No observable SNARC effect with numbers in nonsymbolic format

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The code for running the experiment, the data set generated during the current study, and the code implementing the analysis are publicly available in the dot-SNARC GitHub repository, https://github.com/GaborLengyel/dot-SNARC.

This study was not preregistered.

Significance statement

This work shows that the SNARC interference effect, a key phenomenon in numerical cognition, cannot be observed when using numbers in nonsymbolic formats, indicating that it might be exclusively linked to symbolic processing. This discovery supports a newer proposal (Discrete Semantic System) and challenges existing dominant views (Approximate Number System), offering fresh perspectives on how humans process numbers. This finding could provide insights into perceptual and cognitive processes in the brain and could inform the development of educational tools and cognitive therapies designed to improve numerical understanding.

Abstract

Studying numerical interferences has become a widely used method for investigating the representations that underlie numerical cognition. Here, we contrast the classic pure Approximate Number System (ANS) framework and a more recently proposed hybrid ANS-Discrete Semantic System (DSS) framework with respect to their distinctive predictions for the nonsymbolic and symbolic SNARC effects (the most extensively studied interference between numbers and space). We compare the symbolic (Indo-Arabic numerals) to the nonsymbolic (arrays of dots) version of a SNARC paradigm (n=77). In contrast to previous studies, in the present experiment, (1) the magnitude is irrelevant for solving the task (a color judgment task), and (2) the nonsymbolic stimuli contain arrays of dots outside the subitizing range, ensuring to activate the ANS. We found clear evidence for the SNARC effect in the symbolic color task. However, we found no indication of the SNARC effect in the nonsymbolic color task. This pattern of results supports the hybrid ANS-DSS framework, assuming that the SNARC interference is a symbolic effect while refuting the pure ANS view of the SNARC effect, which necessitates the presence of the SNARC interference using a nonsymbolic format, too.

Keywords: Approximate Number System, Discrete Semantic System, SNARC effect, nonsymbolic number, symbolic number

Introduction

Numerical cognition is essential for our everyday life, and it involves a variety of important abilities, such as judging how many apples there are in a basket, performing basic arithmetics, or even understanding complex mathematical principles. This field has been of great interest among researchers in cognitive neuroscience because it jointly investigates the perception of magnitudes and numerosity of objects (and events), together with the cognition of symbolic numbers and mathematics (Cohen Kadosh & Dowker, 2015). Therefore, it provides an ideal ground for exploring the relationships between the processing of perceptual magnitudes and the understanding of abstract concepts.

Studying interferences between numerosity and perceptual magnitudes has been particularly fruitful for understanding the representations that underlie numerical cognition[1]. The most studied numerical interference is the SNARC (Spatial Numerical Associations of Response Codes) effect. Dehaene and his colleagues (1993) found that, in a parity task, in which participants decided whether a single digit number is even or odd, participants responded faster to small numbers with the left response button than with the right button, while they responded faster to large numbers with the right response button than the left one. This result suggested that the processing of Indo-Arabic numerals interferes with the

[1] *Numerosity* refers to the number of discrete elements in a set, independent of their specific features. For example, a group of five dots and a group of five apples share the same numerosity (five), despite differences in their physical properties. *Perceptual magnitude* refers to continuous dimensions of stimuli that can be perceived but are not necessarily countable. These include size, brightness, loudness, duration, and density—attributes that do not have clear, discrete units like numerosity does. We will use the term *numerical value* in the text to refer to a specific number assigned to a stimulus.

processing of spatial localization along the left-right axis, as if numbers were aligned from left to right.

While several other numerical interferences have been identified—such as the interference between number and physical size (Henik & Tzelgov, 1982) or between number and time duration (Oliveri et al., 2008)—the SNARC effect remains one of the most thoroughly investigated. Moreover, other spatial–numerical associations (SNAs) have been observed across various paradigms and populations, including human adults (e.g., De Hevia et al., 2008; De Hevia & Spelke, 2009; Meng et al., 2019), children (e.g., De Hevia & Spelke, 2009; Lourenco & Longo, 2010; van Galen & Reitsma, 2008), infants (e.g., Bulf et al., 2016; De Hevia et al., 2014), and even newborns (e.g., De Hevia et al., 2017; Di Giorgio et al., 2019). Similar effects have also been documented in non-human species, including monkeys (e.g., Adachi, 2014; Drucker & Brannon, 2014), chicks (e.g., Rugani et al., 2007, Rugani et al., 2010, Rugani et al., 2011), and fish—such as zebrafish (Danio rerio; Potrich et al., 2019), though findings are mixed (e.g., no observed SNA in cleaner fish Labroides dimidiatus; Triki & Bshary, 2018). In this study, however, we focus exclusively on the SNARC effect—the association between numerical symbols and leftward–rightward response biases.

Models of the SNARC effect

There are several different explanations for why abstract symbols of numbers interfere with spatial location. Many of these explanations can broadly be grouped into two sets of characteristic models of numerical cognition, depending on whether the number values are represented in a continuous representation or in a representation with discrete units.

The first set of models assumes that an evolutionary old, continuous, and imprecise representation[2] underlies the processes involved in all numerical abilities, from estimating the quantities of objects to understanding higher-level math (Dehaene, 2011; Piazza, 2010). This system is often called the Approximate Number System (ANS), and it works according to Weber's principle, similar to all other perceptual magnitudes (Dehaene, 2011; Moyer & Landauer, 1967). In this view, the ANS is responsible for the interference between number values and left-right responses. For example, in the original explanation of the SNARC effect, the authors assumed that the values represented by the ANS are associated with spatial locations, causing interference in the parity judgment task (Dehaene et al., 1993). This interference is thought to lead to an interaction where smaller magnitudes are implicitly associated with the left side of space and larger magnitudes with the right. Another related model proposes that numerosity, together with other perceptual magnitudes, is represented by the same continuous system, called the Generalized Magnitude System, and the SNARC effect reflects that the representations in this continuous system can interfere with each other (Cantlon et al., 2009). There are similar additional models proposing interferences between continuous representations, which may underlie the SNARC effect in the parity task (Bueti & Walsh, 2009; Cohen Kadosh et al., 2008; Henik et al., 2012; Oliveri et al., 2008). All these models assume that the SNARC interference emerges due to the involvement of the ANS in number processing (Bueti & Walsh, 2009; Cantlon et al., 2009; Dehaene, 2011; Dehaene et al., 1993; Oliveri et al., 2008). Importantly, these accounts assume that the ANS is involved in number processing independent of the format of the values, including both symbolic (such as Indo-Arabic numerals or number words) and nonsymbolic numbers (such as arrays of dots or series of sounds) (Dehaene, 1992, 2011; Piazza, 2010).

[2] In this context, the use of "*continuous and imprecise representation"* pertains exclusively to the representation of perceptual magnitudes and does not extend to other continuous representations in cognition, such as mental imagery.

