Scientific Reports

https://doi.org/10.1038/s41598-026-44140-0

Article in Press

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Received: 7 July 2025

Accepted: 10 March 2026

Published online: 16 March 2026

Cite this article as: Bulut M., Candemir A., Şefikoğlu M. *et al.* Measuring SNARC effect: different task setups reveal divergent spatial-numerical associations. *Sci Rep* (2026). https://doi.org/10.1038/s41598-026-44140-0

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Measuring SNARC effect: Different task setups reveal divergent spatial-numerical associations

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Abstract

Spatial-Numerical Associations (SNAs) reflect the cognitive link between numerical magnitude and spatial orientation. While the SNARC effect, faster-left responses for small numbers and right responses for large ones, is robust in Western populations, findings from Turkish samples have been inconsistent. This study investigated whether methodological factors, including statistical power, sensitivity of measurement, and task setup, contribute to these inconsistencies. Using high-powered, lab-based parity judgment (PJ) and magnitude classification (MC) tasks, which are standard task setups when investigating the SNARC effect, as well as a novel Go/No-go (GNG) paradigm with lateralized stimuli and a central response, we examined directional SNAs in Turkish participants. Results revealed a weak reverse SNARC effect in the standard PJ task and a weak left-to-right SNA in the GNG PJ task, but no reliable group-level effects in magnitude tasks. Task setup significantly influenced directional SNA patterns, with opposite effects observed between standard and GNG PJ tasks. These findings suggest that SNAs are context-dependent, with different task setups activating distinct directional SNAs. This highlights the critical importance of methodological design when investigating SNAs.

Keywords: SNAs, SNARC effect, parity judgment, magnitude classification, Go/No-go paradigm, Turkish sample

Introduction

Spatial-Numerical Associations (SNAs) refer to behavioral and neural phenomena displaying a strong cognitive connection between numerical and spatial information (for a review [1]). One commonly reported piece of behavioral evidence for the spatial processing of numbers is the *Spatial-Numerical Associations of Response Codes* (SNARC) effect, which refers to faster left-sided responses to smaller numbers and faster right-sided responses to larger numbers [2]. The SNARC effect is considered a robust phenomenon, especially in Western samples [3–5]. It has been replicated across various tasks, including magnitude classification [6], parity judgment [2], phoneme detection [7], font detection [8], color judgment [9], and non-semantic feature detection of numbers (Experiments 1 and 4 in [10]; see also [11]) as well as across different stimulus types, including number words [10, 12], auditory number words, and non-symbolic numerosity [12]. Moreover, the effect generalizes across response modalities, such as pointing [13], oculomotor responses [14], and foot responses [15].

Several accounts have attempted to explain the cognitive mechanism underlying the SNARC effect. One prominent explanation proposes that it arises from a left-to-right (LR) oriented *Mental Number Line* (MNL), on which smaller numbers are mentally represented on the left and larger numbers on the right [2]. The MNL account proposes a fixed visuospatial representation of numerical magnitude. However, subsequent models have argued that the SNARC effect cannot be reduced to visuospatial mechanisms alone. One influential alternative proposal suggests that the SNARC effects can arise from abstract polarity pairings (e.g., "left"/"small" as negative, "right"/"large" as positive), without invoking spatial imagery [16]. The dual route model [17] was proposed in response to accounts that attribute the SNARC effect to a single fixed visuospatial representation, such as the MNL. According to this model, SNAs can arise via two interacting processing routes: an unconditional route reflecting relatively stable long term associations, and a conditional route that relies on short term memory and flexibly adapts to task demands and contextual factors. In contrast, the working memory account [18] argues that spatial coding of numbers does not rely on pre-existing visuospatial or semantic associations, but is actively constructed during task execution through the temporary ordering of numerical information in working memory. Recently, Zhang et al. [19] proposed a more elaborate model suggesting that the SNARC effect unfolds in two stages. The first is the representational stage, during which the spatial mapping of numbers is processed implicitly and automatically. The second is the conflict stage, wherein a response is selected based on stimulus-response compatibility. Both stages are influenced by task demands and are governed by distinct subcomponents of cognitive control, such as working memory, inhibition, and conflict adaptation.

Several studies suggested that there may be a biological basis for the LR spatial processing of numerical magnitudes, based on evidence from animals [20–22] and newborns [23–25] (for a review, see [26]). However, while an innate basis is possible, it is also well established that directional SNAs are context-dependent [27–29] and can be readily modified by situational factors [8, 30–34]. The flexible nature of the SNARC effect is also evident in cross-cultural studies. While the effect has been successfully replicated in numerous Western populations (e.g., French, Canadian, Finnish, German, Belgian, Dutch, and Scottish [3–5]) and in some Asian samples (e.g., Korean [30], Chinese [35], Japanese [36]), findings from Middle-Eastern samples (i.e., Turkish, Farsi, Arabic, and Hebrew; see Table 1) remain inconsistent. Previous research primarily examined participants' reading direction, suggesting that right-to-left (RL) reading habits may account for cross-sample variability in the SNARC effect (e.g., Experiment 7 in [2]; see also [37, 38]).

Table 1

Studies with Middle Eastern samples with inconsistent directional SNA/SNARC findings

Sample	Study	Reading direction	Task	Group-level SNARC/Directional SNAs
Arabic	Zebian, 2005 [38]	RL	Magnitude comparison	RL directional SNAs
Arabic	Shaki et al. 2009 [37]	RL	PJ	Reverse SNARC effect
Arabic	Loppiccolo & Chang, 2021 [39]	RL	Magnitude comparison	Null effect
Hebrew	Shaki et al. 2009 [37]	RL	PJ	Null effect
Hebrew and Arabic	Shaki et al. 2012 (Exp. 3) [40]	RL	Comparative judgment task	RL directional SNAs
Hebrew	Fischer & Shaki, 2016 [41]	RL	Go/No-go task (in which both stimuli and response are central)	LR directional SNAs
Hebrew	Zohar-Shai et al., 2017 (Exp. 1) [42]	RL	PJ	Null effect
Hebrew	Zohar-Shai et al., 2017 (Exp. 2 and 3) [42]	RL	PJ (in a two-day session setup)	SNARC effect
Farsi	Dehaene et al., 1993 (Exp. 7) [2]	RL	PJ	Null effect
Farsi	Rashidi-Ranjbar et al., 2014 [43]	RL	Random number generation	Null effect
Farsi	Bulut et al., 2024 [44]	RL	PJ and MC	SNARC effect (PJ) Null effect (MC)
Farsi	Hochman et al., 2024 [45]	RL	PJ and MC (visual and auditory)	SNARC effect
Turkish	Bulut et al., 2023 [46]	LR	PJ	Null effect
Turkish	Palaz et al., 2024 (see control group) [33]	LR	PJ	Null effect
Turkish	Bulut et al., 2024 [44]	LR	PJ and MC	SNARC effect
Turkish	Bulut et al., 2025 (see control group) [31]	LR	PJ	Null effect
Turkish	Dural et al., 2025 [47]	LR	MC	Null effect
Turkish	Kaya et al., 2025 [48]	LR	PJ	Null effect

However, the reading direction hypothesis fails to account for several key findings in the literature. For instance, if reading direction were sufficient on its own to shape the SNARC effect, one might expect a reverse SNARC effect in RL readers. However, empirical evidence is inconsistent: studies report either SNARC effects consistent with left-to-right SNAs or null effects among RL readers (see Table 1). Null SNARC effects observed in RL languages such as Hebrew have been attributed to LR numerical processing habits, which are assumed to lead to mixed reading directions [37]. However, this explanation fails to account for findings showing that SNARC effects can emerge in some RL-reading samples, even if not consistently across all such samples [e.g., 44, 45]. Moreover, this account implicitly assumes that the reading direction of numbers can selectively influence numerical processing. At the same time, it also presupposes that text reading direction remains dominant, given that individuals are exposed to written language far more frequently than to numerical symbols. Taken together, these assumptions imply that the opposing directional influences of number reading and text reading cancel each other out, resulting in a null SNARC effect. Importantly, the SNARC effect has not been consistently observed even among LR readers. For example, Turkish samples often show null or highly variable SNARC effects despite uniform LR reading habits (see Table 1). Finally, experimental studies have failed to establish a causal relationship between reading direction and the SNARC effect (see Experiment 8 in [2] and [34]). While brief exposure to regular or mirror-inverted orthographies can alter time-space associations (i.e., the Mental Time Line, MTL), such exposure does not appear to affect the SNARC effect [34]. This apparent dissociation raises doubts about the impact of reading direction on the SNARC effect, especially given its well-documented susceptibility to short-term priming and training effects [8, 30–33].

Some cultural factors other than reading direction may explain the emergence of the SNARC effect [49] suggesting that engaging in motor activities involving horizontal trajectories can influence SNAs. Building on this idea, Bulut et al. [44] argued that culturally shaped directional preferences, not limited to reading habits, could contribute to the emergence of the SNARC effect (see also [34, 50]). To test this possibility, they compared the SNARC effect among German (LR reading), Turkish (LR reading), and Iranian (RL reading) participants. The results revealed that the SNARC effect was strongest in the German group, moderate in the Turkish group, and weakest in the Iranian group. A similar pattern was observed in the Cultural Directional Preferences Questionnaire, which assessed horizontal directional tendencies in various tasks (e.g., drawing direction, event sequencing, and action depiction). The LR preference followed the same pattern: strongest in the Germans, intermediate in Turks, and weakest in Iranians. These findings suggest that the variation in the strength of the SNARC effect cannot be explained solely by reading direction. Rather, broader cultural directionalities as reflected in the questionnaire results likely contribute to the observed cross-cultural differences. One common feature among the samples described in Table 1 is the presence of mixed horizontal directionalities in their socio-cultural environment, manifesting at varying levels. Languages such as Hebrew, Arabic, and Farsi are characterized by RL text reading alongside LR numeration systems [37, 39, 43]. Although Turkish consistently employs LR directionality for both text and numbers, certain behavioral tendencies, such as drawing preferences or horizontal placement of sequential events, reflect a mixture of LR and RL patterns [44].

In addition to the culturally rooted directional diversity, the participants in the studies listed in Table 1 are primarily university students who speak English as a foreign language and are likely influenced by global cultural elements such as movies and digital technologies, which predominantly follow LR directionality (for an extended discussion, see [44]). Therefore, despite the presence of RL features in their cultural background, they are likely exposed to dominant LR cues in daily life. Such mixed horizontal directional experiences may weaken SNAs in either direction. Inconsistent SNARC findings in these samples could possibly be explained by the stronger presence of culturally ingrained diversity in horizontal mappings, compared to Western samples which more consistently rely on LR directionality. Depending on the context, stimuli, task, or experimental setup, different directional mappings may be activated, resulting in variability in observed SNAs.

This idea aligns with the *Hierarchical Mental Metaphors Theory* (HMMT) of Casasanto [51], which posits that mental metaphors, including those underlying SNAs, are not fixed but rather flexible and modifiable depending on contextual factors, cultural experiences, and language. It is well demonstrated that contextual cues [27–29], priming [8, 32], or even brief periods of task-specific practice [30, 31, 33] can significantly alter the direction of the SNARC effect. From the perspective of HMMT, these findings support the notion that individuals can rapidly adapt to different mental metaphors. Furthermore, within a cultural context, it is plausible that multiple SNA representations coexist across various cognitive and linguistic frameworks. Therefore, varying task demands and experimental protocols may activate different metaphorical mappings, potentially explaining inconsistencies in empirical findings.

