**Contrasting symbolic and non-symbolic numerical representations in a joint classification task**

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**Abstract**

Both symbolic (digits) and non-symbolic (dots) numerals are spatially coded, with relatively small numbers being responded faster with a left key and large numbers being responded faster with a right key (Spatial-Numerical Association of Response Codes). The idea of format independent SNARC seems to support the existence of a common system for symbolic and non-symbolic numerical representations, although evidence in the field is still mixed. The aim of the present study is to investigate whether symbolic and non-symbolic numerals interact in the SNARC effect when both information is simultaneously displayed. To do so, participants were presented with dice-like patterns with digits being used instead of dots. In two separate magnitude classification tasks, participants had to respond either to the number of digits presented on the screen or to their numerical size. In the non-symbolic task, they had to judge whether the digits on the screen were more or less than three, irrespective of the numerical value of the digits. In the symbolic task, participants had to judge whether the digits on the screen were numerically smaller or larger than three, irrespective of the number of digits being present. The results show a consistent SNARC effect in the symbolic task and no effect in the non-symbolic one. Furthermore, congruency between symbolic and non-symbolic numerals did not modulate the response patterns, thus supporting the idea of independent representations and questioning some propositions of current theoretical accounts.

**Keywords:** SNARC; digit; numerosity; ANS; Approximate Number System; ATOM; A Theory of Magnitude

**Public Significance Statement:**

People use space to mentally represent numbers, with small numbers being associated with left space and large ones with right space. Because of this association, small numbers are responded faster with a left key and large ones with a right key. Both symbolic (digits) and non-symbolic (dots) numerals elicit similar spatial associations and are deemed to share the same neural representation. By presenting both numerical formats simultaneously in modified dice-like patterns, we directly contrasted their spatial representations and showed that these are independent, thus challenging current theoretical accounts.

**1.0 Introduction**

Previous studies suggest that people represent numbers spatially resembling a Mental Number Line (Restle, 1970; for a review see Toomarian & Hubbard, 2018). A consistently replicated phenomenon that supports this view is the Spatial-Numerical Association of Response Codes (SNARC) effect (Dehaene et al., 1993). This consists of faster left key responses for small numbers and faster right key responses for large numbers. The direction of this representation seems to be culturally determined, with reading and writing direction as well as finger counting being considered as the basis for this long-term association (Fischer & Shaki, 2017; Shaki et al., 2009; Pitt & Casasanto, 2020). However, it has been shown that contextual manipulations can reverse the direction of the Spatial-Numerical Association (Bachtold et al., 1998; Mingolo et al., 2021).

Although symbolic numerals have been the most investigated stimuli, SNARC-like effects have been revealed in a multitude of non-numerical dimensions. While examples of symbolic non-numerical stimuli are relatively rare and can be found in music notation (Ariga & Saito, 2019; Fumarola et al., 2020; Prpic et al., 2016) and letters of the alphabet (Gevers et al., 2003), non-symbolic stimuli have been widely studied across different modalities. Most common examples are in the visual modalitywith the size of pictorial figures (Prpic et al., 2020; Ren et al., 2011), luminance (Fumarola et al., 2014; Ren et al., 2011), angle magnitude (Fumarola et al., 2016) as well as emotional magnitude in facial displays (Holmes & Lourenco, 2011, Holmes et al., 2019; but see also Fantoni et al., 2019 and Baldassi et al., 2021). There are also numerous examples in the auditory modality with pitch (Lega et al., 2020; Lidji et al., 2007; Pitteri et al., 2017; Prpic & Domijan, 2018; Rusconi et al., 2006), loudness (Bruzzi et al., 2017; Hartmann & Mast, 2017), and temporal aspects of the auditory stimuli (Ishihara et al., 2008; De Tommaso & Prpic, 2020) being commonly investigated. Recently, somatosensory information has been studied revealing similar effects for weight (Dalmaso & Vicovaro, 2019; Vicovaro & Dalmaso, 2021) and vibrotactile stimuli (Bollini et al., 2020).