In contrast to the ANS view, another set of models assumes that the SNARC interference is rooted in discrete symbolic representations. According to a characteristic model, in simple numerical tasks, symbolic numbers, such as Indo-Arabic numerals or number words, are represented by discrete nodes and their connections in a Discrete Semantic System (DSS) similar to the conceptual or linguistic network models (Krajcsi et al., 2016, Krajcsi et al., 2022). According to the DSS model, the SNARC effect originates from the interference of the left-right and small-large nodes in a DSS (Krajcsi et al., 2022; Krajcsi, Lengyel, & Laczkó, 2018). The left-right and small-large nodes may be associated, for example, for cultural reasons; therefore, the associations and the resulting interference follow the cultural habit of increasing number lines from left to right or from right to left (Dehaene et al., 1993). Similar to the DSS model, other models have also proposed that the SNARC effect originates in the interference of discrete representations (Cho & Proctor, 2007; Gevers et al., 2006; Nuerk et al., 2004; Proctor & Cho, 2006). These latter models assume that the concepts in a pair (such as left-right, or small-large) have positive and negative polarities (Cho & Proctor, 2007; Proctor & Cho, 2006) or markedness (Nuerk et al., 2004), and concepts with similar polarity or markedness are processed faster, while concepts with opposite polarity or markedness are processed slower, which can cause the SNARC interference. The SNARC interference also appeared in a connectionist network model where a small-large magnitude category layer was added to the network before the response layer, which got activated automatically even when the magnitude was not relevant to the task (Gevers et al., 2006). Moreover, the SNARC effect also emerged in Large Language Models (Shaki et al., 2023). Finally, some researchers have proposed that the SNARC effect may rely on working memory (WM), in contrast to earlier models that assumed the effect is rooted in long-term memory representations (van Dijck & Fias, 2011). According to the WM model, the numbers involved in the task are stored in WM, either spontaneously or due to task demands, and the order of these items interferes with response location (van Dijck & Fias, 2011). Importantly, all these models propose that the SNARC effect is rooted in discrete representations rather than attributing it to a continuous representation, such as the ANS (Cho & Proctor, 2007; Gevers et al., 2006; Krajcsi et al., 2022; Krajcsi, Lengyel, & Laczkó, 2018; Nuerk et al., 2004; Proctor & Cho, 2006). These models can only process symbolic values. Consequently, most of these models account for symbolic stimuli-related SNARC effect or phenomena only, and nonsymbolic numerical stimuli are not considered.

The SNARC effect is typically demonstrated with symbolic stimuli (but see a review of SNARC effects using nonsymbolic stimuli below). For this reason, most models focus on symbolic numbers when accounting for the SNARC effect, and in some cases, it is unclear whether their explanations can be extended to nonsymbolic stimuli. Therefore, we first consider whether, in general, symbolic and nonsymbolic stimuli are handled by the same mechanism according to the mentioned models. As described above, the ANS view suggests that elementary symbolic and nonsymbolic numerical phenomena, including the SNARC effect, originate primarily from the ANS. Among the second set of models described above, the DSS model explicitly assumes that while symbolic numbers are processed by the DSS, the ANS is involved only in the processing of numbers in nonsymbolic formats. See Figure 1 illustrating the use of ANS and DSS representations with symbolic and nonsymbolic stimuli in the two views. To avoid ambiguity regarding this more general DSS model where ANS representation is also involved, we introduce the terms Pure ANS framework and Hybrid ANS-DSS framework. The Pure ANS framework refers explicitly to the assumption that the ANS representation may support both nonsymbolic and symbolic numerical stimuli, while the Hybrid ANS-DSS framework refers to the assumption that nonsymbolic and symbolic numerical stimuli are handled by the ANS and DSS representations, respectively (Krajcsi et al., 2022).

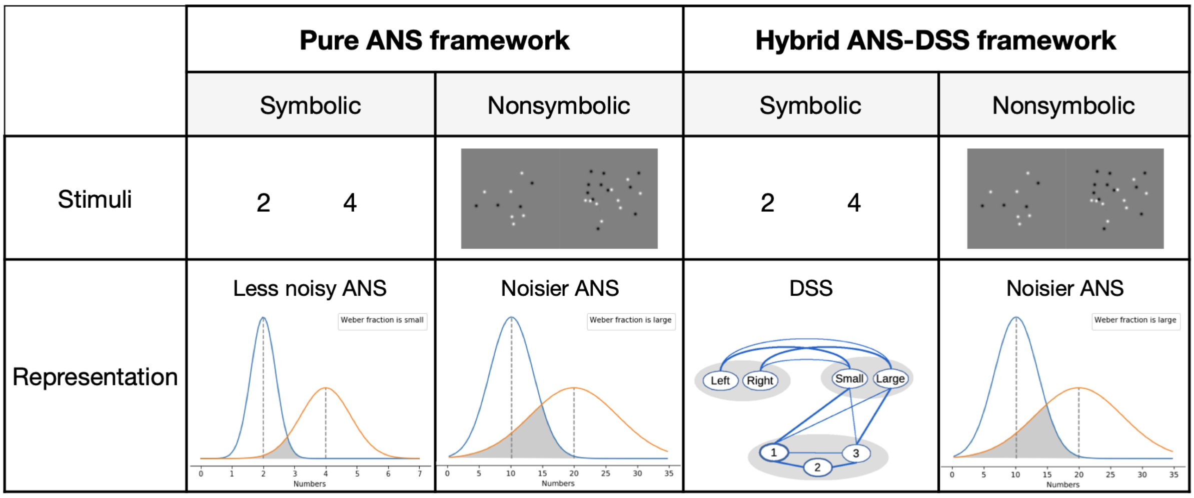

Figure 1. Summary of the pure ANS and the hybrid ANS-DSS frameworks. Top row: Stimuli in the widely used number comparison task in symbolic and nonsymbolic formats. Bottom row: The corresponding representations proposed by the frameworks. *Less noisy* and *Noisier* refer to the amount of uncertainty in the representation of the number values that determine the performance in discrimination and estimation tasks.

While the DSS model has a more general proposal that symbolic numbers are processed by the DSS, and nonsymbolic numerical values are processed by the ANS (i.e., Hybrid ANS-DSS framework), other discrete models of the SNARC effect are less explicit about nonsymbolic stimuli. The polarity and the markedness models discuss only symbolic stimuli; the WM model utilizes only symbolic stimuli in the relevant tests, and the LLM is applicable only for linguistic input. Given the nature of the representations in these models, it is reasonable that nonsymbolic stimuli are irrelevant to these frameworks. Regarding the connectionist model, although an alternative architecture for nonsymbolic stimuli was also proposed, it differs from the architecture for symbolic stimuli, which is used in the SNARC account. Additionally, since the SNARC effect is often demonstrated with a parity task, the parity of nonsymbolic stimuli cannot usually be found when the perceived value is only approximate. Overall, most discrete accounts of the SNARC effect do not consider nonsymbolic stimuli or, more specifically, the nonsymbolic SNARC effect. However, we speculate that while these models are relevant only for the symbolic numerical stimuli, similarly to the DSS model‘s predictions, they allow the use of ANS for nonsymbolic stimuli.

While most SNARC effect models focus on the symbolic SNARC effect, the potential existence of the nonsymbolic SNARC effect may be a valuable phenomenon for differentiating between the models[3]. In the pure ANS framework, the ANS serves as the basis for the SNARC effect for both nonsymbolic and symbolic number stimuli. Therefore, this framework predicts a SNARC effect when either symbolic or nonsymbolic number formats are used in the task (Table 1, 1st column, 1st and 2nd rows). Furthermore, since, in both formats, the interference is attributed to the ANS, in the pure ANS framework, the SNARC effect obtained with symbolic numbers should correlate with the SNARC effect obtained with numbers in nonsymbolic format (Table 1, 1st column, 3rd row)[4]. Contrastingly, the hybrid ANS-DSS framework posits that the underlying representation responsible for the SNARC effect differs between symbolic and nonsymbolic number formats. A symbolic SNARC effect is caused by the DSS, while a possible nonsymbolic SNARC effect could be produced by the ANS. Thus, the hybrid framework also allows the presence of a SNARC effect when either symbolic or nonsymbolic numbers are presented in the task (Table 1, 2nd column, 1st and 2nd row; but see below why the nonsymbolic SNARC effect may not exist). However, unlike the pure ANS framework, the hybrid ANS-DSS predicts no correlation between the symbolic and the nonsymbolic SNARC effects due to their distinct, independent underlying representations (Table 1, 2nd column, 3rd row). Moreover, in the hybrid framework, it is possible that the SNARC effect manifests in one format while being absent in the other (see details below). Therefore, possible differences between symbolic and nonsymbolic SNARC effects can be fundamental in contrasting the pure ANS and the hybrid

[3] In this article, by “symbolic” and “nonsymbolic” SNARC effects we refer to whether the format of the numbers used in the task is symbolic or nonsymbolic.

