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

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

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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.

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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

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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

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120 spatial association of numbers, these results highlight that this association is quite flexible and can
121 be modulated by the context. In particular, when a specific direction is activated by an event
122 preceding the task (e.g., reading a script in a specific language), the SNARC effect is modified
123 according to this experience.

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

134 The SNARC effect can also be overrun by manipulating the ordinal position of numbers in
135 working memory. For instance, when participants are trained to retain a sequence of five random
136 numbers in working memory and to perform typical SNARC tasks using a go/no-go procedure
137 (responding only to numbers in the sequence), the spatial association follows the ordinal position
138 rather than the MNL (ordinal position effect; van Dijck & Fias, 2011). Ginsburg and Gevers (2015)
139 further investigated the role of working memory. In two experiments, the authors manipulated
140 the activation of the canonical number sequence (MNL) and of a newly acquired numerical
141 sequence relevant to the task. Results showed that the SNARC effect and the ordinal position

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142 effect are not mutually exclusive and can determine different spatial associations. They concluded
143 that spatial associations could be determined by both pre-existing representations in long-term
144 memory and temporary representations in working memory, depending on the level of activation
145 of these representations.

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

157

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

159 Another alternative configuration of numbers is the numeric keypad. Similar to the clock-
160 face employed by Bächtold et al. (1998), the spatial arrangement of the keypad is overlearned and
161 culturally shared by the vast majority of the population. Therefore, this configuration is already
162 stored in long-term memory and does not require any training to be encoded and recalled.
163 Moreover, numbers presented in a keypad configuration are recalled more easily compared to

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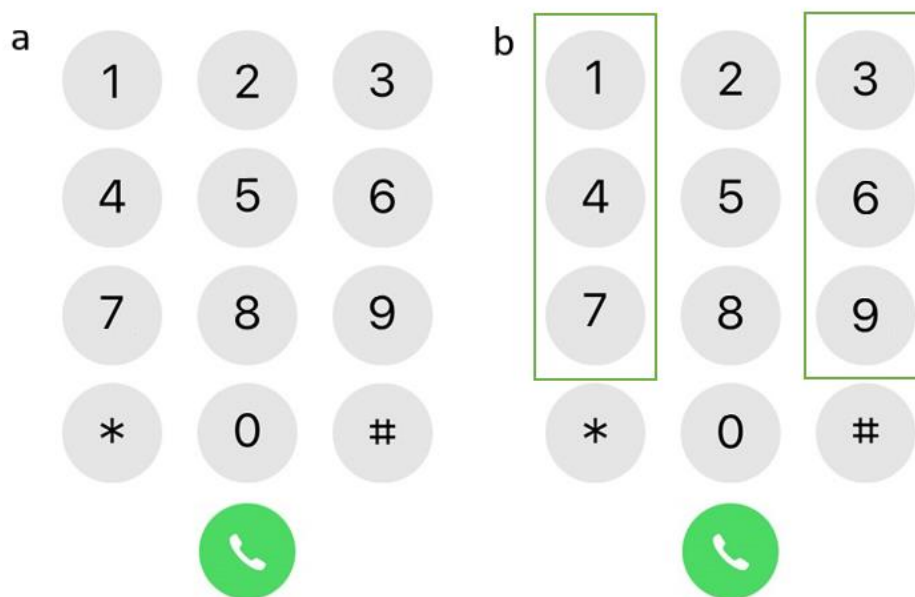
164 when they are presented singularly or in a linear display (Darling & Havelka, 2010). It is
165 noteworthy that numeric keypad can have different formats. For example, the keypad used to dial
166 telephone numbers in mobile phones (see Figure 1a) presents small numbers on the top and large
167 numbers on the bottom; differently, the keypad used in calculators present the opposite vertical
168 arrangement but with the same horizontal arrangement. In the present study, we will refer to the
169 mobile phone keypad.

