reading direction hypothesis (see also Lopiccolo & Chang, 2021; Rashidi-Ranjbar et al., 2014). Another inconsistent finding with the reading direction view came from a study by Ito and Hatta (2004), in which the vertical SNARC effect was present in Japanese participants. Nevertheless, the direction of the effect was opposite (bottom-to-top) to what would be expected based on the Japanese writing habit. Finally, the current study found zero SNARC effects in a culture that reads from left to right, adding one new link to the chain of evidence. Although it is still valid to argue that the reading direction may have played a role in the SNARC effect, these findings suggest that further research is needed to fully understand the cultural influences on the SNARC effect and its underlying cognitive mechanisms.

Furthermore, some studies revealed that SNAs are constructed before literacy is attained (see Ebersbach et al., 2014; Hoffmann et al., 2013; Patro & Haman, 2012). According to Patro et al. (2015), the SNAs observed among preliterate children result from implicit learning of the directional behaviors of their social-cultural environment. In fact, researchers showed that visuo-spatial directional behaviors (moving a frog with fingers in a left-to-right or right-to-left direction on a touch-pad screen) can establish SNAs in an experimental setup. Nuerk et al. (2015) proposed several mechanisms for how SNAs can be constructed in the cultural environment. Accordingly, these mechanisms are not only related to numerosity or reading habits but also include socially conditioned attentional-directional preferences, such as drawing lines (i.e., from left to right or from right to left), drawing objects (i.e., rightward or leftward), arranging and organizing things, and representing the passing of time (i.e., the future progresses to the left or right). These studies argue that focusing on the reading/writing direction alone is insufficient to understand how SNAs are constructed.

The current findings support this position by presenting evidence from adults that reading/writing direction may be only one of the various cultural influences on SNAs. Indeed, directional behaviors follow the culture's reading/writing direction, but this may not always be the case. Note that Turkish culture is under the influence of both Western and Middle Eastern cultures. Although the reading/writing direction is from left to right, some directional behaviors might be under Middle Eastern influence (i.e., right-to-left; Maass & Russo, 2003; Tversky et al., 1991; Vaid, 1995), which prevailed from the previously used script direction. Therefore, future research should clarify how Turkish and Western cultures differ regarding directional habits, and whether these differences account for the variability in SNAs.

The current findings suggest that reading direction alone does not fully determine the establishment of SNAs. It is possible that there are more intricate cultural factors at play. For instance, grammatical number is not prominent in the Turkish language and this difference could be evaluated as one possible reason for the observed variabilities in the SNARC effect compared to Western cultures. On the other hand, the SNARC effect is reported in some other languages which similarly do not often mark grammatical numbers (i.e. Chinese; Hung et al., 2008; Kopiske et al., 2016). We believe that future cross-cultural examinations would reveal these complex modulatory influences that build SNAs. Alongside with linguistic/script related influences some educational factors might play a role in shaping number representations, so the SNARC effect may not be as robust in Turkish speakers as in Western populations. Indeed, the number sequence practices and the emphasis on the development of school children's number sense have only recently been introduced to the mathematics curriculum (Atasoy & Karakoç, 2022). Based on the assumption that the SNARC effect is an expression of MNL, it is quite tenable that such an educational element contributed to the null SNARC we observed.

In conclusion, the current findings provided evidence for the absence of the SNARC effect in Turkish participants with left-to-right reading habits. This finding suggests that a broader range of cultural influences should be examined in cross-cultural samples rather than a narrow focus on reading habits.

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The Authors declare no conflict of interest.

The present research was approved by the Ethics Committee of the Izmir University of Economics (approval number: B.30.2.IEU.0.05.05-020-067).