[4] Note that the ANS account is somewhat inconsistent in this regard. To account for more precise symbolic comparison performance than nonsymbolic comparison performance, it is assumed that while both symbolic and nonsymbolic stimuli are processed by the same *type* of representation, they may be two distinct implementations with higher precision for the symbolic and lower precision for the nonsymbolic stimuli (see Figure 1) (Dehaene, 1992, 2011). In other words, the precision of the symbolic and nonsymbolic number representations may differ, and these representations may be independent. On the other hand, many works propose that precision measured with nonsymbolic stimuli correlates with precision or performance of processing symbolic stimuli (Libertus et al., 2013; Park & Brannon, 2014; Szkudlarek & Brannon, 2017). These latter works assume correlation between symbolic and nonsymbolic precision. Our work relies on the latter assumptions since they are more relevant in arguments describing the role of the ANS.

frameworks. As mentioned above, other discrete models of the SNARC effect consider only symbolic stimuli, therefore, they do not provide direct predictions for nonsymbolic stimuli. Still, it may be reasonable to speculate that, similar to the hybrid ANS-DSS proposal, a separate mechanism for nonsymbolic stimuli is in line with those models, too.

	Pure ANS framework	Hybrid ANS-DSS framework
Symbolic SNARC effect	yes	yes
Nonsymbolic SNARC effect	yes	no prediction yet
Correlation between symbolic and nonsymbolic SNARC effect	yes	no

Table 1. The pure ANS and the hybrid ANS-DSS models' predictions about the SNARC effect with number stimuli in symbolic and nonsymbolic formats.

SNARC effect for numbers in nonsymbolic formats

Numerous studies have demonstrated the SNARC effect using symbolic number format (e.g., Wood et al., 2008 for a meta-analysis). However, only a limited number of experiments have explored the SNARC effect with number stimuli in nonsymbolic formats (e.g., Cleland et al., 2020; Cleland & Bull, 2019; Ebersbach et al., 2014; Mitchell et al., 2012; Nemeh et al., 2018; Nuerk et al., 2005; Prpic et al., 2023; Simmons et al., 2019; Zhang et al., 2024) and its relationship to the symbolic SNARC effect (e.g., Cleland & Bull, 2019; Nuerk et al., 2005; Prpic et al., 2023; Simmons et al., 2019; Zhang et al., 2024). Crucially, the findings of these studies require reassessment for three key reasons, making their results potentially inconclusive.

First, in most studies, numerosity was the relevant feature for solving the task, typically using a “smaller or larger” two-alternative forced-choice task (e.g., Ebersbach et al., 2014; Nemeh et al., 2018; Patro & Haman, 2012; Prpic et al., 2023). If the relevant feature is the numerical value, then its associated symbolic numerical category concepts, such as “smaller” or “larger”, are also activated. These symbolic numerical categories may activate the DSS or similar discrete representations that handle symbolic numerical properties. These smaller-larger and left-right activations then can interfere, leading to the SNARC effect (Gevers et al., 2006; Proctor & Cho, 2006). Therefore, in numerical tasks with nonsymbolic stimuli, it may be ambiguous whether the observed SNARC effect originates from the ANS or the DSS (Cleland et al., 2020). To address this limitation and effectively contrast the hybrid ANS-DSS and pure ANS frameworks, it is crucial to employ a paradigm in which numerosity is an irrelevant feature for solving the task (for such paradigms see Cleland et al., 2020; Cleland & Bull, 2019; Mitchell et al., 2012; Simmons et al., 2019).

Second, the studies that used nonsymbolic number stimuli in a task where numerosity was irrelevant found seemingly contradicting results. While there are findings revealing a SNARC effect when the participants judged about the orientation (and not the numerosity) of the stimuli (Mitchell et al., 2012; Simmons et al., 2019) (i.e., participants produced faster left-hand responses to a smaller number of triangles and faster right-hand responses to a larger number of triangles when they judged the orientation of triangles), other studies could not find a similar nonsymbolic SNARC effect (Cleland et al., 2020; Cleland & Bull, 2019). Importantly, Cleland and colleagues (2020) later demonstrated that the SNARC effect observed in earlier studies were likely driven by specific visual properties of the nonsymbolic displays used in those studies, rather than by numerosity per se (see Mitchell et al., 2012; Simmons et al., 2019 for the specific stimulus generation methods). First, they failed to replicate the SNARC effect using a wide variety of stimuli and large sample sizes. Second, they were only able to replicate the effect when using identical stimulus set as Mitchell et al. (2012). Critically, when they presented those same stimuli flipped along the vertical axis, the direction of the SNARC effect was reversed—strongly suggesting that low-level visual features, rather than numerosity, were responsible for the observed interference. Although Cleland and colleagues did not further investigate which specific visual features caused the effect, their findings point to a more coherent picture: When the task is nonnumerical, nonsymbolic number stimuli do not elicit the SNARC effect.

Finally, while the considerations so far suggest that number stimuli in nonsymbolic formats do not elicit the SNARC effect, the previous empirical results may be inconclusive. None of the previous studies controlled for another related confounding factor: subitizing, the fast enumeration of a small set of items (cf. Kaufman et al., 1949). Perceiving the numerosity of an array containing 1-4 objects does not rely on the ANS (Revkin et al., 2008). Instead, it is likely that a visual pattern detection system is responsible for detecting and discriminating numbers using such arrays (Krajcsi et al., 2013; Mandler & Shebo, 1982). However, to contrast the two frameworks accounting for the SNARC effect, it is essential to use a nonsymbolic stimulus set that engages the ANS. Moreover, since the numerical values of subitized patterns are recognized with high accuracy and their symbolic values are strongly associated with these patterns, they likely serve as stimuli that activate symbolic number representations. As a result, measuring the SNARC effect in this nonsymbolic format would be confounded by symbolic number processing. Unfortunately, all previous studies investigating nonsymbolic SNARC effects used arrays of 1-9 objects, but the smaller set sizes in this range may not activate the ANS (Cleland et al., 2020; Cleland & Bull, 2019; Mitchell et al., 2012; Prpic et al., 2023; Simmons et al., 2019; Zhang et al., 2024). Handling this limitation, some of these works reanalyzed the data, omitting the 1-4 range and considering only the 5-9 range, and the SNARC effect was not observed in the non-subitizing range either (Cleland et al., 2020; Cleland & Bull, 2019). However, it is possible that because in these reanalyses, the limited non-subitizing range included fewer trials, the statistical power was insufficient to reveal the SNARC effect. To summarize, previous works did not consider the possible confound of subitizing, or they handled it in a potentially insufficient way. Overall, previous studies are inconclusive as to whether the SNARC effect emerges for nonsymbolic numbers, and it is an open question whether, in the hybrid ANS-DSS framework, the assumedly ANS-based nonsymbolic SNARC effect should be observed or not (Table 1, right column, second row).