170 In the mobile-phone keypad configuration, numbers from 1 to 9 are not linearly arranged
171 in a typical left-to-right progression but are ordered from left to right in three rows, resulting in a
172 3x3 matrix. Importantly, the numbers of this configuration are exactly the same numbers (from 1
173 to 9) used in the vast majority of studies on the SNARC effect. Thus, unlike the clock-face, the
174 keypad only features single-digit numbers, eliminating the possible confound deriving from two-
175 digit numerical stimuli (Nuerk et al., 2011). By looking at the picture of a keypad, if we assume
176 number 5 to be the middle point reference, we will note that some elements of this configuration
177 violate the MNL representation, while others overlap with it. We can see that 1 and 4, which are
178 smaller than 5, are located on the left of the configuration. Similarly, 6 and 9 are larger than 5 and
179 are located on the right. Conversely, the relative position of 3 and 7 is different from that of MNL:
180 3 is smaller than 5 but is located on its right, whereas 7 is larger than 5 but is located on its left.
181 Hence, the keypad configuration contains numbers that are represented in the same way they are
182 represented in the MNL, and numbers (i.e., 3 and 7) that conflict with this representation (Figure
183 1b).

184 Finally, while the clock-face configuration is evoked by a device (i.e., the clock) which is
185 used passively and does not require any manipulation, the keypad configuration is evoked by

186 devices (e.g., phones, ATM, POS, computers, remote control) which are used actively and require
187 to be manipulated to dial numbers. Hence, the keypad is interactive and strictly related to hand
188 movements.

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



191
192
193 *Figure 1. Figure 1a shows a mobile-phone numeric keypad. Figure 1b highlights the numbers*
194 *displayed on the left and the right of the keypad configuration.*

195

196 **The role of the task**

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

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

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

212 In indirect tasks, participants are asked to judge a feature of the stimuli irrelevant to the
213 study; examples of indirect tasks are the parity judgement, and the orientation task (Notebaert et
214 al., 2006). Unlike direct tasks, the indirect ones do not require ordinal judgement, as participants
215 are not required to directly compare the stimuli with a reference. For example, in the orientation
216 judgement task, participants are asked to judge the orientation of visually presented numbers
217 (upright or tilted 20° to the right). In this case, the only feature activated by instructions is the
218 orientation of the digit, independently from the number itself. Thus, orientation is the only feature
219 that participants use to solve the task. The same reasoning can be applied to parity judgement (in

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220 which participants are asked to classify a number as even or odd) since the only feature activated
221 by instructions and relevant to solve the task is parity/disparity of numbers. Consequently, to
222 solve these tasks, participants do not need to mentally represent an ordinal sequence of the
223 stimuli. For this reason, it is unlikely that this task induces ordinality. We are not claiming that
224 order is not activated at all, but we highlight that this activation is not directly induced by task
225 instructions, as it happens with direct tasks.

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

230

231 **The present study**

232 The present study aims to investigate the role of order in the SNARC effect by examining
233 the factors that elicit ordinality, namely the context of the stimuli and the task. Indeed, in studies
234 on the SNARC effect, both context of the stimuli and task can induce ordinality, and the relative
235 contribution of each factor might be confounded. For instance, in the seminal study by Bächtold et
236 al. (1998), these aspects were not disambiguated. Indeed, the authors manipulated the context of
237 the stimuli (e.g., clock-face vs ruler) and attributed the reversal of the SNARC effect observed in
238 the clock-face condition to the context. It is true that the reverse order of the stimuli of the clock-
239 face condition is a factor potentially driving this effect by itself, however, the context was further
240 reinforced by a direct task that enhanced the ordinal properties of the display. Indeed,
241 participants were asked to imagine a clock face and to judge whether a number indicated a time

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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.

258

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,

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264 the keypad configuration order presented at the beginning is further reinforced by the task
265 requirements.

266 We hypothesized the occurrence of a spatial-numerical association consistent with the
267 keypad configuration rather than with the MNL. In particular, we expected that numbers 1, 4 and
268 7 would be responded faster with the left key and numbers 3, 6 and 9 would be responded faster
269 with the right key. Thus, according to our expectations, the numbers 3 and 7 should be associated
270 with opposite coordinates compared to the MNL. These hypotheses would be consistent with the
271 findings by Bächtold et al. (1998), who used a similar paradigm in which the context was
272 reinforced by the task, namely the order elicited by the stimuli and the task were consistent.