To address the inconsistent findings regarding the SNARC effect, it is essential to examine the methodological differences across studies. As shown in Table 1, cross-cultural studies and replication attempts involving diverse samples often vary significantly in design, hindering meaningful comparisons. One key source of this variability concerns statistical power and measurement sensitivity (i.e., the number of trials in the task). Cipora and Wood [52] recommended at least 20 trials and 20 participants per experimental condition (i.e., number x hand) to reliably detect the SNARC effect; however, this threshold is rarely met in the studies summarized in Table 1 (see also Table 1 in Supplementary Material for details on the sample size and number of trials for each study). If the SNARC effect does exist, albeit possibly weaker in size in these non-Western samples due to varying representations in the socio-cultural environment, then a lack of sufficient statistical power and sensitivity may contribute to some of the null effects reported at the group level.

Another important aspect is the task used to investigate the directional SNAs. The SNARC effect is typically investigated using either parity judgment (PJ) or magnitude classification (MC) tasks [5]. In PJ tasks, participants classify centrally presented digits as odd or even; in MC tasks, they judge them as small or large, responding with either the left or right hand. The key distinction is that numerical magnitude is task-relevant in MC but not in PJ. The SNARC effect observed in PJ tasks is typically interpreted as evidence of automatic magnitude processing. However, PJ tasks are susceptible to confounding from linguistic or cultural variables. For example, the PJ task can also trigger a linguistic polarity effect, in which participants respond faster with the left hand to odd numbers and the right to even numbers. This pattern, known as the *Markedness Associations of Response Codes* (MARC) effect [53], may obscure the SNARC effect. Zohar-Shai et al. [42] proposed that the strong MARC effect in Hebrew may overshadow the SNARC effect in PJ, potentially explaining the absence of a SNARC effect with Hebrew participants. The researchers weakened the MARC effect in a two-day session setup for different spatial mapping for parity (press left for odd and right for even instruction on one day, and press right for odd and left for even instruction on another day) and reported a significant SNARC effect. This finding suggests that PJ findings should be interpreted cautiously in cultural comparisons, as parity may involve culture-specific linguistic codes and influence or overshadow the directional SNAs.

Although the SNARC effect is typically examined in a task setup where the stimuli are central and responses are lateral (left and right; see for a review [5]), alternative task configurations have also been employed. For example, lateralized stimuli with central responses [54–56], fully lateralized designs [57, 58], and central stimuli with central responses [41, 59] have all been used. In a particularly relevant study, Fischer and Shaki [41] used a Go/No-go (GNG) task in Hebrew, eliminating spatial attributes from both stimuli and responses. The stimuli were centrally presented digits (1, 2, 8, and 9) alongside objects indicating leftward or rightward movement (e.g., a duck or a car). Participants were instructed to respond according to one of the four possible rules: “If the digit is small/large and if the object is leftward/rightward, press the spacebar”. This led to congruent (small-leftward and large-rightward) and incongruent (small-rightward and large-leftward) blocks. Although the stimuli were presented centrally and there was only a central press key to which participants responded with one hand, a directional SNA from LR was observed; more specifically, participants responded faster in congruent compared to incongruent blocks. These findings suggest that space and numbers were conceptually linked despite no spatial dimension of the stimuli or responses. Taken together, these divergent findings from studies with Hebrew participants suggest that SNAs are sensitive to both task demands, such as parity processing, and experimental configuration, such as the spatial properties of stimuli and responses. Accordingly, whether an SNA is observed in a given cultural group depends critically on the specific task setup employed. Consistent with this view, although standard PJ tasks often fail to elicit a SNARC effect in Hebrew participants [37], alternative paradigms have successfully revealed LR SNAs [41, 42]. This highlights the importance of using a diverse range of tasks when investigating cultural variability in SNAs, as reliance on a single task type may obscure the underlying cognitive mechanisms.

The Present Study

The current study aimed to investigate the presence and directionality of SNAs among Turkish participants. Although Turkish is written in an LR direction and shares orthographic characteristics with Western languages, prior research has often yielded null SNARC effects in this population [31, 33, 46, 47]. The only study to report a significant SNARC effect in a Turkish sample was Bulut et al. [44], which found a weaker group-level effect compared to

German participants. Additionally, other LR-aligned directional tendencies—such as object drawing direction and horizontal event sequencing—also appeared to be attenuated in Turkish participants [44], suggesting that LR directionalities may be weaker in this population than in other LR-reading cultures. One potential explanation for this phenomenon is historical and cultural. Turkish was written in an Arabic-Farsi RL script, commonly referred to as the Ottoman script, for about six centuries (see cultural directional preferences hypothesis in [44]). Although the Latin alphabet has since been consistently adopted, the Ottoman script was used informally for years after the reform [60]. This prolonged exposure to both RL and LR systems may have fostered a more flexible or less consistent spatial mapping framework, shaped by deep-rooted sociocultural practices rather than formal orthographic conventions [50, 61].

Given the inconsistencies in previous findings, the current study sought to determine whether methodological factors—particularly statistical power and measurement sensitivity—contributed to the absence of group-level SNARC effects in Turkish samples. While Bulut et al. [46] involved the largest Turkish sample to date among the studies that found the null effect ($N = 66$), the study lacked sufficient power to detect small effect sizes. Moreover, it fell short of the recommended minimum of 20 repetitions per condition [52], reducing sensitivity. By contrast, Bulut et al. [44], using an online design that met these criteria, reported a significant SNARC effect.

Therefore, we designed the current study as a high-powered, laboratory-based investigation using standard PJ and MC tasks to assess whether increased statistical power and measurement sensitivity would yield a group-level SNARC effect. Importantly, compared to previous SNARC studies conducted with Turkish samples, the present study is the first laboratory-based investigation to meet the recommended number of trials per condition to reliably detect SNARC effects [52], thereby explicitly increasing measurement sensitivity. Based on this rationale, we hypothesized that a significant group-level SNARC effect would emerge in both PJ and MC tasks (Hypotheses 1 and 2, respectively).

In addition to statistical power, task design has been shown to influence the expression of SNAs. Relying solely on standard tasks with centrally presented stimuli and lateralized responses can be misleading when investigating SNAs in culturally diverse populations. Recent models suggest that directional SNAs can emerge during both the early representational and the later response-selection stages [19, 62], emphasizing that the spatial characteristics of both stimuli and responses must be considered carefully. When spatial information is introduced at the response level, as in classic SNARC paradigms with central stimuli and lateralized keypresses, the effect primarily reflects processes at the response-selection stage, where numerical magnitude interacts with motor codes and spatially polarized response mappings [2, 17, 57]. In contrast, when spatial information is embedded at the encoding level, such as when numerical stimuli are presented laterally or cue spatial attention, directional SNAs arise from representational mechanisms rather than motor competition. Empirical studies using lateralized or spatially cued numbers have shown that numerical magnitude can automatically bias perceptual attention [63], enhance processing when stimulus position and magnitude are congruent [56], and even elicit directional mappings with central responses and stimuli [55, 59]. Recent models integrate these perspectives, suggesting that SNAs can manifest at both representational and motor stages, engaging distinct but interacting mechanisms [19, 62].

The use of lateralized stimuli may have particular implications for samples that typically show unstable SNARC effects. For Turkish participants, whose spatial-numerical mappings are often weak or inconsistent, lateralized encoding could act as an external attentional cue that transiently aligns number representation with spatial direction. Observing a directional bias under such conditions would suggest that attentional mechanisms can temporarily stabilize culturally variable SNAs, whereas its absence would indicate genuinely weak representational spatial coding. If previously reported null SNARC effects in Turkish samples stem from cultural influences that interfere with response selection, then presenting stimuli laterally while keeping the response central may reveal SNAs that are otherwise suppressed.

To this end, we developed a novel GNG task setup in which numerical stimuli (small and large numbers) were presented on either the left or right side of the screen, while responses were executed centrally. This design conceptually relates to perceptual paradigms that introduced spatial information through stimulus features, such as the orientation manipulation used by Lammertyn et al. [11]. In their study, a SNARC effect emerged only when participants judged the spatial orientation of the digit (not the color) that engages parietal spatial mechanisms, suggesting that interference of spatial information to numerical processing depends whether there are shared cortical resources. However, because their task still involved lateralized motor responses, it remained unclear whether these effects reflected motor competition or representational spatial coding. By contrast, the present paradigm introduces spatial information through the stimulus position itself and employs a central GNG response, allowing the representational component of SNAs to be examined independently of motor-related spatial mappings. The present GNG paradigm also shares certain structural features with attentional SNARC paradigms that combine lateralized stimuli with central responses [63, 64]. In those studies, number magnitude modulated covert attention, leading to faster detection of left targets after small numbers and right targets after large numbers, an effect interpreted as an attentional manifestation of SNAs. Our task differs in that the numbers themselves are lateralized, and participants classify their magnitude or parity with a central response. This configuration allows us to examine encoding-level representational spatial-numerical mappings. Unlike attentional SNARC paradigms, in which numerical magnitude biases spatial attention toward a subsequently presented location, the present task embeds spatial information directly in the numerical stimulus itself while keeping spatial position task-irrelevant.

In the GNG paradigms, participants were instructed to respond based on either parity (GNG PJ) or magnitude (GNG MC). This design enabled us to categorize trials as congruent (e.g., small numbers on the left, large numbers on the right) or incongruent (e.g., small numbers on the right, large numbers on the left) based on the MNL. We predicted that, if directional SNAs exist at the group level, participants would respond more quickly during congruent trials and more slowly during incongruent trials in both GNG PJ and GNG MC tasks (Hypotheses 3 and 4, respectively).

Finally, we examined the presence of the MARC effect, which reflects polarity-based associations between parity and spatial responses. In the standard PJ task, MARC congruency is observed as faster left-hand responses to odd numbers and right-hand responses to even numbers. We extended this logic to the GNG PJ task by analyzing reaction times based on MARC-congruent (odd numbers on the left, even on the right) versus MARC-incongruent (odd on the right, even on the left) trials.

In summary, the present study was designed to assess the role of methodological features; specifically statistical power, measurement sensitivity, and task configuration in shaping the emergence of SNAs in Turkish participants. By employing both standard and novel task setups across multiple dimensions (magnitude, parity, spatial position), this study aims to clarify the inconsistent findings in the literature and contribute to a more nuanced understanding of the contextual nature of spatial-numerical representations. All hypotheses were preregistered at https://doi.org/10.17605/OSF.IO/YH93J.

Method

This study was pre-registered on the Open Science Framework (OSF: https://osf.io/yh93j) on March 4, 2024. The data was collected between 04/04/2024 and 18/07/2024.

Participants

Participants were Turkish-speaking students from Izmir University of Economics who took part in the study voluntarily. Participation was compensated with course credit. All participants provided written informed consent and had normal or corrected-to-normal vision. Handedness was assessed via the Edinburgh Handedness Inventory [65]. The study was approved by the Ethics Committee of İzmir University of Economics and was conducted in accordance with the Declaration of Helsinki (approval number: B.30.2.İEÜ.0.05.05-020-343).

PJ and MC

The sample sizes were determined based on a priori power analysis (see pre-registration: https://doi.org/10.17605/OSF.IO/YH93J), which indicated that 83 participants for the PJ task and 97 participants for the MC task would provide high power in a two-sided one-sample *t*-test ($1-\beta = .95$, $\alpha = 0.05$) using R package 'pwr' [66] to detect the effects observed by Bulut et al. [44] ($d = 0.40$ for PJ and $d = 0.37$ for MC). These target sample sizes were slightly exceeded to ensure sufficient statistical power after potential data exclusion.

