SNARCing With a Phone: The Role of Order in Spatial-Numerical Associations Is Revealed by Context and Task Demands

Published Version:
SNARCing With a Phone: The Role of Order in Spatial-Numerical Associations Is Revealed by Context and Task Demands / Mingolo S.; Prpic V.; Bilotta E.; Fantoni C.; Agostini T.; Murgia M.. - In: JOURNAL OF EXPERIMENTAL PSYCHOLOGY-HUMAN PERCEPTION AND PERFORMANCE. - ISSN 0096-1523. - ELETTRONICO. - 47:10(2021), pp. 1365-1377. [10.1037/xhp0000947]

Availability:
This version is available at: https://hdl.handle.net/11585/860386 since: 2022-02-17

Published:
DOI: http://doi.org/10.1037/xhp0000947

SNARCing with a phone: the role of order in spatial-numerical associations is revealed by context and task demands

Serena Mingolo[1*], Valter Prpic[2*], Eleonora Bilotta[3], Carlo Fantoni[1], Tiziano Agostini[1], Mauro Murgia[1*]

[1] Department of Life Sciences, University of Trieste, Trieste, Italy

[2] Institute for Psychological Science, De Montfort University, Leicester, United Kingdom

[3] Department of Physics, University of Calabria, Rende (CS), Italy

[*]these authors contributed equally

Corresponding author: Serena Mingolo

Department of Life Sciences, University of Trieste

Via Edoardo Weiss 21, 34100, Trieste, Italy

E-mail: serena.mingolo@phd.units.it

Phone: +39 3291848658

Abstract

Previous literature on the SNARC effect examined which factors modulate spatial-numerical associations. Recently, the role of order in the SNARC effect has been debated and further research is necessary to better understand its contribution. The present study investigated how the order elicited by the context of the stimuli and by task demands interact. Across three experiments, we presented numbers in the context of a mobile phone keypad, an overlearned numerical display in which the ordinal position of numbers differs from the mental number line. The experiments employed three tasks with different levels of consistency with the order elicited by the context. In Experiment 1, participants judged numbers based on their spatial position on the keypad, and we found a spatial association consistent with the keypad configuration, indicating that the spatial association is driven both by the context and by the task when they consistently elicit the same order. In Experiment 2a, participants performed a magnitude classification task and results revealed a lack of spatial associations, suggesting a conflict between the orders elicited by the context and by the task. In Experiment 2b, participants performed a parity judgement task and the results revealed a SNARC effect, suggesting that the order elicited by the context did not modulate the spatial association. Overall, three different tasks gave rise to three different results. This shows that the context alone is not sufficient in modulating spatial-numerical associations, but that the consistency between the orders elicited by context and task demands is a key factor.

Keywords: SNARC, spatial associations, context, task, flexibility.

Public significance statement:

Humans use spatial coordinates to mentally represent numbers. Typically, small numbers are represented on the left space and large numbers on the right space. However, the association between numbers and space is quite flexible and previous studies showed that it could be modulated by the context in which numbers are presented. Is the context sufficient to modulate spatial-numerical associations? In the present study, we demonstrate that task demands have an important role and that the direction of the spatial-numerical association depends on the interaction between task demands and context.

The Spatial-Numerical Association of Response Codes (SNARC) effect was first investigated by Dehaene, Bossini, & Giraux (1993) and referred to the association of numbers with spatial response coordinates. This effect consists of a left key-press advantage for small numbers (e.g., 1) and a right key-press advantage for large numbers (e.g., 9) in a given numerical interval (e.g., 1-9). This effect has been observed in various tasks and formats, both in the visual and auditory modality (for a review, see Wood et al., 2008). Dehaene et al. (1993) suggested that the SNARC effect could be explained by the existence of a magnitude representation in semantic memory in the form of a hypothetical Mental Number Line (MNL), featuring small numbers on the left side and large numbers on the right side. Therefore, the association between this overlearned mental representation of numbers (i.e., MNL) and the execution of responses in the external space would elicit the SNARC effect (for alternative explanations, see Gevers et al., 2006; Proctor and Cho 2006).

The research on the SNARC effect was later enriched by findings on non-numerical sequences. Indeed, ordinal sequences such as letters of the alphabet, months of the year, and days of the week (Gevers et al., 2003; 2004) as well as newly acquired word sequences (Previtali et al., 2010) elicit SNARC-like effects. These results have been explained by the fact that these types of stimuli are characterized by overlearned ordinality (i.e., the property of items of being classified based on their relative position in a series), which can be spatially coded similar to numbers. Hence, both numerical and non-numerical overlearned ordinal sequences would elicit SNARC-like effects.

Furthermore, SNARC-like effects have been found in the processing of non-symbolic quantities such as luminance (Fumarola et al., 2014; Ren et al., 2011), size (Prpic et al., 2020; Ren et al., 2011), weight (Dalmaso & Vicovaro, 2019), temporal duration and pace (De Tommaso & Prpic, 2020; Ishihara et al., 2008; Vallesi et al., 2008; Vallesi, McIntosh, et al., 2011), angle magnitude (Fumarola et al., 2016) and facial expressions of emotions (Holmes & Laurenco, 2011, see also Fantoni et al. 2019; Baldassi et al., 2021). The stimuli used in these studies are not typically organized as overlearned ordinal sequences, therefore these SNARC-like effects are reasonably accounted for in terms of magnitude.

This body of evidence suggests that both ordinal and magnitude features can elicit a spatial representation (Prpic et al., in press). Notably, there is a natural confound in the ordinal and magnitude properties of numerical stimuli because these features covariate in numbers. Indeed, in western cultures, numbers are represented as an ordinal sequence progressing from left to right, with stimuli increasing in magnitude from left to right. Hence, the spatial mapping of numbers could be determined either by order or by magnitude (or both). To disambiguate this confound, Prpic et al. (2016) performed three experiments on musicians, employing musical note values (i.e., graphic symbols expressing the relative duration of musical notes) as stimuli. These stimuli are typically represented as decreasing from left-to-right, starting from the whole note and followed by progressively smaller note values. Thus, different from numbers, in musical note values, order and magnitude are represented in opposite directions. Interestingly, results showed that when the task explicitly required the processing of the note value (i.e., note value comparison - direct task), a typical left-to-right spatial association emerged, in line with the direction of the overlearned order of note values; conversely, when the note value was not to be processed explicitly (i.e., line orientation judgment - indirect task), a reversed spatial association effect emerged, in line with the direction of the magnitude. Results suggest that SNARC-like effects are determined by two separate mechanisms involved in the processing of order and magnitude, which would be revealed by direct or indirect tasks, respectively. However, the contribution of order and magnitude in the SNARC effect (i.e., with numerical stimuli) has still not been disambiguated.

Flexibility and Context

An important issue of the SNARC effect is its flexibility. Many studies point out that the association between numbers and spatial coordinates is not stable but can be altered by manipulations occurring before or during the experiment (for a review, see Cipora et al., 2018). Modifications of the SNARC effect have been observed in participants with different reading/writing habits. Normally, individuals from different cultures exhibit different SNARC-like effects, consistent with their reading/writing direction (e.g., Dehaene et al., 1993; Zebian, 2005; Shaki et al., 2009, but see also Cipora et al., 2019 and Zohar-Shai et al., 2017 for different results).

In a study by Fischer et al. (2010), the association between reading-writing direction and the SNARC effect was changed by a manipulation occurring before the task. Before performing a parity judgement task, participants read written recipes presenting small or large numbers placed in a congruent or incongruent position with their reading/writing direction. Although the position of the numbers was irrelevant to the task, results in the incongruent condition showed a reduction of the SNARC effect in native English speakers and its reversal in Hebrew speakers.

Similarly, Shaki and Fischer (2008) reported a modification of this association in bilingual participants speaking two languages with opposed reading/writing directions, namely Russian and Hebrew. In this case, participants exhibited the classic left-to-right oriented SNARC effect after reading Cyrillic script (from left to right), whilst this effect was significantly reduced after reading Hebrew script (from right to left). Thus, even though reading/writing habits are crucial for the spatial association of numbers, these results highlight that this association is quite flexible and can be modulated by the context. In particular, when a specific direction is activated by an event preceding the task (e.g., reading a script in a specific language), the SNARC effect is modified according to this experience.

Recently, Pitt and Casasanto (2020) proposed a CORrelations in Experience (CORE) principle in which they suggest that experience with a specific domain (time or numbers) shapes the SNARC effect, arguing against the idea that a common set of cultural experiences could be responsible for the direction of all SNARC/SNARC-like effects. To support their claims, in one experiment (Experiment 2), the authors manipulated the direction of an experience that spatializes numbers, namely finger counting, through a training before the experiment (right-ward vs left-ward finger counting). Results showed that, whereas the right-ward finger counting training produced the typical SNARC effect, the left-ward finger counting training determined a significant reduction of this effect. These results, and the CORE principle they support, indicate that any experience that spatializes numbers, even situational ones, can influence spatial numerical associations.