273

274 ***Method***

275 *Participants*

276 We tested 30 students from the University of Trieste (M = 8; F = 22) with a mean age of
277 22.09 (SD = 2.84). The sample size was determined by means of the software MorePower 6.0.4.
278 For repeated measures ANOVAs, the following parameters were used: power = .90, α = .05, partial
279 eta squared = .27 (estimated effect size from Dehaene, Bossini, and Giraux, 1993); the outcome
280 was a suggested sample size of 16 participants. For paired-samples t-tests, the following
281 parameters were used: power = .90, α = .05, Cohen's d = .65 (estimated effect sizes from Bächtold
282 et al., 1998); the outcome was a suggested sample size of 27 participants. Moreover, a recent
283 article specifically addressed this issue in studies on SNARC effects (Cipora & Wood, 2017). The
284 authors suggest the rule of thumb, "20*20", recruiting at least 20 participants performing 20
285 repetitions per stimulus. According to the power analyses and the guidelines provided by Cipora

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286 and Wood (2017), we designed the experiments to have 20 repetitions per stimulus and recruited
287 a number of participants they considered “large”, namely 30. All participants reported to be
288 righthanded and to have normal or corrected-to-normal vision. They were all used to the left-to-
289 right writing direction and were naive about the purpose of the study. All participants reported
290 that their psychophysiological state was not affected by alcohol consumption or insufficient sleep
291 in the last 24 hours (Murgia et al., 2020). Written informed consent was obtained before
292 participation; the experiment was conducted in accordance with the ethical standards established
293 by the Declaration of Helsinki and with the agreement of the University of Trieste Ethics
294 Committee.

295

296 *Apparatus and stimuli*

297 The experiment was designed and controlled by the Psychopy software, version 3.0.
298 The experiment was run with a Dell desk computer with Intel Core i5 (RAM: 4 Gb). The monitor
299 used to display instructions and stimuli was a Quato Intelli Proof 242 excellence (24 inches), with a
300 1024 × 768 resolution., and a five-button serial response box was employed to collect participants’
301 responses.

302 Participants were presented with a single-digit number and were asked to judge whether
303 the presented number is located on the right or the left of the number 5 on the keypad
304 configuration. Stimuli consisted of six single-digit numbers (1-3-4-6-7-9) and were presented one
305 at a time in the centre of the screen, painted in white against a grey background. The digits 2 and
306 8 could not be used as stimuli because, on the keypad, they are located on the central axis; the
307 digit 5 could not be used as well because it served as the point of reference for the task.

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308

309 *Procedure*

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

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

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

323 The practice session was divided into two parts. The first part of the practice session (6
324 trials x 2 repetitions) started with a fixation cross (500 ms), then, after an interstimulus interval
325 (ISI) of 500 ms, the picture of the keypad appeared at fixation point (2000 ms). When the keypad
326 picture disappeared, a fixation cross for 500 ms was presented, followed by an ISI of 500 ms. After
327 that, a single-digit number appeared in the centre of the screen until a response occurred.
328 Participants were asked to judge whether the presented number is located on the right or the left
329 of the number 5 on the keypad configuration (keypad-position task) by pressing the leftmost or

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330 the rightmost key of the response box. For each trial, feedback about the response was given
331 (“Correct!” or “Wrong!”). This part of the practice session was designed to help participants
332 familiarize themselves with the keypad configuration. The second part of the practice session (6
333 trials x 5 repetitions) followed the same procedure as the first one, except for the lack of the
334 keypad picture at the beginning of the trial.