Aims of the study

In this study, we aim to contrast the pure ANS and the hybrid ANS-DSS frameworks by examining their distinct predictions regarding the SNARC effect. To this end, we compare the symbolic and the nonsymbolic SNARC effects using a paradigm that overcomes the limitations observed in prior research. In the experiment, we use a nonsymbolic task, where (1) similar to some previous studies (e.g., Cleland et al., 2020; Cleland & Bull, 2019; Mitchell et al., 2012; Simmons et al., 2019), magnitude is irrelevant for solving the task (a color judgment task), and (2) unlike in previous studies, the subitizing range is avoided (arrays of dots with more than 4 items are used). In a parallel task, a similar color judgment task with Indo-Arabic numerals is used (cf. Cleland & Bull, 2019; Fias et al., 2001; Roth et al., 2025). Critically, the symbolic (Indo-Arabic numerals) and nonsymbolic (arrays of dots) conditions were identical except for format. Thus, the observed differences in the SNARC effect between these conditions must arise from using different formats in the two conditions, and not from the other design-related factors. Based on previous studies, we expect a SNARC effect using the symbolic Indo-Arabic number format. However, due to the inconclusive results of previous studies, we have no clear expectation regarding the presence of the SNARC effect when using nonsymbolic number format. If the SNARC effect is absent when using nonsymbolic number format, it would contradict the pure ANS framework, regarding the SNARC effect, and lend support to the hybrid ANS-DSS framework. If the SNARC effect is observed in the nonsymbolic task, the presence of a SNARC effect aligns with both frameworks, necessitating an analysis of the correlation between the symbolic and nonsymbolic SNARC effects. The absence of correlation would provide evidence for the hybrid ANS-DSS framework, whereas a positive correlation would lend support to the pure ANS framework.

Method

Participants

Our target sample size of eighty participants was determined based on the SNARC interference effect sizes presented by Cleland and Bull (2019). Based on Cohen's *d* values reported in Cleland and Bull (2019)'s third (d = 0.70) and fifth (d = 0.72) experiments, which used a symbolic number format, we performed a power analysis. These authors used one-sample *t*-tests to evaluate the deviation from zero of the right-left median reaction time slopes differences (details in the Analysis section). Using the `power_ttest` function from the `pingouin` Python library (Vallat, 2018) for a one-sample, two-sided *t*-test with α=0.05, β=0.05 (i.e., 95% power) we determined that 80 participants would allow us to detect an effect size as small as Cohen's d = 0.41. Eighty-two university students participated in the online experiment for partial course credit. They came from various programs, including psychology, economics, math, physics, and education. Participants with an error rate higher than 15% were excluded (5 participants). Data from 77 participants were analyzed (46 women, with a mean age of 22.6 years, and an SD of 4.2 years). All participants were native Hungarians, raised in an environment characterized by left-to-right reading and writing practices. The experiment was carried out in accordance with the recommendations of the Department of Cognitive Psychology ethics committee with written informed consent from all subjects. All participants provided online informed consent after a thorough explanation of the study.

Stimulus

In the symbolic format condition, the number stimulus was a single Indo-Arabic digit from 1 to 9 , excluding 5, with a font size of 36. The actual size of the digits depended on the pixel size and resolution of the participants' displays in the online experiment. Given a pixel size range of 0.2–0.3 mm and a resolution range of 1024 × 768 to 3840 × 2160, the physical size of the digits varied between 7.2 mm and 10.8 mm.

In the nonsymbolic format condition, the number stimulus was an array of dots between 5 and 45 (with an increment of 5), excluding 25. Thus, these numbers were exactly five times the numbers that appeared in the symbolic Indo-Arabic condition. Our selection of the 5-45 range was intentional to isolate ANS effects without the confounding effects of subitization. First, by using numbers above four, we avoid the subitization range (Krajcsi et al., 2013; Mandler & Shebo, 1982; Revkin et al., 2008). Second, the ANS model posits that the ratio between numerical stimuli is the critical determinant of comparison performance (Dehaene, 2011; Krajcsi et al., 2016; Piazza, 2010; Pinhas & Tzelgov, 2012; Verguts & Fias, 2004). By maintaining consistent ratios between number pairs across both symbolic and nonsymbolic formats, we ensured that the effect of the ANS on comparison performance should be the same across the two number format conditions. We excluded 5 from the symbolic and 25 from the nonsymbolic conditions because when the SNARC index is calculated with linear regression, the performance corresponding to the middle value within the range of numbers does not impact the regression slope.

The dots appeared in random positions, with the total surface area and total perimeter of the arrangement (i.e., the sum of the contours of all dots) held constant. Following Cleland & Bull (2019), we aimed for a total area of 450 mm² and a total perimeter of 7.5 cm. However, due to differences in display pixel sizes and resolutions across participants in the online experiment, the actual values of these parameters likely varied between participants . For the same reason, factors such as inter-dot distance, individual dot radius, convex hull area, and dot density differed across displays. Given a pixel size range of 0.2–0.3 mm and a resolution range of 1024 × 768 to 3840 × 2160, the inter-dot distance varied between 1.82 and 29.4 mm, and the dot radius ranged from 1.12 to 16.23 mm. The convex hull area—that is, the smallest convex polygon enclosing all elements in the stimulus—spanned from 381.6 to 492.7 mm², and the dot density (numerosity per convex hull area) ranged from 0.013 to 0.091 dots per mm². All stimuli were presented against a gray background in the center of the display and generated randomly before each trial using JavaScript libraries.

Procedure

Participants completed two main tasks[5]: a color judgment task and the classic parity judgment task (Figure 2). Participants always started with the color judgment task, in which they had to decide whether the color of the stimulus was red or blue. In this task, the magnitude of the numbers that can cause the interference was irrelevant to solving the task. There were two number format conditions in the color judgment task: symbolic number format and nonsymbolic number format. The order of the conditions was counterbalanced across participants (39 participants started with the symbolic and 38 with the nonsymbolic format condition). Participants always completed the classic parity judgment task last, as it served solely as a control task with well-established effects extensively documented in previous research (e.g., Fias & Fischer, 2005; Gevers & Lammertyn, 2005; Van Dijck et al., 2014). Placing this task at the end of the experiment was intended to minimize its influence on the preceding color judgment tasks, in which numerosity was irrelevant. While numerical values during the color task can be processed (that is where the SNARC effect is rooted),

[5] In this manuscript, we use the following terms according to standard conventions: A trial refers to a single instance of stimulus presentation and response collection. A block consists of a set of consecutive trials grouped together, typically with the same task and condition. A condition refers to an experimental manipulation or category of stimuli (e.g., symbolic vs. nonsymbolic). A task is a broader unit defining what participants are instructed to do (e.g., color judgment or parity judgment), and may include multiple blocks and conditions.

we needed to avoid that participants intentionally processed the numerical values, for example, because of the mental set caused by a previous parity task. Nonetheless, given that participants were naive to the study's hypotheses and responded rapidly, typically within 450 ms in the color judgment tasks (see Figure 3C & D), it is unlikely that deliberate strategies influenced their responses.

