UNIVERSITÀ DEGLI STUDI DI TRIESTE

UNIVERSITÀ DEGLI STUDI DI TRIESTE

XXXV CICLO DEL DOTTORATO DI RICERCA IN NEUROSCIENZE E SCIENZE COGNITIVE

PO FRIULI VENEZIA GIULIA - FONDO SOCIALE EUROPEO 2014/2020

THE ROLE OF CONTEXT AND TASK DEMANDS IN SPATIAL-NUMERICAL ASSOCIATIONS

Settore scientifico-disciplinare: **M-PSI/01**

DOTTORANDA
SERENA MINGOLO

COORDINATORE
PROF. ANDREA CARNAGHI

SUPERVISORE DI TESI
PROF.SSA ELEONORA BILOTTA

CO-SUPERVISORE DI TESI
PROF. MAURO MURGIA

ANNO ACCADEMICO 2021/2022

UNIVERSITÀ DEGLI STUDI DI TRIESTE

XXXV CICLO DEL DOTTORATO DI RICERCA IN NEUROSCIENZE E SCIENZE COGNITIVE

PO FRIULI VENEZIA GIULIA - FONDO SOCIALE EUROPEO 2014/2020

THE ROLE OF CONTEXT AND TASK DEMANDS IN SPATIAL-NUMERICAL ASSOCIATIONS

Settore scientifico-disciplinare: **M-PSI/01**

DOTTORANDA
SERENA MINGOLO

COORDINATORE
PROF. ANDREA CARNAGHI

SUPERVISORE DI TESI
PROF. ELEONORA BILOTTA

CO-SUPERVISORE DI TESI
PROF. MAURO MURGIA

ANNO ACCADEMICO 2021/2022

Table of contents

Abstract

The Spatial-Numerical Association of Response Codes (SNARC effect; Dehaene et al., 1993) is perhaps the most studied phenomenon in the field of Spatial-Numerical Associations (SNAs). Due to this effect participants respond faster to small numbers with a left key, and faster to large numbers with a right key. This phenomenon has been replicated with different experimental paradigms, employing various forms of stimuli and tasks. The robust evidence drawn from this past research unequivocally indicates that numbers are mapped spatially in our minds, and that this mapping is not univocal, but rather flexible.

Flexibility in SNAs has been studied extensively. Several studies reported that participants exhibit different SNAs depending on their scanning habits (Dehaene et al., 1993; Zebian, 2005). Other research revealed participants, when trained to conceive numbers in unusual ways, for instance by memorizing random numerical sequences (van Dijck & Fias, 2011) or by spatializing numbers in unusual directions (Pitt & Casasanto, 2020; Bächtold et al., 1998), they exhibit temporary alterations in SNAs. Despite the approach used, these studies manipulated the context in which numbers are processed in similar ways.

The general objective of this thesis is to investigate how context alters the SNARC effect and SNAs in general. Another goal is to clarify if these alterations can be attributed to the context alone, or, if not, to understand which role task demands play in this process. To this end, the three studies presented here used alternative spatial-numerical configurations as contexts and distinct tasks that could reinforce the context or not. In this way, the action of the context could be observed in isolation or in interaction with task demands.

The first study investigates how an atypical spatial numerical context can alter the SNARC effect. Each experiment used distinct task demands, which could be either consistent, inconsistent, or unrelated to the context. Results suggest that the context can shape a SNA only when task demands and context are consistent. The second study reveals that the interaction

between context and task demands observed in the first study is modulated by the salience of the context elicited by task demands. In the third study, the paradigm outlined in the previous studies was used to investigate the role of order and magnitude in the SNARC effect using a context in which people represent numbers in two different orders. The results that emerged are in line with stimuli's magnitude, but order could have played a role as well.

Taken together, the present studies help clarify the mechanisms underlying the influence of context and task on SNAs. From a theorical perspective, such findings give insights about the fact that the connection between number and space in our minds is probably due to a strategical adjustment to the task, rather than an innate feature of number processing.

Chapter 1
General introduction

1.1 The SNARC effect

Research in numerical cognition has widely documented the great overlap between spatial and numerical processing that exists in our minds. The idea of a link between these two abstract concepts is not new, but has origins from the 1880s, when Francis Galton first described introspective reports of people who vividly visualized numbers in recurrent spatial layouts (Galton, 1880). Most of the reported representations could be traced back to childhood and were stable throughout life. The most common visuospatial representation of numbers was a linear layout called *mental number line* (MNL, e.g., Restle, 1970). The MNL accounts for basic performance patterns often observed in numerical cognition experiments, like the Spatial-Numerical Representation of Response Codes, or SNARC effect.

The SNARC effect was systematically investigated and described by Dehaene and colleagues in a seminal study published in 1993. Dehaene et al. performed variations of the parity judgement task, which requires participants to respond with two alternative lateralized keys (left vs. right) in respect to centrally presented numbers, depending on their parity status (even vs. odd). The speed of participants' response was recorded, and their speed was analysed as a function of number magnitude and response side. Statistical analysis of the response times revealed that participants responded faster to small numbers with the left key, and faster to large numbers with the right key.

The SNARC effect can be seen as a particular form of a spatial compatibility effect, in which people respond faster and more accurately when the effectors are placed on the same side as the stimuli (Fitts & Seger, 1953). The same effect occurs even when the spatial location of the stimulus is irrelevant, as in the Simon effect (Simon, 1969). The SNARC effect indicates that our spontaneous spatialization of numbers is so strong that numbers automatically activate a lateralized spatial representation in our minds, even when presented centrally. The congruency between the spatial position activated by a number and the spatial position of a given response effector facilitates performance. This same result occurs even when numbers' magnitude is not explicitly processed.

The SNARC effect has been tested with varied numerical properties. Dehaene et al. (1993) observed that the effect did not emerge with two-digits numbers, a result that was explained by the fact that two-digit numbers are not clearly mapped on the MNL, but the single digits composing these numbers are. Brysbaert (1995) found that participants responded quicker to two-digit numbers in which the smallest number was in the tens position, rather than on the right, compatibly with the MNL.

The SNARC effect has also been tested for negative numbers, to determine whether they are spatialized based on relative or absolute value. Conflicting results emerged. Negative numbers were sometimes associated to the left of positive numbers (Fischer, 2003) and other times showed no reliable spatial associations (Nuerk et al., 2004). Lastly, the SNARC effect emerges with different number formats other than the Arabic one (Dehaene et al., 1993; Fias, 2001; Nuerk et al, 2004), and with various sensory modalities (Nuerk et al., 2005), pointing to an amodal spatial representation of numbers.

Regarding the amodality of SNARC-like effects, it is important to note that they are not exclusively numerical. Similar effects can be found for stimuli expressing quantities in non-symbolic ways, such as luminance (Fumarola et al., 2014), angle-magnitude (Fumarola et al., 2016) and physical size of objects (Ren et al., 2011; Sellaro et al., 2015). These stimuli determine left-to-right intensity driven associations, showing that a numerical analogue is not necessary to elicit the SNARC effect. Indeed, even stimuli that do not express quantities show SNARC-like effects (Gevers et al., 2003; van Dijck & Fias, 2011). This means that the effect cannot be limited to magnitude processing.

1.2 The role of order and magnitude in the SNARC effect

Traditionally, the SNARC effect has been considered to be determined by the automatic activation of magnitude as represented on the MNL. But stimuli that do not convey any quantitative information can elicit SNARC-like effects too. Similarly, evidence has supported the hypothesis that magnitude cannot account for all SNARC-like effects. Hence, there must be another mechanism responsible for them. This mechanism is most likely ordinality, the property of items of being classified based on their relative position in a series.

A well-known example of ordinality (order) in SNARC-like effects is by Gevers et al. (2003). When asked to judge whether a target (either a letter of the alphabet or a month of the year) came before or after a mid-reference standard (O/July), participants responded faster with a left key for early targets (e.g., E/January) and with a right key for late targets (e.g., Y/December). Another famous case is by van Dijck & Fias (2011), who found that items encoded early in a sequence were responded faster with a left key, while items encoded later were responded faster with the right key. These stimuli clearly did not vary in magnitude; hence these effects could only be determined by ordinality.

In two recent works (Casasanto & Pitt, 2019; Pitt & Casasanto, 2020), the authors addressed the longstanding debate on the predominance of ordinality or cardinality (magnitude) in SNARC-like effects. Their work suggests that such effects can be explained by order alone and rejects any role of magnitude. However, this conclusion does not consider that SNARC-like effects can be elicited by stimuli that do vary in magnitude but are not characterized by a clear order. Some examples of these stimuli are non-symbolic magnitudes such as the size of pictorial surfaces (Prpic et al., 2020; Ren et al., 2011), weight (Dalmaso & Vicovaro, 2019, Vicovaro & Dalmaso, 2020) and luminance (Fumarola et al., 2014; Ren et al., 2011). These types of stimuli are continuous magnitudes, while ordinal sequences are typically discrete categories. In these cases, it is likely that their magnitude can explain the SNARC-like effects emerging from them. On the other hand, another possibility is that such stimuli that vary along non-numerical dimensions could be perceived as a sequence of ordered elements, with their order being determined by magnitude.

It is difficult to dissociate the action of order and the magnitude employing numerical stimuli. With numbers, the direction of order follows magnitude, which increases progressively from left to right. Prpic et al. (2016) attempted to disambiguate the role of order and magnitude in SNARC-like effects by employing symbolic stimuli that are typically represented in the reversed order compared to numbers. These stimuli were musical note values, which decrease in magnitude from left to right. The results suggest that ordinality is not the only mechanism involved in SNARC-like effects, but that magnitude plays a role as well, depending on the requirements of the task.

1.3 Flexibility in the SNARC effect: the role of context and task demands

An effective way to understand the origins of a phenomenon is to look at its alterations. This is particularly true for the SNARC effect and SNAs in general. Even though the results are robust and replicable, they can be easily manipulated by the circumstances in which they are measured. Several studies systematically manipulated spatial-numerical experiences in participants and reported the alterations observed in SNAs. The results from these studies highlight that SNAs do not obligatorily originate from stable representations but are modulated by the interaction between long-term representation and the current situation in which they are measured.

Each study that operates manipulations on SNAs should rigorously identify the characteristics of such manipulations, in order to be able to draw conclusions from the observed results. Cipora et al. (in Hubbard, 2018) proposed a taxonomy of the so-called "situated influences" of the SNARC effect, namely those in which the SNARC effect is not observed in its regular form but is temporarily shaped by a manipulation operated in the experimental setting. The authors classified (1) the modality of the manipulation, which can be perceptual, representational, or related to action, (2) the time when the manipulation occurs, namely before the beginning of the experiment (pre-experimental) or during the experiment (intra-experimental), and (3) whether the manipulation is related to the reading direction.

The present thesis includes three studies that address the topic of situated influences in the SNARC effect, focusing on two aspects of the experimental setting: context and task demands. The word "context" refers to the way in which the stimuli are presented, which can be manipulated at a pre-experimental, perceptual level. "Task demands" refer to the way in which the stimuli are required to be processed, which can be manipulated at an intra-experimental, representational level. The aim of the contextual manipulations in the studies is to investigate how context alters the SNARC effect and SNAs in general. The aim of the manipulations at task level is to clarify if the observed alterations can be attributed to the context alone and, if not, to understand which role task demands play in regulating this process. To this end, the studies included in the thesis used alternative spatial-numerical configurations as contexts, tested with various tasks that could reinforce the context or not.

The first study investigates the way in which context and task demands regulate the role of order in SNAs. The second study goes further, investigating the interaction between context and task demands modulated by the salience of the context. Lastly, the third study investigates the role of order and magnitude in a context in which they elicit opposite representations.

Chapter 2

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

This is an Accepted Manuscript of an article published by the Journal of Experimental Psychology: Human Perception and Performance.

Mingolo, S., Prpic, V., Bilotta, E., Fantoni, C., Agostini, T., & Murgia, M. (2021). Snarcing with a phone: The role of order in spatial-numerical associations is revealed by context and task demands. Journal of Experimental Psychology: Human Perception and Performance, 47(10), 1365–1377. https://doi.org/10.1037/xhp0000947

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.

2.1 Introduction

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., 2021). 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.

2.1.1 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.

2.1.2 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.

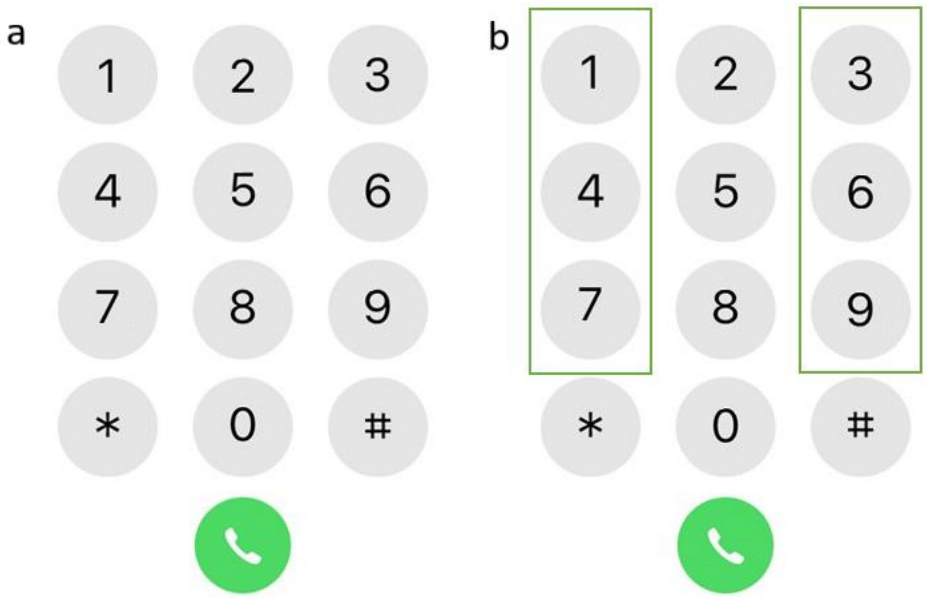

Figure 1. Figure 1a shows a mobile-phone numeric keypad. Figure 1b highlights the numbers displayed on the left and the right of the keypad configuration.

2.1.3 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).

2.1.4 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.

2.2 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.

2.2.1 Method

2.2.1.1 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.

2.2.1.2 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.

2.2.1.3 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.

2.2.2 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 [$t(29) = 3.26$; $p < .005$; $d = .59$; $BF_{10} = 13.1$].

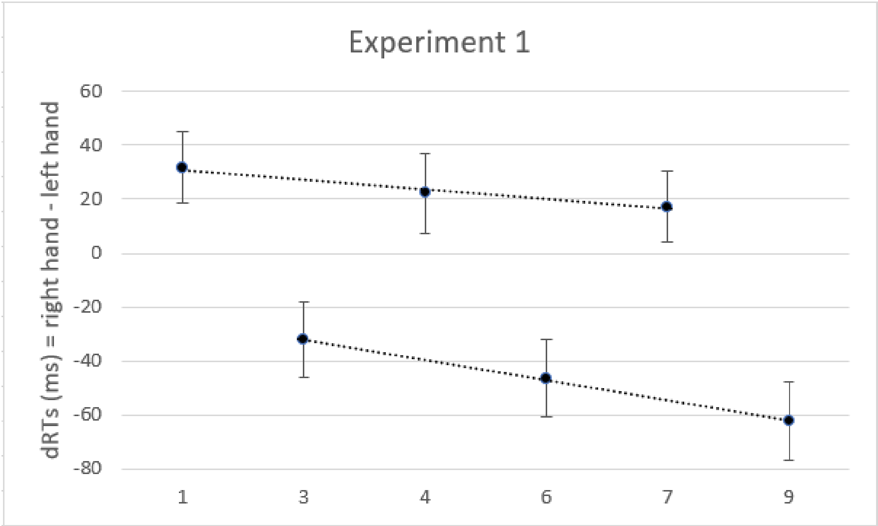

Figure 2. The figure shows the Mean dRTs (right key - left key) for every numerical stimulus in Experiment 1. Positive differences indicate faster left-key responses; negative differences indicate faster right-key responses. Errors bars indicate the standard error of the mean. Separate trend lines are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

2.2.3 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.

2.3 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.

2.3.1 Experiment 2a - Method

2.3.1.1 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 therefore recruited 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).

2.3.1.2 Apparatus

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

2.3.1.3 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.

2.3.1.4 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.

2.3.2 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 [$t(33) = 2.87$; $p < .01$; $d = .49$ $BF_{10} = 5.73$].