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

343

344 ***Data analysis and results***

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

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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

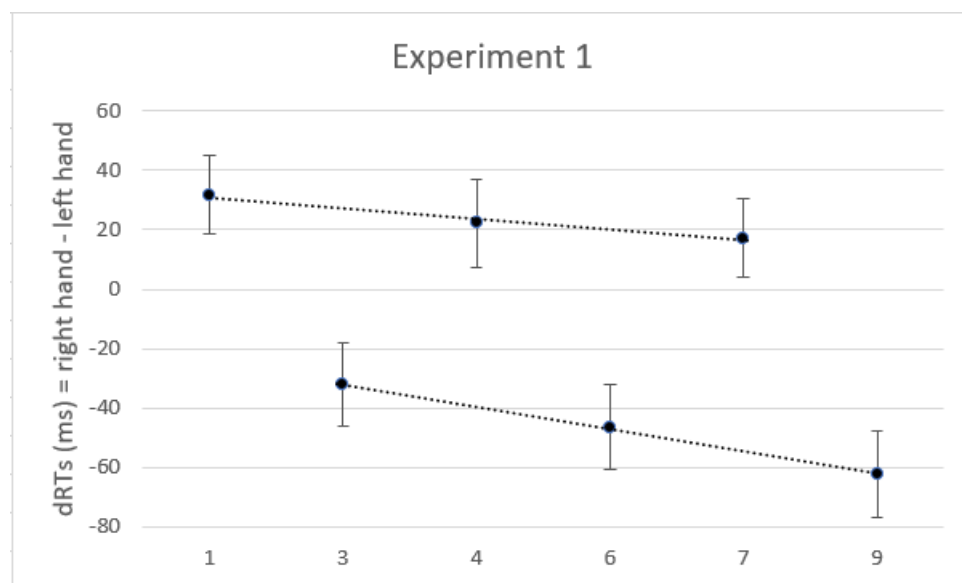
Mean and Standard Deviations of RTs for each condition of Experiment 1. Values are reported in milliseconds.

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: $dRT = RT(\text{right hand}) - RT(\text{left hand})$. 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

370 both a significant effect elicited by the keypad configuration [stimuli 1-4-7 vs. 3-6-9; $t(29) = 3.56$; p
371 $= .001$; $d = .65$; $BF_{10} = 26.5$] and an effect elicited by the Mental Number Line (MNL) configuration
372 [stimuli 1-3-4 vs. 6-7-9; $t(29) = 3.32$; $p < .005$; $d = .60$; $BF_{10} = 15.1$].

373 Finally, a set of paired sample t tests was computed to verify whether the mean dRTs of
374 numbers 3 and 7 were more in line with the keypad or with the MNL arrangement. The first
375 comparison revealed that the mean dRTs for number 3 and 7 significantly differed [$t(29) = -2.70$; p
376 $< .05$; $d = -.49$; $BF_{10} = 4.06$], with number 3 associated to the right compared to number 7.
377 Furthermore, the mean dRTs for number 3 significantly differed from the average values observed
378 for the other small numbers (i.e., 1 and 4), with number 3 associated to the right compared to the
379 average of 1 and 4 [$t(29) = -3.36$; $p < .005$; $d = -.61$; $BF_{10} = 16.5$]. Similarly, the mean dRTs for
380 number 7 significantly differed from the average values observed for the other large numbers (i.e.,
381 6 and 9), with number 7 associated to the left compared to the average of 6 and 9 [$t(29) = 3.26$; p
382 $< .005$; $d = .59$; $BF_{10} = 13.1$].



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

389

390 ***Discussion***

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

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

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

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

411

412 Experiments 2a and 2b

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

420 In the present study, the context consists of the presentation of the keypad at the
421 beginning of each experiment. The keypad is a 3x3 matrix of numbers; thus the main difference
422 with MNL is the spatial arrangement of items, namely their order. Different studies manipulated
423 the ordinal position of numerical items, either verbally or visuo-spatially. For example, van Dijck
424 and Fias (2011) required participants to verbally encode and retrieve a sequence of numbers in
425 random order, thus manipulating their ordinal position in working memory. Conversely, Bächtold

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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.

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447

448 ***Experiment 2a***

449 ***Method***

450 *Participants*

451 Thirty-four students from the University of Trieste (M = 6; F = 28) took part in Experiment
452 2a. They had a mean age of 22.17 (SD = 2.24). Thirty-one participants reported to be right-handed,
453 while three were left-handed; all participants had normal or corrected to normal vision and were
454 used to the left-to-right writing direction. Like in Experiment 1, the sample size was determined
455 using the same power analyses as for Experiment 1, and following the suggestions by Cipora and
456 Wood (2017), we thereforerecruited a number of participants considered “large” for this type of
457 studies. All participants reported that their psychophysiological state was not affected by alcohol
458 consumption or insufficient sleep in the last 24 hours (Murgia et al., 2020).