In the color judgment task, each trial began with a fixation cross presented at the center of the screen for 500 ms (Figure 2). Immediately after the fixation cross, a single (either symbolic or nonsymbolic) number stimulus was presented in white at the same location as the fixation cross for 400 ms. Then, the number stimulus turned either red or blue and remained on the screen until the response. We included the initial 400 ms during which the number was presented in white because a previous study found that increasing the time for processing the numbers before shifting the attention to its color enabled and increased the SNARC effect in a similar color judgment task (Cleland & Bull, 2019). For example, the 400 ms duration before the color information becomes available gives more time for the participants to process the numerical information. After the response, a blank screen was shown between the trials for 1000 ms (i.e., inter-stimulus interval).

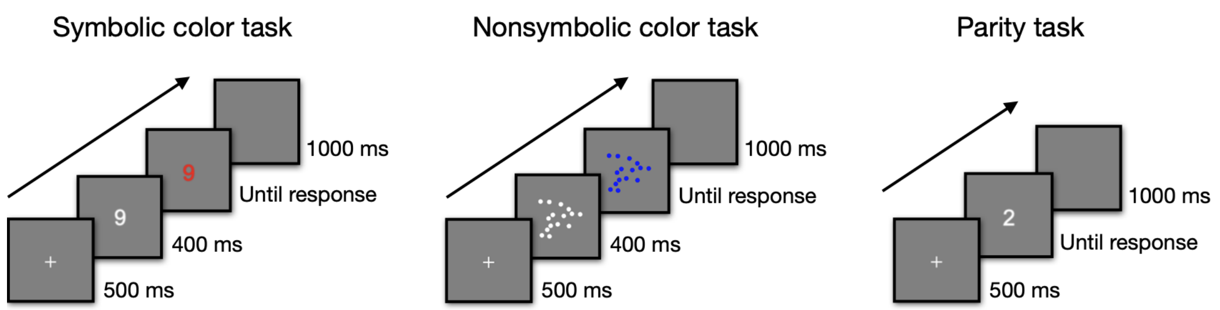

Figure 2. The trial structure and the stimuli in the three tasks.

There were 60 trials per number (30 in red and 30 in blue color) in both symbolic and nonsymbolic format conditions. This resulted in 2 (format) x 8 (number) x 60 (repetition) = 960 trials. There was a short practice block before the main task in each number format condition. In the practice blocks, all numbers appeared once in red and once in blue (i.e., 8 x 2 = 16 trials). In case of erroneous response, auditory feedback was given in the practice trials, but not in the main trials. Each condition was broken into three blocks of 20 trials per number (10 red and 10 blue per number) with a short break at the end of the blocks. Half of the participants responded to blue stimuli with the left shift key on their keyboard and to the red stimuli with the right shift key. For the other half of the participants, the response mapping was reversed.

The second task was the classic parity judgment paradigm and served as a control task in which the expected results were supported by a substantial body of previous studies (e.g., Fias & Fischer, 2005; Gevers & Lammertyn, 2005; Van Dijck et al., 2014). The trial structure was the same as in the color judgment task, except, in the classic parity judgment task, there was only one condition in which only Indo-Arabic digits were presented, only in black color, and remained visible until response (Figure 2). Similar to the color judgment task, the numbers were from 1 to 9, excluding 5. Participants had to decide whether the presented number was odd or even. There were two blocks. In the first block of trials, half of the participants started the task by responding to odd numbers with the left shift key and to even numbers with the right shift key. In the second block, the response mapping was reversed (even numbers - left shift; odd numbers - right shift). The other half of the participants started with the reversed response mapping (which was then reversed in the second block). In contrast to the color judgment task, reversing the response mapping midway through the task was essential in this task to ensure that all number values were tested for each participant. In the color judgment tasks, each number can be presented in both red and blue, allowing all number values to be tested for both left- and right-hand responses under any response mapping. However, in the parity task, each number is exclusively classified as either odd or even. As a result, under a given response mapping, only odd or even numbers can be tested for either left- or right-hand responses. This limitation necessitated the reversal of response mapping to fully assess the range of number values. There was a short break between the two blocks. There were 2 (response mapping, i.e., blocks) x 8 (number) x 14 (repetition) = 224 trials. Before the main task, there was a short practice consisting of two short blocks with two different response mappings. In the practice blocks, all number stimuli appeared once (i.e., 8 (number) x 2 (response mapping) = 16 trials). In case of erroneous response, auditory feedback was given in the practice trials, but not in the main trials.

The instructions stressed both speed and accuracy. The entire experiment took approximately one hour to complete per participant, excluding time spent on obtaining informed consent, providing the general experiment description, and conducting the debriefing. Stimulus presentation and data collection were performed online using the MindProbe.eu server with JATOS 3.8.4 API. The experiment was built with OpenSesame, OSweb software (Mathôt et al., 2012; Mathôt & March, 2022).

Analysis

Following previous studies (e.g., Cleland et al., 2020; Cleland & Bull, 2019; Fias, 1996; Fias et al., 2001; Krajcsi, Lengyel, & Laczkó, 2018; Lorch & Myers, 1990; Roth et al., 2025), the SNARC effects were computed with the following regression analysis. The median reaction time of the correct responses (mRT) was calculated for all numbers separately for right- and left-hand responses for all participants. Then, the slope of the mRT across the numbers was computed for the left- and right-hand responses separately with a linear regression analysis in which the predicted variable was the mRT and the predictor variable was the numbers from 1 to 9. We denote these slopes for left- and right-hand responses, lS and rS, respectively. Finally, the slope for the left-hand responses was subtracted from the slope for the right-hand responses (i.e., $rS - lS$), which we denote by ΔS. The intuition behind the ΔS metric is the following. In the case of the SNARC effect, the responses to smaller numbers are faster than the responses to larger numbers with the left hand. This results in a positive slope for the mRT across the 1-9 numbers. With the right hand, the responses to larger numbers are faster than the responses to smaller numbers. This yields a negative slope for the mRT across the 1-9 numbers. Therefore, in the case of a SNARC interference effect, the difference of the right-left mRT slopes, ΔS is expected to be negative. To ensure results within a comparable range for the nonsymbolic format condition, we also analyzed the nonsymbolic format condition using numbers from 1 to 9, corresponding to dot arrays ranging from 5 to 25. Consequently, in Fig. 3, we plotted the results for the nonsymbolic format condition with an x-axis from 1 to 9, though these values actually represent numerosities ranging from 5 to 25.

To demonstrate the SNARC effect in the experiment, the deviation of ΔS from zero was tested with a parametric one-sample t-test, a nonparametric Wilcoxon signed-rank test, and a Bayesian t-test approximated by the JZS Bayes Factor formula described in Rouder et al., (2009). Full details of the model, posterior characterization, and sensitivity analysis regarding this Bayesian t-test are provided in Rouder et al., (2009). In the Bayesian t-tests, we used uninformative JZS priors with Cauchy scale factor = 0.707 (Rouder et al., 2009). In the results, we report $\text{BayesFactor}_{1,0}$ denoting the evidence favoring the alternative hypothesis in the Bayesian t-test. We decided to report both the parametric and the nonparametric tests together because the assumptions of the parametric test were violated in some conditions and were not violated in some other conditions.