Initially, 92 volunteers participated in the PJ, and 106 in the MC tasks. The datasets of three participants (two in PJ, one in MC) were excluded from the analysis because fewer than 75% of their trials remained valid after response time filtering and removal of incorrect trials (see the *Data Preparation* section below for further details). Consequently, data from 90 participants (62 females and 28 males, $M_{\text{age}} = 20.79$ years, $SD_{\text{age}} = 3.71$ years) in the PJ task and 105 participants (64 females and 41 males, $M_{\text{age}} = 20.89$ years, $SD_{\text{age}} = 2.08$ years) in the MC task were included in the analysis. Handedness assessment indicated ten left-handed and six ambidextrous participants in the PJ task, and four left-handed and four ambidextrous participants in the MC task; the remaining participants were right-handed. Although the sample showed a gender imbalance, previous evidence indicates that gender does not systematically influence SNAs (see Supplementary Materials in [3]). Therefore, this imbalance is unlikely to have affected the present results.

GNG PJ and GNG MC

A priori power analysis for a medium effect size ($f = .25$) in a two-sided 2 x 2 repeated measures ANOVA (magnitude x spatial position of the stimuli) determined that 56 participants would be sufficient to achieve high power ($1\text{-}\beta = .95$, $\alpha = 0.05$) using G*Power 3.1 (see pre-registration: https://doi.org/10.17605/OSF.IO/YH93J). The target sample sizes were increased to 66 for each task to account for potential data loss due to outlier exclusion. Since all participants' valid data was above 75%, none were excluded from the analysis (see Data Preparation section below for further details). Sixty-six volunteers participated in the GNG PJ task (54 females and 12 males, $M_{\text{age}} = 22.24$, $SD_{\text{age}} = 3.78$). Sixty-six volunteers participated in the GNG MC task (49 females and 17 males, $M_{\text{age}} = 21.30$ years, $SD_{\text{age}} = 1.06$ years). Handedness assessment indicated that in the GNG PJ task, seven participants were left-handed and five were ambidextrous, whereas in the GNG MC task, three participants were left-handed and two were ambidextrous; the remaining participants were right-handed.

Stimuli and Apparatus

The stimuli and apparatus were used as they were pre-registered for all tasks. In the PJ and MC tasks, the stimulus set consisted of Arabic numbers ranging from 1 to 9, except 5, and each number was centrally positioned. The "A" (the leftmost letter) and "İ" (the rightmost letter) keys of a standard Turkish QWERTY keyboard served as response keys for left- and right-hand responses. In the GNG tasks, the stimulus set consisted of the numbers 1, 2, 8, and 9. Stimuli were positioned 6° from the center of the screen (either right or left). Left or right presentation of numbers produced congruent (i.e., when a small number was presented on the left side or a large number on the right side) and incongruent trials (i.e., when a small number was presented on the right side or a large number on the left side) in the task. A single-response setup was created utilizing the centrally located “N” key on a standard Turkish QWERTY keyboard. Participants were instructed to respond by pressing the index finger of their dominant hand on the “N” key or withholding it.

In the PJ and MC tasks, numbers smaller than 5 (i.e., 1, 2, 3, and 4) were categorized as small, and numbers larger than 5 (i.e., 6, 7, 8, and 9) were categorized as large. In the GNG tasks, numbers 1 and 2 were categorized as small, and 8 and 9 as large, which is a common practice in studies employing the GNG paradigm [55]. All stimuli were displayed in Courier New font at a size of 55 pt, in black color on a gray background (RGB: 219, 219, 219). The stimuli were presented, and responses were recorded using SuperLab 6.0 software (Cedrus Corp.) on a computer connected to a 20" LCD monitor with a resolution of 1600 x 900 pixels and a refresh rate of 60 Hz.

Procedure

During the pre-registration phase, we initially designed the study as four different experiments, one for each task. However, before data collection, we opted to randomly assign the participants to one of the four tasks instead of conducting separate experiments. In addition, participants were asked to complete a brief, non-computerized object placement task (OPT) immediately following the computerized task; this task was also not included in the pre-registration.

During the OPT, participants sat at a table with a cardboard featuring four horizontally aligned indentations (see Figure 1 in the Supplementary Material). They were given a bowl containing four ping pong balls and instructed to place the balls into the indentations in any order they preferred. No instructions were given regarding which hand to use. The researcher then recorded each participant’s directional placement preference: *LR* if they placed the balls from LR, *RL* if they placed the balls from RL, and *Mixed* if their pattern did not fit either of the first two categories.

The rest of the procedure followed the pre-registered protocol. Upon arrival at the laboratory, participants signed the informed consent form. During the computerized tasks, they were seated approximately 60 cm from the computer monitor.

PJ and MC

Each number was randomly presented 40 times in each task, resulting in a total of 320 trials. Each task had two blocks, comprising half of the trials (i.e., 20 x 8 numbers = 160 trials). There was a 30-second break in between the blocks. Each stimulus was preceded by a black square (9.4 mm x 9.4 mm) serving as a fixation point for 300 ms. The stimuli remained on the screen until the participant responded. After the response, a blank gray screen appeared for 500 ms. No feedback was provided during the test blocks. The experimental flow of PJ and MC tasks is shown in Figure 1.

The order of the blocks was counterbalanced across participants. In the PJ task, the response-key assignment alternated between blocks: in one block, participants pressed the "A" key for odd numbers and the "İ" key for even numbers; in the other block, this assignment was reversed. Similarly, in the MC task, participants pressed the "A" key for small numbers and the "İ" key for large numbers in one block, with the number 5 serving as the reference point. In the other block, this assignment was also reversed. Before each block, participants completed an 8-trial practice session (one trial per number) with accuracy feedback to familiarize them with the task and the response-key assignments. A 30-second break was provided between the two blocks of each task.

GNG PJ and GNG MC

Each number was randomly presented 80 times, yielding 320 trials in each task. Each task had two blocks, comprising half of the trials (i.e., 40 x 4 numbers =160 trials). In half of the trials, numbers were positioned on the left side of the screen, and in the other half, they were on the right. Each task consisted of 50% go and 50% no-go trials. At the onset of each trial, a black square (9.4 mm x 9.4 mm) was displayed for 1000 ms, serving as a fixation point. Until a response was given or 500 ms had elapsed, the number stimuli was presented on the screen's left or right side. A blank screen was then presented for 500 ms, during which the participant could still respond, allowing a total response window of 1000 ms. No feedback was provided during the test blocks. The experimental flow of GNG tasks is shown in Figure 2.

Participants were instructed to respond by pressing the index finger of their dominant hand on the “N” key or by withholding their response. In the GNG PJ task, participants classified numbers as odd or even. In one block, even numbers (2, 8) served as go-stimuli and odd numbers (1, 9) as no-go stimuli, while in the other block, this was reversed. In the GNG MC task, participants were asked to respond according to whether the presented numbers were smaller or larger than 5. Both small (1, 2) and large (8, 9) numbers were presented in each block. The rule for responding changed between blocks: participants responded to small numbers and withheld responses to large numbers in one block, and this rule was reversed in the other block. There was a 30-second break between blocks. The order of the blocks was counterbalanced across participants. At the beginning of each block, an 8-trial (4 numbers x 2 spatial positions on the screen) practice session was completed. During the practice trials, participants were given feedback for correct and incorrect responses.

Figure 1

The Experimental Flow in PJ and MC Experiments

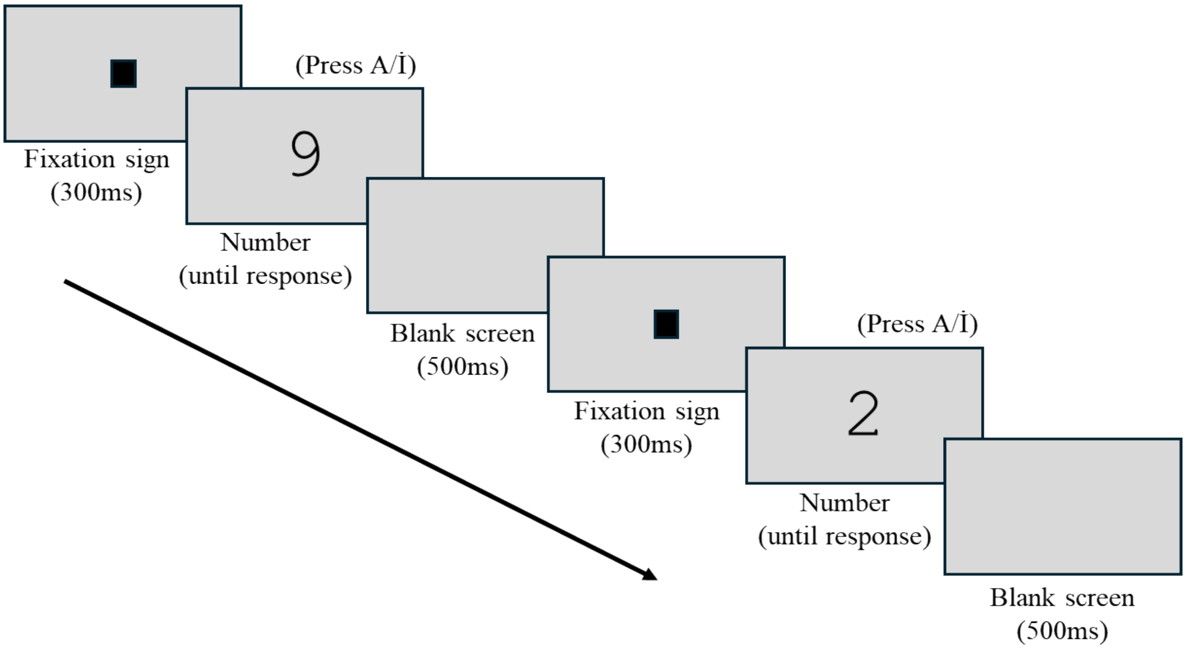
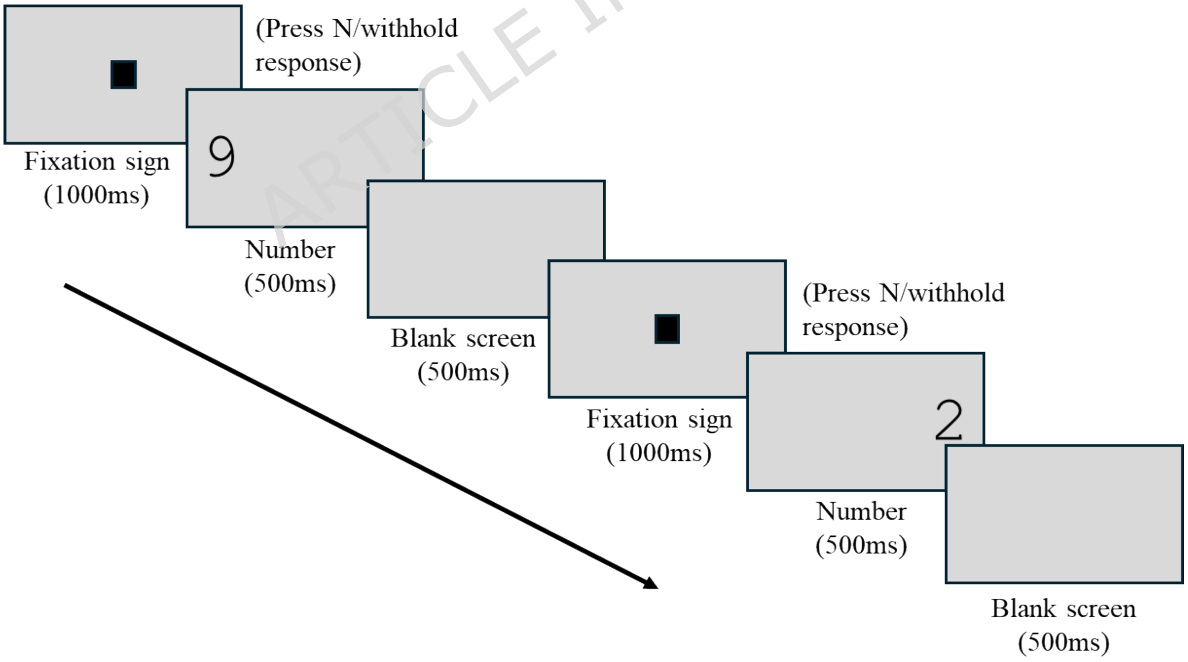


Figure 2

The Experimental Flow in GNG Tasks Experiments



Data Preparation

We followed the pre-registered protocol in all steps of the data preparation. Only experimental trials were analyzed.