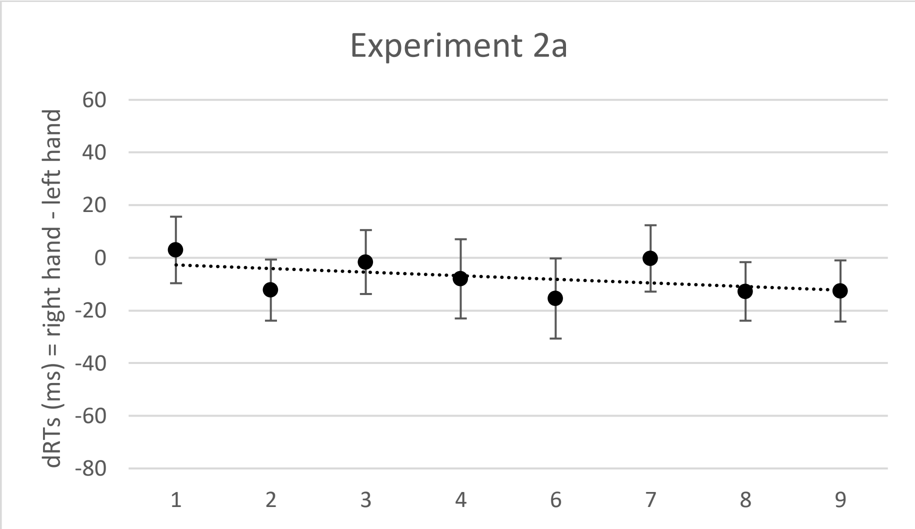

Figure 3. The figure shows the Mean dRTs (right key - left key) for every numerical stimulus in Experiment 2a. Positive differences indicate faster left-key responses; negative differences indicate faster right-key responses. Errors bars indicate the standard error of the mean.

2.3.3 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.

2.3.4 Experiment 2b - Method

2.3.4.1 Participants

The participants were the same as in Experiment 2a.

2.3.4.2 Apparatus

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

2.3.4.3 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.

2.3.4.4 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.

2.3.5 Data analysis and 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 [$t(33) = 2.87$; $p < .01$; $d = .49$ $BF_{10} = 5.79$].

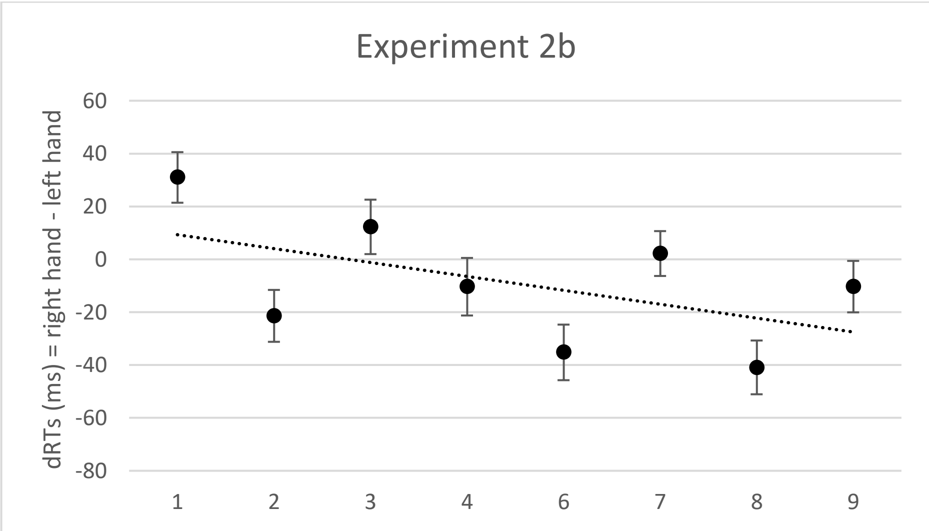

Figure 4. The figure shows the Mean dRTs (right key - left key) for every numerical stimulus in Experiment 2b. Positive differences indicate faster left-key responses; negative differences indicate faster right-key responses. Errors bars indicate the standard error of the mean.

2.3.6 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 et al., 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.

2.4 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.

2.5 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.

Chapter 3

"It's SNARC o' clock: manipulating the salience of the context in a conceptual replication of Bächtold et al.'s (1998) clockface study".

This is a Manuscript submitted to the Journal of Experimental Psychology: Learning, Memory, and Cognition.

Mingolo, S., Prpic, V., Mariconda, A., Brugger, P., Drack, P., Bilotta, E., Agostini, T., & Murgia, M. (submitted). It's SNARC o' clock: manipulating the salience of the context in a conceptual replication of Bächtold et al.'s (1998) clockface study.

Abstract

The Spatial-Numerical Association of Response Codes (SNARC) effect consists in faster left-/right-key responses to small/large numbers. Bächtold et al. (1998) reported the reversal of this effect after eliciting the context of a clockface – where small numbers are represented on the right and large numbers on the left. The present study investigates how the salience of a particular spatial-numerical context, which reflects the level of activation of the context in working memory, can alter Spatial Numerical Associations (SNAs). Four experiments presented the clockface as context and gradually increased its salience using different tasks. In the first two experiments (low salience), the context was presented at the beginning of the experiment and its retrieval was not required to perform the tasks (i.e., random number generation in Experiment 1, magnitude classification and parity judgement in Experiment 2). Results revealed regular left-to-right SNAs, unaffected by the context. In Experiment 3 (medium salience), participants performed magnitude classification and parity judgement (primary task), and a Go/No-go (secondary task) which required the retrieval of the context. Neither the SNARC effect nor a reversed-SNARC emerged, suggesting that performance was affected by the context. Finally, in Experiment 4 (high salience), the primary task required participants to classify numbers based on their position on the clockface. Results revealed a reversed SNARC, as in Bächtold et al. (1998). In conclusion, the SNARC is disrupted when the context is retrieved in a secondary task, but its reversal is observed only when the context is relevant for the primary task.

3.1 Introduction

Spatial-Numerical Associations (SNAs) are among the most important examples of the overlap between space and number representation in human cognition. Among SNAs, the SNARC effect (Spatial-Numerical Association of Response Codes; Dehaene et al., 1993) is paradigmatic and has most frequently been investigated (for a meta-analysis, see Wood & al., 2008). This effect consists in the facilitation, exhibited by people from Western cultures, to respond to a small number with a left key and to a large number with a right key. This facilitation in response execution applies both to speed and accuracy. Dehaene et al. (1993) suggested that the SNARC effect can be attributed to the long-term representation of magnitudes on a "Mental Number Line" (MNL; Restle, 1970), in which small numbers are associated to the left side of the line and large numbers are associated to the right. According to this account, the SNARC effect would originate from a long-term association between numbers and space.

Despite the MNL account is well-known in SNAs research, some studies seem to challenge it. In particular, growing evidence suggest that the relation between numbers and space can be constructed temporarily during task execution (Fias & van Dijck, 2016), which implies a crucial involvement of working memory. Proofs of the involvement of working memory were provided in a seminal study by van Dijck et al. (2009), who found that the SNARC effect depends on the working memory resources available at a given moment. In their experiments, the SNARC effect disappeared under a visuospatial working memory load in magnitude comparison and under a verbal working memory load in parity judgment. In another study, participants were asked to perform a parity judgement on a sequence of random numbers that they had previously memorized (van Dijck & Fias, 2011). Results showed an "ordinal position effect", namely an association between the ordinal position of items in the memorized sequence and the response coordinates (i.e., first items of the sequence were associated to the left and last items to the right, regardless of number's magnitude). According to these studies, the SNARC effect cannot be explained by long-term, immutable associations between numbers and space, rather it seems that working memory plays a crucial role in regulating these associations depending on task requirements.

The SNARC effect and, more in general, SNAs can be observed in a variety of different tasks. Most common are magnitude classification and parity judgement tasks. In magnitude classification, participants are required to classify a centrally presented number (e.g., 2) as smaller or larger than a fixed reference (e.g., 5) by pressing either a left or right key, depending on the condition. In parity judgement, participants are required to classify a centrally presented number (e.g., 3) as even or odd, by pressing either a left or right key, depending on the condition. Magnitude classification is considered a "direct task", because it requires participants to directly compare a feature of the stimuli relevant for the study (i.e., magnitude) with a reference. Conversely, parity judgement is considered an "indirect task", because participants are asked to judge a feature of the stimuli irrelevant to the study, namely parity (Mingolo et al., 2021).

Another task that has been used to investigate spatial biases in number processing is the random number generation task (RNG). This task requires participants to continuously enumerate numbers included in a given numerical interval, usually in combination with spatial instructions. This task revealed that people generally produce more small numbers when turning their head to the left, and more large numbers when turning their head to the right (Loetscher et al., 2008). Similarly, higher production of small numbers was found after spontaneous downward/leftward eye movements, together with higher production of large numbers after upward/rightward eye movements (Loetscher et al., 2010). More in general, a tendency to generate significantly more small numbers than the chance level has been observed in healthy subjects (Loetscher & Brugger, 2007). This preference is referred to as "small number bias" (SNB), and it has been attributed to a leftward bias defined as "pseudoneglect". This bias would lead healthy subjects to preferably allocate their attention to the left side of the MNL when processing numbers (Loetscher & Brugger, 2009).

The SNARC effect has been observed not only using different tasks, but also using different kinds of stimuli. Indeed, this effect does not limit to numerals. Other stimuli conveying a quantity exhibited SNARC-like effects, such as object's size (Prpic et al., 2020; Ren et al., 2011, Sellaro et al., 2015), luminance (Fumarola et al., 2014; Ren et al., 2011), and angle magnitude (Fumarola et al., 2016). Similarly, ordinal stimuli such as weekdays, months, letters (Gevers et al., 2003; 2004) and musical notation (Fumarola et al., 2020) are spatially mapped. The SNARC effect is very consistent and has been replicated not only with different kinds of stimuli, but also with different presentation modalities like the auditory (Bruzzi et al., 2017; De Tommaso & Prpic, 2020; Hartmann & Mast, 2017; Lega et al., 2020; Mariconda et al., 2022; Prpic & Domijan, 2018) and somatosensory ones (Dalmaso & Vicovaro, 2019; Vicovaro & Dalmaso, 2021).

Although the SNARC effect is robust and replicable, a large amount of evidence indicates that this effect is quite flexible. The effect can be influenced by different experiences such as the reading/writing direction of participants (Dehaene et al., 1993; Shaki et al., 2009; Zebian, 2005; but see also Cipora et al., 2019, and Zohar-Shai et al., 2017, for different results), by activities that spatialize numbers in our daily lives, such as finger counting (Fischer, 2008; Hohol et al., 2021; Pitt & Casasanto, 2020), and by the context in which numerical stimuli are presented (Bächtold et al., 1998; Mingolo et al., 2021).

Famously, the study by Bächtold et al. (1998) showed that the context in which number are presented has the potential to alter, and even reverse, the SNARC effect. In that two-part study, participants were instructed to conceive centrally presented numbers (ranging from 1-11) as distances on a ruler (thus evocating the MNL), and to judge whether such distances were shorter or longer than 6 cm. Results were in line with the SNARC effect, with faster left-key responses to small numbers and faster right-key responses to large numbers. In a second experiment, other participants did the same task after being exposed to a clockface context, whose spatial representation of numbers is opposite to the MNL (i.e., small numbers are on the right and large numbers are on the left). In this experiment, faster right-hand responses to small numbers and faster left-hand responses to large ones were observed, showing that the clockface context led to a reversal of the traditional SNARC effect.

A recent study tested the influence of context on the SNARC effect using a mobile-phone keypad (Mingolo et al., 2021). The consistency between the representation elicited by the context and by the task was manipulated using three different tasks. The context shaped a keypad-like SNA when the task elicited a representation consistent with the one elicited by the context. However, an influence of the context emerged at a certain degree in other tasks as well. Overall, from the literature it is not clear whether these results are due to the context alone or to the salience of the context as determined by the task.

3.1.2 The present study

The present study aims to clarify how context may alter typical left-to-right SNAs. Furthermore, we investigate how task demands modulate the salience of the context (which reflects the level of activation of the context in working memory), and thus its effect on SNAs. To achieve these goals, the effect of the context employed by Bächtold et al. will be systematically investigated in different tasks. The clockface context will be kept constant across the experiments, while task demands will be modified to gradually increase the level of salience of this context (low, medium, high).

In the first part of the study (Experiment 1 and Experiment 2), the clockface context is elicited at the beginning of the experiments, while task instructions are completely unrelated to it. In this way, task demands will induce a low level of salience of the context. The tasks used are a random number generation (RNG) task in Experiment 1, and two classical SNARC tasks in Experiment 2 (magnitude classification and parity judgement). In the second part of the study (Experiment 3), the clockface context is introduced at the beginning of the experiment and participants perform a dual task. In particular, the primary tasks consist, as in Experiment 2, in a magnitude classification and a parity judgement. The secondary task reinforces the salience of the context using a Go/No-go procedure. This procedure is meant to retrieve in working memory the contextual configuration processed at the beginning of the experiment. In this way, task demands will induce a medium level of salience of the context. Finally, in the last part of the study (Experiment 4), the clockface context is introduced at the beginning of the experiment, and the instructions of the primary task are directly based on it. The task requires participants to classify numbers depending on their spatial position on the clockface. In this way, task demands will require the retrieval of the contextual configuration from working memory, thus inducing a high level of salience of the context.

3.2 Experiment 1

Experiment 1 investigates the effect of the clockface context – introduced at the beginning of the experiment – on the small-number bias (SNB). SNB indicates the tendency to produce more small numbers than large numbers (in a given numerical interval) during RNG tasks. This effect would be explained by a 'pseudoneglect in number space' exhibited by healthy participants (Loetscher & Brugger, 2007). Pseudoneglect is the tendency to preferentially attend to the left side of space. It can be found, for instance, in traditional bisection tasks, where participants tend to misplace the midpoint to the left of its exact position (Jewell & McCourt, 2000). It has also been demonstrated in "number line bisections", where participants (of Western cultures) tend to misplace the numerical midpoint of two given numbers towards smaller numbers, i.e., to the left on the MNL (e.g., Brugger et al., 2010).

The aim of Experiment 1 is to investigate whether RNG reveals the presence of pseudoneglect when the same configurations employed by Bächtold et al. (1998) are used as context: the clockface configuration (Experiment 1a) and the ruler configuration (Experiment 1b). If this is the case, numbers placed left in context-dependent representational space should be overrepresented in both configurations. This would mean a reversal of the SNB (i.e., an overrepresentation of *large* numbers) in the clockface configuration, and the typical SNB in the ruler configuration.

3.2.1 Method

3.2.1.1 Participants

We tested 35 participants (20 women, 15 men) with a mean age of 30.53 (SD = 10.27). The sample size was determined by means of the software MorePower 6.4. The following parameters were used: power = .80, α = .05, Cohen's d = .44 (the effect size was extracted from Winter & Matlock, 2019); the outcome was a suggested sample size of 34 participants. All participants reported to be right-handed, to have normal or corrected-to-normal vision and to have always been used to exclusively read and write in a left-to-right direction. Before the experiment, participants provided written informed consent to participate in the study. The present experiment was conducted in accordance with the ethical standards indicated by the Declaration of Helsinki and with the approval of the University of Trieste Ethics Committee.

3.2.1.2 Apparatus and stimuli

A Dell desk computer with Intel Core i5 (RAM: 4 Gb) was employed to prepare two images, one representing a clockface (Figure 1a) and the other representing a ruler (Figure 1b). They were displayed on a Quato Intelli Proof 242 excellence (24 inches) monitor, with a 1024 × 768 resolution. A metronome and a tape recorder were used.

3.2.1.3 Procedure

In Experiment 1a, participants sat on a chair located in front of the screen, with their body aligned to the screen's midline. When the participant was ready, the clockface picture (Figure 1a) was presented at the centre of the screen for 20 seconds and participants were asked to pay particular attention to it. After presentation of the clockface picture, participants were asked to close their eyes and to imagine the picture while performing RNG. This task required to vocally produce 60 numbers in the range of 1-12 at the constant rhythm of 0.5 Hz, paced with the beat of a metronome. Numbers had to be generated in a sequence as random as possible, taking into consideration that any number could be followed by any other number with a comparable probability in the long run. Participants' responses were tape-recorded during the task, to allow later annotation of the generated numbers. Experiment 1b followed the exact same procedure as Experiment 1a, but the ruler picture was presented instead (Figure 1b). Every participant performed both Experiment 1a and 1b; the order of execution of the experiments was counterbalanced among participants.