Consistent with recent recommendations (Stosic et al., 2024), we excluded participants with an error rate exceeding 15% as careless responders (5 participants, see Methods, Participants). The final sample included 77 participants, with no further exclusions applied in the analyses presented in Figs. 3 and 4A. We conducted the statistical tests both with and without additional outlier filtering on the mRT right-left slope differences that indicate the SNARC effect. Outliers were defined as values more extreme than the median ± 2.5 × median absolute deviation (MAD) (Leys et al., 2013, Leys et al., 2018). Since the significance of all tests remained consistent regardless of filtering, we report the results with outlier filtering. Based on prior experience, when results are stable with or without filtering, applying MAD filtering helps reduce noise in statistical tests. Using this approach, we excluded two participants from the symbolic condition and three from the nonsymbolic condition in the color judgment task, as well as four participants from the parity judgment task. These exclusions represent only 2.5-5% of the total sample of 77 participants.

Transparency and openness

We report how we determined our sample size, all data exclusions, all manipulations, and all measures in the study in the Methods and the Result sections. All data, analysis code, and research materials are available at https://github.com/GaborLengyel/dot-SNARC.

Results

First, we computed the SNARC effect in the classic parity judgment task to see whether our sample behaved in a typical manner in our experiment with respect to the SNARC interference effect. The mRT of the left- and right-hand responses across the numbers and their slopes (i.e., *lS* and *rS*) are plotted in Fig. 3, subpanels A and B. We found a significant SNARC interference in the parity judgment task (Fig. 4, gray box, and gray bar on the left in A and B), Mean ΔS = -11.15, 95% CI = [-13.50, -8.92], t(72) = -9.42, p = 3.51×10^{-14}, Cohen's d = -1.50; Wilcoxon signed rank T = 152, p = 4.43×10^{-11}, rank-biserial correlation = -0.60, $\text{BayesFactor}_{1,0} = 2.09 \times 10^{11}$. This result replicated many previous studies, confirming that our participants produced the expected numerical interferences in our experiment.

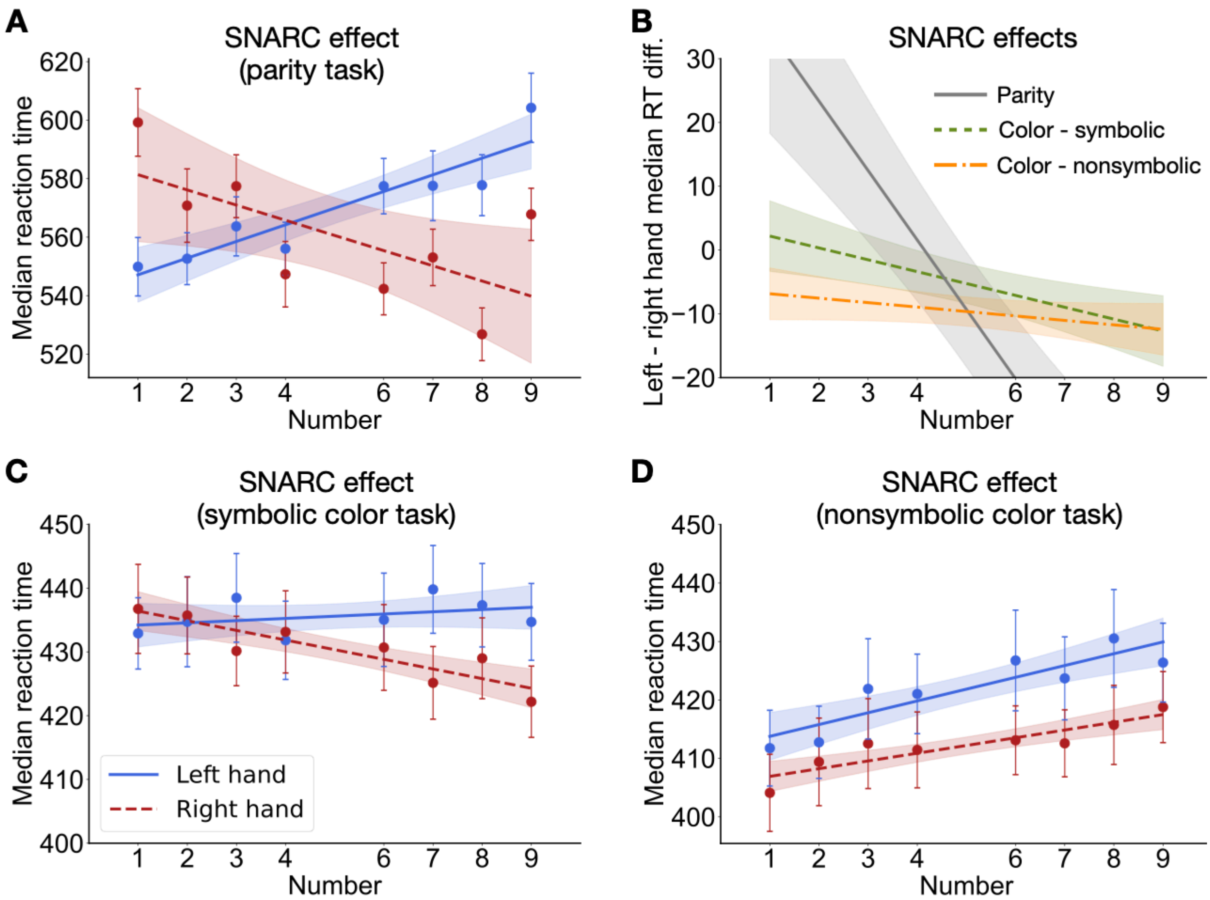

Figure 3. A,C &D : Mean of the median reaction times across the numbers for left- (in blue) and right-hand (in red) responses and the corresponding fitted regression lines (solid for left and dashed for right-hand). Error bars show the standard errors of the mean of the median reaction times, while the shaded areas represent the 95% confidence intervals for regression on the mean median reaction times. **B:** Regression lines fitted to the mean of the median reaction time differences between the left- and right-hand responses in the symbolic, Indo-Arabic condition of the color judgment task (in green with dashed line) in the nonsymbolic condition of the color judgment task (in orange with dash-dot line) and in the parity judgment task (in gray with solid line). Shaded areas represent the 95% confidence intervals for regression on the mean median reaction time differences. **D:** The real number values in the nonsymbolic conditions were five times the number values shown on the x-axis. The absolute value of the number on the x-axis does not influence the left- minus right-hand slope difference measuring the SNARC effect.

Second, we computed the SNARC effect in the two conditions for the color judgment task. In this task, the magnitude of the stimuli was irrelevant as participants had to judge the color of the stimuli (see Methods, Stimuli, and Procedure). The mRT of the left- and right-hand responses across the numbers and their slopes can be seen in Fig. 3B, C & D for both symbolic and nonsymbolic formats, and separately for symbolic and for nonsymbolic conditions, respectively. We found a significant SNARC interference in the symbolic format condition (Fig. 4, green box and green bar in the middle in A & B), Mean ΔS = -1.86, 95% CI

= [-2.63, -1.14], $t(74) = -4.90$, $p = 5.41 \times 10^{-6}$, Cohen's d = -0.75; Wilcoxon signed rank T = 619, $p = 2.08 \times 10^{-5}$, rank-biserial correlation = -0.35, $\text{BayesFactor}_{1,0} = 3.06 \times 10^{3}$. However, we found no SNARC effect in the nonsymbolic format condition (Fig. 4, orange box and orange bar on right in A & B), Mean $\Delta S = -0.17$, 95% CI = [-1.02, 0.67], $t(73) = -0.40$, $p = 0.70$, Cohen's d = -0.07; Wilcoxon signed rank T = 1318, $p = 0.71$, rank-biserial correlation = -0.03, $\text{BayesFactor}_{0,1} = 7.4$ (which, in this case, specifically indicates evidence in favor of the null hypothesis, i.e., no effect). Moreover, there was a significant difference between the symbolic and nonsymbolic SNARC interferences (i.e., the left- minus right-hand slopes) in the symbolic and in the nonsymbolic format conditions ($t(72) = -3.51$, $p = 7.76 \times 10^{-4}$, Wilcoxon signed rank T = 720, $p = 8.58 \times 10^{-4}$, $\text{BayesFactor}_{1,0} = 32$).