DATA AVAILABILITY

The data is available in The Open Science Framework (OSF) at https://osf.io/92pvg/. A preprint is available at PsyArxiv https://doi.org/10.31234/osf.io/a8dwg

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APPENDIX

TABLE A1.
SNARC and MARC Effects Obtained from 3 *SD* Sequential Filtering

Slope	*Mean (SD)*	*t***	*p*
Unstandardized SNARC	1.38 (6.16)	1.82	.07
Standardized SNARC	0.07 (0.35)	1.72	.09
Unstandardized MARC	12.75 (109.63)	0.95	.35
Standardized MARC	1.10 (1.01)	1.10	.28

Note. 3 *SD* sequential filtering was repeated until means and SDs were no longer changed, resulting in a 4.35% data loss in addition to data loss due to repetition of the same numbers (1.40%) and incorrect responses (3.00%). Thus, 91.25% (within 73.86% - 98.30%) of the data was valid and further analyzed.

FIGURE A1.
The Key Arrangement of the Turkish QWERTY Keyboard (red circles signify the response keys used in the study).

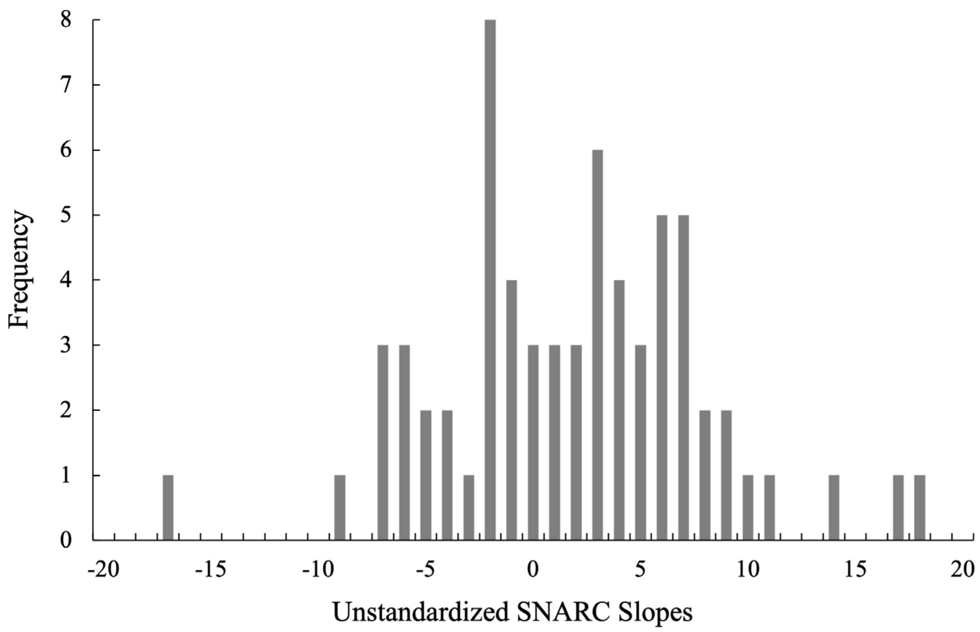

FIGURE A2.
Distribution of individual unstandardized SNARC slopes obtained from 3 SD sequential filtering.

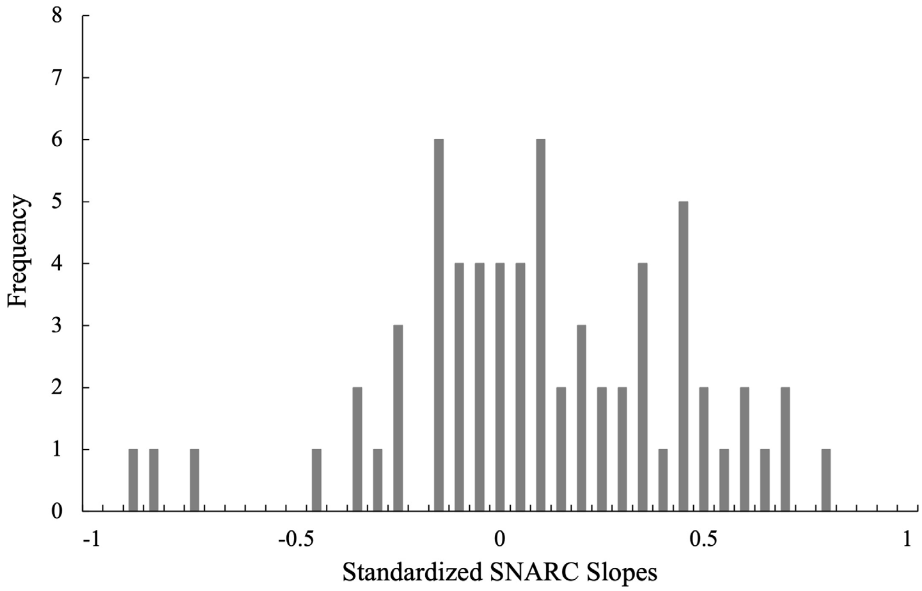

FIGURE A3.
Distribution of individual standardized SNARC slopes obtained from 3 SD sequential filtering.