The ATOM (A Theory of Magnitude) model (Walsh, 2003; Bueti & Walsh, 2009) has been commonly used as a framework to encompass a whole range of SNARC-like effects since the theory posits that space and quantity are processed by a generalized magnitude system. Walsh (2003) also suggested that SNARC could prove to be a SQUARC (Spatial-Quantity Association of Response Codes) effect whereby magnitudes across different domains should be spatially coded similarly to numbers. The large amount of evidence seems to support Walsh’s (2003) prediction, although it is still a matter of debate whether these effects are driven by stimulus magnitude or ordinality (see Casasanto & Pitt, 2019 and Prpic et al., 2021). Indeed, while the ATOM model focuses on the magnitude properties of the stimuli, the working memory (WM) model (van Dijck & Fias, 2011) claims that stimuli (independently from their nature) can be spatially organized in WM and can elicit SNARC-like effects. Thus, both models fundamentally suggest that numbers have no special relationship with space and that numerical and non-numerical stimuli should elicit comparable SNARC-like effects. Conversely, a recent review and meta-analysis (Macnamara et al., 2018) established that the effect size for non-numerical domains (e.g., temporal, musical, size) is substantially smaller than the reported effect size for symbolic numerals (Wood et al., 2008). This evidence adds to other studies suggesting that numbers, specifically in their symbolic format are fundamentally different from other ordinal or magnitude related stimuli (Dodd et al., 2008; Kadosh et al., 2007; Kadosh & Walsh, 2009).

Non-symbolic numerals (or numerosity) are less studied than their symbolic counterpart, however they recently gained renewed interest. To our knowledge, Nuerk et al. (2005) published the first study that investigated the SNARC effect for dot patterns. This study used configurations of dots resembling dice patterns and showed that small (vs. large) numerals are responded faster with a left (vs. right) key, independently from the format of numerical stimuli. More recently, this finding has been replicated by using randomly distributed dot clouds with larger numerosities (Nemeh et al., 2018; Zhou et al., 2016). Another recent study (Cutini et al., 2019) more specifically focussed on stimulus arrangements and revealed that both structured and unstructured patterns elicit a consistent SNARC effect in a small numerosity range (i.e., 1-9). These studies suggest that the SNARC effect for non-symbolic numerals is independent from both the range and the spatial arrangement of the stimuli.

Evidence of format independent SNARC effects supports the existence of a common system for symbolic and non-symbolic number processing. Traditionally it has been considered that both numerical formats share the same neural representation (Approximate Number System or ANS) and that non-symbolic numerals provide a foundation for their symbolic counterparts (Dehaene, 1993; Nieder, 2016; Nieder & Dehaene, 2009; Piazza, 2010; Piazza et al., 2007). However, several recent studies that have been questioning the existence of ANS (Núñez, 2017; Van Hoogmoed & Kroesbergen, 2018; Van Hoogmoed et al., 2021). Growing empirical evidence suggests a fundamental distinction between symbolic and non-symbolic numerals that challenges the idea of a common system for representing and processing these two numerical formats. In sum, symbolic numerals are deemed to be represented in a linear fashion, while non-symbolic numerals in a logarithmic fashion. Thus, psychophysical laws only apply to non-symbolic numerals, which are processed in the same way as all other perceptual continua (such as loudness or brightness), while symbolic numerals are processed in a unique and exact way (Algom, 2021; Bar et al., 2019). The assumption, proposed by ANS, that non-symbolic numerals are somehow unique and different from other perceptual continua has been challenged, and consequently the idea that a dedicated number system is needed to process and represent numerosity (Núñez, 2017).

Evidence from studies that compared the SNARC effect for symbolic and non-symbolic numerals are scarce, thus no contribution in the ANS debate was provided from this line of research. A study that showed a SNARC effect for both symbolic and non-symbolic numerals in either adults or children managed to demonstrate that the two effects are not correlated, thus suggesting that symbolic and non-symbolic numerals are independently associated with space (He et al., 2021). Although behavioural evidence is still mixed, a growing number of research seem to be in favour of a dissociation for symbolic and non-symbolic numerical representations, at least for studies using SNARC paradigms (for a review see Buijsman & Tirado, 2019). However, a limitation of previous studies that compared symbolic and non-symbolic SNARC effects is that these were tested separately, thus not allowing to directly assess whether these two representations interact.