There was also a significant difference in symbolic SNARC interference between the color judgment and parity tasks ($t(72) = -7.96$, $p = 1.95 \times 10^{-11}$; Wilcoxon signed-rank T = 238, $p = 1.56 \times 10^{-9}$; $\text{BayesFactor}_{1,0} = 4.7 \times 10^{8}$). However, this difference was expected, as previous research has shown that SNARC-like interference effects are twice as large when the numerical value or magnitude of a stimulus is task-relevant (e.g., judging the parity of a number) compared to when it is task-irrelevant (e.g., judging the color of a number stimulus) (Macnamara et al., 2018).

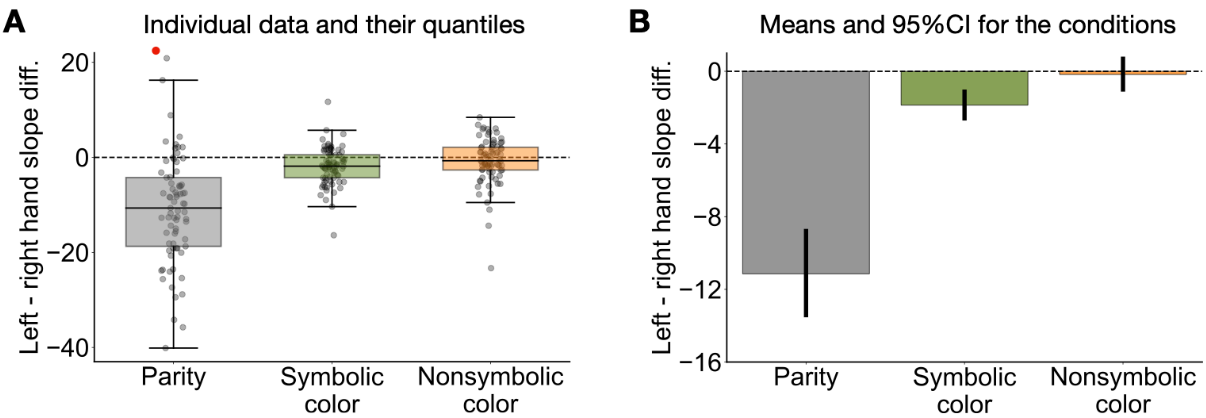

Figure 4. A: The slope differences of the regression lines fitted to the median reaction times of the left- and right-hand responses across the numbers. Gray dots show the left minus right-hand slope differences of the individual participants. The box shows 25%, 50% (median), and 75% quantiles. The whiskers extend from the box to the farthest data point, lying within 1.5x the interquartile range from the box. The red point represents one outlier point with a y value of 32.1. **B:** The estimated mean and

corresponding 95% confidence intervals of the populations for the left minus right-hand slope differences in the symbolic, Indo-Arabic condition of the color judgment (in green, on the left) in the nonsymbolic condition of the color judgment task (in orange, on the right) and in the parity judgment task (in gray, in the middle).

Notably, the results are consistent across frequentist parametric, nonparametric, and Bayesian statistical tests. Both the interval estimates of the slopes and the relevant hypothesis tests indicate the absence of the SNARC effect in the nonsymbolic format condition. As such, the variability in this condition should be regarded as noise stemming from nuisance variables unrelated to the SNARC effect. Consequently, analyzing the optionally planned correlation between the SNARC effects in the symbolic and nonsymbolic conditions is no longer meaningful.

Discussion

In the present work, we contrasted two frameworks in numerical cognition with respect to their distinct predictions for the SNARC effect: the pure ANS (Dehaene, 2011; Piazza, 2010) and the hybrid ANS-DSS frameworks (Krajcsi et al., 2022). We found clear evidence for the SNARC effect both in the symbolic format condition of the color task and in the classic parity task. However, we found no indication of the SNARC interference with number stimuli in nonsymbolic formats. This pattern of result supports the hybrid ANS-DSS framework while refuting the pure ANS view of the SNARC effect that necessitates the presence of the SNARC interference using the nonsymbolic format, too.

The present study handled two critical issues that were not or were only partly handled in previous works. First, in contrast to many previous studies investigating the nonsymbolic SNARC effect, we used a color judgment task in which magnitude was irrelevant so that we could rule out the possibility of a SNARC interference caused by the symbolic representations of the relevant magnitude concepts in the nonsymbolic format condition (see a similar approach in Cleland & Bull, 2019). Therefore, the absence of the

SNARC effect in the nonsymbolic format condition in our experiment suggests that the seeming nonsymbolic SNARC interference in previous studies (e.g., Ebersbach et al., 2014; Nemeh et al., 2018; Nuerk et al., 2005; Patro & Haman, 2012; Prpic et al., 2023) emerged as a consequence of the tasks in which magnitude was the relevant feature. Second, in contrast to all previous studies, we used a nonsymbolic number stimulus set that excluded the subitizing range to exclude stimuli that do not rely on the ANS (cf. Revkin et al., 2008). Consequently, the lack of nonsymbolic SNARC effect in our work cannot be attributed to the bias of subitizing or the lack of statistical power of a more limited number range.

The pure ANS framework predicts that the SNARC effect should be present both for symbolic and nonsymbolic formats because the same type of representation is assumed behind both formats for the SNARC effect. This was not the case in our results; the SNARC effect was observable only with symbolic numbers, contradicting the pure ANS framework prediction. One might argue that the nonsymbolic SNARC effect may be smaller than the symbolic SNARC effect, thus requiring larger statistical power to detect it. However, if one assumes a difference between the size of the SNARC effect in nonsymbolic and symbolic formats, then one should expect a stronger effect in nonsymbolic format because, as an evolutionarily old representation, the ANS is primarily involved in processing nonsymbolic numerical information. One may also raise the possibility that nonsymbolic stimuli do not activate the ANS automatically. In this reasoning, one should also explain why, at the same time, symbolic stimuli activate the assumed ANS.

Additionally, the assumed lack of ANS activation for nonsymbolic stimuli contradicts many previous findings. First, previous studies provided substantial evidence that arrays of dots elicit magnitude-specific behavioral effects using paradigms with no explicit task (e.g., Brannon et al., 2004; Lipton & Spelke, 2003; Xu & Spelke, 2000) or where magnitude was irrelevant to solving the task (Furman & Rubinsten, 2012; Gebuis et al., 2009; Naparstek & Henik, 2010). Second, passively looking at arrays of dots also elicits numerosity-specific activations in the brain, for example, in the bilateral intraparietal sulci in humans (Ansari et al., 2006; Piazza et al., 2004) and in the parietal area LIP in monkeys (Roitman et al., 2007). Crucially, in our study, the same color judgment task was insufficient for the nonsymbolic but sufficient for the symbolic comparison to demonstrate the SNARC effect. From the viewpoint of the pure ANS framework, it is perplexing why symbolic format elicits a SNARC effect while nonsymbolic format does not – especially since nonsymbolic stimuli are considered the primary input of the ANS. Therefore, we rather argue that the SNARC effect, observed in a simple forced-choice paradigm, is a symbolic-only effect that is incompatible with the pure ANS framework.