459 *Apparatus*

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

462

463 *Task and stimuli*

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

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467 3-4-6-7-8-9), with the addition of numbers 2 and 8 compared to Experiment 1. Stimuli were
468 presented one at a time in the centre of the screen, painted in white against a grey background.

469

470 *Procedure*

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

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

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

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

493

494 **Results**

495 Data analyses were the same as in Experiment 1. The repeated measures ANOVA revealed
496 a significant main effect for Hand [$F(1, 33) = 12.62$; $p = .001$; $\eta_p^2 = .28$; $BF_{10} = 5.18$], with faster
497 response times for right hand, and a significant main effect for Number [$F(7, 231) = 29.87$; $p <$
498 $.001$; $\eta_p^2 = .47$; $BF_{10} > 100$], but did not reveal a significant interaction [$F(7, 231) = .94$; $p = .47$; $\eta_p^2 =$
499 $.03$; $BF_{10} = .05$]. See Table 2 for details.

500

501 **Table 2**

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

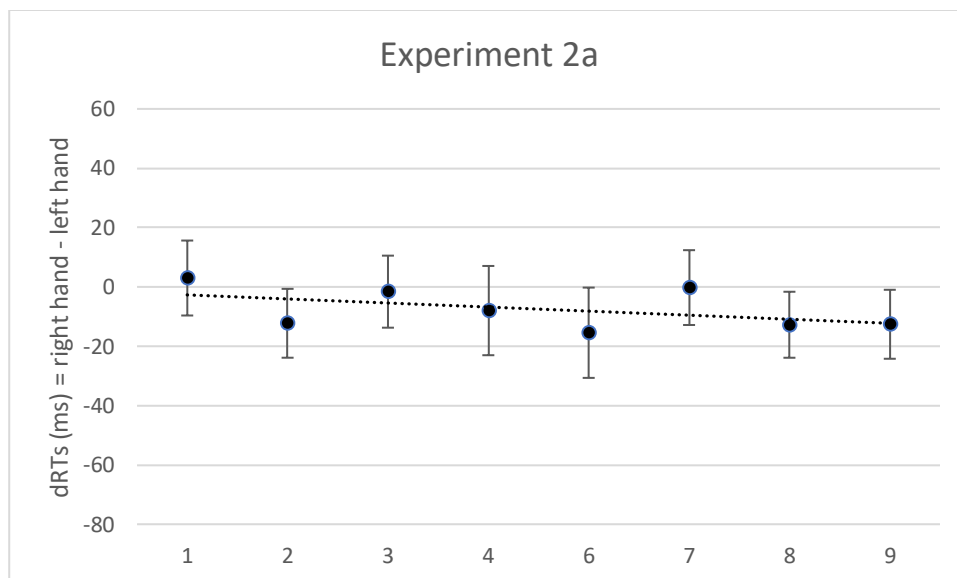
Hand	Numbers							
	1	2	3	4	6	7	8	9
Left hand	416 (68)	424 (72)	437 (77)	462 (101)	468 (89)	439 (71)	432 (63)	437 (66)
Right hand	419 (81)	412 (64)	435 (65)	454 (75)	452 (89)	439 (75)	419 (67)	424 (69)

504

505 A set of paired-sample t tests was computed in order to compare the mean of the dRTs of
506 the stimuli 1-4-7 vs. 3-6-9 (Keypad configuration); 1-3-4 vs. 6-7-9 (MNL configuration with the
507 same numbers of the keypad comparison); 1-2-3-4 vs. 6-7-8-9 (MNL configuration including
508 numbers 2 and 8). The paired samples t tests did not reveal any significant effect for the keypad
509 configuration [stimuli 1-4-7 vs. 3-6-9; $t(33) = 1.36$; $p = .18$; $d = .23$; $BF_{10} = .43$], nor for the MNL
510 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-
511 8-9; $t(33) = .46$; $p = .65$; $d = .07$; $BF_{10} = .20$].