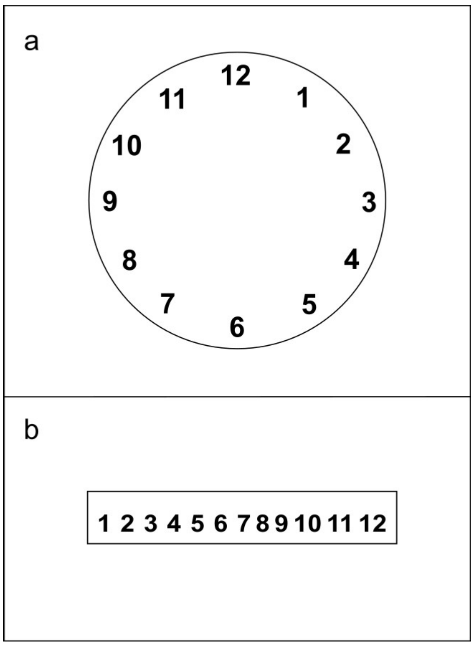

Figure 1. The clockface (a) and the ruler (b) presented at the beginning of Experiments 1a and 1b, respectively.

3.2.2 Data analysis and results

The number of times each number was generated was counted for each participant in each experiment. The numbers generated were labelled "small" (i.e., 1-2-3-4-5) or "large" (i.e., 7-8-9-10-11).

In Experiment 1a (clockface), small (rightward) numbers were generated more often than large (leftward) numbers (small numbers: M = 26.60, SD = 2.43; large numbers: M = 23.40, SD = 2.67). A paired-sample *t* test showed that this difference was significant [$t(34) = 4.05$; $p < .001$; $d = .68$; $BF_{10} = 99.8$].

In Experiment 1b (ruler), small (leftward) numbers were generated more often than large (rightward) numbers (small numbers: M = 27.1, SD = 2.94; large numbers: M = 23.9 times, SD = 2.87). A paired-sample *t* test showed that this difference was significant [$t(34) = 3.51$; $p < .005$; $BF_{10} = 25.4$; $d = .59$].

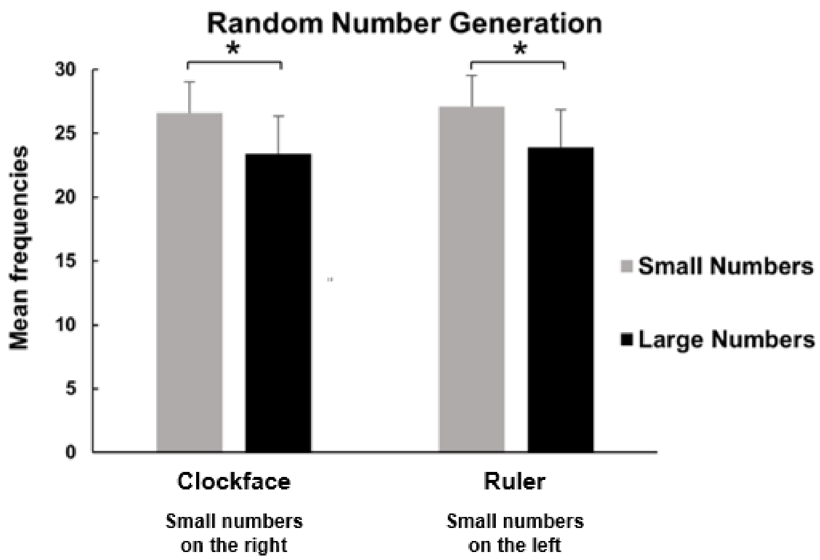

Figure 2. Mean frequencies of small vs. large numbers generated in Experiment 1a (clockface) and Experiment 1b (ruler). A significant difference was found in both configurations. Errors bars indicate the standard error of the mean.

3.2.3 Discussion

Results from Experiment 1 clearly indicate the presence of a SNB in both configurations. This evidence can be interpreted in two different ways: either the SNB is not determined by pseudoneglect, or the clockface context presented at the beginning of the experiment was not strong enough to produce an overrepresentation of large numbers.

The latter explanation is partially consistent with the results obtained by Mingolo et al. (2021) with the keypad context. Indeed, Mingolo et al. showed that context does not reverse the direction of SNAs as long as it is exclusively introduced at the beginning of the experiment. In this case, the lack of effect of the context on SNB could be because the task did not require to retrieve the context in working memory. This did not lead to the creation of a new SNA consistent with the clockface context since there was no strategical advantage in doing so.

The study by Mingolo et al. (2021) however shows that the context can affect SNAs to a certain degree, depending on particular task demands. To further explore how the clockface context affects SNAs we decided to run further experiments with the same tasks employed in their study, using the clockface instead of the keypad configuration.

3.3 Experiment 2

Experiment 2 investigates the effect of the clockface context – introduced at the beginning of the experiment – on the SNARC effect. Some studies reported alterations of the SNARC effect due to a manipulation performed at the beginning of the experiment, although results are not always consistent. For instance, Fischer et al. (2010) manipulated the position of numbers in the context of written recipes. When numbers were located in a position that was incongruent with the SNARC effect (i.e., small/large numbers on the right/left side of the page), a reduction of the SNARC effect was observed, thus revealing an influence of the context on SNA. Similarly, Shaki and Fischer (2008) asked Russian/Hebrew bilinguals to read a text in Cyrillic (left-to-right) or Hebrew (right-to-left) before performing a parity judgment. They observed a regular SNARC after activating the left-to-right reading direction and a reduction of SNARC after activating the right-to-left reading direction. Furthermore, Mingolo et al. (2021) reported that the context prevented the SNARC effect in magnitude classification, but not in parity judgment.

In Experiment 2, the effect of the clockface context is tested in two typical SNARC tasks: magnitude classification (Experiment 2a) and parity judgement (Experiment 2b). In absence of trainings or context manipulations, these tasks typically reveal a regular SNARC effect. If the context elicited at the beginning of the experiment is salient enough, it should affect this expected pattern.

3.3.1 Method

3.3.1.2 Participants

We tested 35 participants (28 women, 7 men) from the University of Trieste with a mean age of 19.80 (SD = 1.95). The sample size was determined by means of the software MorePower 6.4. The following parameters were used: power = .80, α = .05, Cohen's d = .45 (estimated effect size from the average of the three most relevant experiments: Mingolo et al., 2021, Exp. 2a and Exp. 2b, and Bächtold et al., 1998); the outcome was a suggested sample size of 32 participants.

On being questioned, all participants reported to be right-handed, to have normal or corrected-to-normal vision and have always been used to exclusively read and write in a left-to-right direction. All participants reported that their psychophysiological state was not affected by alcohol consumption or insufficient sleep in the last 24 hr (Murgia et al., 2020). Written informed consent was obtained by all participants. The present experiment was conducted in accordance with the ethical standards indicated by the Declaration of Helsinki and with the approval of the University of Trieste Ethics Committee.

3.3.1.3 Apparatus and stimuli

The experiment was designed and run through the Psychopy software, version 3.0, on the same computer and monitor as employed in Experiment 1. A five-button serial response box was used to collect participants' responses.

Stimuli consisted of ten numbers, i.e., 1-2-3-4-5-7-8-9-10-11, and were presented in the centre of the screen, one at a time and in randomized order, in white against a grey background. Stimulus numbers thus consisted of the numbers displayed on a standard clockface. Numbers 6 and 12 were not included as both take a position on the vertical midline through a clockface and are not associated with either left or right half of a clockface.

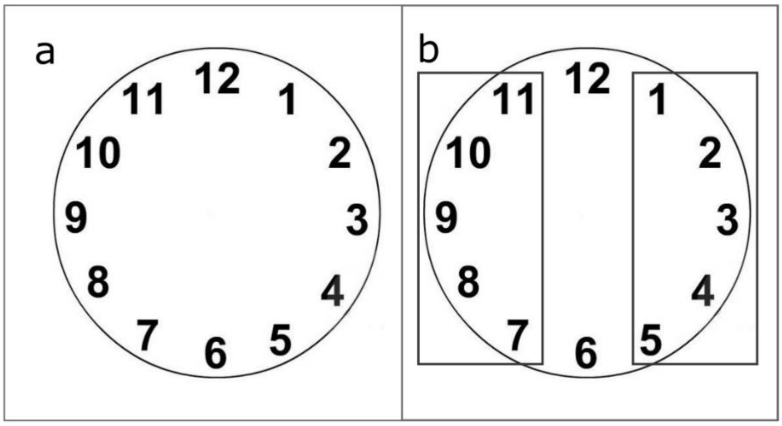

Figure 3. The clockface as presented to participants before the beginning of Experiment 2. Clockface exposure lasted 20 s. During the first 10 s only the clockface as shown in (a) was exposed and participants were instructed to watch it and to pay particular attention to it. During the following 10 s the two rectangles in (b) were superimposed, to highlight the numbers placed on the left and on the right side of the clockface.

3.3.1.4 Procedure

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

Each participant performed two different tasks: magnitude classification in Experiment 2a and parity judgement in Experiment 2b. The order of presentation of the two tasks was counterbalanced among participants. Each task was split into two blocks (block A and block B), each including a practice session consisting of 50 trials (not considered for data analysis) and an experimental session (150 trials).

Before the beginning of each block, participants were exposed for 20 seconds to the picture of a clockface (Figure 3a) and were instructed to look at the display and to pay particular attention to the spatial arrangement of the numbers. In the last 10 seconds of presentation of the clockface, two rectangles appeared on the left and right portion of the clockface, to highlight the numbers in those positions (Figure 3b). Participants were instructed to keep an image of the clockface in mind during the entire experiment.

The practice session was divided into two parts. The first part (20 trials) started with a fixation cross (500 ms) followed, after an interstimulus interval (ISI) of 500 ms, by the picture of the clockface at fixation for 2000 ms. When the clockface picture disappeared, a fixation cross was presented for 500 ms, followed by an ISI of 500 ms. Finally, the target stimulus (a single-digit number) appeared in place of the fixation cross, until a response occurred (within a response time deadline of 2000 ms). Participants responded by pressing the leftmost or the rightmost key of the response box. The combination of the response buttons was reversed from block A to block B, and the order of presentation of the two blocks was counterbalanced among participants.

In the magnitude classification task (Experiment 2a), participants had to judge whether the presented number was smaller or larger than 6. In the parity judgement task (Experiment

2b), participants had to judge whether the presented number was even or odd. In this phase of the practice session, feedback about the response was given at each trial ("Correct!" or "Wrong!"). The second part of the practice session (30 trials) followed the same procedure as the first one but did not present the clockface at the beginning of the trial. The order of presentation of the tasks was counterbalanced among participants.

The experimental session (150 trials) followed the same procedure as the second part of the practice session, but without any feedback. Participants could decide to take a short break between the two blocks or to continue with the experiment. Instructions explicitly asked participants to be as accurate and as fast as possible.

3.3.2 Data analysis and results

The independent variables were Hand (left vs. right) and Number (1-2-3-4-5-7-8-9-10-11), the dependent variable was the Response Time (RT). RTs of incorrect trials were not included in data analysis. Similarly, RTs shorter than 150 ms or those that differed by more than 2.5 standard deviations from a participant's mean RT were considered outliers and removed from data analysis. In Experiment 2b, five participants were excluded because less than half of their RTs in at least one condition could be considered for the analyses. Then, mean RTs of the correct trials for the left and for the right hand were computed separately for each participant in each experimental session. Finally, to obtain the dRTs, the mean RTs of the left hand were subtracted to the mean RTs of the right hand: dRT = RT (right hand) – RT (left hand). Hence, positive dRTs indicate faster responses with the left hand, whereas negative dRTs indicate faster responses with the right hand.

To determine if the SNARC effect emerged, a regression analysis was conducted (Fias, 1996; Lorch & Myers, 1990). A regression equation was computed for each participant with the variable Number as predictor, and dRTs as criterion. Next, a one-sample *t* test was performed on the regression weighs of all equations.

In Experiment 2a (magnitude classification) a *t* test showed that the regression weighs deviated significantly from zero [$t(34) = -2.02$; $p < .05$; $BF_{10} = 2.13$; $d = -.34$], in the direction of the SNARC effect (Figure 4a). Similarly, in Experiment 2b (parity judgement) a one-sample *t* test showed that the regression weights deviated significantly from zero [$t(29) = -1.73$; $p < .05$; $BF_{10} = 1.39$; $d = -.32$], in the direction of the SNARC effect (Figure 4b).

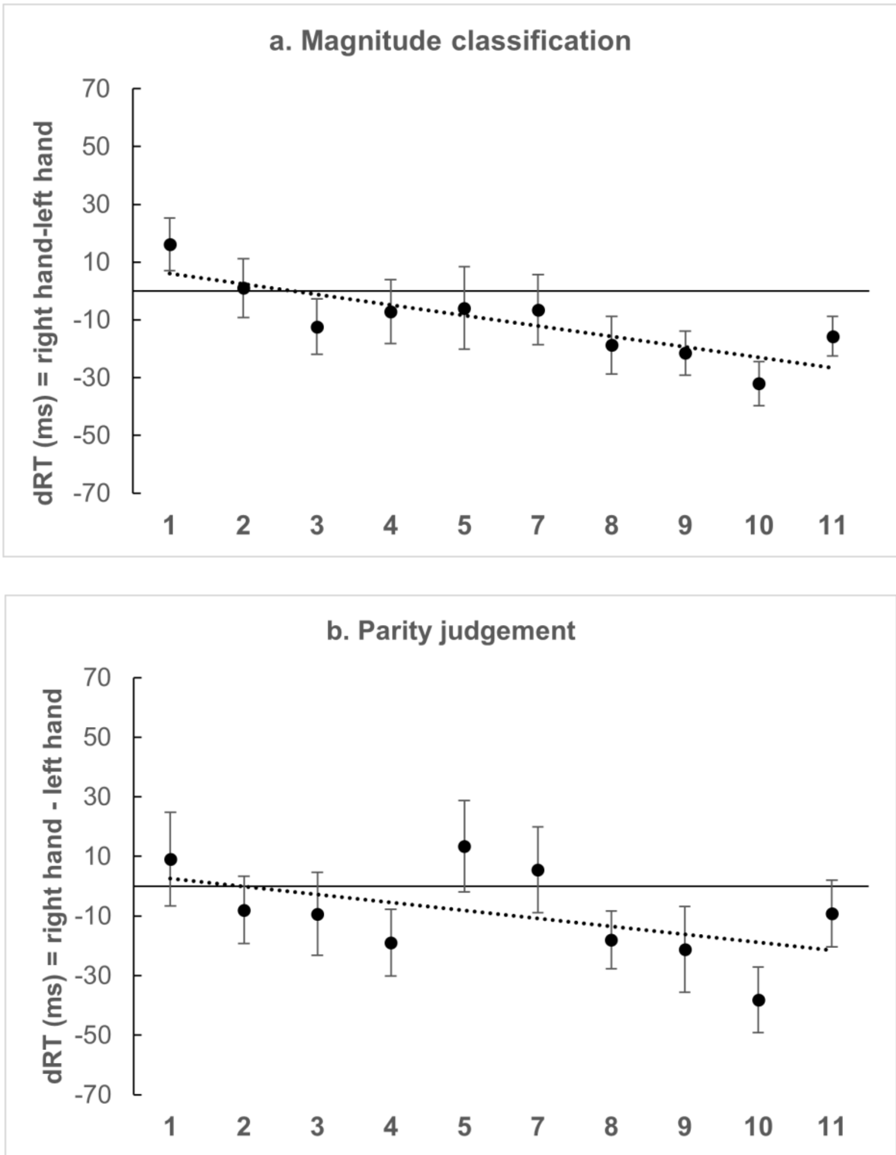

Figure 4. Mean dRTs (right key - left key) for every numerical stimulus in the magnitude classification (a) and in the parity judgement task (b). Positive differences indicate faster left-key

responses; negative differences indicate faster right-key responses. Errors bars indicate the standard error of the mean.

3.3.3 Discussion

Results from Experiment 2a and 2b both revealed a regular SNARC effect, showing no influence of the clockface. These results are in line with those from Experiment 1. In both cases, the context presented at the beginning of the experiment did not affect the expected results (i.e., SNB in random number generation and SNARC in magnitude classification and parity judgement). Once again, the task did not involve the retrieval of the context in working memory, and this might explain why no context-like SNAs were observed.

However, results observed in Experiment 2 are inconsistent with those studies which reported alterations of the SNARC effect due to a manipulation performed at the beginning of the experiment (Fischer et al., 2010; Mingolo et al., 2021, experiment 2a; Shaki and Fischer, 2008). Conversely, they are consistent with the one reported by Mingolo et al. (2021, experiment 2b), which showed that context alone cannot influence SNAs. The apparently contradictory results considered here might be attributed to the different tasks and contexts employed, as well as to the way contexts were activated. Our interpretation is that the *salience* of the context – when it is only elicited at the beginning of the experiment – is quite low. Consequently, the influence of the context on SNAs, if present, is modest. In order to observe an influence of the context on SNAs, we hypothesize that the context should be retrieved during task execution, and not only highlighted before the task. In a further experiment we tested this hypothesis.