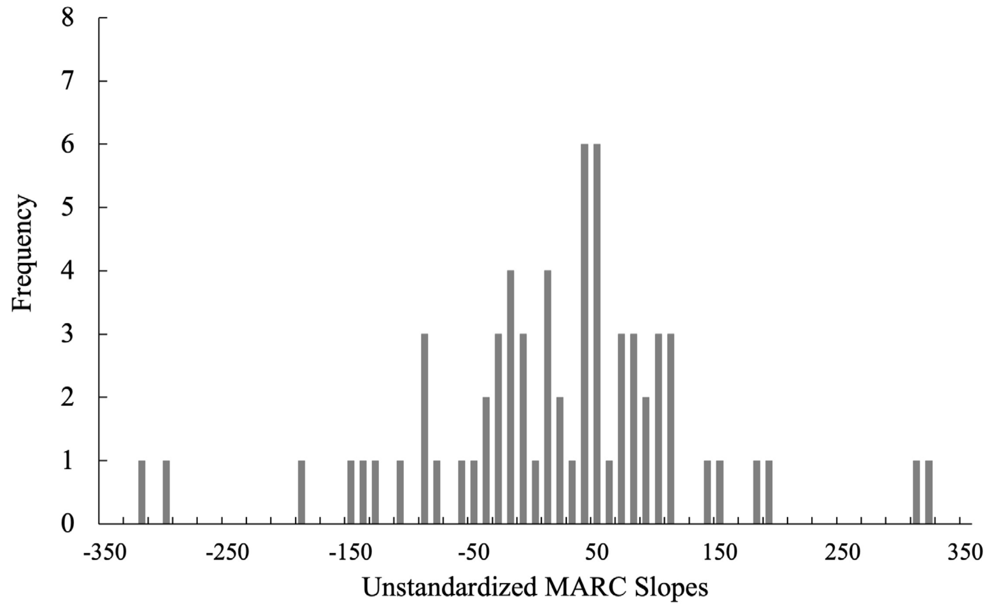

FIGURE A4.
Distribution of individual unstandardized MARC slopes obtained from 3 SD sequential filtering.

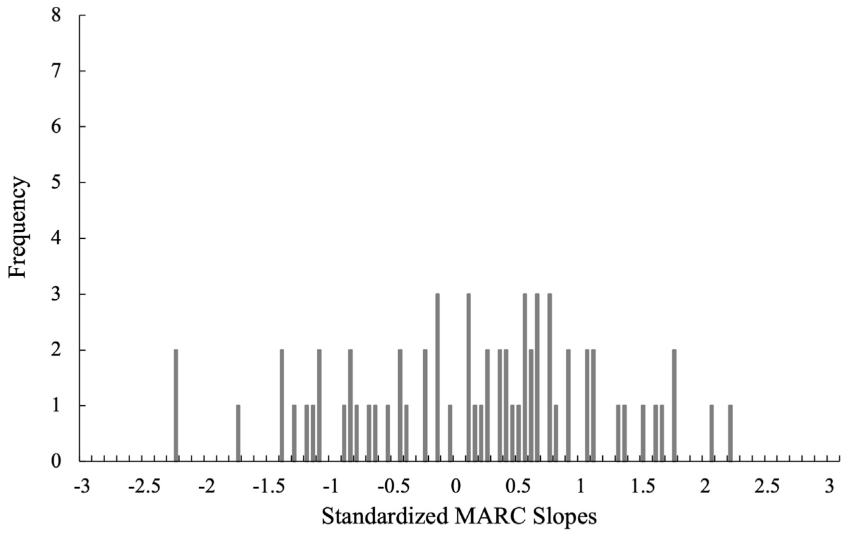

FIGURE A5.
Distribution of individual standardized MARC slopes obtained from 3 SD sequential filtering.