The SNARC effect can also be overrun by manipulating the ordinal position of numbers in working memory. For instance, when participants are trained to retain a sequence of five random numbers in working memory and to perform typical SNARC tasks using a go/no-go procedure (responding only to numbers in the sequence), the spatial association follows the ordinal position rather than the MNL (ordinal position effect; van Dijck & Fias, 2011). Ginsburg and Gevers (2015) further investigated the role of working memory. In two experiments, the authors manipulated the activation of the canonical number sequence (MNL) and of a newly acquired numerical sequence relevant to the task. Results showed that the SNARC effect and the ordinal position effect are not mutually exclusive and can determine different spatial associations. They concluded that spatial associations could be determined by both pre-existing representations in long-term memory and temporary representations in working memory, depending on the level of activation of these representations.

Similarly, an alternative long-term representation of numbers (e.g., clock-face) can elicit SNARC-like effects when it is emphasized by the context. A classic example is a study by Bächtold et al. (1998), which shows that it is possible to reverse the SNARC effect by manipulating the context. Participants were instructed to imagine numbers as indicating length on a ruler (Experiment 1) or time on a clock-face (Experiment 2). It is noteworthy that in the clock-face configuration, the order of numbers is opposite to that of the MNL (small numbers are depicted on the right, and large numbers are depicted on the left). In Experiment 1, the authors found a left key-press advantage for small numbers (1-5) and a right key-press advantage for large numbers (7-11). Differently, in Experiment 2, they found the opposite pattern of results. This indicates that the clock-face representation replaced the MNL, leading to a reversed SNARC effect. These results reveal that contexts can elicit ordinal representations of numbers opposed to the MNL.

The mobile-phone keypad as an alternative spatial representation of numbers

Another alternative configuration of numbers is the numeric keypad. Similar to the clock-face employed by Bächtold et al. (1998), the spatial arrangement of the keypad is overlearned and culturally shared by the vast majority of the population. Therefore, this configuration is already stored in long-term memory and does not require any training to be encoded and recalled. Moreover, numbers presented in a keypad configuration are recalled more easily compared to when they are presented singularly or in a linear display (Darling & Havelka, 2010). It is noteworthy that numeric keypad can have different formats. For example, the keypad used to dial telephone numbers in mobile phones (see Figure 1a) presents small numbers on the top and large numbers on the bottom; differently, the keypad used in calculators present the opposite vertical arrangement but with the same horizontal arrangement. In the present study, we will refer to the mobile phone keypad.

In the mobile-phone keypad configuration, numbers from 1 to 9 are not linearly arranged in a typical left-to-right progression but are ordered from left to right in three rows, resulting in a 3x3 matrix. Importantly, the numbers of this configuration are exactly the same numbers (from 1 to 9) used in the vast majority of studies on the SNARC effect. Thus, unlike the clock-face, the keypad only features single-digit numbers, eliminating the possible confound deriving from two-digit numerical stimuli (Nuerk et al., 2011). By looking at the picture of a keypad, if we assume number 5 to be the middle point reference, we will note that some elements of this configuration violate the MNL representation, while others overlap with it. We can see that 1 and 4, which are smaller than 5, are located on the left of the configuration. Similarly, 6 and 9 are larger than 5 and are located on the right. Conversely, the relative position of 3 and 7 is different from that of MNL: 3 is smaller than 5 but is located on its right, whereas 7 is larger than 5 but is located on its left. Hence, the keypad configuration contains numbers that are represented in the same way they are represented in the MNL, and numbers (i.e., 3 and 7) that conflict with this representation (Figure 1b).

Finally, while the clock-face configuration is evoked by a device (i.e., the clock) which is used passively and does not require any manipulation, the keypad configuration is evoked by devices (e.g., phones, ATM, POS, computers, remote control) which are used actively and require to be manipulated to dial numbers. Hence, the keypad is interactive and strictly related to hand movements.

For these reasons, the keypad represents a useful context in which numbers can be represented, eliciting an order alternative to the MNL.

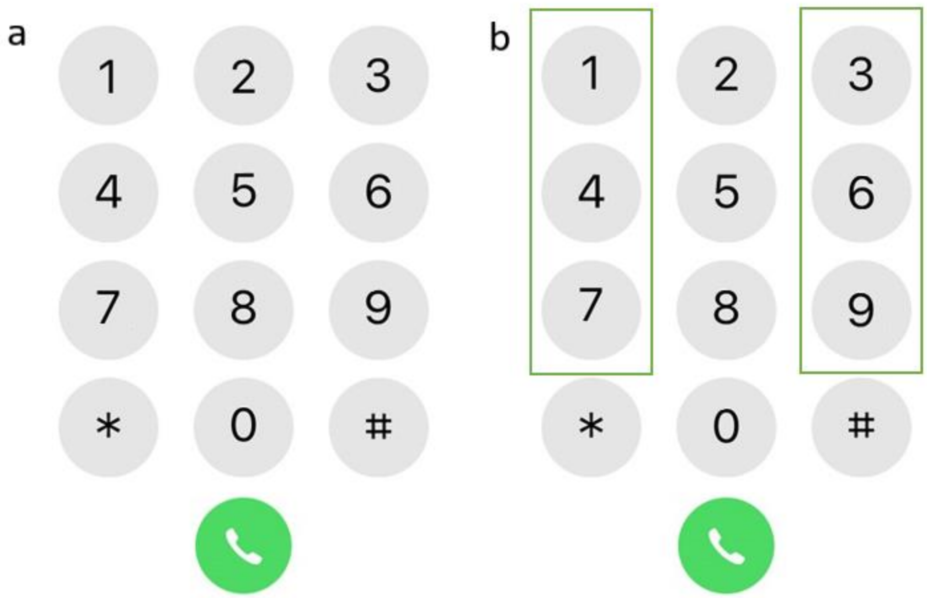

Figure 1. Figure 1a shows a mobile-phone numeric keypad. Figure 1b highlights the numbers displayed on the left and the right of the keypad configuration.

The role of the task

Another important issue regarding the flexibility of the SNARC effect is the role of the task.

Typically, in studies on the SNARC effect, two families of tasks are employed. The first one includes tasks that are commonly called *order-relevant*, *explicit,* or *direct*; the second one includes tasks that are commonly called *order-irrelevant*, *implicit* or *indirect*.

In direct tasks, participants are directly asked to compare a feature of the stimuli (which is relevant for the study) with a reference. It has been suggested that the direct tasks induce an ordinal judgement (Pitt & Casasanto, 2020; Prpic et al., 2016). A typical example of a direct task is the magnitude classification task, which, despite its name, paradoxically relies on order rather than on magnitude (Pitt & Casasanto, 2020). In this task, participants are asked to classify numbers as smaller or larger than a middle reference standard (e.g., 5). To solve this task, participants are induced by instructions to mentally represent the entire sequence of the stimuli in a linear fashion (MNL). Once the representation of the MNL is activated, the participant must retrieve the ordinal positions of both the reference and the target number and compare them to make an ordinal judgement. For this reason, a magnitude classification task requires participants to classify numbers depending on their ordinal position, namely *before* or *after* 5, in the MNL.

In indirect tasks, participants are asked to judge a feature of the stimuli irrelevant to the study; examples of indirect tasks are the parity judgement, and the orientation task (Notebaert et al., 2006). Unlike direct tasks, the indirect ones do not require ordinal judgement, as participants are not required to directly compare the stimuli with a reference. For example, in the orientation judgement task, participants are asked to judge the orientation of visually presented numbers (upright or tilted 20° to the right). In this case, the only feature activated by instructions is the orientation of the digit, independently from the number itself. Thus, orientation is the only feature that participants use to solve the task. The same reasoning can be applied to parity judgement (in which participants are asked to classify a number as even or odd) since the only feature activated by instructions and relevant to solve the task is parity/disparity of numbers. Consequently, to solve these tasks, participants do not need to mentally represent an ordinal sequence of the stimuli. For this reason, it is unlikely that this task induces ordinality. We are not claiming that order is not activated at all, but we highlight that this activation is not directly induced by task instructions, as it happens with direct tasks.

It is noteworthy that results from direct and indirect tasks usually reveal different patterns of spatial association. For instance, it is well-known that the SNARC effect arising from the magnitude classification task generally presents a categorical shape, whereas the parity judgement tends to exhibit a continuously distributed SNARC slope (Gevers et al., 2006; Wood et al., 2008).