PJ and MC

Incorrect trials (3.79% in PJ and 2.88% in MC) were removed from the RT analysis. Moreover, RTs that were not between 200 ms and 1500 ms were discarded (1.77% in PJ and 1.38% in MC). Finally, RTs that were outside ±2.5 SD from the individual mean RT were excluded from the analysis (3.15% in PJ and 3.10% in MC). At the end of this protocol, the number of remaining valid trials was below 75% for two participants in PJ and one participant in MC. Data from these participants were excluded, leaving data from 90 participants in PJ and 105 participants in MC for further analysis. Consequently, 91.29% of the data in PJ and 92.64% of the data in MC were retained for further analysis.

GNG PJ and GNG MC

Incorrect trials were removed from the RT analysis (1.57% in GNG PJ and 1.20% in GNG MC). RTs below 150 ms were discarded (0.01% in GNG PJ, none in GNG MC). Lastly, RTs falling beyond ±2.5 SD from the mean individual RT were excluded (2.24% in GNG PJ and 2.26% in GNG MC). After this filtering process, the number of participants in the remaining valid trials was above 75%, so no participants were excluded from the analysis. As a result, 96.19% of the data in GNG PJ and 96.53% of the data in GNG MC were retained for further analysis.

Data Analysis

A significance level of $\alpha = .05$ and two-sided tests were applied for all statistical tests. Bonferroni correction was applied to all post-hoc tests. We reported the corresponding Bayes factor after each frequentist *t*-test or follow-up comparison finding to differentiate evidence of the absence of an effect from the absence of evidence for an effect. The default r-scale of

0.707 as an uninformed prior in the Cauchy distribution was used. We did not pre-register for how to interpret the Bayes factor. We followed Dienes' [67] recommendations: a BF_{10} above 3 or 10 is considered moderate or strong evidence for the alternative hypothesis, and a BF_{10} below 1/3 or 1/10 is considered moderate or strong evidence for the null hypothesis. BF_{10} between 1/3 and 3 is regarded as an inconclusive finding.

Pre-registered analyses

PJ and MC. The SNARC effect in PJ and MC tasks was first examined using a repeated-measures regression approach [7]. For PJ, the difference in RTs (dRTs) between left- and right-hand responses (calculated as $dRT = RT_{right\ hand} - RT_{left\ hand}$) was regressed on two predictors: number magnitude (i.e., with the values 1, 2, 3, 4, 6, 7, 8, and 9) and number parity (contrast-coded as -0.5 for odd and +0.5 for even numbers). For MC, dRTs were regressed only on magnitude. The number magnitude was defined as a categorical predictor (i.e., 1, 2, 3, and 4 were categorized as small and contrast coded with -0.5; 6, 7, 8, and 9 were categorized as large and contrast coded with 0.5; see [5, 17].

These regressions' resulting slopes from number magnitude and number parity slopes were used to quantify the SNARC and MARC effects, respectively. A negative slope for magnitude indicates a SNARC effect, while a negative slope for parity indicates a MARC effect. Positive slopes for either predictor reflect reverse effects. The absolute values of the slopes represent the strength of these effects. The slopes were compared against zero using a one-sample *t*-test to examine the SNARC effect in both tasks (Hypotheses 1 and 2) and the MARC effect in PJ. The potential effects of the block order on the SNARC effect were examined using an independent-sample *t*-test on the SNARC slopes. Block order was included as a between-subject factor to control for possible short-term practice effects, as prior studies have shown that recent stimulus-response mappings can transiently influence subsequent performance [30, 31, 33].

Additionally, to have more comparable findings with GNG tasks, we performed a mixed-design ANOVA on RTs for numbers 1, 2, 8, and 9. RTs were examined based on magnitude (small vs. large) x parity (odd vs. even) x response side (left vs. right) x block order (odd-left, even-right first vs. odd-right, even-left first) for PJ and magnitude (small vs. large) x response side (left vs. right) x block order (small-left, large-right first vs. small-right, large-left first) for MC. The block order was between-participants, and other variables were within-participant variables. Both tasks interpret the magnitude x response side interaction as the SNARC effect.

GNG PJ and GNG MC. In the GNG PJ task, a mixed-design ANOVA was performed on RTs, examining the effects of magnitude (small vs. large), parity (odd vs. even), the spatial position of the stimuli (left vs. right) as within-participants variables, and block order (press odd then press even vs. press even then press odd) as a between-participants variable. Similarly, in the GNG MC task, a mixed-design ANOVA was used to explore the effects of magnitude (small vs. large), the spatial position of the stimuli (left vs. right) as within-participants variables, and block order (odd-then-even vs. even-then-odd) as a between-participants variable. In both tasks, the magnitude x spatial position interaction was interpreted as the presence of a directional SNA. Faster responses for small numbers on the left side and large numbers on the right side would indicate an LR SNA. In comparison, faster responses for small numbers presented on the right and large numbers on the left would indicate an RL SNA.

To test hypotheses 3 and 4, the trials were merged as congruent (small numbers-left responses/positions and large numbers-right responses/positions) and incongruent (small numbers-right responses/positions and large numbers-left responses/positions). The congruency of the trial was compared by using a paired samples *t*-test for both tasks.

Non-registered analyses

Comparing the Task Setups: Standard versus GNG. For both PJ and MC tasks, we compared the task setups to examine whether the two different configurations—standard (with two lateral response keys and centrally presented stimuli) and GNG (with a central response key and laterally presented stimuli)—influence directional SNAs. To this end, trials in all tasks were categorized as congruent (small numbers–left responses/positions; large numbers–right responses/positions) or incongruent (small numbers–right responses/positions; large numbers–left responses/positions). Mixed ANOVAs with task setup (standard vs. GNG) as between-participant and congruency (congruent vs. incongruent) as within-participant factors were conducted on participants' RTs, separately for parity and magnitude.

Comparing Task Demands: Parity versus Magnitude. In each task setup, we also aimed to determine whether parity or magnitude processing elicits stronger directional SNAs. For the standard task setups, we compared PJ and MC slopes to assess whether the SNARC effect was more prominent in either task. In the main analysis, MC slopes were calculated using a categorical predictor. However, because categorical predictors typically yield larger slopes, we additionally computed MC SNARC slopes using a continuous predictor (i.e., number magnitude), as was done for PJ, to ensure comparability across tasks. Slopes were compared with an independent samples t-test. For the GNG task setup, we conducted a mixed ANOVA with task demand (parity vs. magnitude) as a between-participant factor and congruency (congruent vs. incongruent) as a within-participant measure, to examine whether the congruency effect varied as a function of task demand.

OPT. For the standard task setups—PJ and MC, participants with LR or RL preferences were compared in terms of their SNARC slopes using an independent-sample *t*-test. For the MC task, slopes were extracted from the continuous predictor analysis described earlier to ensure comparability with the PJ slopes.

Results

PJ and MC

The results of the one-sample *t*-test analyses used to examine the SNARC and MARC effects in the PJ and MC tasks are summarized in Table 2. In the PJ task, a reverse SNARC effect was found at the group level, as indicated by a significant positive slope. Note that the Bayesian *t*-test showed inconclusive evidence. Also, there was no significant MARC effect in the PJ task. Furthermore, no significant SNARC effect was observed in MC. Bayesian *t*-tests provided moderate evidence for the null hypothesis of the SNARC effect in MC and the MARC effect in PJ. The SNARC slopes for PJ and MC are depicted in Figure 3 (see also Table 2 in Supplementary Material for the individual prevalence of the SNARC effect in PJ and MC).

The independent samples *t*-test findings for block order on the SNARC slopes showed that there was no significant block order in PJ, $t(78.94) = -0.54$, $p = .59$, $BF_{10} = 0.25$. On the other hand, there was a significant block order effect in MC, $t(100.72) = 2.42$, $p = 0.02$, $BF_{10} = 2.71$. The mean SNARC slope was smaller in the SNARC-incongruent-first order ($M = -13.92$, $SE = 10.50$) compared to the SNARC-congruent-first order ($M = 24.72$, $SE = 12.10$).

Table 2

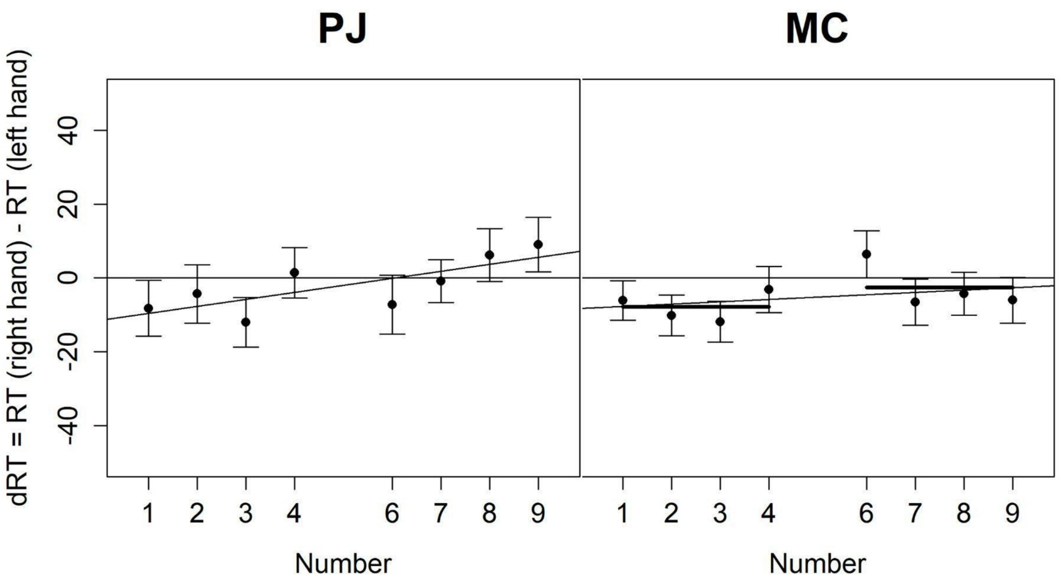
The SNARC and MARC effects

Task	Measure	Mean Slope (*SD*)	*t**	*df*	*p*	BF_{10}
PJ	SNARC	1.90 *(7.57)*	2.39	89	**.02**	1.70
PJ	MARC	2.03 *(91.93)*	0.21	89	.83	0.12
MC	SNARC	5.21 *(83.68)*	0.64	104	.52	0.13

*All tests were against zero.