Although symbolic and non-symbolic numerals have been previously investigated in combined settings (Flowers et al., 1979; Pansky & Algom, 2002), the present work is the first attempt to directly contrast the spatial-numerical association for symbolic and non-symbolic numerals by presenting both stimuli simultaneously. To do so, we created dice-like patterns but instead of dots, we displayed digits. In two separate tasks, participants were required to either respond to the symbolic value of the digits whilst ignoring their numerosity, or to respond to the number of digits present whilst ignoring their symbolic value. According to previous literature, both symbolic and non-symbolic numerals should elicit a SNARC effect. Therefore, when judging non-symbolic numerals, small (vs. large) numerosity should elicit faster left (vs. right) responses. However, since symbolic numerals are also simultaneously present with numerosity, these should also elicit a SNARC effect despite being task irrelevant (Fias et al., 2001). The same should work in the other direction, although evidence of non-symbolic numerals eliciting SNARC effects when numerical magnitude is task irrelevant are scarce (for an example see Nuerk et al., 2005).

If both symbolic and non-symbolic numerals are represented by a shared system, we would expect the SNARC effects to positively interact in the congruent condition (small digits/small numerosity; large digits/large numerosity), leading to a stronger spatial-numerical association. Conversely, in the incongruent condition (small digits/large numerosity; large digits/small numerosity), we should expect the SNARC effects to negatively interact as the effects for symbolic and non-symbolic numerals would have opposite directions. In this condition we would expect an absent or weak SNARC effect. Finally, if these two representations are independent, as suggested by recent evidence (Buijsman & Tirado, 2019; Marinova et al., 2021; Sasanguie et al., 2017), congruency between different numerical information should not impact the SNARC effect.