The present study

The present study aims to investigate the role of order in the SNARC effect by examining the factors that elicit ordinality, namely the context of the stimuli and the task. Indeed, in studies on the SNARC effect, both context of the stimuli and task can induce ordinality, and the relative contribution of each factor might be confounded. For instance, in the seminal study by Bächtold et al. (1998), these aspects were not disambiguated. Indeed, the authors manipulated the context of the stimuli (e.g., clock-face vs ruler) and attributed the reversal of the SNARC effect observed in the clock-face condition to the context. It is true that the reverse order of the stimuli of the clock-face condition is a factor potentially driving this effect by itself, however, the context was further reinforced by a direct task that enhanced the ordinal properties of the display. Indeed, participants were asked to imagine a clock face and to judge whether a number indicated a time earlier or later than 6 o'clock. Thus, the task required a judgement based on the same clock face order elicited by the context (large numbers on the left and small numbers on the right). Therefore, it is not clear whether spatial-numerical associations are driven by the context of the stimuli or by the task (or both).

In the present study, we investigated the contribution of order induced by the context and by the task to spatial-numerical associations. We manipulated the context by asking participants to visualize numbers on the keypad configuration. The keypad should elicit a spatial representation of numbers compatible with its spatial arrangement, whose order partly differs from that of the numerical stimuli in the MNL. Furthermore, we manipulated the task demands to obtain different levels of compatibility between the order elicited by the context and elicited by the task. In Experiment 1, we used a direct task (keypad-position task) that elicited an order consistent with the one elicited by the context (i.e., the keypad). In Experiment 2a, we used a direct task (magnitude classification) that elicited an order (i.e., MNL) inconsistent with the one elicited by the context (i.e., the keypad). In Experiment 2b, we used an indirect task (parity judgement) that did not elicit a specific order; thus, there was neither consistency nor inconsistency with the order elicited by the context.

Experiment 1

In Experiment 1, the order of the keypad configuration is emphasized by both the context and the task. In particular, the keypad is used as context at the beginning of the experiment; moreover, it was used as a direct task (keypad-position task) that requires participants to judge the spatial location of numbers based on their position on the keypad. Hence, in this experiment, the keypad configuration order presented at the beginning is further reinforced by the task requirements.

We hypothesized the occurrence of a spatial-numerical association consistent with the keypad configuration rather than with the MNL. In particular, we expected that numbers 1, 4 and 7 would be responded faster with the left key and numbers 3, 6 and 9 would be responded faster with the right key. Thus, according to our expectations, the numbers 3 and 7 should be associated with opposite coordinates compared to the MNL. These hypotheses would be consistent with the findings by Bächtold et al. (1998), who used a similar paradigm in which the context was reinforced by the task, namely the order elicited by the stimuli and the task were consistent.

Method

Participants

We tested 30 students from the University of Trieste (M = 8; F = 22) with a mean age of 22.09 (SD = 2.84). The sample size was determined by means of the software MorePower 6.0.4. For repeated measures ANOVAs, the following parameters were used: power = .90, α = .05, partial eta squared = .27 (estimated effect size from Dehaene, Bossini, and Giraux, 1993); the outcome was a suggested sample size of 16 participants. For paired-samples t-tests, the following parameters were used: power = .90, α = .05, Cohen's d = .65 (estimated effect sizes from Bächtold et al., 1998); the outcome was a suggested sample size of 27 participants. Moreover, a recent article specifically addressed this issue in studies on SNARC effects (Cipora & Wood, 2017). The authors suggest the rule of thumb, "20*20", recruiting at least 20 participants performing 20 repetitions per stimulus. According to the power analyses and the guidelines provided by Cipora and Wood (2017), we designed the experiments to have 20 repetitions per stimulus and recruited a number of participants they considered "large", namely 30. All participants reported to be righthanded and to have normal or corrected-to-normal vision. They were all used to the left-to-right writing direction and were naive about the purpose of the study. All participants reported that their psychophysiological state was not affected by alcohol consumption or insufficient sleep in the last 24 hours (Murgia et al., 2020). Written informed consent was obtained before participation; the experiment was conducted in accordance with the ethical standards established by the Declaration of Helsinki and with the agreement of the University of Trieste Ethics Committee.

Apparatus and stimuli

The experiment was designed and controlled by the Psychopy software, version 3.0. The experiment was run with a Dell desk computer with Intel Core i5 (RAM: 4 Gb). The monitor used to display instructions and stimuli was a Quato Intelli Proof 242 excellence (24 inches), with a 1024 × 768 resolution., and a five-button serial response box was employed to collect participants' responses.

Participants were presented with a single-digit number and were asked to judge whether the presented number is located on the right or the left of the number 5 on the keypad configuration. Stimuli consisted of six single-digit numbers (1-3-4-6-7-9) and were presented one at a time in the centre of the screen, painted in white against a grey background. The digits 2 and 8 could not be used as stimuli because, on the keypad, they are located on the central axis; the digit 5 could not be used as well because it served as the point of reference for the task.

Procedure

The experiment took place in a quiet, dimly lit room. Participants were invited to sit in front of the PC screen, at a viewing distance of approximately 60 cm, with their body aligned to the midline of the screen. They were instructed to move as little as possible and to put their left index finger on the leftmost key of the response box and their right index finger on the rightmost key.

The experiment was composed of two blocks; each block included a practice session (not considered for data analysis) and an experimental session.

Before starting each block, participants were exposed for 20 seconds to the picture of a mobile phone's keypad and were asked to pay particular attention to the spatial arrangement of the numbers. In the last 10 seconds of the presentation of the configuration, the left and right portion of the keypad were highlighted (Figure 1b) with two rectangles showing the three numbers at the left of the keypad (1-4-7) and the three numbers at its right (3-6-9). Participants were asked to keep in mind the keypad's configuration for the entire duration of the experiment while performing the task.

The practice session was divided into two parts. The first part of the practice session (6 trials x 2 repetitions) started with a fixation cross (500 ms), then, after an interstimulus interval (ISI) of 500 ms, the picture of the keypad appeared at fixation point (2000 ms). When the keypad picture disappeared, a fixation cross for 500 ms was presented, followed by an ISI of 500 ms. After that, a single-digit number appeared in the centre of the screen until a response occurred. Participants were asked to judge whether the presented number is located on the right or the left of the number 5 on the keypad configuration (keypad-position task) by pressing the leftmost or the rightmost key of the response box. For each trial, feedback about the response was given ("Correct!" or "Wrong!"). This part of the practice session was designed to help participants familiarize themselves with the keypad configuration. The second part of the practice session (6 trials x 5 repetitions) followed the same procedure as the first one, except for the lack of the keypad picture at the beginning of the trial.

In the experimental session (6 trial x 20 repetitions), participants performed the same task as the second part of the practice session, without any feedback. In block A, participants were required to press the leftmost key when the presented number was in the left part of the keypad, and the rightmost key, when the number was located on the right part of the keypad, compared to number 5. In block B, the response keys were reversed. The order of the blocks (A-B or B-A) was counterbalanced among participants. Participants were allowed to take a break between the two blocks if needed, otherwise, they could continue with the experiment. Instructions explicitly invited the participant to be as fast and accurate as possible.

Data analysis and results

Experimental variables were manipulated within a repeated measures design. The independent variables were Hand (left vs right) and Number (1,3,4,6,7,9). The dependent variable was the response time (RT). First, mean RTs were calculated for each participant in each session, separately for the left hand and right hand. Next, RTs of incorrect trials and outliers were removed. An RT was considered an outlier if it differed by more than 2.5 standard deviations from the mean RT of a participant in a session.

Based on these RTs, a 2x6 (Hand x Number) repeated measures ANOVA was computed. Repeated measures ANOVA revealed a significant main effect for Hand [$F(1, 29) = 8.84$; $p < .01$; $\eta_p^2 = .23$; $BF_{10} = 1.34$], showing faster response times with right-hand over left hand, and a significant main effect for Number [$F(5, 145) = 5.19$; $p < .001$; $\eta_p^2 = .15$; $BF_{10} = 0.67$], although Bayes Factor values are inconclusive. A significant interaction emerged as well [$F(5, 145) = 10.29$; $p < .001$; $\eta_p^2 = 0.26$; $BF_{10} > 100$], showing faster left-hand response times for numbers 1, 4 and 7, and faster right-hand response times for numbers 3, 6 and 9. See Table 1 for details.

Table 1

Mean and Standard Deviations of RTs for each condition of Experiment 1. Values are reported in milliseconds.

Hand	Numbers					
	1	3	4	6	7	9
Left hand	449 (52)	503 (86)	482 (69)	509 (97)	476 (64)	517 (104)
Right hand	481 (92)	471 (67)	504 (94)	462 (60)	493 (80)	455 (56)

Secondly, dRTs were computed by subtracting the mean RTs of the left hand from the mean RTs of the right hand: dRT = RT(right hand) - RT(left hand). Positive dRTs indicate faster responses with the left hand, whereas negative dRTs indicate faster responses with the right hand (Figure 2). Then, two paired-sample *t* tests were computed in order to compare the mean of the dRTs of the stimuli 1-4-7 vs. the stimuli 3-6-9 (Keypad configuration), and to compare the mean of the dRTs for stimuli 1-3-4 vs. 6-7-9 (Mental Number Line configuration). These analyses revealed both a significant effect elicited by the keypad configuration [stimuli 1-4-7 vs. 3-6-9; $t(29) = 3.56$; $p = .001$; $d = .65$; $BF_{10} = 26.5$] and an effect elicited by the Mental Number Line (MNL) configuration [stimuli 1-3-4 vs. 6-7-9; $t(29) = 3.32$; $p < .005$; $d = .60$; $BF_{10} = 15.1$].