Figure 3

The SNARC slopes in PJ and MC



A repeated-measures ANOVA, using only the numbers 1, 2, 8, and 9, to investigate the SNARC effect in PJ, showed that the main effect of magnitude was significant, $F(1, 88) = 21.51$, $p < .001$, $\eta_p^2 = .196$, $\mathrm{BF}_{10} = 1000.52$. Responses to small numbers (*M* = 599, *SE* = 4.18) were faster than responses to large numbers (*M* = 615, *SE* = 4.59). There was also a significant main effect of parity, with faster responses for even numbers (*M* = 599, *SE* = 4.32) compared to odd numbers (*M* = 615, *SE* = 4.46), $F(1, 88) = 18.23$, $p < .001$, $\eta_p^2 = .172$, $\mathrm{BF}_{10} = 62.44$. The magnitude and response side interaction was significant, $F(1, 88) = 5.11$, $p = .03$, $\eta_p^2 = .055$. The simple effect analysis revealed that there was no significant difference between small (*M* = 603, *SE* = 6.17) and large (*M* = 611, *SE* = 6.25) numbers of RT for left-hand responses, $F(1, 89) = 2.84$, $p = .19$, $\mathrm{BF}_{10} = 0.44$. On the other hand, responses to small numbers (*M* = 596, *SE* = 5.65) were faster than responses to large numbers (*M* = 618, *SE* = 6.74) when responding with the right hand, $F(1, 89) = 22.05$, $p < .001$, $\mathrm{BF}_{10} = 644.57$. These findings indicate that the reverse SNARC pattern was only present for the right-hand responses (Figure 4). Furthermore, the interaction between magnitude and parity was significant, $F(1, 88) = 44.26$, $p < .001$, $\eta_p^2 = .335$. The simple effect analysis revealed that there was no significant difference between odd (*M* = 596, *SE* = 5.71) and even (*M* = 603, *SE*

= 6.11) for small numbers (i.e., 1 and 2), *F*(1, 89) = 2.55, *p* = .23, BF_{10} = 0.18. On the other hand, responses to even numbers (*M* = 595, *SE* = 6.13) were faster than responses to odd ones (*M* = 634, *SE* = 6.56) for large numbers (i.e., 8 and 9), *F*(1, 89) = 54.60, *p* < .001, $BF_{10} = 9.38 \times 10^7$. The three-way interaction of block order, parity, and response side was significant, *F*(1, 88) = 9.47, *p* = .003, η_p^2 = .097. The simple effect analysis showed that when participants received the MARC-incongruent block first, the main effect of parity was significant, indicating that responses to even numbers (*M* = 592, *SE* = 5.83) were faster than odd numbers (*M* = 611, *SE* = 6.31), *F*(1, 45) = 17.10, *p* < .001, BF_{10} = 36.20. The parity and response side interaction was also significant for the same group, *F*(1, 45) = 5.74, *p* = .04. Follow-up analysis broke down this interaction and revealed no difference between odd (*M* = 604, *SE* = 8.59) and even (*M* = 600, *SE* = 8.52) for left responses, *F*(1, 45) = 0.24, *p* < .63, BF_{10} = 0.13. On the other hand, responses to even numbers (*M* = 584, *SE* = 7.90) were faster than odd numbers (*M* = 618, *SE* = 9.24) with the right responses. When participants received the MARC-congruent block first, none of the effects were significant, *F*’s < 4.37, *p*’s > .05. None of the other effects from the main analysis reached significance, *F*’s < 1.00, *p*’s > .05 (for results including all numbers see Supplementary Material Table 3 and Figure 2 for PJ; Table 4 and Figure 3 for MC).

A repeated-measures ANOVA, using only the numbers 1, 2, 8, and 9, to investigate the SNARC effect in MC, showed that the only significant effect was the main effect of response side, *F*(1, 103) = 6.81, *p* = .01, η_p^2 = .062, BF_{10} = 1.74, showing that right-side responses (*M* = 547, *SE* = 4.77) were faster than left-side responses (*M* = 554, *SE* = 4.88). Other main and interaction effects did not reach a significance level, *F*’s < 3.20, *p*’s > .05, suggesting that there was no SNARC effect (Figure 4).

GNG PJ and GNG MC

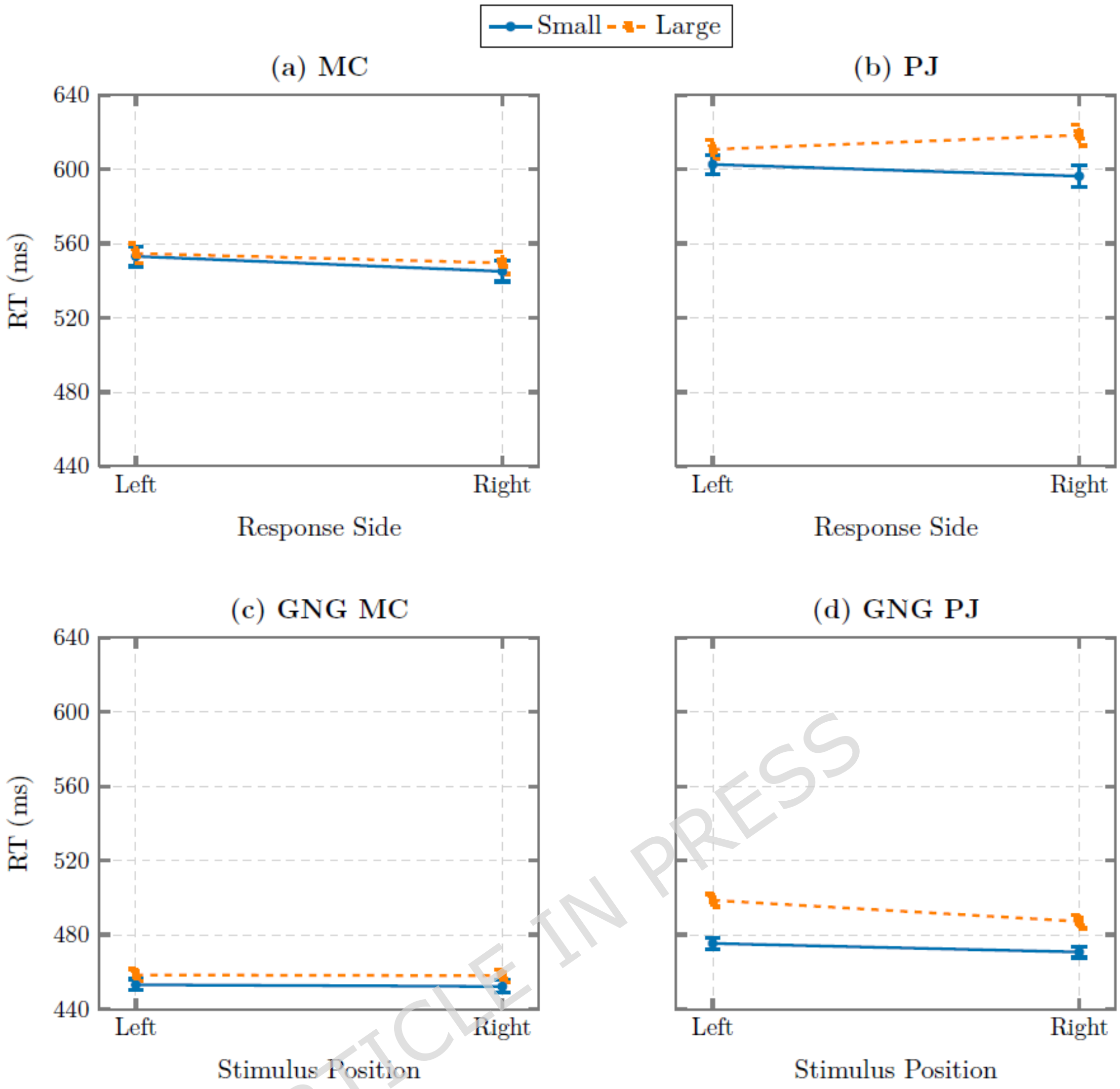
Omission and commission error rates in the GNG tasks are provided in Supplementary Material Table 5. A mixed-design ANOVA, to investigate the directional SNAs in GNG PJ, revealed that there was a significant main effect of magnitude, $F(1, 64) = 72.96$, $p < .001$, $\eta_p^2 = .533$, $BF_{10} = 7.16 \times 10^{11}$, showing that responses to small numbers ($M = 473$, $SE = 2.92$) were faster than large numbers ($M = 493$, $SE = 3.11$). There was also a significant main effect of parity, $F(1, 64) = 17.19$, $p < .001$, $\eta_p^2 = .212$, $BF_{10} = 2.55 \times 10^3$, showing that responses to even numbers ($M = 477$, $SE = 2.83$) were faster than odd numbers ($M = 489$, $SE = 3.26$). The main effect of the spatial position of the stimuli was also significant, $F(1, 64) = 18.00$, $p < .001$, $\eta_p^2 = .219$, $BF_{10} = 1.89 \times 10^3$, indicating that responses to stimuli presented on the right side ($M = 479$, $SE = 3.06$) were faster than those to stimuli presented on the left side ($M = 487$, $SE = 3.08$). The interaction effect of magnitude and parity was significant, $F(1, 64) = 37.65$, $p < .001$, $\eta_p^2 = .37$. Simple effect analysis showed that there was no significant difference between odd ($M = 470$, $SE = 4.17$) and even ($M = 476$, $SE = 4.09$) numbers for small magnitude (i.e., 1 and 2), $F(1, 65) = 1.53$, $p = .22$, $\eta_p^2 = .023$, $BF_{10} = .32$. On the other hand, responses to even numbers ($M = 478$, $SE = 3.93$) were faster than odd numbers ($M = 508$, $SE = 5.48$) for large magnitude (i.e., 8 and 9), $F(1, 65) = 57.58$, $p < .001$, $\eta_p^2 = .470$, $BF_{10} = 1.15 \times 10^{12}$. Importantly, the interaction between magnitude and stimulus position was significant, $F(1, 64) = 4.67$, $p = .03$, $\eta_p^2 = 068$. The simple effect analysis revealed that there was no significant difference between left ($M = 475$, $SE = 4.22$) or right-side presentation ($M = 471$, $SE = 4.04$) for small numbers, $F(1, 65) = 4.86$, $p = .06$, $\eta_p^2 = .070$, $BF_{10} = 1.01$. On the other hand, responses to large numbers were faster when presented on the right ($M = 487$, $SE = 4.49$) compared to the left side ($M = 499$, $SE = 4.27$), $F(1, 65) = 17.10$, $p < .001$, $\eta_p^2 = .209$, $BF_{10} = 304.31$ (Figure 4). The parity and spatial position of the number interaction did not reach significance ($F(1, 64) = 0.99$, $p = .32$), indicating that there was no MARC-congruency effect. The other main and interaction effects did not reach statistical significance, F's < 2.19, p's $> .05$.

Direct comparison of congruent trials with the incongruent ones with a paired-samples *t*-test showed that responses to congruent trials (*M* = 481, *SE* = 1.22) were significantly faster than responses to incongruent trials (*M* = 484, *SE* = 1.22), *t*(65) = -2.11, *p* = .04, BF_{10} = 1.08, suggesting LR SNAs in GNG PJ.

A mixed-design ANOVA, to investigate the directional SNAs in GNG MC, revealed that the main effect of magnitude was significant, *F*(1, 64) = 6.61, *p* = .01, η_p^2 = .094, BF_{10} = 4.61, indicating that responses to small numbers (*M* = 453, *SE* = 4.04) were faster than large numbers (*M* = 458, *SE* = 4.24). There was also a significant interaction of block order and magnitude, *F*(1, 64) = 13.68, *p* < .001, η_p^2 = .176. The simple effect analysis revealed that when “press the large” instruction was the first block, there was no significant difference between small (*M* = 455, *SE* = 6.19) and large (*M* = 452, *SE* = 5.62) numbers’ RT, *F*(1, 32) = 0.79, *p* = .38, η_p^2 = .024, BF_{10} = 0.22. On the other hand, when “press the small” instruction was the first block, responses to small numbers (*M* = 451, *SE* = 5.22) were faster than responses to large numbers (*M* = 464, *SE* = 6.31), *F*(1, 32) = 16.56, *p* < .001, η_p^2 = .341, BF_{10} = 2.99×10^3. The other main and interaction effects did not reach a significance level, *F*’s < 0.22, *p*’s > .05, suggesting that there were no directional SNAs (Figure 4).