**2.0 Method**

**2.1 Participants**

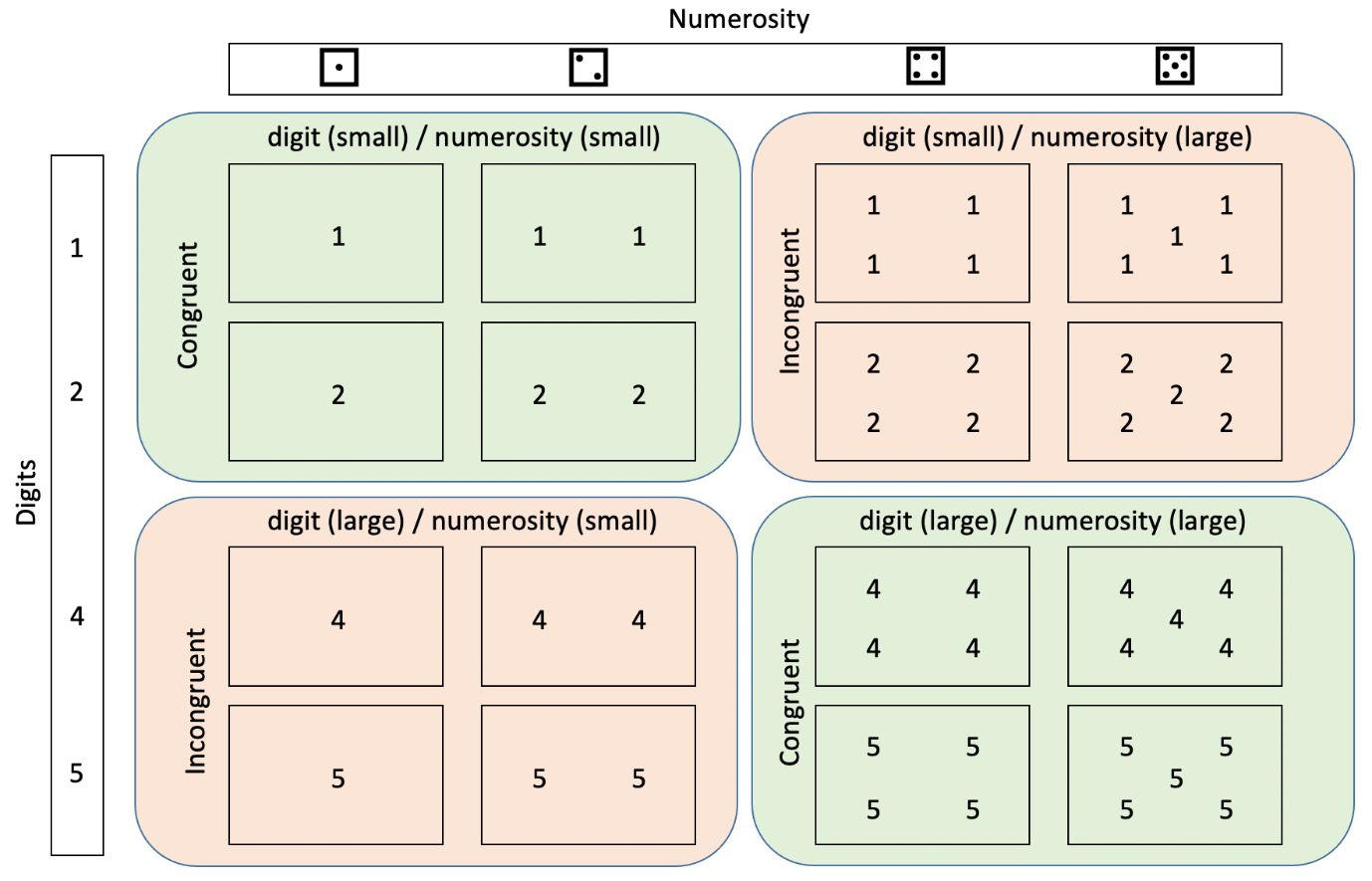
An a priori power analysis was conducted using the software MorePower 6.0.4. Based on a recent study that investigated the SNARC effect for non-symbolic numerals (Cutini et al., 2019) we set the following parameters: power = .80, α = .05, partial eta squared = .21 for repeated measures ANOVAs; power = .80, α = .05, Cohen’s d = .43 for one sample t-tests. The largest sample size suggested by the two tests was 44. We decided to be more conservative and considered a sample of approximately 50 participants to be adequate.

Fifty-two students (48 females) from De Montfort University took part in the study and were rewarded with coursework credits. The mean age was 21.0 (*SD* = 4.7). 41 participants were right-handed, whilst seven were left-handed. All participants reported to have normal or corrected-to-normal vision and were naïve about the purpose of the study. Written informed consent was obtained before participation. The study was approved by the Faculty of Health and Life Sciences Research Ethics Committee (Ref: 3488) and was conducted in accordance with the ethical standards established by the Declaration of Helsinki.

**2.2 Apparatus and stimuli**

The online experiment was designed using PsychoPy (Peirce et al., 2019), version 2020.2.5 and then conducted on Pavlovia through the participants’ personal computers. Responses were collected using the ‘A’ and ‘L’ keys on the participants’ computer ‘qwerty’ keyboards.

Stimuli consisted of four numbers (1,2,4 and 5) presented in white against a grey background with the letter height set at 0.08 height units. Each trial presented only one number out of the four, and in each trial, the numbers were displayed as a dice-like formation (see Figure 1). When only one number was shown, it was positioned in the centre of the screen (0,0), two numbers were positioned with the co-ordinates (-.08,0) and (.08,0), four numbers were positioned at (-.08,.08), (.08,.08), (-.08,-.08), and (.08,-.08), whilst five numbers were positioned at (0,0), (-.08,.08), (.08,.08), (-.08,-.08), and (.08,-.08). Between each trial, there was a fixation cross set at the centre of the screen with a height of 0.1.