Finally, a set of paired sample *t* tests was computed to verify whether the mean dRTs of numbers 3 and 7 were more in line with the keypad or with the MNL arrangement. The first comparison revealed that the mean dRTs for number 3 and 7 significantly differed [$t(29) = -2.70$; $p < .05$; $d = -.49$; $BF_{10} = 4.06$], with number 3 associated to the right compared to number 7. Furthermore, the mean dRTs for number 3 significantly differed from the average values observed for the other small numbers (i.e., 1 and 4), with number 3 associated to the right compared to the average of 1 and 4 [$t(29) = -3.36$; $p < .005$; $d = -.61$; $BF_{10} = 16.5$]. Similarly, the mean dRTs for number 7 significantly differed from the average values observed for the other large numbers (i.e., 6 and 9), with number 7 associated to the left compared to the average of 6 and 9 [$t(29) = 3.26$; $p < .005$; $d = .59$; $BF_{10} = 13.1$].

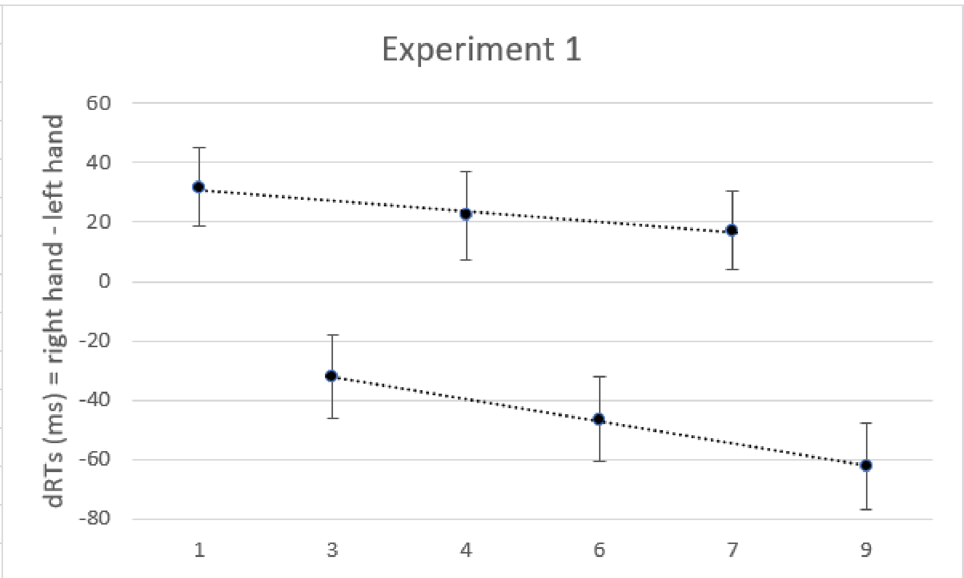

Figure 2. The figure shows the Mean dRTs (right key - left key) for every numerical stimulus in Experiment 1. Positive differences indicate faster left-key responses; negative differences indicate faster right-key responses. Errors bars indicate the standard error of the mean. Separate trend lines are computed for numbers 1-4-7 and 3-6-9, graphically showing that dRTs are organized dichotomously according to the keypad configuration.

Discussion

The results of Experiment 1 revealed both a significant effect elicited by the keypad configuration (stimuli 1-4-7 vs 3-6-9) and an effect elicited by the MNL configuration (stimuli 1-3-4 vs 6-7-9). Thus, both configurations may have played a role; this is not surprising since the configurations partly overlap.

However, by looking at Figure 2, it is immediately observable that the mean dRTs are dichotomously distributed. They are organized in two categories reflecting a response time advantage compatible with the keypad configuration. Indeed, responses to 1, 4 and 7 are faster with the left hand, whereas responses to 3, 6 and 9 are faster with the right hand. The analyses performed to verify whether the dRTs of numbers 3 and 7 reflected the MNL or the keypad configuration indicated that the keypad configuration prevails. Results showed that numbers 3 and 7 significantly differed from each other, and their spatial association is opposed to the one predicted by MNL and consistent with the keypad. Furthermore, number 3 was associated to the right in opposition to the other small numbers (i.e., 1 and 4); similarly, number 7 was associated to the left compared to the other large numbers (i.e., 6 and 9).

In summary, Experiment 1 indicates that when participants are asked to encode numbers on the keypad configuration and execute a keypad-position task, the response time advantage favours the keypad configuration.

However, we do not know whether the order elicited by the context is sufficient to determine a keypad-related association in the absence of a task eliciting the same order. For this reason, we designed Experiments 2a and 2b.

Experiments 2a and 2b

In Experiments 2a and 2b, we tried to disambiguate the results observed in Experiment 1 and to isolate the contribution of the order elicited by the context to spatial-numerical associations. For this reason, we employed two classic SNARC tasks (i.e., magnitude classification and parity judgement), in which the keypad configuration is irrelevant to solve the task. Typically, in the absence of trainings or context manipulations, these tasks elicit a SNARC effect. In our experiments, we investigate whether the context alone could interfere with these tasks, modifying the SNARC effect.

In the present study, the context consists of the presentation of the keypad at the beginning of each experiment. The keypad is a 3x3 matrix of numbers; thus the main difference with MNL is the spatial arrangement of items, namely their order. Different studies manipulated the ordinal position of numerical items, either verbally or visuo-spatially. For example, van Dijck and Fias (2011) required participants to verbally encode and retrieve a sequence of numbers in random order, thus manipulating their ordinal position in working memory. Conversely, Bächtold et al. (1998) required participants to visualize numbers on a clock-face display, thus manipulating the ordinal position in a visual display. These examples (and the results of our Experiment 1) suggest that the ordinal position of presented items can modify the SNARC effect, eliciting spatial associations that reflect their ordinal position in the configuration.

Several studies suggest that the order of items is a key element to perform the magnitude classification task (Prpic et al., 2016; Pitt & Casasanto, 2020). Indeed, to classify a number as smaller or larger than a middle reference (e.g., 5), it is necessary to retrieve the ordinal position of the target number and compare it with the ordinal position of the reference. Thus, this task is based on the order of the MNL. Differently, the parity judgement task does not induce participants to directly process ordinality because parity is a feature that is not bound to the order.

Based on these considerations, in Experiment 2a, we asked participants to perform a magnitude classification task. In this case, the context elicited the keypad order, while the task elicited an order of numbers consistent with the MNL. Thus, the orders elicited by the context and by the task would conflict since magnitude classification is based on ordinality. In Experiment 2b, we asked participants to perform a parity judgment task. In this case, the context elicited the keypad order, while the task does not elicit any order because parity is a feature that is not bound to ordinality. Thus, the order elicited by the context should not conflict with the task since parity judgement is not based on ordinality. In Experiment 2a, we expect that the keypad order would have a greater influence in modifying the spatial associations because of the conflict between the orders elicited by the context and the task. Conversely, in Experiment 2b, we expect the keypad to be less relevant in affecting the SNARC effect.

Experiment 2a

Method

Participants

Thirty-four students from the University of Trieste (M = 6; F = 28) took part in Experiment 2a. They had a mean age of 22.17 (SD = 2.24). Thirty-one participants reported to be right-handed, while three were left-handed; all participants had normal or corrected to normal vision and were used to the left-to-right writing direction. Like in Experiment 1, the sample size was determined using the same power analyses as for Experiment 1, and following the suggestions by Cipora and Wood (2017), we thereforerecruited a number of participants considered “large” for this type of studies. All participants reported that their psychophysiological state was not affected by alcohol consumption or insufficient sleep in the last 24 hours (Murgia et al., 2020).

Apparatus

The apparatus used in Experiment 2a was the same as the one used in the previous experiment.

Task and stimuli

Participants performed a magnitude classification task; namely, they were asked to judge whether the presented number was smaller or bigger than number 5. The stimuli set was slightly different from the one employed in Experiment 1 and consisted of eight single-digit numbers (1-2-

3-4-6-7-8-9), with the addition of numbers 2 and 8 compared to Experiment 1. Stimuli were presented one at a time in the centre of the screen, painted in white against a grey background.

Procedure

Experiment 2a followed the same procedure as the one described in experiment 1. The experiment was composed of two blocks (Block A and Block B); each block included a practice session (56 stimuli; not considered for data analysis) and an experimental session (160 stimuli).