Figure 4

Interaction effects of magnitude and spatial factors on RTs across tasks



Note. Panels (a) and (b) illustrate the magnitude (small vs. large) x response side (left vs. right) interaction effects on RTs in the MC and PJ tasks, while panels (c) and (d) show the magnitude x stimulus position (left vs. right) response side (left vs. right) interaction effects on RTs in the GNG MC and GNG PJ tasks. Error bars represent 95% CIs adjusted for repeated measures.

Direct comparison of congruent trials with the incongruent ones with a paired-samples t-test showed that RTs of congruent trials (*M* = 455, *SE* = 1.20) were similar to incongruent trials (*M* = 455, *SE* = 1.19), *t*(65) = 0.13, *p* = .89, BF_{10} = 0.14, suggesting no directional SNAs in GNG MC.

Comparing Task Setups: Standard versus GNG

For parity, mixed ANOVA revealed that the task setup had a main effect, indicating that RTs were faster in GNG PJ (*M* = 483, *SE* = 3.66) compared to PJ (*M* = 607, *SE* = 5.23), *F*(1, 154) = 169.22, $p < .001$, $\eta_p^2 = .524$, $BF_{10} = 5.70 \times 10^{46}$. The main effect of congruency, on the other hand, had no significant effect, *F*(1, 154) = 0.90, *p* = .34, $\eta_p^2 = .006$. The interaction effect of task and congruency was statistically significant, *F*(1, 154) = 7.30, *p* = .008, $\eta_p^2 = .045$. Although effects were insignificant after the correction, the simple effect analysis showed that responses to congruent trials (*M* = 481, *SE* = 5.31) were faster than responses to incongruent trials (*M* = 485, *SE* = 5.07) in GNG PJ task (*F*(1, 65) = 4.47, *p* = .08, $\eta_p^2 = .064$, $BF_{10} = 1.36$) and responses to incongruent trials (*M* = 604, *SE* = 7.00) were faster than responses to congruent ones (*M* = 610, *SE* = 7.79) in PJ (*F*(1, 89) = 5.21, *p* = .05, $\eta_p^2 = .055$, $BF_{10} = 1.08$), demonstrating the exact opposite pattern for different task setups (Figure 5).

For magnitude, mixed ANOVA revealed that only task setup had a significant main effect, indicating that RTs were faster in GNG MC (*M* = 455, *SE* = 4.00) compared to MC (*M* = 551, *SE* = 4.64), *F*(1, 169) = 111.30, $p < .001$, $\eta_p^2 = .397$, $BF_{10} = 1.50 \times 10^{33}$. Other effects did not reach statistical significance, *F*'s < 0.08, *p*'s > .05 (Figure 5).

Comparing Task Demands: Parity versus Magnitude

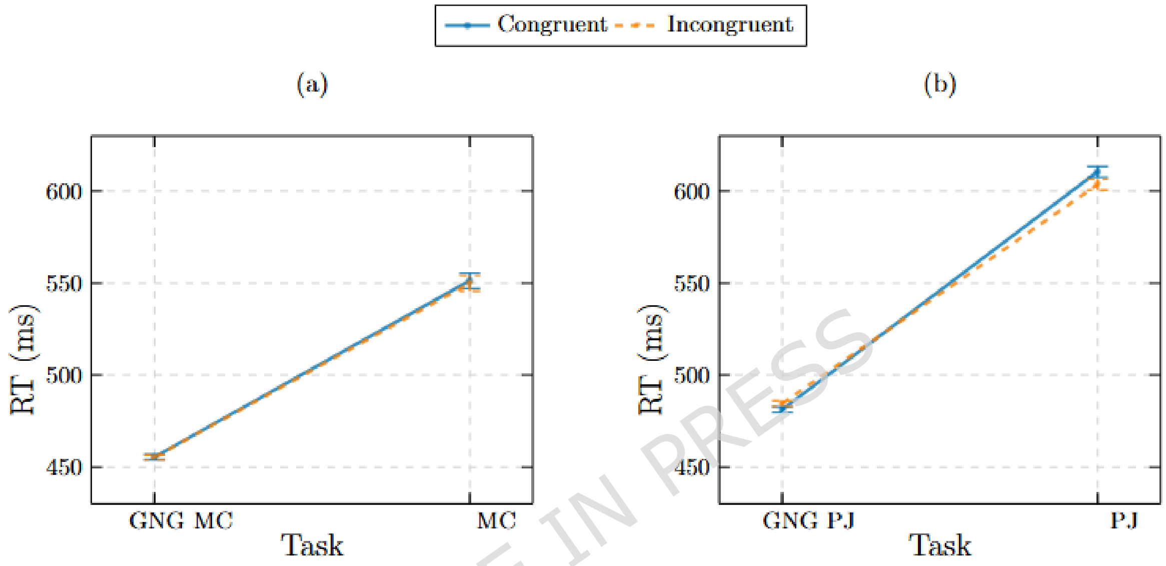
There was no significant difference between the PJ (*M* = 1.90, *SE* = 0.80) and MC slopes (*M* = 0.64, *SE* = 1.37), *t*(164.11) = 0.80, *p* = .43, $BF_{10} = 0.21$, showing that the SNARC effect was similar across two task demands in the standard task setup.

For GNG tasks, mixed ANOVA revealed that the only significant effect was the main effect of task demand, *F*(1, 130) = 13.08, $p < .001$, $\eta_p^2 = .091$, $BF_{10} = 58.95$, indicating that participants responded faster in the GNG MC (*M* = 455, *SE* = 5.63) compared to GNG PJ (*M*

= 483, *SE* = 5.13). Other effects did not reach significance, *F*'s < 2.68, *p* > .05, showing that the congruency effect was similar across the two task demands in the GNG task setup.

Figure 5

Mean RTs for congruent and incongruent trials in GNG MC vs. MC (a) and GNG PJ vs. PJ (b)



Note. Panel (a) shows RTs in the magnitude comparison task for GNG MC and MC. Panel (b) displays RTs in the parity judgment task for GNG PJ and PJ. Error bars represent 95% CIs adjusted for repeated measures.

OPT

For the standard task versions ninety-four (48.21%) of the participants had LR and 28 (14.36%) of them had RL preference in the OPT (for detailed descriptive statistics, see Supplementary Material Table 6). An independent sample *t*-test showed that there was a significant difference between these two groups of participants on their SNARC slope, $t(36.67) = -2.24$, $p = .03$, $BF_{10} = 4.19$. Participants who had an RL preference had larger

SNARC slopes (*M* = 5.78, *SE* = 2.51) compared to participants who had an LR preference (*M* = -0.29, *SE* = 1.03).

For the GNG task versions, detailed descriptive statistics of congruency effects are provided separately for the LR, RL, and Mixed preferences in Supplementary Material Table 8. No further analyses were performed due to unequal group sizes across OPT directions. To ensure that potential differences between task setups were not driven by uneven distribution of OPT performance, we compared the frequency of LR, RL, and Mixed preferences across tasks (for detailed results, see Supplementary Material Table 7).

Discussion

This study aimed to determine whether methodological variations, specifically statistical power, measurement sensitivity, and task setup, could account for the inconsistent SNA findings previously reported in Turkish samples. To this end, we examined the directional SNAs using high-powered designs with increased measurement sensitivity, employing two task demands (parity judgment vs. magnitude classification) and two task setups (standard setup: centrally presented stimuli with lateralized responses; and GNG setup: lateralized stimuli with central responses).

At the group level, a weak reverse SNARC effect emerged in the PJ task, while the GNG PJ task elicited a weak LR SNA. No significant directional SNA patterns were observed in the MC tasks. Importantly, the comparison of task setups revealed contrasting response patterns for the PJ task: an RL pattern in the standard setup and an LR pattern in the GNG setup. Such divergence was absent in the MC tasks. These findings highlight the critical role of task setup and cognitive demand in shaping group-level SNA effects. Furthermore, a novel GNG paradigm successfully captured an LR SNA, suggesting it as a promising tool for future SNA investigations.

In prior research with Turkish samples, the PJ task often yielded a null group-level SNARC effect [31, 33, 46]. In contrast, Bulut et al. [44] reported a reliable SNARC effect. A central question in the current study was whether these discrepancies stem from insufficient power or inadequate measurement sensitivity. Despite our explicit effort to enhance both, the anticipated SNARC pattern did not emerge. Instead, a reverse SNARC effect was observed in the PJ task, opposite to Bulut et al. [44]. However, it is important to note that this reverse SNARC effect was small in magnitude and supported only by inconclusive Bayesian evidence, requiring cautious interpretation. For the MC task, contrary to Bulut et al. [44], findings replicated Dural's [47] null results, despite a substantially larger sample and increased trial count. These findings fail to support Hypotheses 1 and 2 (i.e., that a significant group-level SNARC effect would emerge in both the PJ and MC tasks) suggesting that increased power and sensitivity alone do not resolve the inconsistencies in SNARC findings among Turkish participants. Rather, task-specific factors may exert a stronger influence.

While previous studies with Turkish participants relied exclusively on the standard task setup [44, 46, 47], the present study adopted a broader approach by examining whether specific task setups influence the spatial processing of numbers. Therefore, we implemented the PJ and MC tasks within a GNG paradigm. In the GNG PJ task, participants responded faster to large numbers presented on the right, consistent with LR alignment. In contrast, RTs for small numbers were similar for left and right-side presentations, suggesting an asymmetrical effect. A similarly asymmetrical but reversed pattern appeared in the standard PJ task, where faster left-hand responses to large numbers drove the RL pattern (see Figure 4). One potential mechanism underlying the asymmetrical effect observed in both task setups is the *numerical size effect*—the tendency for smaller magnitudes to be processed more easily than larger ones, resulting in faster RTs for smaller numbers [68]. Because this effect is prominent across both hands (in PJ) and presentation sides (in GNG PJ), the generally fast RTs for small numbers may overshadow any additional effects. As a result, asymmetries become more apparent. This interpretation is consistent with previous findings showing that the SNARC effect tends to be stronger at slower RTs. When responses are generally fast, spatial-numerical compatibility effects may remain weak, whereas they become more pronounced as RTs increase (e.g., [3, 17]).

Although the LR SNA pattern observed in the GNG PJ task was weak and asymmetrical—being driven primarily by faster responses to large numbers on the right, without a corresponding advantage for small numbers on the left—it represents the first such effect observed using a non-standard task setup in a Turkish sample. A direct comparison of congruent and incongruent trials in the GNG PJ task supported Hypothesis 3, which predicted that directional SNAs would emerge in the GNG PJ task, with faster responses for congruent than incongruent trials. In contrast, the GNG MC task did not show significant SNAs, providing no support for Hypothesis 4, which predicted a similar congruency effect in the GNG MC task.