3.4 Experiment 3

Experiment 3 investigates the influence of the context on the SNARC effect when it is not only elicited before the proper experiment, but when it is further reinforced by the task. To better understand the effect of the context, in Experiment 3 task demands are manipulated in order to enhance the salience of the clockface by inducing the retrieval of the context in working memory at the moment of task execution. Experiment 3 is based on a dual task, namely participants perform both a primary and a secondary task.

Following the paradigm described in the previous experiment, the effect of the clockface context was tested through a primary task, consisting in magnitude classification for Experiment 3a and parity judgement for Experiment 3b. To enhance the salience of the context, a secondary task was added. The secondary task consisted in a Go/No-go procedure based on the spatial arrangement of the clockface, which induces participants to retrieve the context in working memory on a trial-to-trial basis to perform the task. When the context was only elicited at the beginning of the experiment (Experiment 2), a regular SNARC effect was observed. Our hypothesis is that the secondary task added in Experiment 3 will enhance the salience of the context, which will consequently influence the SNARC effect.

3.4.1 Method

3.4.1.1 Participants

We tested 35 participants (29 women, 6 men) from the University of Trieste with a mean age of 21.11 (SD = 3.12). The sample size calculation was the same as Experiment 2. Four participants were left-handed, and all participants had normal or corrected-to-normal vision and have always been used to exclusively read and write in a left-to-right direction. All participants reported not be affected by alcohol consumption or insufficient sleep. Written informed consent was obtained by all participants. The present experiment was conducted in accordance with the ethical standards indicated by the Declaration of Helsinki and with the approval of the University of Trieste Ethics Committee.

3.4.1.2 Apparatus and stimuli

The experimental apparatus was the same as in experiments 1 and 2. The stimulus set was slightly different from that of Experiment 2; numbers 6 and 12 were this time included, for a total of 12 stimuli (1-2-3-4-5-6-7-8-9-10-11-12). See Fig. 5 for the way the context was presented.

3.4.1.3 Procedure

The procedure of Experiment 3 was similar to that of Experiment 2. The only difference with Experiment 2 is that a Go/No-go procedure was added to the tasks. Participants were instructed to respond to all numbers except those located on the cardinal points of the clockface (Go-stimuli were: 1-2-4-5-7-8-10-11; No-go-stimuli were: 3-6-9-12). To help participants memorize this rule, Figure 5b was presented at each trial in the first part of the practice session, while it was not presented in the second part. Beside the Go/No-go secondary task, participants performed magnitude classification (Experiment 3a) and parity judgement (Experiment 3b). The order of presentation of the tasks was counterbalanced among participants. In the experimental session the 12 stimuli were repeated 15 times, for a total number of 180 trials for each block.

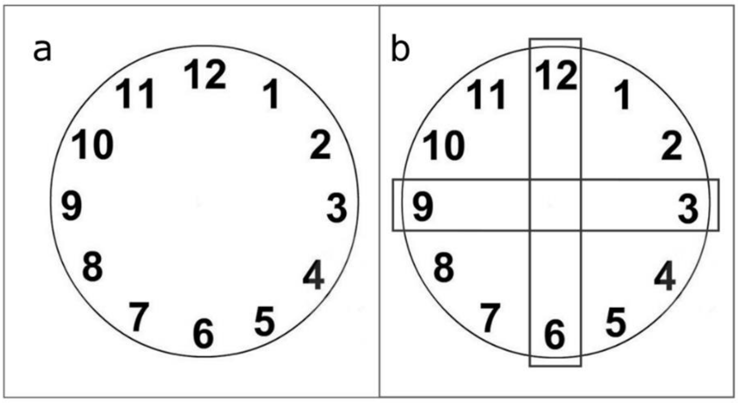

Figure 5. The clockface as presented to participants before the beginning of the experiment (a), and during practice trials (b) in Experiment 3.

3.4.2 Data analysis and results

The independent variables were Hand (left vs. right) and Number (1-2-4-5-7-8-10-11). The same analyses as in Experiment 2a and 2b were performed. In Experiment 3b (parity judgement) two participants were excluded because less than half of their RTs in at least one condition could be considered for the analyses. False alarm rate was 1.4% in Experiment 3a and 1.3% in Experiment 3b.

The one-sample *t* test conducted on individual regression weights showed that they did not deviate significantly from zero neither in Experiment 3a (magnitude classification) [$t(34) = -1.13$; $p = .27$; $BF_{10} = .32$; $d = -.19$] (Figure 6a) nor in Experiment 3b (parity judgement) [$t(32) = -.38$; $p = .71$; $BF_{10} = .20$; $d = -.06$] (Figure 6b). It is noteworthy that, despite the pattern of results displayed in Figure 6a seems to be in line with the SNARC effect, in magnitude classification the regression weights do not differ significantly from zero. In parity judgement, a paired sample *t* test revealed that the mean dRTs for odd numbers differed significantly from that of even numbers [$t(32) = -2.37$; $p < .05$; $BF_{10} = 4.12$; $d = -.41$].

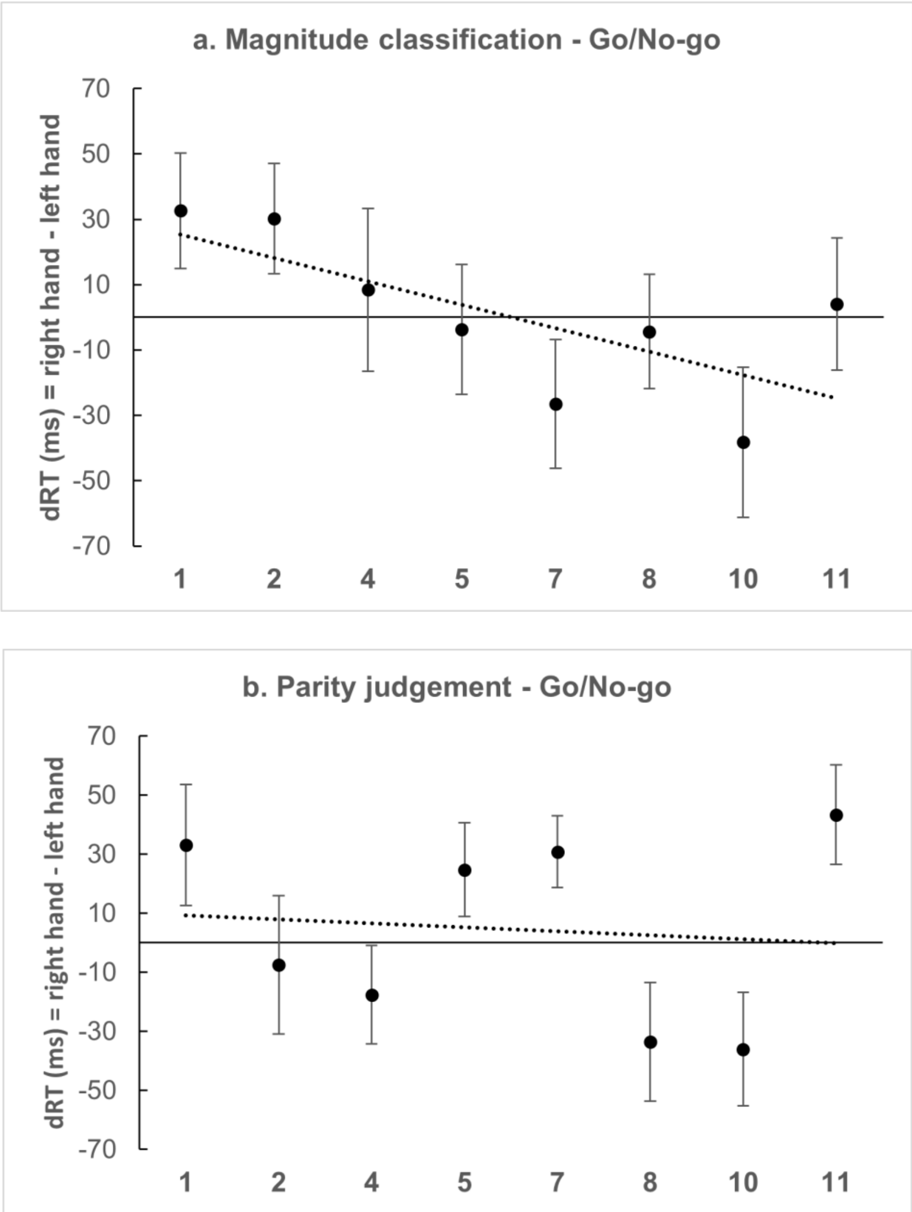

Figure 6. Mean dRTs (right key - left key) for every numerical stimulus in magnitude classification (a) and in parity judgement (b) in a Go/No-go procedure.

3.4.3 Discussion

Different from Experiment 2, in Experiment 3 results revealed a pattern neither in line with the SNARC effect, nor with the clockface, in both magnitude classification and parity judgement. It is noteworthy that previous studies reported regular SNARC effects using a Go/No-go procedure (e.g., Fischer and Shaki, 2016, 2017; Lachmair & al., 2014; Pinto & al., 2019), hence we can exclude that the mere use of this procedure prevented the SNARC effect to emerge.

These findings suggest that, when a secondary task induces the retrieval of context in working memory, it enhances its salience and in this way the context does have an effect. The different representations elicited by the context and by the primary task demands conflict, and this conflict would prevent the SNARC effect from emerging. However, in Experiment 3 the salience of the context was enhanced only by a secondary task (i.e., Go/No-go) but not by the primary task (i.e., magnitude classification or parity judgement).

In the previous literature, those experiments that showed a reversal of the SNARC effect used primary tasks in which the context was directly involved (Bächtold et al., 1998; Mingolo et al., 2021, Experiment 1). We therefore hypothesize that context is not salient enough to reverse the effect when it is only involved in a secondary task. We predict that the clockface context should be involved in the primary task to reverse the standard SNARC effect.

3.3 Experiment 4

Experiment 4 investigated the effect of the context when it is reinforced by primary task demands. To this end, task demands in Experiment 4 rely directly on the processing of clockface information. No secondary task is used. That is, the salience of the clockface context is an intrinsic property of the task itself.

When the context was only elicited at the beginning of the experiment, a regular SNARC effect emerged (Experiments 1 and 2), while when it was reinforced by a secondary task it prevented the SNARC effect to emerge (Experiment 3). Moreover, previous experiments showed that tasks that directly rely on the context have the potential to determine SNAs consistent with the context (Bächtold et al., 1998; Mingolo et al., 2021, Experiment 1). Thus, our hypothesis is that the task used in Experiment 4 will enhance the salience of the context to the point that it reverses the SNARC effect.

3.5.1 Method

3.5.1.1 Participants

We tested 35 participants (30 women, 5 men) from the University of Trieste with a mean age of 22.80 (SD = 6.66). The sample size calculation was the same as in Experiments 2 and 3. Two participants were left-handed, and all participants had normal or corrected-to-normal vision and were exclusively used a left-to-right reading/writing direction. All participants reported not be affected by alcohol consumption or insufficient sleep. Written informed consent was obtained by all participants. The present experiment was conducted in accordance with the ethical standards indicated by the Declaration of Helsinki and with the approval of the University of Trieste Ethics Committee.

3.5.1.2 Apparatus and stimuli

The same apparatus as the one in the previous experiments was employed. The numerical stimuli were the same as in Experiments 2a and 2b (i.e., 1-2-3-4-5-7-8-9-10-11).

3.5.1.3 Procedure

The procedure employed in Experiment 4 is the same as in Experiments 2a and 2b, except for the task demands. In Experiment 4 participants performed a "clockface-position task", namely they had to judge whether the presented number was located on the left or the right of the central axis of the clockface. Participants responded by pressing the leftmost or the rightmost key of the response box. In the experimental session the 10 stimuli were repeated 15 times, for a total number of 150 trials for each block.

3.5.2 Data analysis and Results

The same analyses as in Experiments 2a and 2b were performed. Five participants were excluded because less than half of their RTs in at least one condition could be considered for the analyses. The one-sample *t* test conducted on individual regression weights showed that they deviated significantly from zero [$t(29) = 1.78$; $p < .05$; $BF_{10} = 1.50$; $d = .32$] (Figure 7).

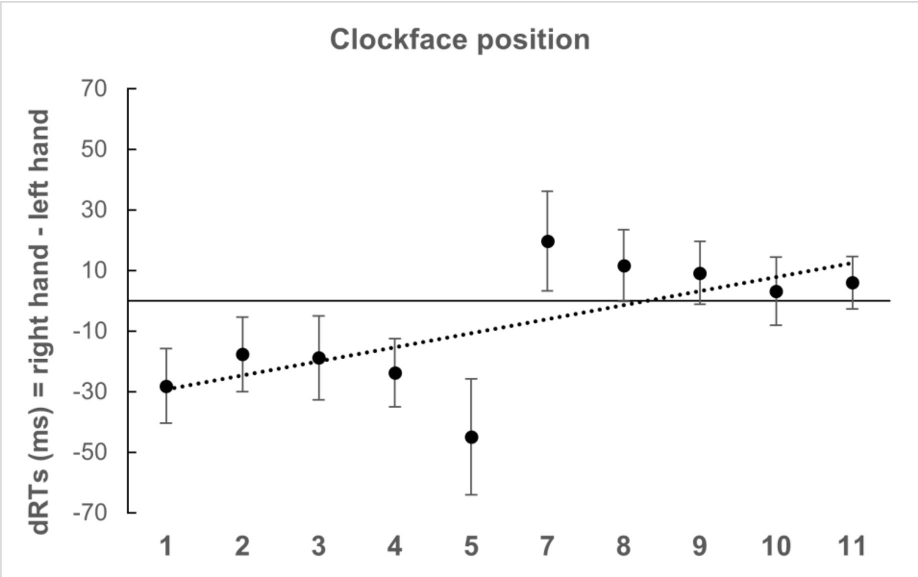

Figure 7. Mean dRTs (right key - left key) for every numerical stimulus in Experiment 4 (clockface position task).

3.5.3 Discussion

Different from all previous experiments of this study, results from Experiment 4 indicate a response time advantage in line with the clockface, namely a reversed SNARC effect: small numbers are responded faster with the right key and large numbers are responded faster with the left key. This finding is in line with the result obtained by Bächtold et al. (1998) and with those by Mingolo et al. (2021, exp. 1). This result indicates that, when the context is retrieved to perform the primary task, its salience is strong enough to determine the shape of a particular SNA.

Among the experiments included in the present study, Experiment 4 represents the closest replication of Bächtold et al.'s (1998) clockface condition. For this reason, we were not surprised to see that the results from the original experiment were conceptually replicated. Nonetheless, it is noteworthy that the same results emerged even though task instructions were different. This suggests that, if the context is highly salient, it influences SNAs regardless of the specific processing required by the task (i.e., semantic in Bächtold et al. and visuospatial in the present study).

3.6 General discussion

The aim of the present study was to investigate the role of context in SNAs. In particular, the aim was to investigate how task demands can modulate the salience of the context (reflecting the level of activation of the context in working memory), and thus its effect on SNAs. To answer these questions, the same context was employed in all experiments, namely a clockface display. Conversely, task demands were manipulated across experiments to gradually enhance the level of salience of this context. Overall, results showed that the effect of the context on SNAs is determined by its salience level, modulated here by task demands.

Experiments 1 and 2 investigated whether the context can influence the small number bias and the SNARC effect in conditions of "low salience". To achieve this, the context was elicited at the beginning of the experiment and was not further reinforced by task demands. Results revealed a regular small number bias in Experiment 1 and a regular SNARC effect in Experiment 2. Previous studies reported alterations of the SNARC effect with contexts that elicited different reading-writing directions (Fischer et al., 2010; Shaki & Fischer, 2008) or atypical spatial-numerical configurations (Mingolo et al., 2021 – Experiment 2a) at the beginning of the experiments. In contrast with these studies, the present results suggest that when a context is only elicited at the beginning of the experiment and not reinforced by task demands, it cannot influence the small number bias and the SNARC effect. This inconsistency in results might be due to the differences in the types of contexts and tasks used in the different experiments, probably because the influence of the context in these cases is weak.

To further clarify the impact of the context, Experiment 3 investigated whether the context can influence the SNARC effect in conditions of "medium salience". To this end, the context was elicited at the beginning of the experiment and then reinforced by a secondary

Go/No-go task. Results showed that the SNARC effect did not emerge. Previous studies reported the emergence of the SNARC effect despite the use of a secondary Go/No-go task (Fischer and Shaki 2016, 2017; Lachmair & al., 2014; Pinto & al., 2019). Therefore, this null result can be attributed to conflicting representations, one elicited by the typical representation of numbers, and one elicited by the context, which was reinforced through a secondary task.