Before starting each block, participants were exposed for 20 seconds to the picture of a mobile phone's keypad and were asked to pay particular attention to the spatial arrangement of the numbers. In the last 10 seconds of the presentation of the configuration, the left and right portion of the keypad were highlighted (Figure 1b) with two rectangles showing the three numbers at the left of the keypad (1-4-7) and the three numbers at its right (3-6-9). Participants were asked to keep in mind the keypad's configuration for the entire duration of the experiment while performing the task.

After being exposed to the keypad, participants performed a practice session, which was structured in the same way as in Experiment 1. In the first part of the practice session (8 trials x 2 repetitions), the keypad picture appeared at the fixation point (2000 ms) before each trial. This part of the practice session was designed to further help participants familiarize themselves with the keypad configuration. The second part of the practice session (8 trials x 5 repetitions) followed the same procedure as the first one, except for the lack of the keypad picture at the beginning of the trial.

In block A, participants were required to press the leftmost key when the presented number was smaller than 5 and the rightmost key when the number was bigger than 5. In block B, the response keys were reversed. The order of the blocks (A-B or B-A) was counterbalanced among participants. All participants performed both Experiments 2a and 2b in counterbalanced order.

Results

Data analyses were the same as in Experiment 1. The repeated measures ANOVA revealed a significant main effect for Hand [$F(1, 33) = 12.62$; $p = .001$; $\eta_p^2 = .28$; $BF_{10} = 5.18$], with faster response times for right hand, and a significant main effect for Number [$F(7, 231) = 29.87$; $p < .001$; $\eta_p^2 = .47$; $BF_{10} > 100$], but did not reveal a significant interaction [$F(7, 231) = .94$; $p = .47$; $\eta_p^2 = .03$; $BF_{10} = .05$]. See Table 2 for details.

Table 2

Mean and Standard Deviations of RTs for each condition of Experiment 2a. Values are reported in milliseconds.

Hand	Numbers							
	1	2	3	4	6	7	8	9
Left hand	416 (68)	424 (72)	437 (77)	462 (101)	468 (89)	439 (71)	432 (63)	437 (66)
Right hand	419 (81)	412 (64)	435 (65)	454 (75)	452 (89)	439 (75)	419 (67)	424 (69)

A set of paired-sample *t* tests was computed in order to compare the mean of the dRTs of the stimuli 1-4-7 vs. 3-6-9 (Keypad configuration); 1-3-4 vs. 6-7-9 (MNL configuration with the same numbers of the keypad comparison); 1-2-3-4 vs. 6-7-8-9 (MNL configuration including numbers 2 and 8). The paired samples *t* tests did not reveal any significant effect for the keypad configuration [stimuli 1-4-7 vs. 3-6-9; $t(33) = 1.36$; $p = .18$; $d = .23$; $BF_{10} = .43$], nor for the MNL configuration [stimuli 1-3-4 vs. 6-7-9; $t(33) = .61$; $p = .54$; $d = .10$; $BF_{10} = .21$; stimuli 1-2-3-4 vs. 6-7-8-9; $t(33) = .46$; $p = .65$; $d = .07$; $BF_{10} = .20$].

Finally, a set of paired sample *t* tests was computed to verify whether the mean dRTs of numbers 3 and 7 were more in line with the keypad or with the MNL arrangement. The first comparison revealed that the mean dRTs for number 3 and 7 did not significantly differ [$t(33) = -.06$; $p = .95$; $d = -.01$; $BF_{10} = .18$]. Furthermore, the mean dRTs for number 3 did not differ from the average values observed for the other small numbers (1, 2, and 4) [$t(33) = 1.12$; $p = .24$; $d = .21$; $BF_{10} = .36$]. Conversely, the mean dRTs for number 7 significantly differed from the average values observed for the other large numbers (6, 8, and 9), with number 7 associated to the left compared to the other large numbers [$t(33) = 2.87$; $p < .01$; $d = .49$ $BF_{10} = 5.73$].

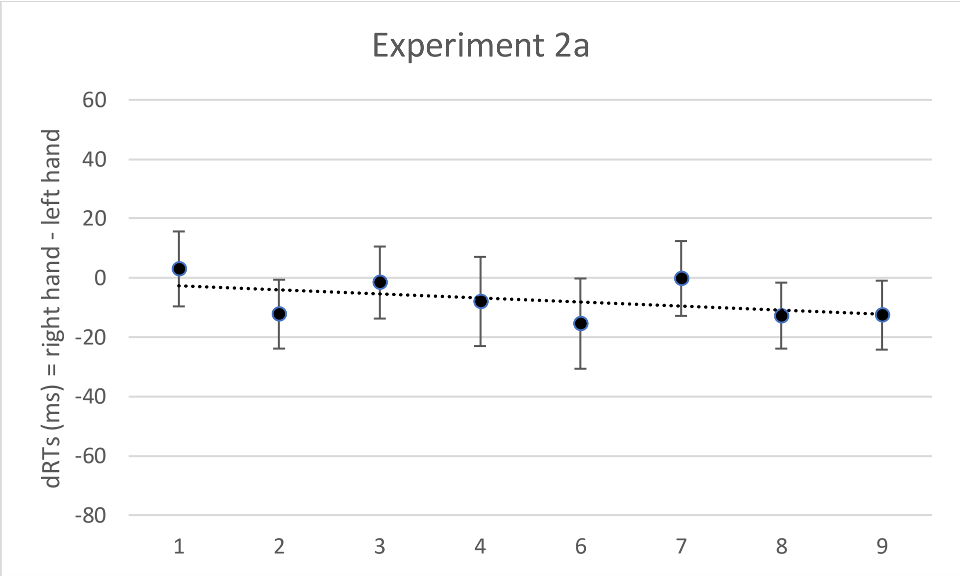

Figure 3. The figure shows the Mean dRTs (right key - left key) for every numerical stimulus in Experiment 2a. Positive differences indicate faster left-key responses; negative differences indicate faster right-key responses. Errors bars indicate the standard error of the mean.

Discussion

In Experiment 2a, the ANOVA revealed a lack of spatial-numerical association, and the Bayes Factor provides strong support to the null-hypothesis for the interaction (BF_{10} = .05 is equal to BF_{01} = 20). Furthermore, neither the MNL configuration (stimuli 1-3-4 vs 6-7-9 and 1-2-3-4 vs 6-7-8-9) nor the keypad configuration (stimuli 1-4-7 vs 3-6-9) elicited significant effects on the speed of manual responses. The analyses on numbers 3 and 7 did not provide clear support in favour of one of the two configurations. The lack of any significant effect is well displayed in figure 3. Indeed, the figure shows that there is no clear hand-related response time advantage for any number.

The most interesting finding of this experiment is that the magnitude classification task failed to produce the SNARC effect when the context elicits an alternative configuration before the task. Notably, in the absence of manipulations of the context, this task should have determined the SNARC effect. A possible interpretation is that the conflict between the configuration elicited by the context (keypad) and the configuration elicited by the task (MNL) determined the lack of any spatial association. Different from Experiment 1, in Experiment 2a the keypad configuration activated at the beginning of the experiment was not used to solve the task, hence the context was irrelevant and perhaps detrimental; therefore, we might speculate that – at a certain level – the context caused an interference preventing the SNARC effect from occurring.

Experiment 2b

Method

Participants

The participants were the same as in Experiment 2a.

Apparatus

The apparatus used in Experiment 2b was the same as the one used in previous experiments.

Task and stimuli

Participants performed a parity judgement task; namely, they were asked to judge whether the presented number was even or odd. The stimuli set was the same as in Experiment 2a. In particular, stimuli consisted of eight single-digit numbers (1-2-3-4-6-7-8-9) and were presented one at a time in the centre of the screen, painted in white against a grey background.

Procedure

Experiment 2b followed the same procedure as the one described in previous experiments. The experiment was composed of two blocks (Block A and Block B); each block included a practice session (56 stimuli; not considered for data analysis) and an experimental session (160 stimuli).

Before starting each block, participants were exposed for 20 seconds to the picture of a mobile phone's keypad and were asked to pay particular attention to the spatial arrangement of the numbers. In the last 10 seconds of the presentation of the configuration, the left and right portion of the keypad were highlighted (Figure 1b) with two rectangles showing the three numbers at the left of the keypad (1-4-7) and the three numbers at its right (3-6-9). Participants were asked to keep in mind the keypad's configuration for the entire duration of the experiment while performing the task.

After being exposed to the keypad, participants performed a practice session, which was the same as Experiment 2a. In the first part of the practice session (8 trials x 2 repetitions), the keypad picture appeared at the fixation point (2000 ms) before each trial. This part of the practice session was designed to further help participants familiarize themselves with the keypad configuration. The second part of the practice session (8 trials x 5 repetitions) followed the same procedure as the first one, except for the lack of the keypad picture at the beginning of the trial.