The PJ and MC tasks are the most frequently used methods to study directional SNAs. While MC entails explicit magnitude processing, PJ does not; both reliably evoke SNARC effects (see [5] for a meta-analysis). This suggests that magnitude processing in PJ is automatic [69]. Although MC is often assumed to elicit stronger SNARC effects due to its direct processing nature, faster RTs in MC may reduce the observable SNARC effect [70], which tends to be more robust in slower responses (e.g., [3, 17]). In the current study, although RTs were faster in MC than in PJ (see Figure 4), we found no significant differences in the strength of the SNARC effect or directional SNAs between the two tasks. In fact, significant group-level effects appeared only in PJ. On the other hand, fast RTs in the standard and GNG MC tasks could explain why group-level effects are only observed when the task demand is PJ. Previous studies show mixed results regarding SNARC strength across tasks: some found stronger SNARC effects in MC [30, 71, 72], others in PJ [17, 73], and some reported no difference between PJ and MC slopes [44, 74]. Overall, the literature has no definitive conclusion regarding SNARC strength differences between PJ and MC.

As mentioned above, we do not have sufficient evidence to determine whether PJ or MC is better at capturing SNAs, or whether they reflect the same underlying cognitive mechanism. However, some evidence suggests that PJ can be influenced by cultural and linguistic factors, potentially overshadowing the effect in some cultural contexts. For instance, Zohar-Shai et al. [42] demonstrated that when the MARC effect was weakened in their experiment, the SNARC effect emerged among Hebrew participants, who typically show null effects. They therefore suggested that a strong MARC effect can overshadow the SNARC effect during PJ. This explanation is also consistent with the finding of LR SNAs during magnitude-related tasks among Hebrew participants [41]. This argument, however, does not account for the findings observed in Turkish participants. First, no MARC effects were observed in the PJ task in the current study. Similarly, parity status did not significantly interact with the presentation side, suggesting the absence of a MARC-congruency effect in the GNG PJ task. Furthermore, if the variability in SNAs were attributable to parity, we would expect to observe the effect more clearly in the MC task, which was not the case. Therefore, the variability in SNAs observed in the Turkish sample cannot be attributed to culturally or linguistically driven codes activated during PJ.

When the task demand is PJ, we observed reverse SNA patterns depending on task setup: a reversed effect in the standard task and a weak left–right effect in the GNG version. This divergence suggests that directional SNAs are shaped by the stage at which spatial information becomes functionally relevant, whether during stimulus encoding or response selection. While both task types were examined under the common framework of SNAs, they differ in the spatial dimension that drives performance. Standard parity and magnitude tasks rely on response-based lateralization, in which spatial codes are integrated during motor-response selection. In contrast, GNG tasks depend on stimulus-based lateralization, where spatial biases arise from the lateralized presentation of numerical stimuli and primarily reflect attentional orienting rather than motor mapping.

The GNG paradigms used here therefore do not elicit a SNARC effect in the strict motor-response sense but capture a stimulus-based SNA that emerges from attentional shifts toward lateralized numerical input. This interpretation aligns with theoretical accounts proposing that spatial-numerical mappings can arise at multiple representational levels—perceptual and motor-response—that rely on partially dissociable neural mechanisms [4, 17, 41, 75]. Accordingly, the consistency effect observed in the GNG tasks should be viewed as complementary to, but conceptually distinct from, the classical SNARC effect. It should be noted that the standard and GNG task setups also differed in the numerical stimulus range employed. While the standard tasks included the full set of digits (1–4 and 6–9), the GNG tasks were restricted to extreme values (1, 2, 8, and 9). Although this design choice follows common practice in GNG paradigms and was intended to enhance response discrimination, future studies could benefit from equating stimulus ranges across task types to rule out potential confounding effects of number range or stimulus polarity on spatial-numerical mappings. A further methodological difference between the standard and GNG task setups concerns response timing. In the standard tasks, stimuli remained on the screen until a response was made, whereas in the GNG tasks a fixed 1000-ms response window was applied. Differences between self-paced and time-limited responding may influence the balance between automatic and controlled processes in numerical-spatial mapping. Nevertheless, given that opposite directional patterns emerged across task setups, it is unlikely that response timing alone can account for the observed divergence in SNAs.

According to the HMMT [51], multiple spatial-numerical representations may coexist and be selectively activated depending on task demands. The present findings support this view, suggesting that different representations are recruited at different stages of processing [19, 62]. Embodied accounts further propose that SNAs are grounded in sensorimotor experiences, such as reading, counting, or object manipulation, which bias mental number lines in culturally shaped directions [64, 76]. Attentional models likewise predict that small numbers orient attention leftward and large numbers rightward, even in the absence of spatial responses [54, 77]. Thus, GNG paradigms may better capture these early, automatic, and embodied spatial-numerical mappings, whereas standard tasks may be more susceptible to interference from later-stage cognitive and linguistic processes, including competing polarity codes. Together, these findings underscore the critical role of task structure in eliciting SNAs, particularly in populations with heterogeneous directional experiences.

In line with previous findings, we observed a block-order effect in the MC task, with smaller SNARC slopes when participants started with a SNARC-incongruent block rather than a congruent one. This pattern has been reported mainly for magnitude-relevant tasks [44, 78], but not for PJ tasks [3, 9, 79]. Although not central to our hypotheses, this effect may reflect a short-term increase in attentional engagement and sensitivity to spatial–numerical conflicts when the task begins with an incompatible mapping, consistent with practice- and context-dependent updating mechanisms [33]. Beyond SNARC-related measures, block order also yielded some additional effects on general task performance (e.g., parity or magnitude main effects). These findings were exploratory and not theoretically predicted; therefore, they are reported for completeness without strong interpretative claims.

Finally, we investigated whether the observed SNARC effect in standard tasks differs based on participants' directional preference in the OPT. This task was adapted from the *Directional Preference for Object Counting* (DPOC) used in Shaki and Fisher [55], in which participants counted horizontally aligned circles appearing on a screen. The DPOC task was successful as an interindividual variable in differentiating the attentional-SNARC effect among Hebrew participants; participants with a LR counting preference exhibited the SNARC effect, whereas those with an RL preference showed the reverse pattern (see Experiment 4). Given that Turkish participants typically read and count from left to right and frequently demonstrate LR tendencies when interacting with horizontally aligned stimuli (see [44]), we adapted the DPOC into a non-computerized object placement task. We reasoned that presenting the task on a computer screen might yield uniform LR scanning behaviors, thus limiting its ability to differentiate participants. The OPT, by contrast, allowed us to capture more natural directional preferences. Our results showed that participants with an RL preference in the OPT displayed a positive slope, indicating a reverse SNARC pattern, whereas those with an LR preference showed slopes close to zero, indicating a null effect. These findings suggest that directional preference as measured by the OPT may serve as a valid and informative interindividual variable in SNARC research, particularly within standard task configurations.

In conclusion, the present study demonstrates that task setup plays a critical role in modulating both the direction and presence of SNAs, beyond the influence of statistical power and measurement sensitivity. Although increasing power and sensitivity did not consistently produce SNARC effects in Turkish samples, the implementation of alternative task setups, particularly the GNG paradigm, revealed previously undetected directional SNAs. While no significant differences emerged between PJ and MC tasks when compared directly, it is notable that consistent effects were observed in PJ across both setups, warranting further investigation. Overall, the findings indicate that SNAs are not fixed traits but dynamic constructs shaped by task demands and individual differences. Accordingly, we propose that the OPT offers a promising avenue for capturing interindividual variability in SNARC effects. Future research should continue to explore how variations in task setup and interindividual directional preferences interact to shape the diverse SNA profiles observed across cultural and contextual settings.

Acknowledgement: We would like to thank Prof. Martin Fischer and Prof. Samuel Shaki for their valuable suggestions regarding the measurement of directional preferences in SNARC studies.

Funding: None.

Declaration of Conflicting Interests: The Authors declare no conflict of interest.

Author contributions. S.D., H.Ç, M.B., and A.C. conceptualized the study. A.C., M.Ş. and B. H. designed the experiments and collected the data. M.B and S.D. performed the formal analysis. M.B., A.C. and M.Ş wrote the original draft. S.D. and H.Ç. and B.H. reviewed and edited the manuscript. S.D. and H.Ç. supervised the project. All authors reviewed the final manuscript and approved its submission.

Data Availability: The pre-registration, data, and analysis are available in The Open Science Framework (OSF) at https://osf.io/g3b84/

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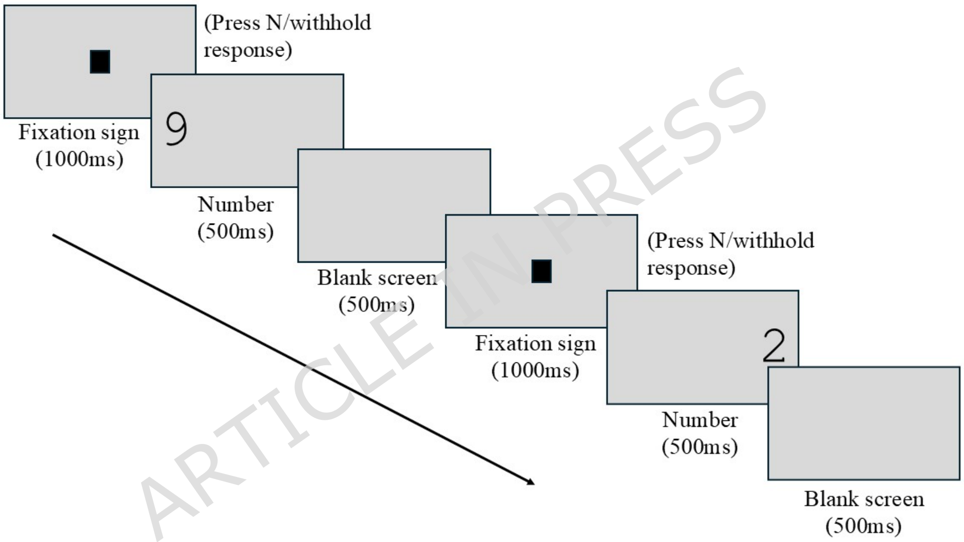
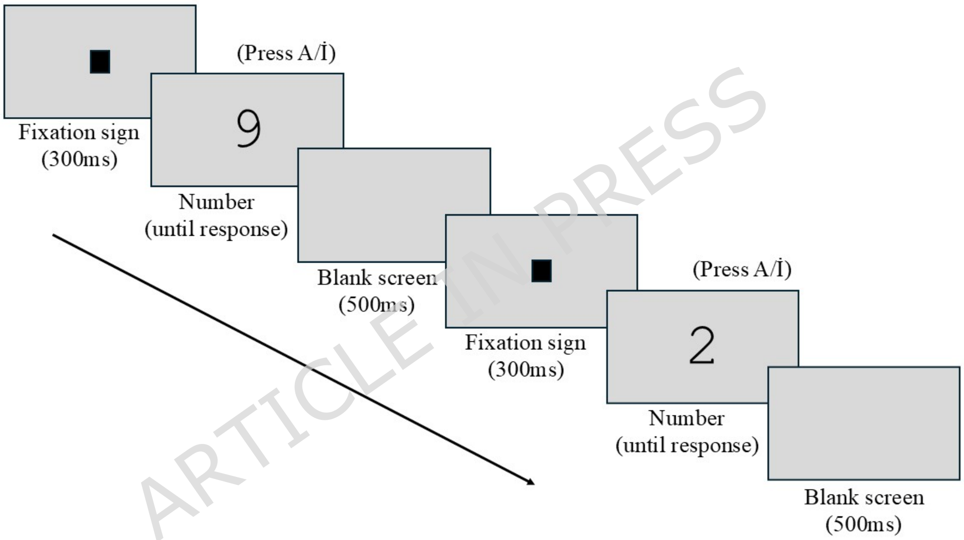

(Press N/withhold response)
Fixation sign (1000ms)
9
Number (500ms)
Blank screen (500ms)
(Press N/withhold response)
Fixation sign (1000ms)
2
Number (500ms)
Blank screen (500ms)