512 Finally, a set of paired sample t tests was computed to verify whether the mean dRTs of
513 numbers 3 and 7 were more in line with the keypad or with the MNL arrangement. The first
514 comparison revealed that the mean dRTs for number 3 and 7 did not significantly differ [$t(33) = -$
515 $.06$; $p = .95$; $d = -.01$; $BF_{10} = .18$]. Furthermore, the mean dRTs for number 3 did not differ from the
516 average values observed for the other small numbers (1, 2, and 4) [$t(33) = 1.12$; $p = .24$; $d = .21$;
517 $BF_{10} = .36$]. Conversely, the mean dRTs for number 7 significantly differed from the average values
518 observed for the other large numbers (6, 8, and 9), with number 7 associated to the left compared
519 to the other large numbers [$t(33) = 2.87$; $p < .01$; $d = .49$ $BF_{10} = 5.73$].

520



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Discussion

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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.

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.

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

544

545 ***Experiment 2b***

546 ***Method***

547 *Participants*

548 The participants were the same as in Experiment 2a.

549

550 *Apparatus*

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

553

554 *Task and stimuli*

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

559

560 *Procedure*

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

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

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

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

581

582 **Results**

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

590

591 **Table 3**

592 *Mean and Standard Deviations of RTs for each condition of Experiment 2b. Values are reported in*
593 *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)

594

595

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

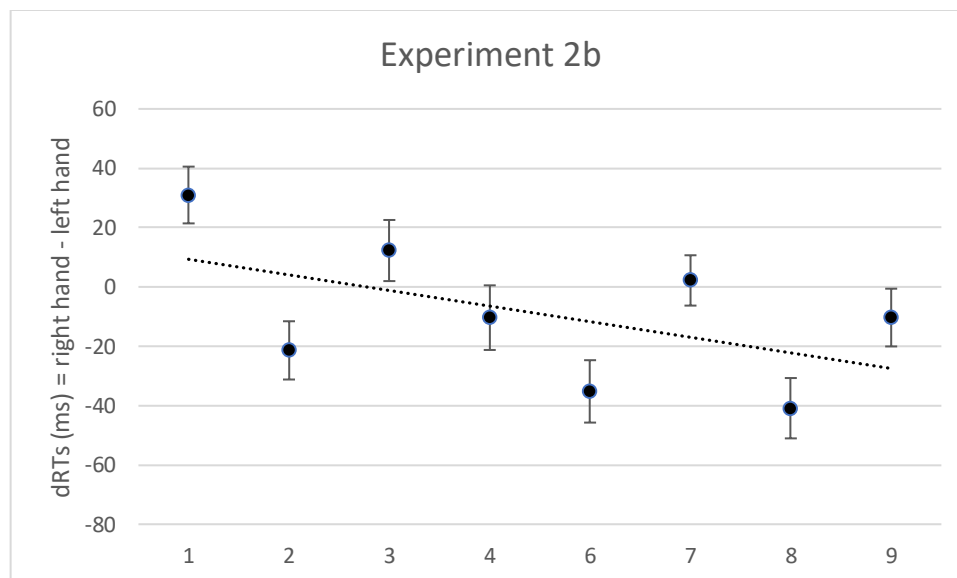
603 A set of paired sample t tests was then computed to verify whether the mean dRTs of
604 numbers 3 and 7 were more in line with the keypad or with the MNL arrangement. The first
605 comparison revealed the mean dRTs for number 3 and 7 did not significantly differ [$t(33) = 1.10$; p
606 $= .28$; $d = .19$; $BF_{10} = .32$. Furthermore, the mean dRTs for number 3 did not differ from the average
607 values observed for the other small numbers (1, 2, and 4) [$t(33) = .95$; $p = .35$; $d = .16$; $BF_{10} = .28$].
608 Conversely, the mean dRTs for number 7 significantly differed from the average values observed
609 for the other large numbers (6, 8, and 9), with number 7 associated to the left compared to the
610 other large numbers [$t(33) = 3.07$; $p < .005$; $d = .52$ $BF_{10} = 8.98$].