Finally, Experiment 4 investigated whether context can reverse the SNARC effect in conditions of "high salience". To do so, the context was elicited at the beginning of the experiment and reinforced by primary task demands, without any secondary task. Results revealed a reversed SNARC effect, namely a SNA compatible with the arrangement of digits on a clockface. This result is in line with the findings by Bächtold et al. (1998), which have often been interpreted as proof that the SNARC effect is flexible and that it can be altered by contextual manipulations (Dalmaso et al., 2022; Pfister et al., 2013; Shaki & Fischer, 2008; Zhao et al., 2017). Similarly, the experiments performed on the keypad context (Mingolo et al., 2021) showed that the context can determine a consistent SNA. In that study, however, a keypad-like SNA only emerged when the configuration elicited by the context and the one elicited by the task were consistent. The present results further support this, indicating that a clockface-like SNA (like the one reported by Bächtold et al.) only emerges if task instructions reinforce the configuration elicited by the context.

Overall, the present study suggests that an atypical context can drive SNAs only if primary task demands enhance its salience. A possible explanation for this might come from the well-known working memory account for SNAs (van Dijck & Fias, 2011). According to this account, SNAs are driven by the associations between ordinal position of numbers in working memory and space. The default association between numbers and space is consistent with the MNL (i.e., first items/left, last items/right), which explains the commonly observed SNARC effect. However, depending on task demands, temporary associations can be built to facilitate task execution.

The results from the present study are in line with Ginsburg and Gevers (2015), who showed that the ordinal position effect (namely the association between the ordinal position of items in a sequence and the response coordinates) emerges only when retrieval is required. This was observed in Experiment 3 and in Experiment 4. In both of these experiments, the retrieval of the context induced either by a secondary task (Experiment 3) or a primary task (Experiment 4) altered the SNARC effect in some way. However, the complete reversal of the effect is only observed when the retrieval of the context is induced by the primary task (Experiment 4). In this view, an atypical spatial-numerical context can change the default MNL mapping, replacing it with a more convenient context-driven mapping, only if the retrieval of the context is explicitly required by the primary task.

It is noteworthy that the task originally employed by Bächtold et al. (1998) and the one used in the present study (Experiment 4) were based on different instructions. In the original study, participants performed a semantic judgement on numbers (i.e., is the presented number a time earlier or later than 6 o' clock?), while in our Experiment 4 participants performed a visuospatial judgement (i.e., is the presented number located on the left or on the right side of the clockface?). Therefore, these tasks rely on different working memory processes (i.e., verbal vs. visuospatial). The common factor of these experiments is that, in both cases, it was necessary to retrieve the context in working memory to solve the primary task. In this sense, finding of our Experiment 4 can be seen as an extension of the original findings, since either verbal or visuospatial instructions lead to equivalent results if they constitute a primary task. Potentially, any other primary task that requires the retrieval of the context in working memory should reveal similar results.

The results from Experiment 4 are also in line with a model that explains the role of order and magnitude in the SNARC effect (Prpic et al., 2016). This model describes an Order-Related Mechanism (ORM) responsible for the processing of stimuli's order and a Magnitude-Related Mechanism (MRM) responsible for the processing of stimuli's magnitude. In Experiment 4, the ordinal position of numbers elicited by the context is relevant to perform the task. Therefore, in line with the model, the ORM would be activated by both the context and the task, and this activation would induce a spatial association consistent with the clockface. For a debate on the role of order and magnitude on the genesis of the SNARC effect, see also Pitt & Casasanto (2019) and Prpic et al. (2021).

Overall, the present study contributed to investigate the mechanisms that regulate the influence of an atypical context on SNAs. The gradual manipulation of task demands helped understand which aspects of the task enhance the salience of the context, contributing to its influence on SNAs. It was clarified that an atypical context does not influence SNAs if not further reinforced by the task. The present study extends the knowledge on SNA by unveiling the mechanisms behind the original clockface finding (Bächtold et al., 1998), which would be responsible for the flexibility of these effects. Here we clarify that the original clockface finding would not have been observed if the task did not involve the clockface configuration to be performed. Namely, the retrieval of the context in working memory – induced during the primary task – would be the crucial mechanism underlying the original effect reported by Bächtold et al. From a methodological perspective, the present study aimed to raise attention over possible biases that could occur when interpreting results in SNAs research. Namely, when investigating the effect of an atypical context over SNAs, particular attention should be paid to task characteristics and, where appropriate, the effect of the context should be investigated in combination with different tasks.

3.7 Conclusions

The previous literature showed how SNAs in general and the SNARC effect in particular, are flexible and can be modulated by the context in which stimuli are presented. Bächtold et al. (1998) reported the reversal of the SNARC effect determined by the influence of an atypical context, namely a clockface. However, the mechanisms that regulate this modulation were not clear. In the present study, we investigated whether and how the salience of an atypical spatial-numerical context can alter SNAs. To this aim, the clockface was presented as context and its salience level was gradually increased by task demands across four experiments. Results highlighted that when the task does not enhance the salience of the clockface context, a regular SNARC effect emerges, which indicates that the context does not influence it. Secondly, when the task enhances the salience of the context at a medium level, conflict between different representations seem to prevent the SNARC effect from emerging. Finally, when the task enhances the salience of the context at the highest level, namely when it is based on the same configuration as the context, a reversal of the SNARC effect emerges in consistency with the context. In a nutshell, the results of the present study highlight that context can shape SNAs only when primary task demands make it sufficiently salient and, thus, active in working memory.

Chapter 4

“Ace in the hole: playing cards reveal the role of order and magnitude in the SNARC effect.”

Abstract

The Spatial-Numerical Association of Response Codes (SNARC) effect (Dehaene et al., 1993) indicates that numbers are mapped from left to right as in a mental number line. Accumulating evidence suggests that this effect could be attributed both to the magnitude or to the order of numbers, but the role of these two aspects has not yet been disambiguated because the two are tightly correlated. This study investigated the influence of order and magnitude in the SNARC effect using playing cards as stimuli. Indeed, while most people organize cards in ascending order (AO), according to the reading-writing direction, some people dispose them in descending order (DO). In this regard DO people should spontaneously associate low magnitude cards (e.g., 2) to the right, and high magnitude cards (e.g., 6) to the left. Therefore, in DO individuals, cards' order and magnitude would elicit opposite spatial mappings. In Experiment 1, participants belonging to the DO group performed magnitude classification on simple numerals and on playing cards as stimuli, showing a regular SNARC effect when classifying numbers and no effect when classifying cards. Conversely, in Experiment 2, participants belonging to the AO group showed a regular SNARC effect when classifying cards. In Experiment 3 a larger sample of DO participants was tested to replicate Experiment 1 and clarify the occurrence of spatial associations in card classification. Results of the replication indicated that DO participants showed regular SNARC effects both in number and card value classification, thus suggesting that magnitude played a key role overruling the order of card disposition. This is apparently in contradiction with the predictions of the CORE model which states that specific experience with ordinal arrangements of the stimuli should determine the direction of an association.

4.1 Introduction

Cognitive psychology has widely investigated how people represent abstract concepts in their minds. It has been observed that an abstract activity such as number processing is tightly correlated with spatial representation. The spatial coding of numbers is demonstrated by a well-known phenomenon named Spatial-Numerical Association of Response Codes (SNARC) effect (Dehaene et al., 1993). Due to this effect, participants who respond to centrally presented numbers within a certain range in a bimanual task tend to respond faster to relatively small numbers with a left key and to relatively large numbers with a right key. This effect has been interpreted as evidence that humans mentally represent numbers from left to right according to a mental number line (MNL; Restle, 1970).

With the increasing interest in the SNARC effect, it soon became clear that the way in which we spatially map numbers is not fixed and immutable but is rather flexible. For example, the same number can be associated to opposite response sides depending on which stimuli range is considered (Dehaene et al., 1993, Experiment 3). Our spatial representation of numbers is deeply influenced by the context in which we encounter them, as well as by task requirements (Mingolo et al., 2020). For instance, the context can alter the SNARC effect if it activates opposite scanning direction in participants that speak different languages with different reading/writing directions (Shaki and Fischer, 2008). Moreover, if the task requires to process numbers in the context of a clockface, in which small/large numbers are represented on the opposite sides compared to the MNL, the SNARC effect is reversed (Bächtold et al., 1998). In general, when the context or the task demands are subjected to various situated influences, different alterations of the SNARC effect can emerge (Cipora et al., 2018).

Despite many existing theories on the functioning of the SNARC effect, the mechanisms underpinning it are still debated. It is still not clear how, exactly, order and magnitude are spatially mapped in numbers. Indeed, a number conveys both information about quantity, defined "magnitude" (e.g., 3 is a smaller than 4), and information about order (e.g., the 3rd comes before the 4th). But in numbers, order and magnitude covary: either due to their order or due to their magnitude small numbers are associated to the left and large numbers are associated to the right. That is, independently from order, small magnitudes would be mapped on the left (Walsh, 2003). Similarly, independently from magnitude, the first numbers would be mapped on the left (van Dijck & Fias, 2011). For this reason, it is very difficult to determine whether small numbers are associated to the left due to their order, or to their magnitude. According to Toomarian and Hubbard (2018), a magnitude-based mapping originates from innate tendencies, while the ordinality mapping comes from cultural factors.

Evidence supporting the role of order for spatial-numerical associations (SNAs) was provided by Gevers et al. (2003). The study showed the occurrence of SNARC-like effects for letters, an overlearned set of stimuli that do not possess magnitude properties (i.e., left-key advantage for the first letters of the alphabet and right-key advantage for the last). The relevance of a culturally learned order for SNAs is as well demonstrated by various studies based on reading-writing habits (e.g., Shaki et al., 2009). Moreover, the working memory account for SNAs provides a strong argument in favor of order, considering the evidence that newly acquired sequences of numbers are spatially mapped according to their ordinal position in working memory, and not to the MNL (van Dijck & Fias, 2011).

Conversely, the role of magnitude is supported by the observed spatial associations for magnitudes that do not have a culturally overlearned order. For instance, luminance (Fumarola et al. 2014) and animals' typical size (Sellaro et al., 2015). Moreover, the small-left and large-right associations were found in newborn chicks (Rugani et al., 2015; 2020) and human neonates too (Di Giorgio et al., 2019). This finding suggests that the left-to-right spatial mapping of magnitudes may be based on innate mechanisms, independent of the culturally acquired order. In line with this, from a theoretical perspective, the ATOM (A Theory Of Magnitude) model by Walsh (2003) suggests that all quantities are spatially mapped, stating also that this shared magnitude system would origin in early childhood.

Past research suggests, accordingly, that both order and magnitude are relevant for SNARC-like effects. Although it is difficult to dissociate their contribution because these two factors naturally confound in numbers. An attempt to disambiguate the roles of order and magnitude was made by Prpic et al. (2016), who tested expert musicians using musical note values. This kind of stimuli are typically represented in a descending order, starting from the largest value, and progressing to the smaller one. They found that, depending on the task, spatial associations were either in line with the magnitude or with the order of the stimuli. The authors proposed that two separate mechanisms elicit SNARC-like effects: one based on order (Order-Related Mechanism - ORM) and one based on magnitude (Magnitude-Related Mechanism - MRM).

The model proposed by Prpic et al. (2016) states that the two mechanisms are activated depending on the task requirements. The ORM would be mainly activated by direct tasks, which require to directly compare a feature of the stimuli with a reference (e.g., magnitude classification). Indeed, to judge whether a quantity is smaller or larger than a reference, an ordinal comparison between the two would be necessary. On the other hand, the MRM would be mainly activated by indirect tasks, which require participants to judge a feature of the stimuli irrelevant for the study (e.g., orientation judgement). Thus, according to this model, different tasks can unveil the predominance of the different mechanisms underlying SNARC-like effects.

Previous attempts to separately investigate order and magnitude in SNARC-like effects were either done on non-numerical stimuli or based on manipulations that altered the natural order of representation of the stimuli. For instance, van Dijck and Fias (2011) observed the ordinal position effect, namely the spatial mapping of number's order, by transitorily altering the order of numbers in working memory. Prpic et al. (2016) used non-numerical stimuli (i.e., musical notes values) which are only familiar to the population of musicians, and found that the order of notes reversed the SNARC effect only in a direct task. Mingolo et al. (2021) altered the natural order of numbers by making participants process numbers in an atypical spatial numerical configuration and found that the alternative order can alter the SNARC effect only if it is further reinforced by task demands.

Recently, an attempt to disambiguate order and magnitude in numerical stimuli without altering their order has been done by Koch et al. (2023). They manipulated the set of stimuli in a way that could dissociate the contribution of ordinal and magnitude number representations. The results of the study are better described by the magnitude model; however, order seems to have played a role as well. Hence, the disambiguation of order and magnitude using numerical stimuli in a representative population is still an open question.

4.1.2 The present study

The aim of the present study is to disambiguate the role of order and magnitude in the SNARC effect, without artificially manipulating the order of numbers, and using numerical stimuli familiar to most people. Instead of manipulating the natural order of numbers, the present study uses a novel kind of stimuli that consist in a particular representation of numbers known to most people, namely playing cards, given that they are spatially organized differently among people.

When playing cards, people stably dispose cards according to their "individual order of disposition". Most people dispose them in *ascending order* ("AO"; Figure 1A), namely they dispose low value cards to the left and high value cards to the right. This arrangement is consistent with the typical left-to-right mapping of numbers and, in general, with the SNARC effect. For AO individuals, card order and card magnitude would elicit consistent representations, which should reflect a regular, left-to-right, SNARC-like effect for cards.

Conversely, some people (around 15%, according to our data collection experience) spontaneously and systematically dispose cards in *descending order* ("DO"; Figure 1B), namely they dispose high value cards to the left and low value cards to the right. Thus, according to their individual order of disposition, DO people should associate low value cards (e.g., 2) to the right, and high value cards (e.g., 6) to the left. However, according to their value (i.e., magnitude), numerals on cards are expected to be associated to the opposite spatial coordinates: small quantities to the left, and large quantities to the right. Hence, for DO individuals, card order and magnitude should elicit opposite spatial mappings. It is not clear whether this inconsistency would determine a regular SNARC-like effect for cards stimuli, determined by card magnitude, or a reversed SNARC-like effect due to card order.

According to the CORrelations in Experience (CORE) principle (Pitt and Casasanto, 2020), the MNL is shaped by specific experiences that spatialize numbers, such as repeatedly seeing numbers arrayed in a certain way, thus based on order rather than magnitude. Based on the CORE principle, we should expect a similar effect with cards. Namely, the specific experience accumulated with playing cards, should lead participants to spatialize cards according to the individual order of disposition (i.e., in ascending vs. descending order). Therefore, the CORE principle would predict that order would prevail on magnitude, determining a reversed SNARC-like effect when DO participants classify card values. However, it is reasonable to expect that this specific experience would have an effect only within the domain of cards and would not extend to that of numbers in general, given the large amount of experience with the left-to-right mapping of numbers in western cultures.

In the present study, we conducted three experiments testing both DO and AO participants. The study employs two direct tasks, using cards or numbers as stimuli. According to Prpic et al. (2016), the use of direct tasks would induce the processing of the ordinal properties of the stimuli. According to this hypothesis DO participants – who have inconsistent mappings of card order and magnitude – should exhibit the regular SNARC effect with numbers, and a reversed SNARC-like effect with cards. Conversely, in the same task with cards, AO participants should exhibit a regular SNARC-like effect.

Importantly, these effects are expected to occur at group level and not at individual level, since the SNARC effect is not always stable and consistent across individuals (Cipora et al., 2019; Wood et al., 2006). Despite this individual instability, we expect that both AO and DO participants will show a regular SNARC effect with numbers, since they belong to a western culture and are used to the left-to-right representation of regular numbers. Conversely, cards would spontaneously elicit an overlearned order (descending or ascending) that is context-specific and limited to that category of stimuli. Using this type of stimuli, it will be possible to disentangle the contribution of order and magnitude without "artificially" altering the order of numbers through experimental manipulations.