(Press A/İ)
9
Fixation sign
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Number
(until response)
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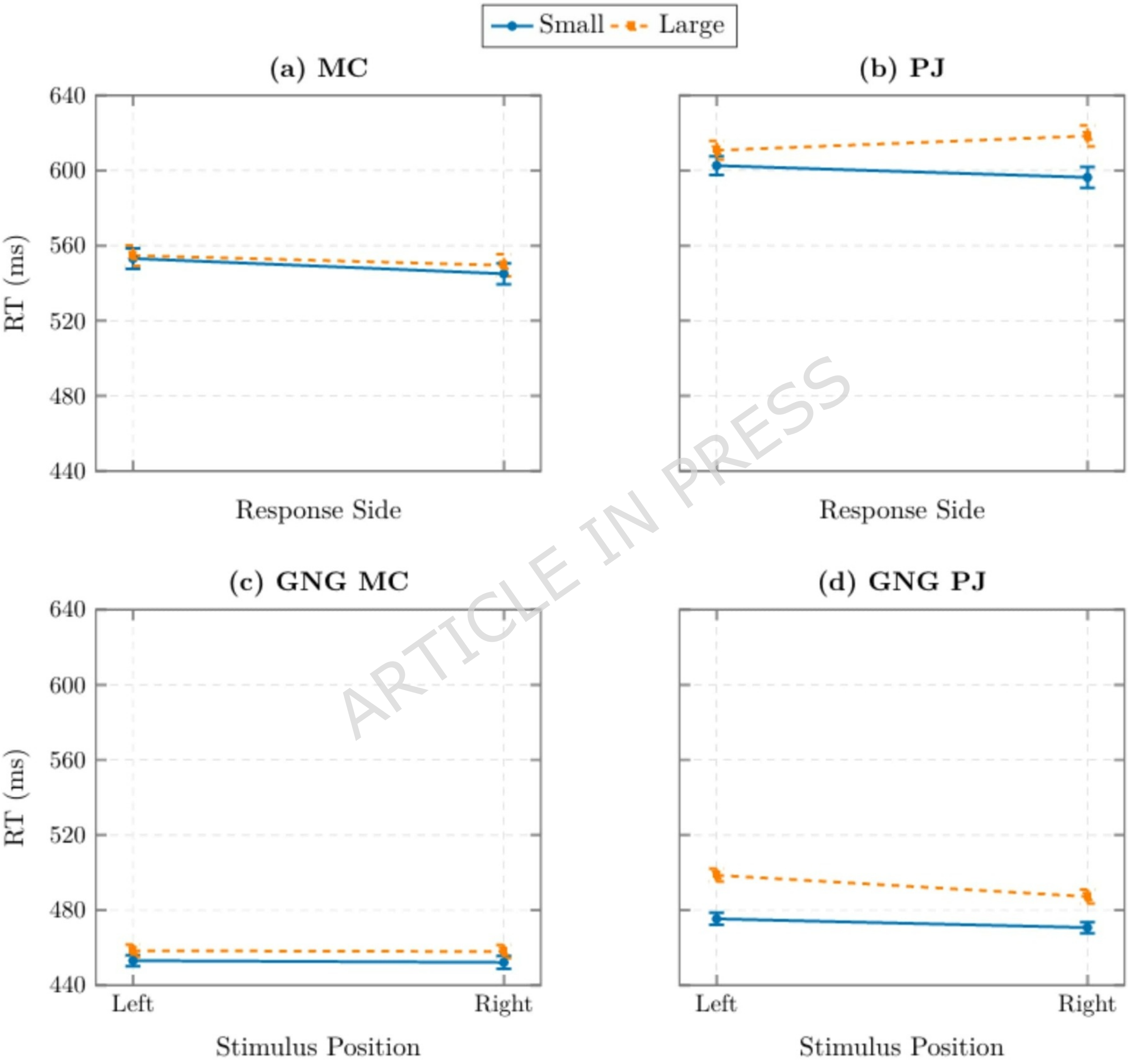
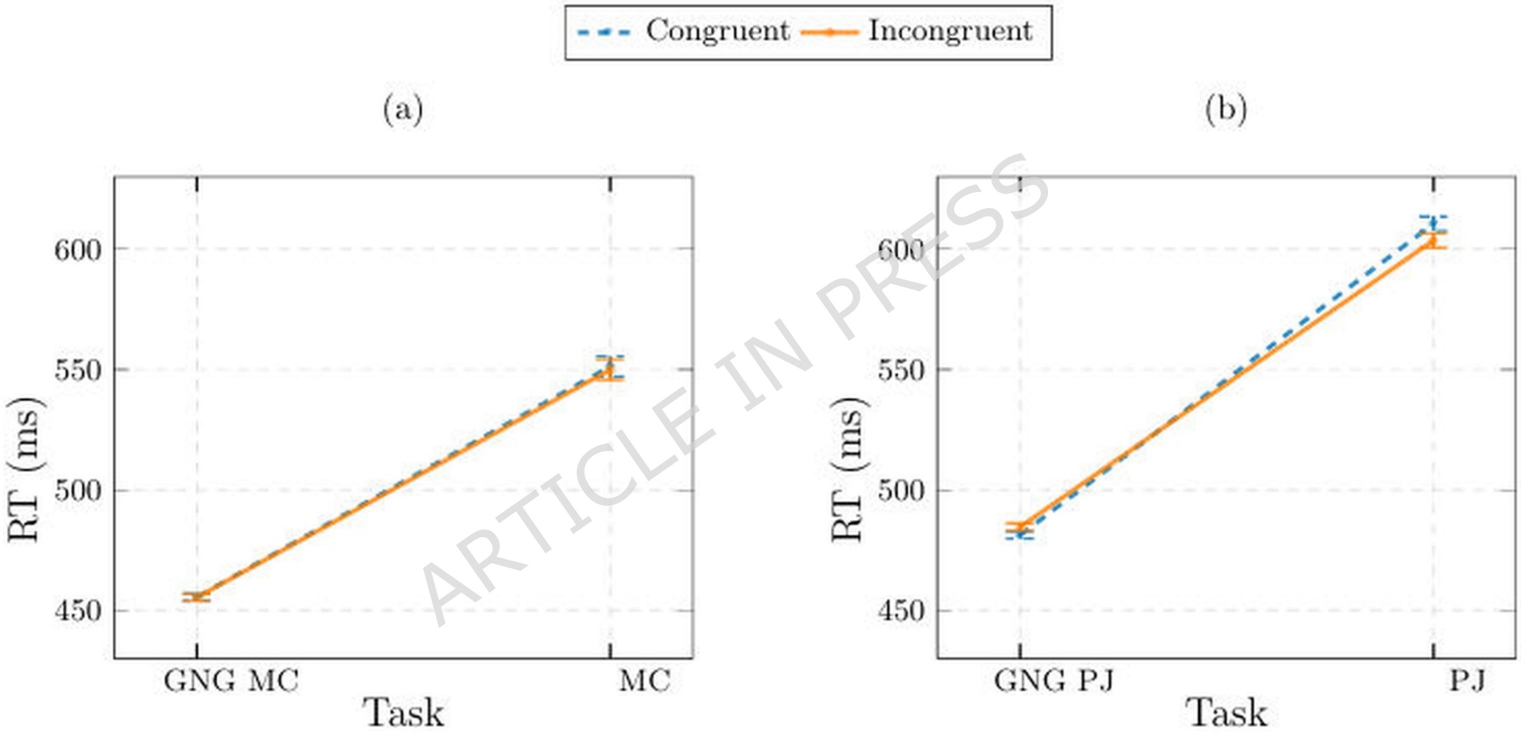
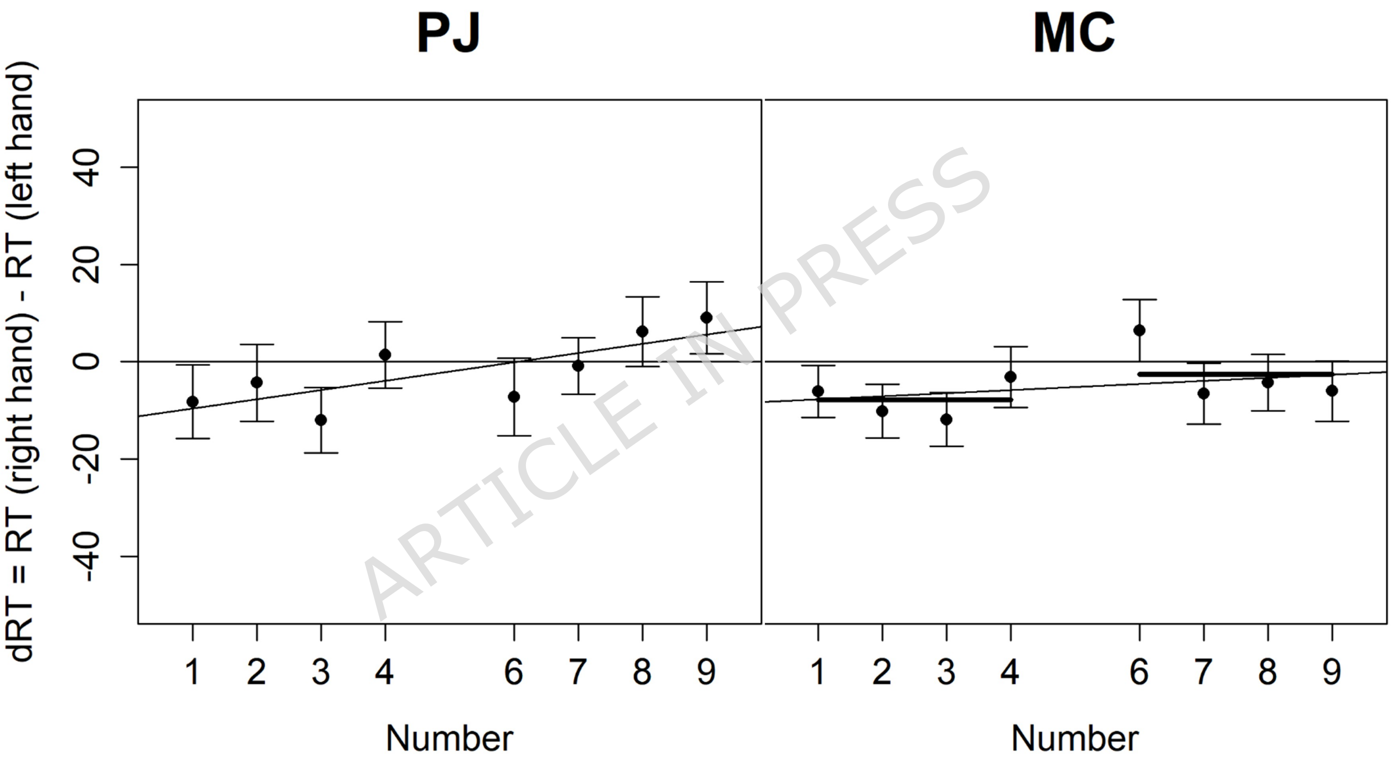
(500ms)
Fixation sign
(300ms)
(Press A/İ)
2
Number
(until response)
Blank screen
(500ms)


Small
Large
(a) MC
(b) PJ
(c) GNG MC
(d) GNG PJ
RT (ms)
640
600
560
520
480
440
Response Side
Left
Right
Stimulus Position


Congruent
Incongruent
(a)
(b)
RT (ms)
600
550
500
450
GNG MC
MC
Task
RT (ms)
600
550
500
450
GNG PJ
PJ
Task


PJ
MC
dRT = RT (right hand) - RT (left hand)
40
20
0
-20
-40
1
2
3
4
6
7
8
9
Number
Number