A key concern when using nonsymbolic numerosities, such as dot patterns, is their correlation with physical properties including surface area, perimeter, density, and convex hull, which may influence responses (Clayton et al., 2015). While isolating numerosity would be ideal, complete separation from non-numerical cues is not fully achievable (DeWind et al., 2015). In our experiment, we controlled only the total area and perimeter. As a result, density was positively correlated with numerosity, while individual dot radius was negatively correlated. However, convex hull area, total area, and total perimeter showed no correlation with numerosity. Although, to our knowledge, no study has directly examined the effect of density or individual dot radius on ANS performance, Clayton et al. (2015) found that total area and convex hull correlations influenced accuracy in a nonsymbolic dot comparison task. This suggests that covarying density and dot radius may also play a role, though their impact on ANS acuity remains unclear. Crucially, studies show that responses are primarily driven by numerosity rather than non-numerical features (DeWind et al., 2015). Since our goal was to activate the ANS, these correlations do not affect the validity of our experiment.

The primary motivation of the present study was to contrast the pure ANS framework with the hybrid ANS-DSS framework, along with other functionally similar models. We have categorized the working memory (WM) account of the SNARC effect (van Dijck & Fias,

2011) as belonging to models that assume discrete rather than continuous numerical representations (such as the ANS). This classification is based on the fact that the WM account has only been discussed in the context of symbolic numbers (e.g., Abrahamse et al., 2016; Roth et al., 2025; van Dijck et al., 2015), and, to our knowledge, no study has extended it to numbers in nonsymbolic formats.

However, since WM is not inherently specific to symbolic processing, in principle, the model could be extended to nonsymbolic stimuli—though doing so presents significant practical challenge. According to the WM account, the SNARC effect depends on the ordinal position of items, where order is typically determined by their numerical values. In the case of symbolic numbers, this ordinal structure is easily identifiable. However, for numbers in nonsymbolic formats, discrimination becomes increasingly difficult when neighboring values have small ratios (Krajcsi et al., 2023; Krajcsi, Lengyel, & Kojouharova, 2018). In such cases, establishing a clear ordinal sequence may be challenging, potentially leading to interference effects that deviate from the actual numerical values of the stimuli.

Furthermore, in the original SNARC effect paradigm (Dehaene et al., 1993) and in many subsequent studies (e.g., Cleland et al., 2020; Cleland & Bull, 2019; Ebersbach et al., 2014; Fias et al., 2001; Gevers et al., 2006; Gevers & Lammertyn, 2005; Krajcsi, Lengyel, & Laczkó, 2018; Mitchell et al., 2012; Nemeh et al., 2018; Notebaert et al., 2006; Nuerk et al., 2005; Reynvoet & Brysbaert, 1999; Schwarz & Keus, 2004; Simmons et al., 2019), participants processed more than seven numerical items (e.g., Indo-Arabic digits digits from 1 to 9). However, empirical research suggests that most humans cannot reliably maintain more than seven items in WM simultaneously (Miller, 1956). This raises a potential limitation for the WM account, as it assumes that ordinal position information in WM underlies the SNARC effect, regardless of whether the numbers are stored in canonical (e.g., 1, 2, 3, 4, 5) or noncanonical (e.g., 4, 2, 5, 1, 3) sequences. Although we are not aware of any research that directly addresses this WM capacity constraint within the WM account of the SNARC effect, we acknowledge the theoretical relevance of the model. Further investigations are needed to determine how WM limitations might influence SNARC-like effects, particularly in the context of nonsymbolic numerical processing.

The present results are clearly in contrast with many previous findings in which SNAs were found using nonsymbolic numerical stimuli. Preverbal infants and animals show a preference for left-to-right orientation for increasing magnitudes and numerosities (see Rugani & De Hevia, 2017 for a review). Several possible explanations can account for this apparent contradiction. Not all spatial-numerical interferences necessarily arise from the same spatial and numerical representations (Patro et al., 2014), and different tasks with different measures could require independent explanations. The existing accounts in the literature can be broadly categorized into three main perspectives. First, the right-hemispheric dominance theory of spatial information processing (Rugani et al., 2011) suggests that animals exhibit a left-to-right counting bias due to right hemisphere dominance in spatial processing. This bias results from an attentional shift toward the left hemispace, favoring a left-to-right orientation when processing increasing magnitudes. Second, the brain asymmetry in control functions model (Vallortigara, 2018) posits that the left and right hemispheres are specialized for approach and withdrawal behaviors, respectively, and are linked to positive and negative emotional responses. If larger magnitudes are inherently associated with positive valence (approach) and smaller magnitudes with negative valence (withdrawal), then changes in numerosities could differentially activate the hemispheres. An abrupt increase in numerosity might preferentially activate the left hemisphere (positive emotion, approach), leading to rightward shifts in attention or movement, whereas an abrupt decrease might engage the right hemisphere (negative emotion, withdrawal), promoting leftward shifts. Consequently, this mechanism could drive a leftward bias for smaller numerosities and a rightward bias for larger ones. Third, the brain’s asymmetric frequency tuning (BAFT) hypothesis (Felisatti et al., 2020) proposes that some nonsymbolic number-space associations arise as a byproduct of spatial frequency processing rather than numerical representation per se. This model is based on three key assumptions: (1) the brain decomposes visual input into power spectra across spatial frequencies, (2) the right hemisphere preferentially processes low spatial frequencies, while the left hemisphere favors high spatial frequencies, and (3) at the optic chiasm, nasal optic fibers cross to the opposite hemisphere while temporal fibers remain on the same side—resulting in the left hemisphere processing input from the right visual field, and the right hemisphere processing input from the left visual field. Together, these factors create an inherent association between low spatial frequency (corresponding to fewer items) and left space, and high spatial frequency (corresponding to more items) and right space, due to the hemispheric asymmetry in spatial frequency tuning.

These alternative explanations highlight the complexity of spatial-numerical associations and suggest that different underlying mechanisms may drive SNAs depending on the specific stimuli, tasks, and cognitive demands involved. Therefore, it is important to clarify that we do not claim that there is no ANS-driven space-number association, but we claim that specifically the SNARC effect (i.e., the interference between Indo-Arabic numerals and left-right responses) cannot be demonstrated with nonsymbolic stimuli; therefore, we argue that the SNARC effect is a symbolic interference effect that emerges in a discrete semantic system.

Finally, the present findings could inform the development of educational tools and cognitive therapies aimed at improving numerical understanding. Since the SNARC effect appears to be tied specifically to symbolic number representations, interventions targeting numerical cognition should prioritize symbolic number processing rather than nonsymbolic numerosity training. For example, cognitive therapies for individuals with dyscalculia or numerical processing deficits may benefit from exercises that enhance symbolic number comprehension, rather than focusing on numerosity estimation with nonsymbolic magnitudes or number-line spatial associations. Future research could explore how structured interventions leveraging symbolic numerical representations might enhance mathematical fluency and reduce numerical processing difficulties in both typically developing individuals and those with learning disabilities.

Conclusion

The present study demonstrated that the SNARC effect, the most extensively studied numerical-spatial interference, tends to manifest with symbolic stimuli and remains undetectable when nonsymbolic numbers are used. These results provide substantial evidence that the SNARC effect originates from interferences between discrete, symbolic representations, such as concept pairs in the discrete semantic system, rather than originating from a number magnitude representation like the approximate number system.

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