In block A, participants were required to press the leftmost key when the presented number was even and the rightmost key when the number was odd. In block B, the response keys were reversed. The order of the blocks (A-B or B-A) was counterbalanced among participants. All participants performed both Experiments 2a and 2b in counterbalanced order.

Results

Data analyses were the same as in previous experiments. The repeated measures ANOVA revealed a significant main effect for Hand [$F(1, 33) = 14.04$; $p < .001$; $\eta_p^2 = .30$; $BF_{10} = 2.01$], with faster response times for right hand, for Number [$F(7, 231) = 7.98$; $p < .001$; $\eta_p^2 = .19$; $BF_{10} > 100$], and a significant interaction [$F(7, 231) = 7.23$; $p < .001$; $\eta_p^2 = 0.18$; $BF_{10} > 100$], with small numbers globally associated to the left and large numbers to the right, although this pattern is influenced by the association of odd numbers to the left and even numbers to the right. See Table 3 for details.

Table 3

Mean and Standard Deviations of RTs for each condition of Experiment 2b. Values are reported in milliseconds.

Hand	Numbers							
	1	2	3	4	6	7	8	9
Left hand	477 (52)	478 (52)	493 (60)	481 (60)	508 (63)	473 (52)	514 (60)	500 (59)
Right hand	508 (60)	457 (62)	505 (60)	471 (67)	472 (60)	475 (47)	473 (59)	490 (54)

A set of paired-sample *t* tests was computed in order to compare the mean of the dRTs of the stimuli 1-4-7 vs. 3-6-9 (Keypad configuration); 1-3-4 vs. 6-7-9 (MNL configuration with the same numbers of the keypad comparison); 1-2-3-4 vs. 6-7-8-9 (MNL configuration including numbers 2 and 8). The *t* tests revealed both a significant effect elicited by the keypad configuration [stimuli 1-4-7 vs. 3-6-9; $t(33) = 3.67$; $p < .001$; $d = .63$ $BF_{10} = 36.7$] and an effect elicited by the MNL configuration [stimuli 1-3-4 vs. 6-7-9; $t(33) = 3.80$; $p < .001$; $d = .65$; $BF_{10} = 51.7$; stimuli 1-2-3-4 vs. 6-7-8-9; $t(33) = 3.79$; $p < .001$; $d = .65$; $BF_{10} = 50.3$].

A set of paired sample *t* tests was then computed to verify whether the mean dRTs of numbers 3 and 7 were more in line with the keypad or with the MNL arrangement. The first comparison revealed the mean dRTs for number 3 and 7 did not significantly differ [$t(33) = 1.10$; $p = .28$; $d = .19$; $BF_{10} = .32$. Furthermore, the mean dRTs for number 3 did not differ from the average values observed for the other small numbers (1, 2, and 4) [$t(33) = .95$; $p = .35$; $d = .16$; $BF_{10} = .28$]. Conversely, the mean dRTs for number 7 significantly differed from the average values observed for the other large numbers (6, 8, and 9), with number 7 associated to the left compared to the other large numbers [$t(33) = 3.07$; $p < .005$; $d = .52$ $BF_{10} = 8.98$].

Finally, given that the dRTs appeared to be different for odd and even numbers, we compared the average values observed for 1-3-7-9 vs. 2-4-6-8. The results revealed a significant association for odd numbers to the left and right numbers to the right [$t(33) = 2.87$; $p < .01$; $d = .49$ $BF_{10} = 5.79$].

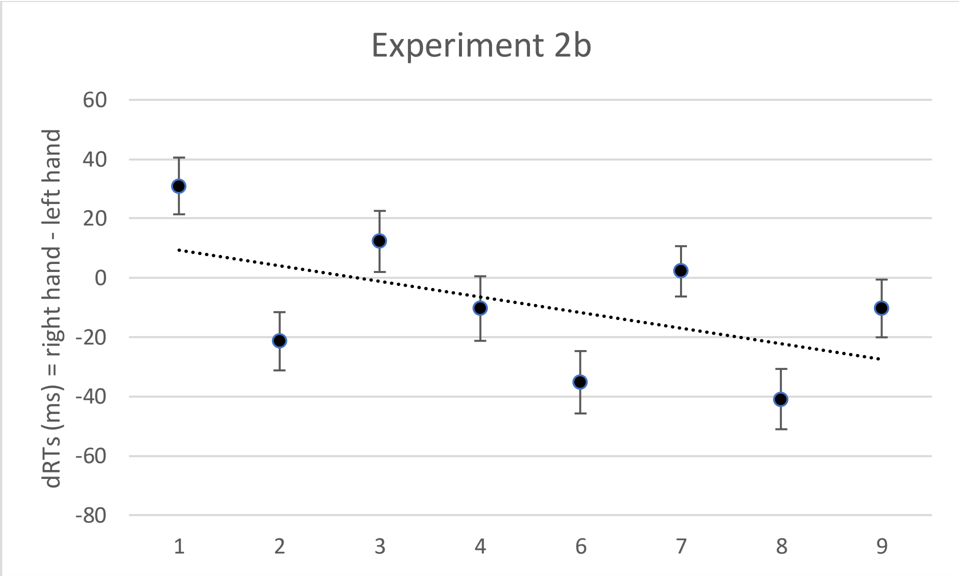

Figure 4. The figure shows the Mean dRTs (right key - left key) for every numerical stimulus in Experiment 2b. Positive differences indicate faster left-key responses; negative differences indicate faster right-key responses. Errors bars indicate the standard error of the mean.

Discussion

The results of Experiment 2b revealed both a significant effect elicited by the keypad configuration (stimuli 1-4-7 vs 3-6-9) and an effect elicited by the Mental Number Line (MNL) configuration (stimuli 1-3-4 vs 6-7-9). Moreover, results revealed a significant MARC effect (Linguistic Markedness of response codes; Nuerk, Iversen & Willmes, 2004; Huber et al., 2015; Cipora et al., 2019), namely a left-hand advantage for odd numbers and right-hand advantage for even numbers.

By looking at Figure 4, we can see that the mean dRTs are distributed in a quite linear fashion, reflecting a response time advantage which seems to fit more with the MNL configuration than with the keypad, although the pattern is influenced by the MARC effect (the linearity appears clearer when observing odd and even numbers, separately). The MARC effect seems to affect also the values observed for numbers 3 and 7 (both odd), which do not provide clear information in favour of one of the two configurations.

Overall, it seems difficult to disentangle between the two configurations; this can be due to the overlap between them and/or because the MARC effect prevents numbers 3 and 7 from providing a clear direction. However, it is noteworthy that: 1) the Bayes factor computed for the paired samples *t* tests revealed a higher value for the MNL compared to the Keypad configuration, 2) the pattern of results we found is not different from the one expected for parity judgement tasks in the absence of any context manipulation.

Thus, our interpretation of the results of Experiment 2b is that the keypad configuration did not influence the spatial associations that would occur in a typical parity judgement experiment. Therefore, we conclude that a typical SNARC effect emerged. Furthermore, these results suggest that the order elicited by the context did not influence RTs, probably because order is not a relevant feature to perform indirect tasks, such as the parity judgement.

General discussion

The aim of the present study was to investigate the role of order elicited by the context and by the task in the SNARC effect. To reach this goal, we used a context that allowed us to alter the order of the stimuli compared to MNL, and we manipulated the task demands. The same context was provided at the beginning of each experiment to elicit a spatial representation of numbers compatible with the spatial arrangement of the keypad. The context was kept constant, while the tasks of the three experiments were designed to induce representations with different levels of consistency with the context.

In Experiment 1, we asked participants to judge the spatial location of numbers based on their position on the keypad. This allowed us to investigate the role of order elicited by the context when it is consistent with the order elicited by the task. We found a spatial-numerical association resembling the spatial arrangement of the keypad. In Experiment 2a, we asked participants to perform a magnitude classification task. This allowed us to investigate the role of context when it conflicts with the order elicited by the task. We found a lack of spatial-numerical association. In Experiment 2b, we asked participants to perform a parity judgement task. This allowed us to investigate the role of context when the task does not elicit a specific order. We found a spatial-numerical association consistent with the SNARC effect.

These results indicate that the order elicited by the context (the keypad) determined a spatial association only in Experiment 1. However, since in Experiment 1, the order elicited by the context is the same as the one elicited by the task, it is not possible to state whether the observed association was induced by the context or by the task. Therefore, to disentangle the role of the context from that of the task, we performed Experiments 2a and 2b. At the beginning of these experiments, the context was activated in the same way as in Experiment 1 by showing the keypad picture, and participants were instructed to pay attention to the spatial arrangement of numbers and to keep it in mind throughout the entire experiment. Notably, participants were not aware that the keypad would be irrelevant; rather it is likely that they expected that a keypad-related task would occur at some point, maintaining a certain level of activation of the keypad configuration.