*Figure 1. A depiction of the stimuli and the experimental manipulations. Symbolic (digits) and non-symbolic (numerosity) numerals were combined to create congruent (small digit/small numerosity; large digit/large numerosity) and incongruent (small digit/large numerosity; large digit/small numerosity) conditions.*

**2.3 Procedure**

The experiment took place online and participants were required to complete the experiment in a quiet room without distractions. Participants were instructed to place their right index finger on the rightmost key ‘A’ and their left index finger on the leftmost key ‘L’. Each trial started with a blank screen and was followed by a fixation cross that was presented at 500ms and stayed for 500ms. 1500ms after the start of the trial, the target numbers were presented for 3000ms, the keyboard response was activated simultaneously and had a duration of 3500ms. For this task, all participants completed two conditions that had two separate blocks of trials each. In one condition, participants were required to judge symbolic numerals (digits) and ignore non-symbolic numerals (numerosity). They had to determine if the digit was larger or smaller than the reference standard (3); when the digit was larger, participants had to press the ‘L’ key; when the digit was smaller, participants had to press the ‘A’ key. After completing the first block in the first condition, the keys were switched for the second block; if the digit was smaller, the ‘L’ key was pressed, and if the digit was larger, the ‘A’ key was pressed. The instructions were the same for the second condition, where the task required the participant to determine whether there were more or less than three digits on the screen (non-symbolic numeral/numerosity) while ignoring the digits’ magnitude (symbolic numerals). Similar to the first condition, the response keys for the second block of the second condition were switched.

Participants were randomly split into four groups where the order of the two conditions and their consequent blocks was counterbalanced across all participants. Each block started with 16 practice trials before the participant completed 80 trials for the main trials. Trials in each block were randomised and all four numbers were equally presented in each of the four dice-like positions. Additionally, there were an equal number of ‘smaller’/’larger’ responses in each block. This resulted in each participant completing 320 main trials. Participants were allowed a break between each block until they were ready to continue to the next block. Both speed and accuracy of responses were stressed in the instructions.

**3.0 Results**

**3.1 Pre-processing**

Reaction times less than 150ms were removed (Brenner & Smeets, 1997). Data from two participants were also removed for having a high number of errors (over 20%). The remaining sample made few errors (0.93-13.47%) with average error percentage being 5.70%. Because of this, accuracy was not analysed. 34 trials where participants failed to make a response were removed from the analysis alongside all incorrect responses. For outliers, we specified a threshold of 3 standard deviations and calculated the individual means and standard deviations within each condition. This approach detected 304 outlier trials, which were removed from the sample before analysis. Data and analysis scripts are available on the Open Science Framework (https://osf.io/e7rj3/).

**3.2 Symbolic task**

Individual mean reaction times were entered into a response hand (left vs. right) X number magnitude (small vs large) X congruency (congruent vs incongruent) Repeated Measures ANOVA. A main effect of congruency [F(1, 51) = 25.06, *p* < 0.001, = .330] was found, suggesting that reaction times were faster when the numerical information was congruent (M = 502.06, SE = 2.56) versus incongruent (M = 520.39, SE = 2.73) (small/large digits were presented in small/large numerosity). A main effect of magnitude [F(1, 51) = 4.96, *p* = 0.03, = .089] was also found, suggesting that participants were faster in responding to smaller numerical magnitude (M = 507.98, SE = 2.51) in comparison to larger numerical magnitudes (M = 514.38, SE = 507.98). Most importantly, a significant hand X magnitude interaction was found [F(1, 51) = 7.53, *p* = 0.008, = .129] which is clear evidence of a SNARC effect (Figure 2). No other interactions were significant and there was no evidence of a 3-way interaction between hand, magnitude and congruency, suggesting that the SNARC effect was not modulated by congruent/incongruent non-symbolic numerals. A table containing mean values and standard errors can be found in the appendix.