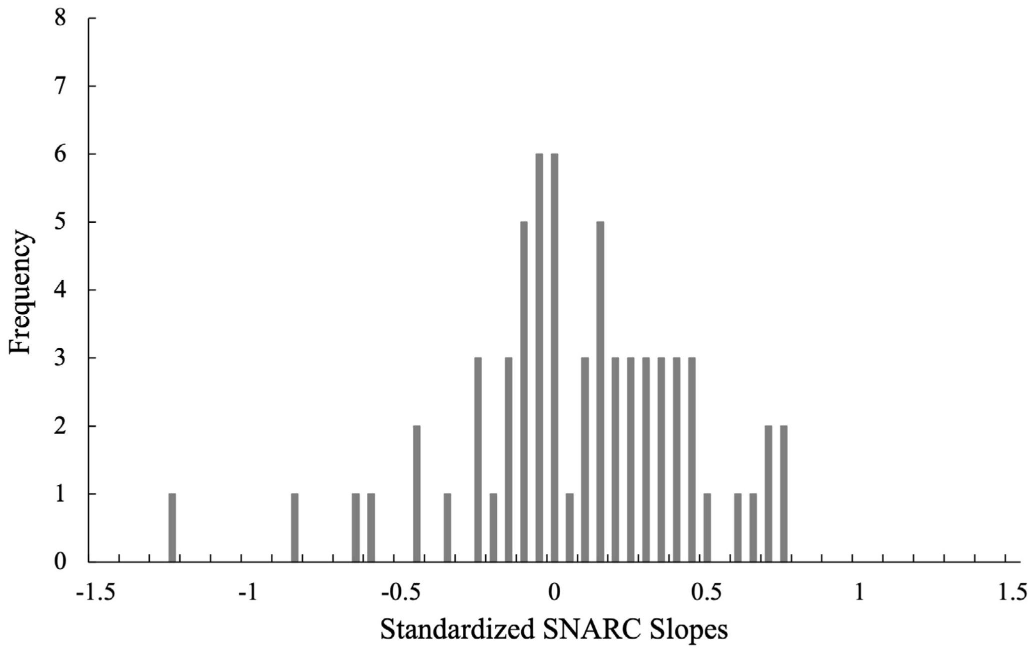

FIGURE A6.
Distribution of individual standardized SNARC slopes.