In Experiment 2a, the context and the task elicited different orders, that is, the keypad and the MNL, respectively. It is noteworthy that Experiment 2a employed a direct task that requires comparing stimuli with a reference, thus inducing an ordinal judgement (Pitt & Casasanto, 2020; Prpic et al., 2016). Results indicate an absence of spatial association instead of the typical SNARC effect, which would be expected with this task. This result suggests that the conflict between the two orders might have caused an interference in the processing of the stimuli. In Experiment 2b, we aimed to investigate the role of the order elicited by the context in the lack of ordinal information provided by the task. To do so, we employed an indirect task (i.e., parity judgement), which revealed a spatial association in line with the MNL order. This result suggests that the order elicited by the context does not determine a consistent spatial association in the presence of an indirect task.

Our results are consistent with the model proposed by Prpic et al. (2016), who describe two distinct mechanisms underlying SNARC-like effects: An Order-Related Mechanism (ORM) and a Magnitude-Related Mechanism (MRM). The ORM would be activated by direct tasks (e.g., magnitude classification), whereas the MRM would be activated by indirect tasks (e.g., parity judgement). Based on this model, in Experiment 1, the ORM would be consistently activated by both context and task, thus inducing a spatial association congruent with the keypad. In Experiment 2a, the representations elicited by the context and the task would generate a conflict in the ORM, thus determining a lack of spatial associations. It is noteworthy that the cancellation of the SNARC effect has been interpreted as an indicator of conflicting spatial-numerical representations in other studies (e.g., Shaki & Fischer, 2012). In Experiment 2b, the ORM would be only activated by the context, but the task would activate the MRM. Therefore, in this case, no conflict would have occurred. Given that the task does not require to process the ordinal properties of the stimuli directly, the MRM would elicit the SNARC effect.

The observed results could be explained based on the interplay between the keypad configuration stored in long-term memory and its contextual activation in working memory. Since the keypad is an overlearned configuration, it can be assumed that it is stored in long-term memory and does not require any training to be encoded. However, numbers are not represented according to the keypad spatial arrangement "by default"; rather, this arrangement becomes salient only when it is activated in working memory. In the present study, the activation of the keypad in working memory can occur before the task (i.e., pre-experimental manipulation) and/or during the task (i.e., intra-experimental manipulation).

The context was pre-experimentally activated in all three experiments. However, only Experiment 1 produced a concurrent intra-experimental activation of the keypad since the task required the retrieval of this configuration to be executed. Results indicate that the keypad determined an association only in Experiment 1, while in Experiment 2a and 2b, the keypad configuration did not emerge since there was no retrieval. These results are in line with the study by Ginsburg and Gevers (2015), who showed that the ordinal position effect is activated only when retrieval is required.

In Experiments 2a and 2b, which did not require retrieval of the keypad configuration, the influence of the context can be interpreted in light of previous studies comparing visuospatial and verbal working memory. Van Dijck et al. (2009) found that the SNARC effect disappeared under visuospatial load in magnitude classification tasks, while this inhibition did not occur in the parity judgment. The context used in the present study was of visuospatial nature; hence it might have acted as visuospatial load, consequently interfering with the SNARC effect in the magnitude classification but not in the parity judgement. Referring to Prpic et al.'s model, it is noteworthy that in direct tasks, the judgment (e.g., comparing whether the ordinal position of a target is before or after a reference in a mapped sequence) – processed at ORM level – would be based on visuospatial information. Thus, the visuospatial conflict activated by the context would interfere with ORM during the magnitude classification task (Experiment 2a). Conversely, in indirect tasks, the judgement would not be based on visuospatial information. Thus, the information activated by the context would not interfere with MRM during the parity judgment task (Experiment 2b).

The visuospatial context employed in the present study is similar to the clock-face employed by Bächtold et al. (1998); moreover, the procedure of our Experiment 1 resembles the one employed by Bächtold et al., because the task is based on the spatial representation elicited by the context and retrieval was necessary during the experiment because of the task. Indeed, the results of our Experiment 1 are consistent with the results found in the clock-face experiment, namely, in both cases, it was observed a spatial-numerical association resembling the spatial arrangement elicited by the context. However, different from Bächtold et al., the present study adds further manipulations, employing two tasks that do not reinforce the order elicited by the context. In Bächtold et al.'s study, the relative contribution of the context and the task in inducing ordinality was confounded. In the present study, we demonstrated that the order elicited by the context alone is not sufficient to alter spatial-numerical associations if it is not reinforced by the task. Thus, the effect observed by Bächtold et al. is probably due to the order consistently elicited by both the context and the task.

It is noteworthy that three different tasks revealed three different results, thus helping us to better understand how the order elicited by the context and by the tasks interact. Since the context of the stimuli was the same in the three experiments, we assume that the different results emerged because of the different contribution of the tasks. Indeed, in Experiment 1, the task reinforced the context; in Experiment 2a, it conflicted with the context; in Experiment 2b, it was unbound to the context. Thus, our interpretation is that the tasks determined different levels of consistency with the context of the stimuli, revealing different levels of influence on spatial associations.

A limitation of the present study is that it did not address the issue of vertical spatial-numerical associations (Aleotti et al., 2020; Ito and Hatta, 2004). In this regard, the keypad would be useful to investigate this kind of associations because it appears in different formats with different vertical arrangements in devices that are used daily (e.g., phone vs calculator). Future studies could manipulate the context using such ecological and overlearned configurations to activate different vertical arrangements in working memory in order to investigate the role of the context better. Another limitation of the present study is that it did not manipulate the level of activation of the context within the same task. Future studies should systematically manipulate the level of activation of the context (pre- vs intra- experimental manipulation) for each type of task (direct and indirect) in order to determine if a greater activation of the context could lead to a stronger interference with the order elicited by the task and if this interference could lead to different spatial associations based on the type of task.

Conclusions

Previous literature highlighted the importance of ordinality in spatial-numerical associations; however, the way ordinality can be elicited by the context and by the task is still unexplored. To better investigate the role of the order in spatial-numerical associations, we employed an atypical configuration of numerical stimuli as context and three different tasks, each involving different representations that were consistent or inconsistent with the order of the context or unbound to it. According to the observed results, the context shaped a spatial association when the task was based on the same configuration, it produced a conflict when it was inconsistent with the representation evoked by the task, and it did not affect the SNARC effect when it was unbound to the task. Taken together, the results of the present study highlight that spatial-numerical associations can be modulated by the order elicited by the context depending on the tasks.

Acknowledgements

We thank Yasmine Basamh for the English proofreading.

Dataset

https://osf.io/gbfx6/

Declarations of interest

none

References

Aleotti, S., Di Girolamo, F., Massaccesi, S., & Priftis, K. (2020). Numbers around Descartes: A preregistered study on the three-dimensional SNARC effect. Cognition, 195, 104111. https://doi.org/10.1016/j.cognition.2019.104111

Bächtold, D., Baumüller, M., & Brugger, P. (1998). Stimulus-response compatibility in representational space. *Neuropsychologia*, *36*(8), 731–735. https://doi.org/10.1016/s0028-3932(98)00002-5

Baldassi, G., Murgia, M., Prpic, V., Rigutti, S., Domijan, D., Agostini, T., & Fantoni, C. (2021). Large as being on top of the world and small as hitting the roof: A common magnitude representation for the comparison of emotions and numbers. *Psychological Research*, 85, 1272–1291. https://doi.org/10.1007/s00426-020-01306-3

Cipora, K., Soltanlou, M., Reips, U.-D., & Nuerk, H.-C. (2019). The SNARC and MARC effects measured online: Large-scale assessment methods in flexible cognitive effects. Behavior Research Methods, 51(4), 1676–1692. https://doi.org/10.3758/s13428-019-01213-5

Cipora, K., & Wood, G. (2017). Finding the SNARC Instead of Hunting It: A 20∗20 Monte Carlo Investigation. Frontiers in Psychology, 8. https://doi.org/10.3389/fpsyg.2017.01194

Cipora, K., Patro, K., & Nuerk, H. (2018). Situated Influences on Spatial–Numerical Associations. In T. Hubbard (Ed.), Spatial Biases in Perception and Cognition (pp. 41-59). Cambridge: Cambridge University Press. https://doi.org/10.1017/9781316651247.004

Dalmaso, M., & Vicovaro, M. (2019). Evidence of SQUARC and distance effects in a weight comparison task. Cognitive Processing, 20(2), 163–173. https://doi.org/10.1007/s10339-019-00905-2

Darling, S., & Havelka, J. (2010). Visuospatial bootstrapping: Evidence for binding of verbal and spatial information in working memory. Quarterly Journal of Experimental Psychology, 63(2), 239–245. https://doi.org/10.1080/17470210903348605

De Tommaso, M., & Prpic, V. (2020). Slow and fast beat sequences are represented differently through space. *Attention, Perception, & Psychophysics*. https://doi.org/10.3758/s13414-019-01945-8