Chart

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*Figure 2: Mean reaction times with error bars representing standard error of the mean (SEM) for congruent (A) and incongruent (B) conditions in the symbolic task.*

**3.3 Non-symbolic task**

Individual mean reaction times for the numerosity condition were entered into a response hand (left vs right) X non-symbolic numerical magnitude (small vs large) X congruency (congruent vs incongruent) Repeated Measures ANOVA. A significant main effect of congruency was found [F(1, 51) = 28.44, p < 0.001, = .358]. Once again this suggests that participants were faster to react when the numerosity stimuli were congruent (M = 485.68, SE = 2.42) versus incongruent (M = 502.34, SE = 2.58). We also found a significant main effect of response hand [F(1, 51) = 5.13, p= 0.02, = .091). This suggests that participants were significantly faster at responding when using their right (M = 489.35, SE = 2.53) versus left (M = 498.35, SE = 2.47) hand. Finally, we find a significant main effect of magnitude, whereby responses to large magnitudes (M = 486.57, SE = 2.38) were faster than small magnitudes (M = 501.18, SE = 2.61) [F(1, 51) = 13.32, p < 0.001, = .207). However, no interactions were significant in the ANOVA, therefore there was no evidence of a SNARC effect (hand X magnitude interaction) [F(1, 51) = 0.38, p = 0.542, = .007)] (Figure 3). A table containing mean values and standard errors can be found in the appendix.

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*Figure 3: Mean reaction times with error bars representing SEM for congruent (A) and incongruent (B) conditions in the non-symbolic task.*

**4.0 Discussion**

The aim of this study was to directly contrast the SNARC effect for symbolic and non-symbolic numerals within the same experiment. To do so we created a novel set of stimuli consisting of dice-like patterns with digits being displayed instead of dots. Therefore, both symbolic (numerical value of digits) and non-symbolic (number of digits on the screen) numerals were simultaneously present within the same stimuli. This resulted in congruent (small numerosity/small digits or large numerosity/large digits) and incongruent (small numerosity/large digits or large numerosity/small digits) conditions. Participants were required to perform a symbolic and a non-symbolic magnitude classification task in separate sessions, while all other variables were kept constant. Based on both ANS and ATOM, we should expect that congruency between symbolic and non-symbolic numerals would interact with the SNARC effect; conversely, our results are in line with recent evidence suggesting independent representations for symbolic and non-symbolic numerals (Buijsman & Tirado, 2019; Marinova et al., 2021; Sasanguie et al., 2017.

When participants were required to process symbolic numerals a robust SNARC effect was found, with small digits being responded to faster with left key presses, and large digits with right key presses. Contrary to what should be expected from a shared numerical representation, symbolic and non-symbolic numerals did not interact. More specifically, non-symbolic numerals neither facilitated nor inhibited the SNARC effect in the congruent and incongruent conditions, respectively, thus supporting the idea of independent representations. Although we cannot exclude that non-symbolic numerals did not interact with the SNARC effect simply because they were task irrelevant (see Cleland et al., 2020; Pellegrino et al., 2021), our data clearly show overall slower response times in the incongruent conditions. This indicates that, despite being task irrelevant, numerosity was still processed and did impact participants’ responses, but did not interact with the SNARC effect.

When participants were required to process non-symbolic numerals, a SNARC effect was not detected. This is in contrast with previous studies that revealed a SNARC effect for dots arranged either as dice patterns (Cutini et al., 2019; Nuerk et al., 2005) or distributed randomly in the visual field (Cutini et al., 2019; Nemeh et al., 2018; Zhou et al., 2016). The absence of a SNARC effect for numerosity might be ascribed to our ‘atypical’ non-symbolic stimuli which contained symbolic numerals instead of dots. However, if the symbolic nature of the stimuli were responsible for this result, we should expect a SNARC effect to be driven by digit magnitude which is known to elicit SNARC effects even when task irrelevant (e.g., Fias et al., 2001). Conversely, our data show that digits did not modulate the response pattern for non-symbolic numerals. However, similarly to the symbolic task, slower responses were detected in the incongruent condition suggesting that irrelevant symbolic numerals were still processed during the task.