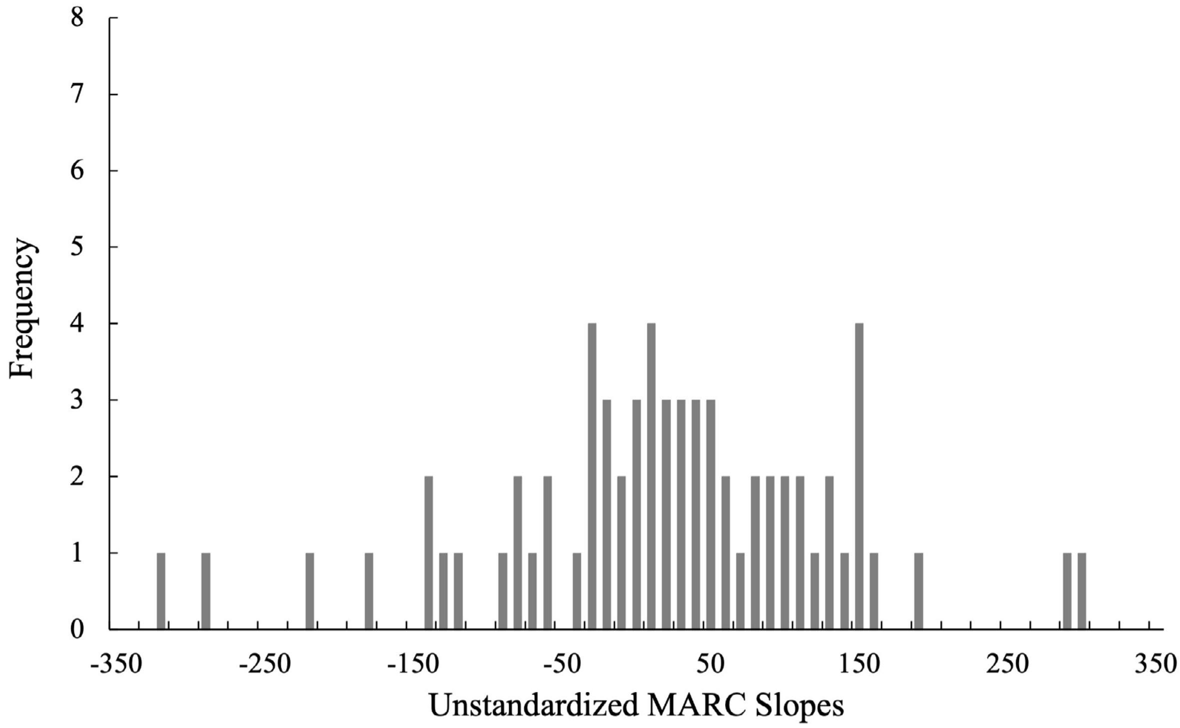

FIGURE A7.

Distribution of individual unstandardized MARC slopes.

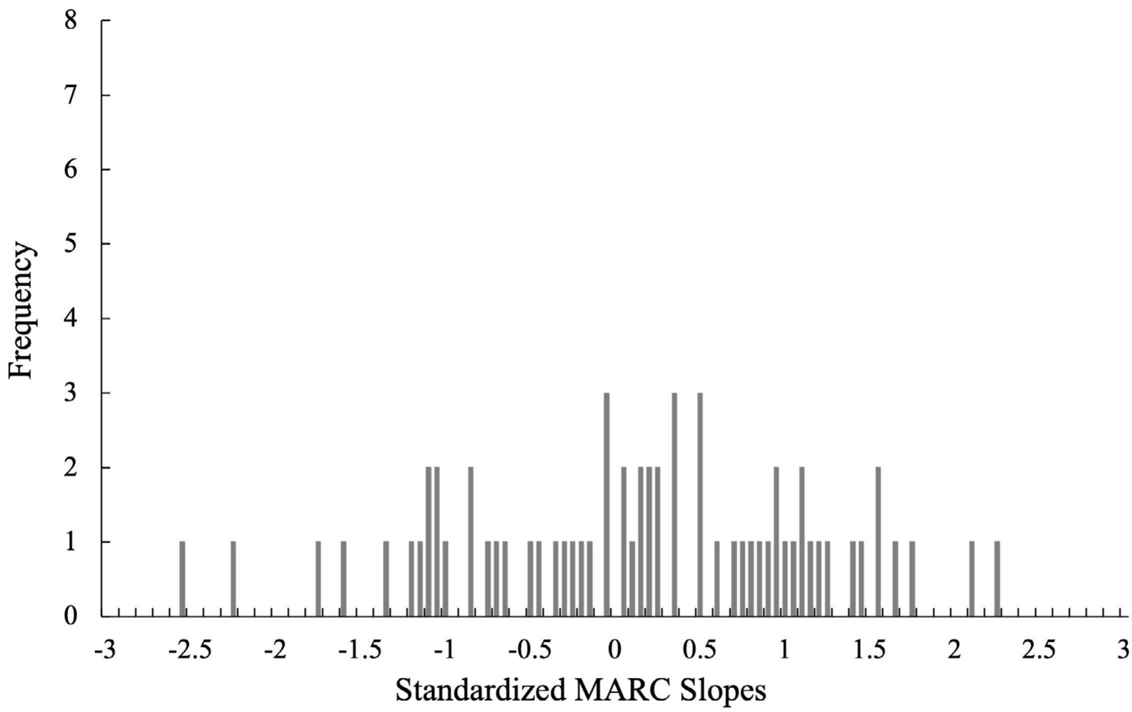

FIGURE A8.

Distribution of individual standardized MARC slopes.