611 Finally, given that the dRTs appeared to be different for odd and even numbers, we
612 compared the average values observed for 1-3-7-9 vs. 2-4-6-8. The results revealed a significant
613 association for odd numbers to the left and right numbers to the right [$t(33) = 2.87$; $p < .01$; $d = .49$
614 $BF_{10} = 5.79$].

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616

617

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

621

622 **Discussion**

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

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

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

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

646

647 **General discussion**

648 The aim of the present study was to investigate the role of order elicited by the context
649 and by the task in the SNARC effect. To reach this goal, we used a context that allowed us to alter

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650 the order of the stimuli compared to MNL, and we manipulated the task demands. The same
651 context was provided at the beginning of each experiment to elicit a spatial representation of
652 numbers compatible with the spatial arrangement of the keypad. The context was kept constant,
653 while the tasks of the three experiments were designed to induce representations with different
654 levels of consistency with the context.

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

664 These results indicate that the order elicited by the context (the keypad) determined a
665 spatial association only in Experiment 1. However, since in Experiment 1, the order elicited by the
666 context is the same as the one elicited by the task, it is not possible to state whether the observed
667 association was induced by the context or by the task. Therefore, to disentangle the role of the
668 context from that of the task, we performed Experiments 2a and 2b. At the beginning of these
669 experiments, the context was activated in the same way as in Experiment 1 by showing the keypad
670 picture, and participants were instructed to pay attention to the spatial arrangement of numbers
671 and to keep it in mind throughout the entire experiment. Notably, participants were not aware

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672 that the keypad would be irrelevant; rather it is likely that they expected that a keypad-related
673 task would occur at some point, maintaining a certain level of activation of the keypad
674 configuration.

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

686 Our results are consistent with the model proposed by Prpic et al. (2016), who describe
687 two distinct mechanisms underlying SNARC-like effects: An Order-Related Mechanism (ORM) and
688 a Magnitude-Related Mechanism (MRM). The ORM would be activated by direct tasks (e.g.,
689 magnitude classification), whereas the MRM would be activated by indirect tasks (e.g., parity
690 judgement). Based on this model, in Experiment 1, the ORM would be consistently activated by
691 both context and task, thus inducing a spatial association congruent with the keypad. In
692 Experiment 2a, the representations elicited by the context and the task would generate a conflict
693 in the ORM, thus determining a lack of spatial associations. It is noteworthy that the cancellation

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694 of the SNARC effect has been interpreted as an indicator of conflicting spatial-numerical
695 representations in other studies (e.g., Shaki & Fischer, 2012). In Experiment 2b, the ORM would be
696 only activated by the context, but the task would activate the MRM. Therefore, in this case, no
697 conflict would have occurred. Given that the task does not require to process the ordinal
698 properties of the stimuli directly, the MRM would elicit the SNARC effect.

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

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

714 In Experiments 2a and 2b, which did not require retrieval of the keypad configuration, the
715 influence of the context can be interpreted in light of previous studies comparing visuospatial and

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716 verbal working memory. Van Dijck et al. (2009) found that the SNARC effect disappeared under
717 visuospatial load in magnitude classification tasks, while this inhibition did not occur in the parity
718 judgment. The context used in the present study was of visuospatial nature; hence it might have
719 acted as visuospatial load, consequently interfering with the SNARC effect in the magnitude
720 classification but not in the parity judgement. Referring to Prpic et al.'s model, it is noteworthy
721 that in direct tasks, the judgment (e.g., comparing whether the ordinal position of a target is
722 before or after a reference in a mapped sequence) – processed at ORM level – would be based on
723 visuospatial information. Thus, the visuospatial conflict activated by the context would interfere
724 with ORM during the magnitude classification task (Experiment 2a). Conversely, in indirect tasks,
725 the judgement would not be based on visuospatial information. Thus, the information activated by
726 the context would not interfere with MRM during the parity judgment task (Experiment 2b).

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

738 task. Thus, the effect observed by Bächtold et al. is probably due to the order consistently elicited
739 by both the context and the task.

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

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

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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.

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Dataset

<https://osf.io/gbfx6/>

Declarations of interest

none

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