Our results for numerosity judgment add to recent evidence suggesting that, differently from digits, non-symbolic numerals do not offer a direct route to spatial-numerical associations (Cleland et al., 2020; Pellegrino et al., 2021). Furthermore, this evidence questions the ATOM model (Walsh, 2003) which posits that magnitudes across different domains and formats should be spatially coded similarly to digits. Conversely, in our study, SNARC seems to be closely related to symbolic numerals, thus failing to prove to be a SQUARC effect as predicted by Walsh (2003). Finally, our findings are also challenging to be explained in terms of the WM model (van Dijck et al., 2011). Indeed, this account posits that every type of stimuli can be spatially organized in WM during task execution and, consequently, can elicit a SNARC-like effect (first items of the sequence are associated with left responses and later items with the right, independently from their identity). Therefore, according to this account, similar SNARC effects should be elicited by both symbolic and non-symbolic numerals, while a clear and consistent difference emerged in our study.

Taken together, the facts that 1) non-symbolic numerals did not modulate the SNARC effect for digits and 2) symbolic numerals did not interact with the response pattern for numerosity, are in contrast with the idea of a common system for number processing (ANS) (Dehaene, 1993; Nieder, 2016; Nieder & Dehaene, 2009; Piazza, 2010; Piazza et al., 2007). Indeed, if symbolic numerals are directly mapped onto their non-symbolic counterparts, we would expect compatible representations to positively interact in the congruent condition and incompatible representations to negatively interact in the incongruent condition. However, our data show that this was not the case. Therefore, our findings are in line with recent studies that question the existence of ANS and support the idea of separate processing mechanisms for symbolic and non-symbolic numerals (Núñez, 2017; Marinova et al., 2021; Sasanguie et al., 2017; Van Hoogmoed & Kroesbergen, 2018; Van Hoogmoed et al., 2021). Furthermore, our results suggest that non-symbolic numerals are fundamentally different from digits and comparable to other non-numerical magnitudes (Algom, 2021; Bar et al., 2019). This is supported by a previous review and meta-analysis, which showed that the effect size of the SNARC-like effect for non-numerical magnitudes is smaller than the effect size normally detected for symbolic numerals (Macnamara et al., 2018). Furthermore, this study also revealed a clear publication bias which suggests that non-significant results have not been published in studies investigating non-numerical magnitudes. Based on this evidence, it is not that surprising that symbolic numerals showed a clear SNARC effect in our study while non-symbolic numerals failed to do so.

A possible limitation of our study is that, from a perceptual point of view, symbolic and non-symbolic numerals were processed at different levels. Indeed, digits were processed at a local level in our stimuli while numerosity was processed at a global level (see Navon, 1977). This might have been a confound in our design and could have influenced our findings, in particular regarding the absence of a SNARC effect for non-symbolic numerals. However, Navon (1977) clearly showed that the analysis of the global features of a visual pattern preceded the one of local features, thus suggesting a superiority of global over local processing. With this in mind, we are relatively confident that our results have not been influenced by this phenomenon. However, future studies should systematically manipulate the global and local features of the stimuli and determine whether these have an influence on the SNARC effect. Further developments from our study that future works should consider consist in using different non-symbolic configurations, numerosity range, and tasks. For example, instead of employing dice patterns, digits in random position could be displayed and the range of the stimuli could be manipulated to extensively test numerosity outside of the subitizing range. Finally, as different task demands produced different results in some contexts (see Prpic et al., 2016 and Mingolo et al., 2021), our findings should be replicated with different SNARC tasks, such as parity judgment.

To conclude, our results support recent evidence in favour of two independent processing systems for symbolic and non-symbolic numerals (Marinova et al., 2021; Sasanguie et al., 2017) and are in line with studies suggesting a fundamental distinction between these two numerical formats (Algom, 2021; Bar et al., 2019). Our study provides challenging evidence for the ANS theory, which predicts an interaction between the spatial representation of symbolic and non-symbolic numerals. Furthermore, the fact that only symbolic numerals elicited a clear SNARC effect is against both the ATOM (Walsh, 2003) and the WM model (van Dijck & Fias, 2011), which predict similar spatial associations for symbolic and non-symbolic numerals.

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**Dataset:**

All data and codes have been made publicly available at the Opens Science Framework and can be accessed at https://osf.io/e7rj3/.

**Declaration of interest:**

none

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