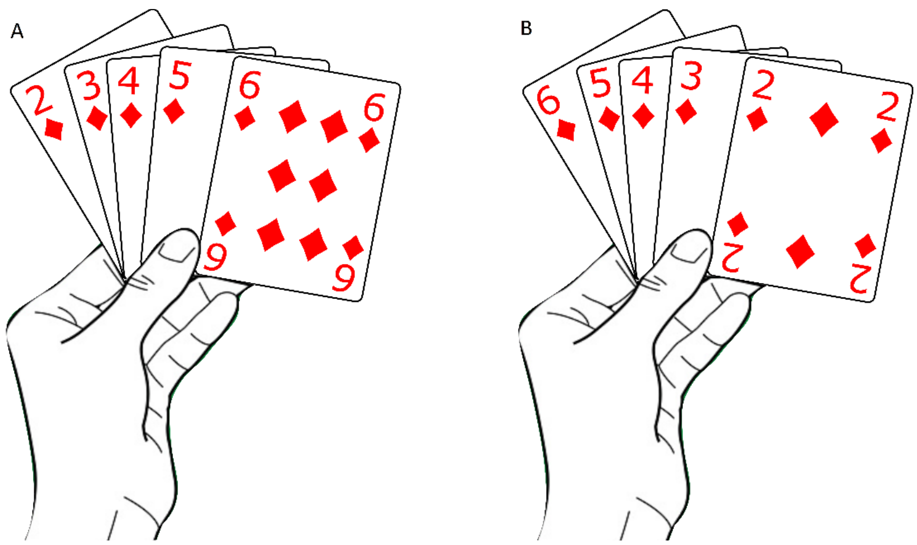

Figure 1. Individual order of the disposition of cards: Ascending Order - AO (panel A) and Descending Order - DO (panel B)

4.2 Experiment 1

The first experiment was performed by a sample of participants belonging to the DO category. The same participants performed a magnitude classification task on numerical stimuli in Experiment 1a and on cards stimuli in Experiment 1b. In Experiment 1a we expected to observe a regular SNARC effect, since these participants should have a left-to-right representation of numbers consistently elicited by both number's order and magnitude. In Experiment 1b different outcomes could emerge, depending on which mechanism between order and magnitude prevails, given that they would elicit opposite mappings in these participants. According to the prediction made by Prpic et al.'s model (2016) on direct tasks, participants should exhibit a reversed, right-to-left SNARC, determined by the predominance of order. On the other hand, if DO participants exhibit a regular left-to-right SNARC, this would indicate the predominance of magnitude.

4.2.1 Method

4.2.1.2 Participants

We tested 35 students from the University of Trieste (24 females, 11 males) belonging to the DO category, with a mean age of 21.62 (SD = 3.93). Sample size calculation was performed with G*Power using the following parameters for one-sample t test: power = .80, α = .05, Cohen's d = .50 (medium effect size, in line with previous studies on context manipulation in the SNARC effect: Mingolo et al., 2021 and Bächtold et al., 1998); the outcome was a suggested sample size of 34 participants. Moreover, we designed the experiments to have 20 repetitions per stimulus and recruited a number of participants considered "large", according to the guidelines provided by Cipora and Wood (2017).

All participants had normal or corrected-to-normal vision and one participant was lefthanded; all of them were used to the left-to-right reading/writing direction. Furthermore, we ascertained that their psychophysiological state was not affected by alcohol consumption or insufficient sleep in the 24 hours preceding the experiment (Murgia et al., 2020). Participants provided written informed consent before taking part to the experiment; 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.

4.2.1.2 Apparatus and stimuli

The experiment was designed and run through the open-access software Psychopy (Peirce et al., 2019), in the version 3.0. The computer used to control the experiment was a Dell desk computer with Intel Core i5 (RAM: 4 Gb). Instructions and stimuli were displayed on a Quato Intelli Proof 242 excellence (24 inches) monitor, with a 1024 × 768 resolution. Participants' responses were collected through a five-button serial response box.

The stimuli displayed in Experiment 1a (magnitude classification) consisted in single digit numbers, presented at the center of the screen, in white against a grey background. The stimuli set was the following: 2 – 3 – 4 – 6 – 7 – 8. The stimuli displayed in Experiment 1b (card value classification) consisted in pictures of playing cards (Fig. 2), presented at the center of the screen, in color. The set included cards with the same values as the numbers used in Experiment 1a, namely: "Two of diamonds", "Three of diamonds", "Four of diamonds", "Six of diamonds", "Seven of diamonds" and "Eight of diamonds". The cards presented were all the same suit to avoid effects driven by cards color or suit.

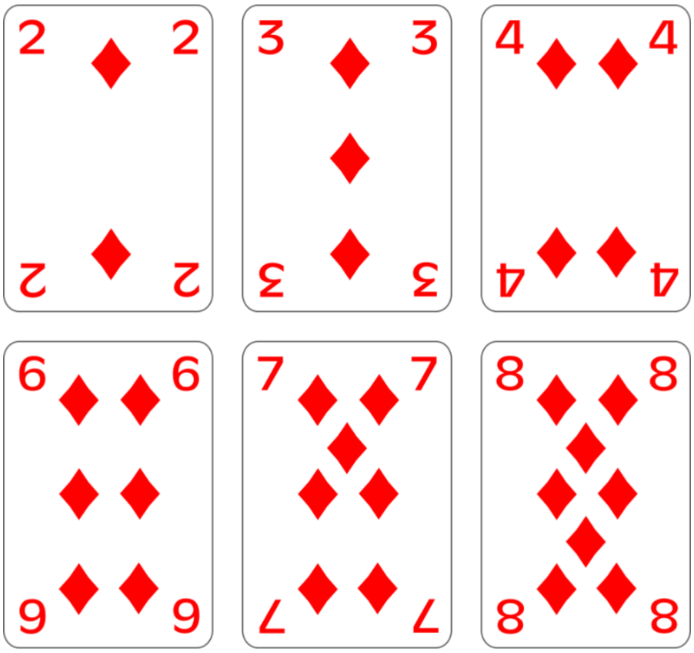

Figure 2. Cards pictures presented as stimuli in card value classification task (Experiment 1b). The reference value was 5, and a picture of the card with the value of 5 was presented at the beginning of the experiment, during instruction presentation.

4.2.1.3 Procedure

a) Assessment of participants' individual order of disposition

A crucial passage of the present study was the assessment of participants' individual order of disposition of cards, which allowed to identify whether a participant's arranged cards in ascending or descending order. This procedure had to be as neutral and ecological as possible, in order to observe the participants' instinctive behaviour without influencing it, and to be confident about the stability of their behaviour in time. For these reasons, we articulated the assessment in two parts, which occurred in separate occasions, and we designed the assessment as an ecological card game simulation.

The first part of the assessment took place before the beginning of the first experiment, which, due to counterbalancing, could be either Experiment 1a (magnitude classification) or Experiment 1b (card value classification). To avoid influences of the screening on participants' performance in the experiments, the screening took place a few days before the first experiment. During the card game simulation, the participant was invited to sit at a desk, on which 6 shuffled cards were placed face down. The cards were the same as those displayed as stimuli in Experiment 1b (Fig. 2). The experimenter asked a standard question to every participant, namely: "Please, pick up the cards and arrange them in your hands as you were about to start playing a card game. When you are satisfied with the arrangement, put the cards down, face up." When the participant put down the cards, the experimenter simply took note of the arrangement exhibited by the participant (namely ascending or descending order) without giving any further information.

The second part of the assessment took place at the end of the second experiment. In this case, participants were once again asked to arrange the same cards as if they were about to start playing a card game, and once again the experimenter took note of which arrangement was exhibited. Furthermore, for the final step of the assessment (which concluded the experiments as well), participants filled in a questionnaire. The questionnaire presented two pictures displaying the two possible card arrangements (ascending and descending order). Participants were asked to indicate, on a scale from 1 to 10, how likely it was for them to arrange cards in each order (1 = "very unlikely", 10 = "very likely").

Depending on the arrangement they exhibited, and on the matching between the information obtained in the first and second part of the assessment, participants were either included in the AO or in the DO group. Participant who exhibited different arrangements in the two parts of the screening, or who gave uncertain answers to the questionnaire (namely scores between 4 and 6 for both arrangements), could not be included in any group, and their data were excluded from data analysis. 4 participants who were recruited for the experiment then reported to prefer the opposite arrangement in the second part of the assessment and were therefore excluded from data analysis.

b) Tasks

The experiment took place in a quiet room, using dim lights. Participants each sat on a chair at a viewing distance of approximately 60 cm from the PC screen, with their bodies aligned to the midline of the screen. They had a response box in front of them and were instructed to put their left index finger on the leftmost key and their right index finger on the rightmost key.

In Experiment 1a each participant performed a magnitude classification task, which was divided into two blocks (block A and block B). Each block included a practice session, composed of 30 trials, which were not considered for data analysis. During the practice session, trials started with a fixation cross at the centre of the screen, which lasted for 500 ms and was followed by an interstimulus interval (ISI) of 500 ms. After the ISI, the target stimulus (a single-digit number) appeared at the centre of the screen, and lasted until a response occurred, within a response time deadline of 2000 ms. Participants responded by pressing the leftmost or the rightmost key of the response box and, specifically for practice purposes, received feedback about their accuracy ("Correct!" or "Wrong!") and speed in response.

After practice session, each block presented an experimental session, composed by 120 trials. In the experimental session, the structure of the trials was the same as in practice session, except for the fact that no feedback was given. In Experiment 1a, the magnitude classification task required participants to judge whether the presented number was smaller or larger than 5, by pressing the leftmost or the rightmost key of the response box. Depending on the block, the combination of the response buttons could be either SNARC-congruent ("left = smaller" / "right = larger") or SNARC-incongruent ("left = larger" / "right = smaller"). The combination of response buttons was reversed from block A to block B, and the order of presentation of the two blocks was counterbalanced among participants. If needed, participants were allowed to take a short break between the two blocks, otherwise they continued with the experiment. Instructions explicitly asked participants to be as accurate and as fast as possible.

In Experiment 1b participants performed a card value classification task. The procedure was exactly the same as in Experiment 1a, but this time participants judged cards stimuli instead of numbers. The task required participants to judge whether the value of the presented card was smaller or larger than 5, by pressing the leftmost or the rightmost key of the response box, depending on the response button combination. The two experiments were performed in separate days to prevent any effects of one task on the other and the order of administration of the two tasks was counterbalanced.

4.2.2 Data analysis, results, and discussion

The independent variables were Hand (left vs. right) and Stimulus (2 – 3 – 4 – 6 – 7 – 8), the dependent variable was the Response Time (RT). RTs of incorrect trials were not included in data analysis. Similarly, RTs shorter than 150 ms or those that differed by more than 2.5 standard deviations from a participant's mean RT were considered outliers and removed from data analysis. Mean RTs of the correct trials for the left and right hand were computed separately for each participant for each number. To obtain the dRTs, the mean RTs of the left hand were subtracted 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.

To determine if the SNARC effect emerged, a regression analysis was conducted (Fias, 1996; Lorch & Myers, 1990). A regression equation was computed for each participant with the variable Number as predictor, and dRTs as criterion. A one-sample t test was performed on the regression weighs of all equations to test whether they significantly deviated from zero.

In Experiment 1a (magnitude classification) a one-tailed t test showed that the regression weighs deviated significantly from zero [M_{slopes} = -3.00; $t(30) = -1.83$; $p < .05$; BF_{10} = 1.60; d = -0.33], in the direction of the SNARC effect (Figure 3a). Differently, in Experiment 1b (card value classification) a two-tailed one-sample t test showed that the regression weights did not deviate significantly from zero [M_{slopes} = 0.95; $t(30)$ = .41; p = .68; BF_{10} = .21; d = 0.07] (Figure 3b).

DO participants exhibited the SNARC effect only in the magnitude classification task performed on numbers, while the same effect did not emerge in the card value classification task. Results from Experiment 1b did not give a clear indication about the predominance of order or magnitude. However, a comparison of Figures 3a and 3b reveals an interesting pattern of results. Specifically, in the card value classification task, small-value cards seem to elicit faster responses with the right-side key compared to the left-side key, whereas the opposite is observed in the magnitude classification task. Moreover, although large numbers were responded to faster with the right-side key in the magnitude classification task, no clear advantage for either key emerged in the card value classification task. This could have been due to the variability present in the sample, but it could also indicate that order was not the only mechanism involved in card processing. That is, magnitude could have had a certain influence as well. Moreover, we cannot exclude that the lack of SNARC effect was determined by the particular kind of stimuli used. To rule out the possibility that these stimuli prevented the SNARC effect from emerging, in Experiment 2 we ran the card value classification task on a sample of AO participants.

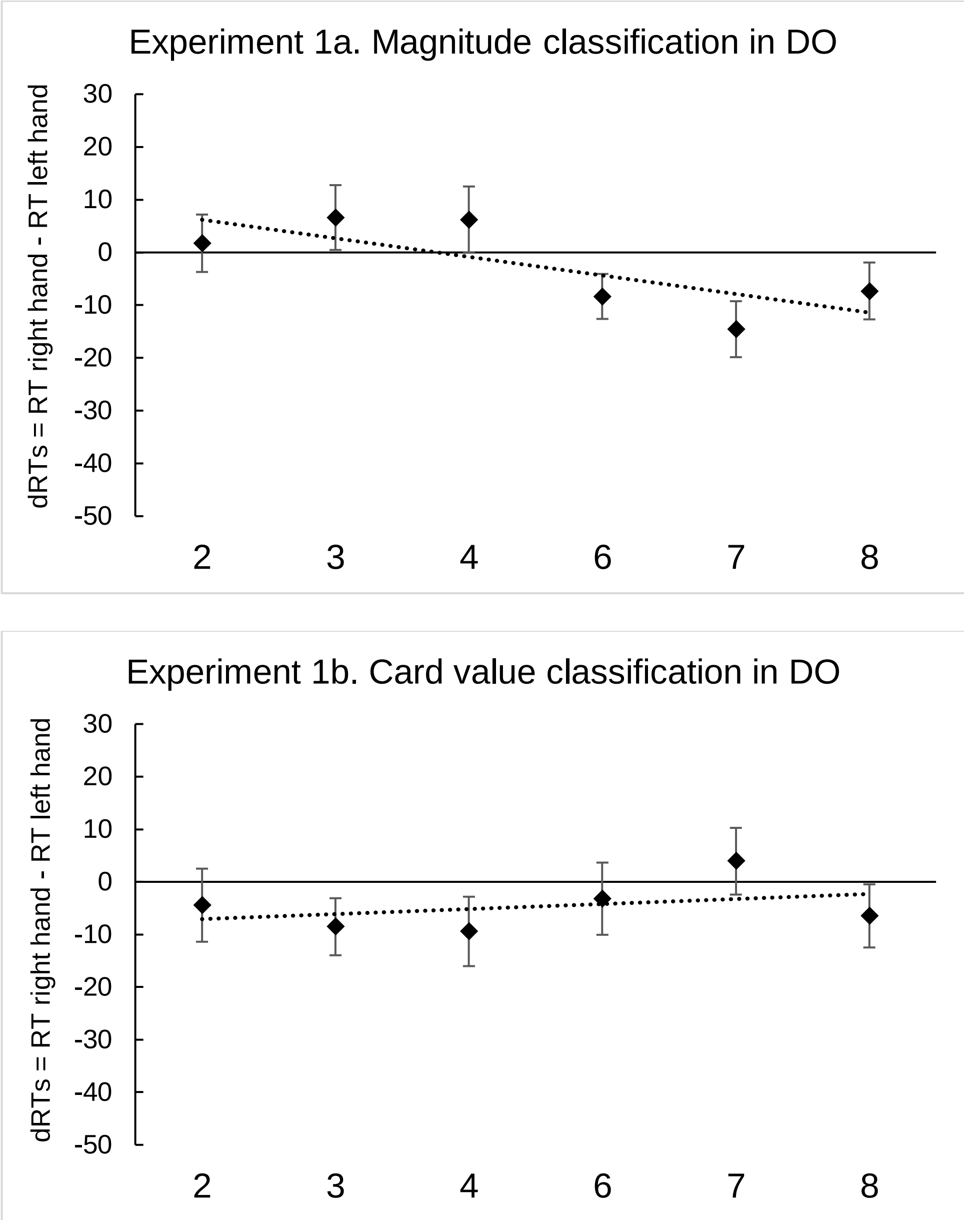

Figure 3. Mean dRTs (right key - left key) for every numerical stimulus in the magnitude classification (1a) and in the card value classification task (1b) in DO participants. Positive differences indicate faster left-key responses; negative differences indicate faster right-key responses. Error bars indicate the standard error of the mean.

4.3 Experiment 2

In Experiment 1 we observed that DO participants do not exhibit the SNARC effect in the card value classification task. However, we do not know whether the effect did not emerge because of the particular kind of stimuli we used. In Experiment 2, a sample of participants belonging to the AO category will perform a card value classification task. In this way, we will test whether participants in which cards' order and magnitude elicit the same mapping exhibit a regular SNARC effect when they classify cards stimuli.