Dehaene, S., Bossini, S., & Giraux, P. (1993). The Mental Representation of Parity and Number Magnitude. *Journal of Experimental Psychology*, *122*, 371–396. https://doi.org/10.1037//0096-3445.122.3.371

Fantoni, C., Baldassi, G., Rigutti, S., Prpic, V., Murgia, M., & Agostini, T. (2019). Emotional Semantic Congruency based on stimulus driven comparative judgements. *Cognition*, *190*, 20–41. https://doi.org/10.1016/j.cognition.2019.04.014

Fischer, M. H., Mills, R. A., & Shaki, S. (2010). How to cook a SNARC: Number placement in text rapidly changes spatial–numerical associations. Brain and Cognition, 72(3), 333–336. https://doi.org/10.1016/j.bandc.2009.10.010

Fischer, M. H., & Shaki, S. (2014). Spatial Associations in Numerical Cognition—From Single Digits to Arithmetic. *Quarterly Journal of Experimental Psychology*, *67*(8), 1461–1483. https://doi.org/10.1080/17470218.2014.927515

Fumarola, A., Prpic, V., Da Pos, O., Murgia, M., Umiltà, C., & Agostini, T. (2014). Automatic spatial association for luminance. *Attention, Perception, & Psychophysics*, *76*(3), 759–765. https://doi.org/10.3758/s13414-013-0614-y

Fumarola, A., Prpic, V., Fornasier, D., Sartoretto, F., Agostini, T., & Umiltà, C. (2016). The Spatial Representation of Angles: *Perception*. https://doi.org/10.1177/0301006616661915

Gevers, W., Reynvoet, B., & Fias, W. (2003). The mental representation of ordinal sequences is spatially organized. *Cognition*, *87*(3), B87–B95. https://doi.org/10.1016/S0010-0277(02)00234-2

Gevers, W., Reynvoet, B., & Fias, W. (2004). The mental representation of ordinal sequences is spatially organized: Evidence from days of the week. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior*, *40*(1), 171–172. https://doi.org/10.1016/S0010-9452(08)70938-9

Gevers, W., Verguts, T., Reynvoet, B., Caessens, B., & Fias, W. (2006). Numbers and space: A computational model of the SNARC effect. *Journal of Experimental Psychology: Human Perception and Performance*, *32*(1), 32–44. https://doi.org/10.1037/0096-1523.32.1.32

Ginsburg, V., & Gevers, W. (2015). Spatial coding of ordinal information in short- and long-term memory. *Frontiers in Human Neuroscience*, *9*. https://doi.org/10.3389/fnhum.2015.00008

Holmes, K. J., & Lourenco, S. F. (2011). Common spatial organization of number and emotional expression: A mental magnitude line. *Brain and Cognition*, *77*(2), 315–323. https://doi.org/10.1016/j.bandc.2011.07.002

Hubbard, T. L. (2018). Spatial Biases in Perception and Cognition. Cambridge University Press. https://doi.org/10.1017/9781316651247

Huber, S., Klein, E., Graf, M., Nuerk, H.-C., Moeller, K., & Willmes, K. (2015). Embodied markedness of parity? Examining handedness effects on parity judgments. Psychological Research, 79(6), 963–977. https://doi.org/10.1007/s00426-014-0626-9

Ishihara, M., Keller, P. E., Rossetti, Y., & Prinz, W. (2008). Horizontal spatial representations of time: Evidence for the STEARC effect. Cortex, 44(4), 454–461. https://doi.org/10.1016/j.cortex.2007.08.010

Ito, Y., & Hatta, T. (2004). Spatial structure of quantitative representation of numbers: Evidence from the SNARC effect. Memory & Cognition, 32(4), 662–673. https://doi.org/10.3758/BF03195857

Murgia, M., Mingolo, S., Prpic, V., Sors, F., Santoro, I., Bilotta, E., & Agostini, T. (2020). University Students' Hangover May Affect Cognitive Research. Frontiers in Psychology, 11. https://doi.org/10.3389/fpsyg.2020.573291

Nuerk, H.-C., Moeller, K., Klein, E., Willmes, K., & Fischer, M. H. (2011). Extending the Mental Number Line. *Zeitschrift für Psychologie*, 219(1), 3–22. https://doi.org/10.1027/2151-2604/a000041

Notebaert, W., Gevers, W., Verguts, T., & Fias, W. (2006). Shared spatial representations for numbers and space: The reversal of the SNARC and the Simon effects. Journal of Experimental Psychology: Human Perception and Performance, 32(5), 1197–1207. https://doi.org/10.1037/0096-1523.32.5.1197

Nuerk, H., Iversen, W., & Willmes, K. (2004). Notational Modulation of the SNARC and the MARC (Linguistic Markedness of Response Codes) Effect. The Quarterly Journal of Experimental Psychology Section A, 57(5), 835–863. https://doi.org/10.1080/02724980343000512

Pitt, B., & Casasanto, D. (2020). The correlations in experience principle: How culture shapes concepts of time and number. *Journal of Experimental Psychology: General*, *149*(6), 1048–1070. https://doi.org/10.1037/xge0000696

Previtali, P., de Hevia, M. D., & Girelli, L. (2010). Placing order in space: The SNARC effect in serial learning. *Experimental Brain Research*, *201*(3), 599–605. https://doi.org/10.1007/s00221-009-2063-3

Prpic, V., Fumarola, A., De Tommaso, M., Luccio, R., Murgia, M., & Agostini, T. (2016). Separate mechanisms for magnitude and order processing in the spatial-numerical association of response codes (SNARC) effect: The strange case of musical note values. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(8), 1241–1251. https://doi.org/10.1037/xhp0000217

Prpic, V., Mingolo, S., Agostini, T., Murgia, M. (in press). Magnitude and order are both relevant in SNARC and SNARC-like effects: A commentary to Casasanto & Pitt (2019). *Cognitive Science*. https://doi.org/10.1111/cogs.13006

Prpic, V., Soranzo, A., Santoro, I., Fantoni, C., Galmonte, A., Agostini, T., & Murgia, M. (2020). SNARC-like compatibility effects for physical and phenomenal magnitudes: a study on visual illusions. *Psychological research*, *84*(4), 950-965. https://doi.org/10.1007/s00426-018-1125-1

Proctor, R. W., & Cho, Y. S. (2006). Polarity correspondence: A general principle for performance of speeded binary classification tasks. *Psychological Bulletin*, *132*(3), 416–442. https://doi.org/10.1037/0033-2909.132.3.416

Ren, P., Nicholls, M. E. R., Ma, Y., & Chen, L. (2011). Size Matters: Non-Numerical Magnitude Affects the Spatial Coding of Response. *PLOS ONE*, *6*(8), e23553. https://doi.org/10.1371/journal.pone.0023553

Shaki, S., & Fischer, M. H. (2008). Reading space into numbers – a cross-linguistic comparison of the SNARC effect. *Cognition*, *108*(2), 590–599. https://doi.org/10.1016/j.cognition.2008.04.001

Shaki, S., Fischer, M. H., & Petrusic, W. M. (2009). Reading habits for both words and numbers contribute to the SNARC effect. *Psychonomic Bulletin & Review*, *16*(2), 328–331. https://doi.org/10.3758/PBR.16.2.328

Vallesi, A., Binns, M. A., & Shallice, T. (2008). An effect of spatial–temporal association of response codes: Understanding the cognitive representations of time. *Cognition*, *107*(2), 501–527. https://doi.org/10.1016/j.cognition.2007.10.011

Vallesi, A., McIntosh, A. R., & Stuss, D. T. (2011). How time modulates spatial responses. *Cortex*, *47*(2), 148–156. https://doi.org/10.1016/j.cortex.2009.09.005

van Dijck, J.-P., & Fias, W. (2011). A working memory account for spatial–numerical associations. *Cognition*, *119*(1), 114–119. https://doi.org/10.1016/j.cognition.2010.12.013

van Dijck, J.-P., Gevers, W., & Fias, W. (2009). Numbers are associated with different types of spatial information depending on the task. *Cognition*, *113*(2), 248–253. https://doi.org/10.1016/j.cognition.2009.08.005

Wood, G., Willmes, K., Nuerk, H.-C., & Fischer, M. H. (2008). On the cognitive link between space and number: A meta-analysis of the SNARC effect. Psychology Science Quarterly, 50(4), 489–525.

Zebian, S. (2005). Linkages between Number Concepts, Spatial Thinking, and Directionality of Writing: The SNARC Effect and the REVERSE SNARC Effect in English and Arabic

Monoliterates, Biliterates, and Illiterate Arabic Speakers. Journal of Cognition and Culture, 5(1–2), 165–190. https://doi.org/10.1163/1568537054068660

Zohar-Shai, B., Tzelgov, J., Karni, A., & Rubinsten, O. (2017). It does exist! A left-to-right spatial–numerical association of response codes (SNARC) effect among native Hebrew speakers. Journal of Experimental Psychology: Human Perception and Performance, 43(4), 719–728.