4.3.1 Method

4.3.1.1 Participants

We tested 34 students from the University of Trieste (28 females, 6 males) belonging to the AO category, with a mean age of 20.77 (SD = 1.06). The sample size was determined with the same method used in Experiment 1. All participants had normal or corrected-to-normal vision and one participant was lefthanded; all of them were used to the left-to-right writing direction. Furthermore, we ascertained that their psychophysiological state was not affected by alcohol consumption or insufficient sleep in the 24 hours preceding the experiment (Murgia et al., 2020). Participants provided written informed consent before taking part to the experiment; 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.

4.3.1.2 Apparatus and stimuli

The apparatus employed in Experiment 2 was the same as in Experiment 1b, but this time participants only performed one task, namely card value classification.

4.3.1.3 Procedure

The assessment of the individual order of disposition was performed as previously described and the procedure of the experiment was the same as in Experiment 1b.

4.3.2 Data analysis, results, and discussion

The analyses performed in Experiment 2 were the same as in Experiment 1b. The one-tailed one-sample *t* test showed that the regression weighs deviated significantly from zero [M_{slopes} = -3.90; $t(33) = -1.94$; $p < .05$; BF_{10} = 1.89; d = -0.33], in the direction of the SNARC effect (Figure 4).

Results suggest that AO participants exhibited a regular SNARC effect in the card value classification task. For this reason, we can rule out the possibility that card stimuli prevented the SNARC effect from emerging and we can affirm that cards are a suitable stimulus to investigate the SNARC effect. To further clarify the ambiguous result observed in Experiment 1b, in Experiment 3 we performed an online replication of this experiment on a larger sample of DO participants.

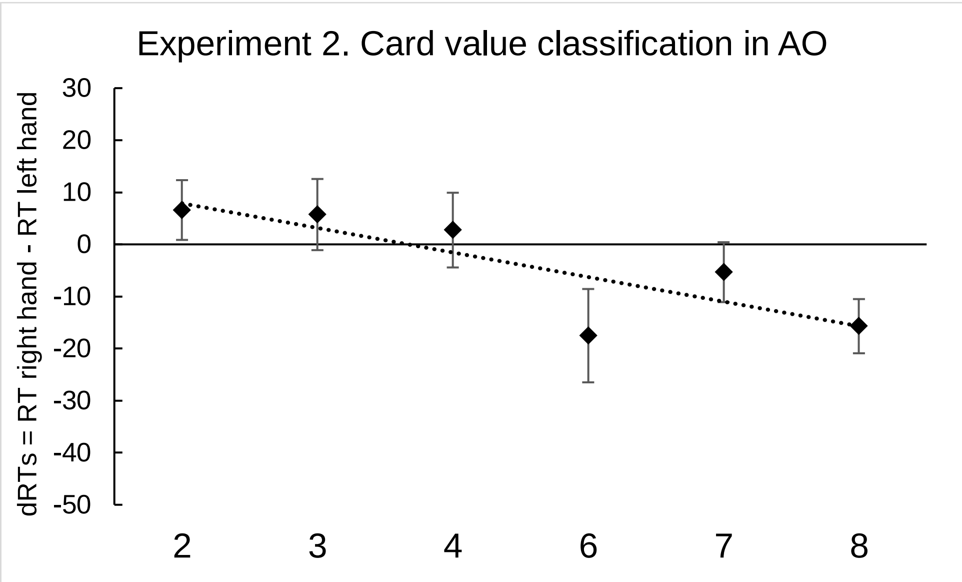

Figure 4. Mean dRTs (right key - left key) for every numerical stimulus in the magnitude classification task in AO participants. Positive differences indicate faster left-key responses; negative differences indicate faster right-key responses. Error bars indicate the standard error of the mean.

4.4 Experiment 3

Experiment 1b found that DO participants do not show the SNARC effect in the card value classification task. In Experiment 2 it was ascertained that card stimuli do not prevent the SNARC effect to occur. However, we still do not know whether the lack of SNARC effect observed in Experiment 1b was due to the conflicting representations elicited by order and magnitude or to the fact that the fact that there could still have been a certain variability in the sample. For example, despite reporting the DO arrangement in all the steps of the assessment, some participants could have still preferred the opposite arrangement or have an instable one. If this was the case, the sample size in Experiment 1b could have been not large enough to detect an effect of order/magnitude smaller than the average of studies on the context in the SNARC effect, that we were not able to detect.

Experiment 3 consisted in a replication of Experiment 1 conducted online, allowing the recruitment of a larger sample of DO participants. The same participants performed a magnitude classification task in Experiment 3a and a card value classification task in Experiment 3b. As in Experiment 1, two possible outcomes could emerge. If order prevails on magnitude, a reversed SNARC effect should emerge in Experiment 1b. If magnitude prevails on order, a regular SNARC effect should emerge.

4.4.1 Method

4.4.1.1 Participants

Seventy participants belonging to the DO category were recruited via the platform Prolific; 66 of them completed all parts of the experiment (39 females, 27 males) with a mean age of 28.21 (SD = 4.20); nine participants were lefthanded. Sample size calculation was performed with G*Power using the following parameters for two-sided one-sample t test: power = .80, α = .05, Cohen's d = .35 (small-medium effect size); the outcome was a suggested sample size of 67 participants. Participants provided informed consent before taking part to the experiment; 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.

4.4.1.2 Apparatus

The experiment was designed on Pavlovia and Qualtrics and conducted online, so the apparatus was replaced by participants' own laptops. Responses were given through the keyboard. Stimuli were the same as in Experiment 1.

4.4.1.3 Procedure

a) Assessment of participants' individual order of disposition

As in the experiments conducted in person, participants' individual order of disposition of cards was carried out before the beginning of the Experiment 3. The screening was conducted on an initial sample of 800 participants. The procedure was articulated in a two-parts survey, conducted in Qualtrics. The first part of the assessment took place a few days before the beginning of the first experiment and consisted in a questionnaire. The first question presented two pictures exemplifying the two possible arrangements (i.e., ascending and descending order, see Figure 1), and asked participants "When you play cards, in which of these two arrangements do you typically dispose them in your hands?". Response options were "ascending order", "descending order" or "I don't know". Then, participants were asked to rate how likely it was for them to dispose cards in either arrangement on a scale from 1 to 10 (1 = very unlikely, 10 = very likely).

The second and final part of the assessment took place at the end of the second experiment and consisted in another questionnaire. In this case, participants were once again asked to report what was their usual card arrangement. Moreover, participants were asked to report how they usually represented number's order. Answer options were: "I normally represent numbers in ascending order (e.g., 1-2-3-4-5-6-7-8-9)" or "I normally represent numbers in descending order (e.g., 9-8-7-6-5-4-3-2-1)".

Participants who selected the options "ascending order" or "I don't know" in the initial screening survey or gave uncertain answers to the questionnaire (namely scores between 4 and 6 for both arrangements) could not be recruited and were compensated for the screening survey. Participants who selected the option "descending order" (n = 105) were invited to perform the experiment, and 66 of them completed it. Among the participants who completed the experiment, 7 reported to prefer the ascending arrangement in the second part of the screening and were therefore excluded from data analysis. All participants reported to represent numbers in ascending order.

b) Tasks

The experiment was performed online on the platform Pavlovia. In Experiment 3a participants performed a magnitude classification task, and in Experiment 3b they performed a card value classification. The structure and the instructions of the experiment were exactly the same as in Experiment 1.

4.4.2 Data analysis, results, and discussion

The analyses performed in Experiment 3 were the same as in Experiment 1. In Experiment 3a (magnitude classification) a two-tailed one-sample t test showed that the regression weighs deviated significantly from zero [M_{slope} = -13.7; $t(58) = -2.45$; $p < .05$; BF_{10} = 2.20; d = -0.32], in the direction of the SNARC effect (Figure 5a). Similarly, in Experiment 3b (card value classification) a two-sided one-sample t test showed that the regression weights deviated significantly from zero [M_{slope} = -9.71; $t(58) = -3.74$; $p < .001$; BF_{10} = 59.2; d = -.49], in the direction of the SNARC effect (Figure 5b).

In Experiment 3, DO participants exhibited a regular SNARC effect both in magnitude classification task and in card value classification task. These results did not confirm the finding from Experiment 1, where a null result emerged in card value classification. In this case, results clearly indicate that DO participants show a regular SNARC effect when judging cards. For this reason, it is reasonable to interpret this result as evidence that the SNARC effect was determined by magnitude rather than by order. It is likely that results from Experiment 3 are more reliable, since the online procedure allowed to reach a larger sample of DO participants and made it easier to exclude those participants who showed uncertainties in their individual order of disposition of cards.

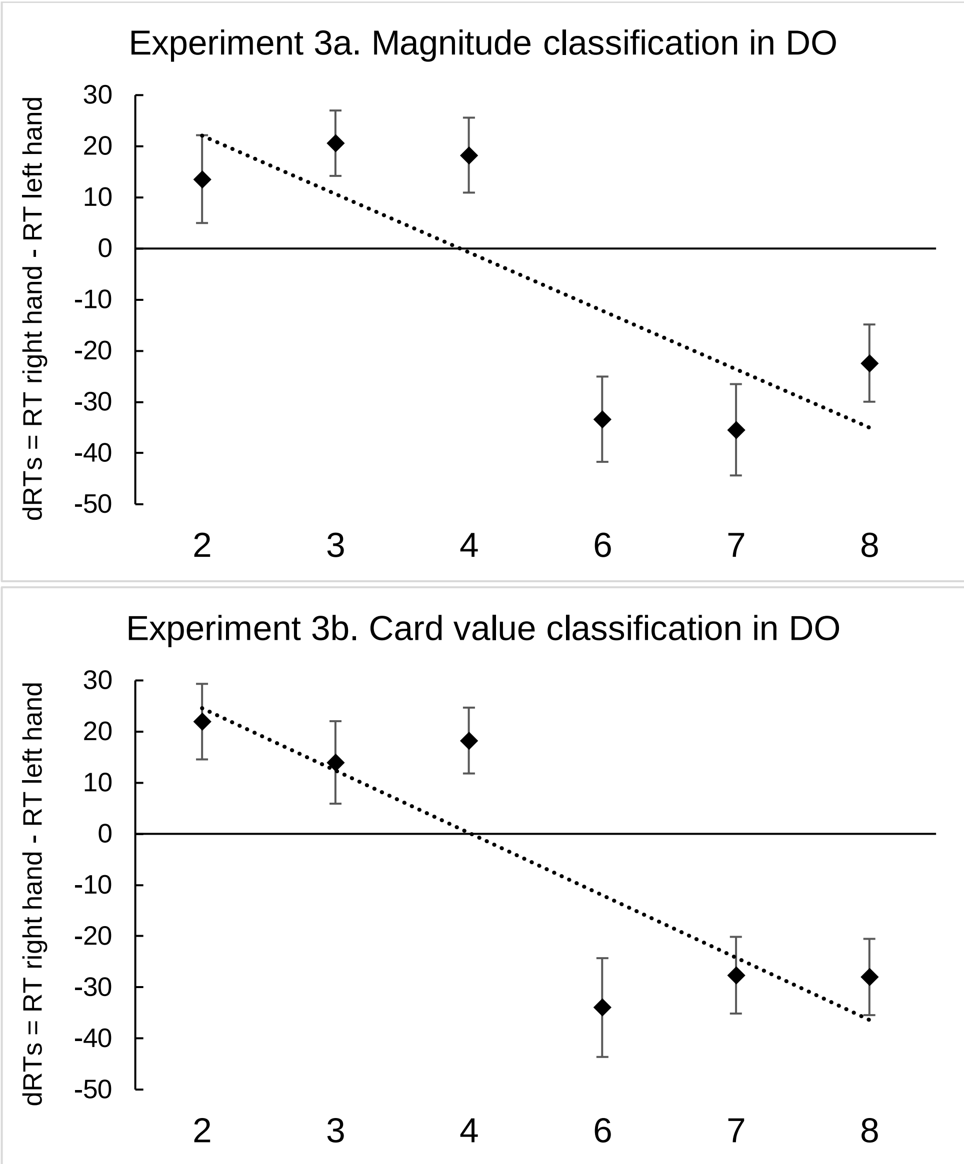

Figure 5. Mean dRTs (right key - left key) for every numerical stimulus in the magnitude classification (3a) and in the card value classification task (3b) in DO participants. Positive differences indicate faster left-key responses; negative differences indicate faster right-key responses. Error bars indicate the standard error of the mean.

4.5 General discussion

The aim of the present study was to disambiguate the role of order and magnitude in the SNARC effect, without artificially manipulating the order of numbers, and using numerical stimuli familiar to most people. To achieve this goal, the study tested participants that arrange playing cards in opposite ways (ascending vs. descending order) in direct tasks performed either on cards or on numbers.

In Experiment 1 DO participants showed a regular SNARC effect in magnitude classification, while they exhibited no SNARC effect in card value classification. The different results observed in the two tasks could indicate that DO participants had a different spatial representation of numbers and cards. These results seemed to be influenced by stimuli's order, since they led to a clear SNARC effect for numbers and to the lack of such effect for cards. However, no inversion of the SNARC effect was clearly observed in card value classification, and thus the influence of magnitude could not be ruled out completely.

In Experiment 2 we tested AO participants in card value classification to ascertain whether the lack of SNARC effect found in DO participants could have been determined by cards themselves. Results showed that this was not the case, since AO participants showed a regular SNARC effect with these stimuli. This experiment confirmed that cards can elicit a reliable SNARC effect. Still, it was not clear whether the lack of SNARC effect in DO reflects the influence of cards' order or magnitude.

In Experiment 3, the procedure used in Experiment 1 was replicated online on a larger sample. This time results revealed that DO participant exhibited the SNARC effect both in magnitude classification and in card value classification, differently from what was observed in Experiment 1. These results clarified the outcomes of Experiment 1. They suggested that the lack of SNARC effect observed in Experiment 1b was probably determined by the well-known variability in the SNARC effect rather than by an interference between cards' order and magnitude.

Altogether, results suggest a prevalence of magnitude over order. This is apparently in contrast with the model described by Prpic et al. (2016), which states that direct tasks preferentially activate the Order Related Mechanism. However, it is in line with Koch et al.

(2023), who found that magnitude explained their data better than order. This finding is supported by ATOM (A Theory of Magnitude; Walsh, 2003). In fact, this theory states that magnitudes belonging to the domains of numbers, time and space are mentally represented in a *generalized magnitude system*. Such a generalized system would explain evidence of SNAs exhibited using different paradigms (Shaki and Fisher, 2013; Sellaro et al. 2015), and different categories of participants, such as human neonates (Di Giorgio et al., 2019) and animals (e.g., 3-days-old chicks; Rugani et al., 2015), who are unluckily biased by the left-to-right order preference typical of western cultures.

Interestingly, our results are not in line with predictions of the CORE principle (Pitt and Casasanto, 2020). Indeed, according to the CORE principle *"the way a source and target domain are mapped in the mind is determined by the way those domains are correlated in experience"* (p. 1051). Our results indicate that the specific spatial experience with cards of DO participants does not shape the spatial mapping of cards, as the CORE would predict. Moreover, based on the same theory, DO participants consistently exhibit a behavior that should not emerge in a western culture, namely organizing cards from right to left. It is noteworthy that, differently from cards, all DO participants reported to consistently dispose numbers from left to right. This suggests that although these people absorbed the typical left-to-right mapping from their culture, they exhibit an opposite pattern when disposing cards in their hands, which is itself in contrast with CORE.

Furthermore, our results suggest that spatial associations for stimuli stored in long-term memory are different from those arising for stimuli temporarily stored in working memory. As previously discussed, cards are a set of stimuli spontaneously ordered from right-to-left by DO participants, in absence of any training or working memory manipulation. Despite this overlearned ordinal disposition, small quantities result to be still associated to the left and large quantities to the right. Apparently, this result is in contrast with studies showing that spatial associations arise from the ordinal position of items in working memory (e.g., van Dijck & Fias, 2011). However, it is noteworthy that the task used by van Dijck & Fias required to memorize and retrieve the order of a random sequence of numbers, while our tasks required neither to encode nor to retrieve the order of cards in working memory. Hence, order seems to affect spatial associations only when participants are "forced" to encode and retrieve the order itself, otherwise, the effect of magnitude seems to spontaneously emerge.

Interestingly, in the present study, the order elicited by the context of cards did not influence the typical small-left/large-right pattern of results, despite the context was embedded in each stimulus. To use the definitions proposed in the taxonomy of situated influences on SNAs (Cipora et al., 2018), the context was manipulated intraexperimentally, at a perceptual level, and unrelatedly to the reading/writing direction. This manipulation is different from others that showed to influence the SNARC effect in previous studies (see for example Bächtold et al., 1998; Mingolo et al., 2021). In those studies, in fact, the context was elicited both by being presented at the beginning of the experiment and through task demands. Despite each stimulus highlights the context, the irrelevance of the context for task demands might indicate that the manipulation used in the present study does not make the context salient enough to reverse the pattern of results. Future studies could clarify the effect of the context's influence, for instance making participants play cards before the experiment or keeping a picture of the individual order of disposition during the whole experiment.

It cannot be excluded that participants' strategies prevented the effect of cards order from emerging. For instance, participants could have focused exclusively on the digits while ignoring the cards in their entirety. Indeed, cards are complex stimuli that represents numbers both in a symbolic (i.e., the digits at the corners) and a non-symbolic format (i.e., the array of suits in the centre). This strategy could have disrupted the cards context, turning card value classification in a regular magnitude classification task. If this was the case, the effect we observed could reflect the regular arrangement of numbers, instead of that of cards. Such strategy could be controlled in future studies by analysing participants eye movements. An alternative possibility is that, although participants have processed cards in their entirety, the effect of digits could still have prevailed on the context. In this regard, a recent study showed that, when symbolic and non-symbolic numerals are simultaneously displayed, the symbolic values of digits drive SNAs, preventing the spatial association for non-symbolic numerals to emerge (Prpic et al., 2023). This could again be controlled by presenting modified cards which only display the suits, or by using those cards that naturally do not present numerical values (i.e., face cards), or, finally, by using a Go/No-go setup in which response is only given to cards with certain suits/colours.

4.6 Conclusions

Previous literature on the SNARC effect showed that both the order and the magnitude of numbers play a role in this effect, but their specific contribution has not been clarified yet. In this regard, a study by Prpic et al. (2016) showed that order and magnitude are differentially involved in SNARC-like effects depending on task requirements. The present study tried to disambiguate these aspects by using a kind of stimuli that are conceived in opposite orders by different people, namely playing cards. In particular, we tested people who order cards in a descending way, because in these people order and magnitude would elicit opposite representations. Results showed that these participants exhibit the same association when they classify cards' magnitude and when they classify number's magnitude, namely a SNARC effect. These results seem to be more indicative of an involvement of magnitude rather than order. This observation is apparently in contradiction with recent literature (CORE principle) supporting the sole involvement of order in SNARC-like effects and suggests that the effect of order is mostly observable when it is encoded and retrieved due to task demands otherwise the effect of magnitude would spontaneously emerge.

Chapter 5

General summary and conclusion

The present thesis addressed two important elements that determine flexibility in Spatial-Numerical Associations (SNAs) and in the SNARC effect in particular: context and task demands. The objective was to investigate the influence of the context on such effects and to clarify the role played by task demands in regulating this influence. Three studies were presented: each of them used a specific spatial-numerical configuration as context and distinct tasks that could reinforce the context or not. In this way the effect of the context has been observed in isolation or in interaction with task demands.

The first study used the context of a mobile-phone keypad, a numerical display in which some items violate the order of the mental number line (MNL). The tasks used in the three experiments could be either consistent, inconsistent, or unrelated to the context. Results showed that the order elicited by the context shaped a SNA only when it was consistent with the one elicited by task demands. When task demands did not require the processing of the context's order results were not influenced by it.

The second study used the well-known clockface context (Bächtold et al., 1998), in which numbers are represented in the opposite way compared to the MNL. The tasks were designed to gradually increase the level of salience of the context across the experiments. Results revealed that the task modulates the level of activation of the context in working memory and consequently its influence on SNAs.

The third study employed a context in which people represent numbers in two different ways, namely playing cards. This context was used in combination with two direct tasks to investigate the role of order and magnitude in the SNARC effect, when they elicit opposite representations. Results once more confirmed that if the task does not explicitly require the processing of the context's order, this order cannot influence the SNARC effect. Results, in this case, follow the direction of numbers' magnitude.

Context was carefully investigated across the three studies. From a methodological point of view, the paradigm used ensured that participants processed the context at a pre-experimental level. Moreover, the contexts used are extremely common in our society, and did not need a specific training to be represented by participants. Nonetheless, in all studies the context alone produced only a weak influence, which never altered the SNARC effect significantly.

One of the strengths of the present studies is that context has been systematically investigated in interaction with different task demands. The different tasks used throughout the experiments were of different nature: they could either reinforce the context at an intra-experimental level or not. Results from all the studies clearly indicated that the influence produced by the context is only visible if enhanced by task demands at intra-experimental level.

The enhancement of the context operated by task demands, defined as "salience" in the second study, is explained by the well-documented involvement of working memory in the SNARC effect (van Dijck et al., 2009). The paradigm used in the present studies can help us refine our understanding of this process. Indeed, the contexts presented in all experiments are long-term mappings of numbers that each participant possess. Despite being accessed pre-experimentally during context presentation, these mappings do not elicit an alternative SNA unless reactivated intra-experimentally in working memory during task execution. This is in line with the study by Ginsburg and Gevers (2015), in which the ordinal position effect emerged only when the task required the retrieval of the context.

When the context was made salient by task demands the stimuli were probably processed according to their order, rather than their magnitude. This tendency was evident in the keypad and clockface studies, where the significant alterations of the SNARC effect were clearly driven by the context order. However, when the effect of stimuli's order and magnitude were directly compared in the cards study, results seemed to go in the direction of magnitude rather than order. Considering previous evidence this result was somehow unexpected but could probably be once more explained by the task's nature.

It is important to clarify that the tasks used in the studies varied also on another level: the tasks could either enhance the spatial characteristics of the context (e.g., Experiment 1 in the keypad study and Experiment 4 in the clockface study) or the semantic characteristics of the context (e.g., Experiment 1b and 3b in the cards study). Results suggest that the strongest effect of the context order is observed in the first kind of task, namely when the task explicitly requires to process the spatial mapping of the context. This is not surprising, since it is in line with stimulus-response compatibility and the Simon effect but could tell us something about the nature of SNAs.

The fact that spatially characterized tasks lead to an ordinal processing of numbers seems to reflect a strategic adjustment employed by participants to achieve a better performance. When participants are directly asked to judge the spatial location of a stimulus in the context, it would be more convenient for them to retrieve the ordinal representation of the context. Differently, if the task does not require a similar judgement, participants would probably perform their judgement on the base of stimuli's magnitude. Overall, the results observed in the present studies point toward a strategical, task-related explanation of the flexibility existing in SNAs.

The strategical nature of the flexibility observed in SNAs seems to indicate that, despite being very common since it is formally taught in school and used in many daily activities, the MNL is only one of the possible ways in which numbers can be mapped in our brains. It could be speculated that this representation usually determines the SNARC effect, whereas when an atypical context is involved, its order could influence the effect.

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. (2020). 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, undefined-undefined. https://doi.org/10.1007/s00426-020-01306-3

Brugger, P., Schubiger, M., & Loetscher, T. (2010). Leftward Bias in Number Space Is Modulated by Magical Ideation. Cognitive and Behavioral Neurology, 23(2), 119–123. https://doi.org/10.1097/WNN.0b013e3181d74901

Bruzzi, E., Talamini, F., Priftis, K., & Grassi, M. (2017). A SMARC Effect for Loudness. I-Perception, 8(6), 2041669517742175. https://doi.org/10.1177/2041669517742175

Brysbaert, M. (1995). Arabic number reading: On the nature of the numerical scale and the origin of phonological recoding. Journal of Experimental Psychology: General, 124, 434–452. https://doi.org/10.1037/0096-3445.124.4.434

Casasanto, D., & Pitt, B. (2019). The Faulty Magnitude Detector: Why SNARC-Like Tasks Cannot Support a Generalized Magnitude System. Cognitive Science, 43(10), e12794. https://doi.org/10.1111/cogs.12794

Cipora, K., Dijck, J.-P. van, Georges, C., Masson, N., Goebel, S., Willmes, K., Pesenti, M., Schiltz, C., & Nuerk, H.-C. (2019). A Minority pulls the sample mean: On the individual prevalence of robust group-level cognitive phenomena – the instance of the SNARC effect. PsyArXiv. https://doi.org/10.31234/osf.io/bwyr3

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

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

Dalmaso, M., Schnapper, Y., & Vicovaro, M. (2022). When time stands upright: STEARC effects along the vertical axis. Psychological Research. https://doi.org/10.1007/s00426-022-01693-9

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

Di Giorgio, E., Lunghi, M., Rugani, R., Regolin, L., Dalla Barba, B., Vallortigara, G., & Simion, F. (2019). A mental number line in human newborns. Developmental Science, 22(6), e12801. https://doi.org/10.1111/desc.12801

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

Fias, W. (1996). The Importance of Magnitude Information in Numerical Processing: Evidence from the SNARC Effect. Mathematical Cognition, 2(1), 95–110. https://doi.org/10.1080/135467996387552

Fias, W. (2001). Two routes for the processing of verbal numbers: Evidence from the SNARC effect. Psychological Research, 65(4), 250–259. https://doi.org/10.1007/s004260100065

Fias, W., & van Dijck, J.-P. (2016). The temporary nature of number—Space interactions. Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale, 70(1), 33–40. https://doi.org/10.1037/cep0000071

Fischer, M. H. (2003). Cognitive representation of negative numbers. Psychological Science, 14(3), 278–282. https://doi.org/10.1111/1467-9280.03435

Fischer, M. H. (2008). Finger counting habits modulate spatial-numerical associations. Cortex, 44(4), 386–392. https://doi.org/10.1016/j.cortex.2007.08.004

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

Fischer, M. H., Warlop, N., Hill, R. L., & Fias, W. (2004). Oculomotor Bias Induced by Number Perception. Experimental Psychology, 51(2), 91–97. https://doi.org/10.1027/1618-3169.51.2.91

Fischer, U., Moeller, K., Class, F., Huber, S., Cress, U., & Nuerk, H.-C. (2016). Dancing with the SNARC: Measuring spatial-numerical associations on a digital dance mat. Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale, 70(4), 306–315. https://doi.org/10.1037/cep0000084

Fitts, P. M., & Seeger, C. M. (1953). S-R compatibility: Spatial characteristics of stimulus and response codes. Journal of Experimental Psychology, 46, 199–210. https://doi.org/10.1037/h0062827

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

Fumarola, A., Prpic, V., Luccio, R., & Umiltà, C. (2020). A SNARC-like effect for music notation: The role of expertise and musical instrument. Acta Psychologica, 208, 103120. https://doi.org/10.1016/j.actpsy.2020.103120

Galton, F. (1880). Visualised Numerals. Nature, 21(533), Art. 533. https://doi.org/10.1038/021252a0

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 organised: 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

Hartmann, M., & Mast, F. W. (2017). Loudness counts: Interactions between loudness, number magnitude, and space. The Quarterly Journal of Experimental Psychology, 70(7), 1305–1322. https://doi.org/10.1080/17470218.2016.1182194

Hohol, M., Woloszyn, K., & Cipora, K. (2021). No fingers, no SNARC? Spatial-Numerical Associations and temporal stability of finger counting. PsyArXiv. https://doi.org/10.31234/osf.io/23mya

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

Jewell, G., & McCourt, M. E. (2000). Pseudoneglect: A review and meta-analysis of performance factors in line bisection tasks. Neuropsychologia, 38(1), 93–110. https://doi.org/10.1016/S0028-3932(99)00045-7

Koch, N. N., Huber, J. F., Lohmann, J., Cipora, K., Butz, M. V., & Nuerk, H.-C. (2023). Mental Number Representations Are Spatially Mapped Both by Their Magnitudes and Ordinal Positions. Collabra: Psychology, 9(1), 67908. https://doi.org/10.1525/collabra.67908

Lachmair, M., Dudschig, C., de la Vega, I., & Kaup, B. (2014). Relating numeric cognition and language processing: Do numbers and words share a common representational platform? Acta Psychologica, 148, 107–114. https://doi.org/10.1016/j.actpsy.2013.12.004

Lega, C., Cattaneo, Z., Ancona, N., Vecchi, T., & Rinaldi, L. (2020). Instrumental expertise and musical timbre modulate the spatial representation of pitch. Quarterly Journal of Experimental Psychology, 73(8), 1162–1172. https://doi.org/10.1177/1747021819897779

Loetscher, T., Bockisch, C. J., & Brugger, P. (2008). Looking for the answer: The mind’s eye in number space. Neuroscience, 151(3), 725–729. https://doi.org/10.1016/j.neuroscience.2007.07.068

Loetscher, T., Bockisch, C. J., Nicholls, M. E. R., & Brugger, P. (2010). Eye position predicts what number you have in mind. Current Biology, 20(6), R264–R265. https://doi.org/10.1016/j.cub.2010.01.015

Loetscher, T., & Brugger, P. (2007). Exploring number space by random digit generation. Experimental Brain Research, 180(4), 655–665. https://doi.org/10.1007/s00221-007-0889-0

Loetscher, T., & Brugger, P. (2009). Random number generation in neglect patients reveals enhanced response stereotypy, but no neglect in number space. Neuropsychologia, 47(1), 276–279. https://doi.org/10.1016/j.neuropsychologia.2008.08.005

Lorch, R. F., & Myers, J. L. (1990). Regression analyses of repeated measures data in cognitive research. Journal of Experimental Psychology: Learning, Memory, and Cognition, 16(1), 149–157. https://doi.org/10.1037/0278-7393.16.1.149

Mariconda, A., Prpic, V., Mingolo, S., Sors, F., Agostini, T., & Murgia, M. (2022). A systematic investigation reveals that Ishihara et al.’s (2008) STEARC effect only emerges when time is directly assessed. Scientific Reports, 12(1), Art. 1. https://doi.org/10.1038/s41598-022-23411-6

Mingolo, S., Prpic, V., Bilotta, E., Fantoni, C., Agostini, T., & Murgia, M. (2021). Snarcing with a phone: The role of order in spatial-numerical associations is revealed by context and task demands. Journal of Experimental Psychology: Human Perception and Performance, 47(10), 1365–1377. https://doi.org/10.1037/xhp0000947

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

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

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

Nuerk, H.-C., Wood, G., & Willmes, K. (2005). The Universal SNARC Effect: The Association between Number Magnitude and Space is Amodal. Experimental Psychology, 52(3), 187–194. https://doi.org/10.1027/1618-3169.52.3.187

Peirce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., Kastman, E., & Lindeløv, J. K. (2019). PsychoPy2: Experiments in behavior made easy. Behavior Research Methods, 51(1), 195–203. https://doi.org/10.3758/s13428-018-01193-y

Pfister, R., Schroeder, P. A., & Kunde, W. (2013). SNARC struggles: Instant control over spatial–numerical associations. Journal of Experimental Psychology: Learning, Memory, and Cognition, 39(6), 1953–1958. https://doi.org/10.1037/a0032991

Pinto, M., Pellegrino, M., Marson, F., Lasaponara, S., Cestari, V., D'Onofrio, M., & Doricchi, F. (2021). How to trigger and keep stable directional Space–Number Associations (SNAs). Cortex, 134, 253–264. https://doi.org/10.1016/j.cortex.2020.10.020

Pinto, M., Pellegrino, M., Marson, F., Lasaponara, S., & Doricchi, F. (2019). Reconstructing the origins of the space-number association: Spatial and number-magnitude codes must be used jointly to elicit spatially organised mental number lines. Cognition, 190, 143–156. https://doi.org/10.1016/j.cognition.2019.04.032

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

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

Prpic, V., Basamh, Y. A., Goodridge, C. M., Agostini, T., & Murgia, M. (2023). Contrasting symbolic and non-symbolic numerical representations in a joint classification task. Psychonomic Bulletin & Review. https://doi.org/10.3758/s13423-023-02246-w

Prpic, V., & Domijan, D. (2018). Linear Representation of Pitch Height in the SMARC Effect. Psihologijske Teme, 27(3), 437–452. https://doi.org/10.31820/pt.27.3.5

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. (2021). Magnitude and Order are Both Relevant in SNARC and SNARC-like Effects: A Commentary on Casasanto and Pitt (2019). Cognitive Science, 45(7), e13006. 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

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

Restle, F. (1970). Speed of adding and comparing numbers. Journal of Experimental Psychology, 83(2, Pt.1), 274–278. https://doi.org/10.1037/h0028573

Rugani, R., Vallortigara, G., Priftis, K., & Regolin, L. (2015). Number-space mapping in the newborn chick resembles humans' mental number line. Science, 347(6221), 534–536. https://doi.org/10.1126/science.aaa1379

Rugani, R., Vallortigara, G., Priftis, K., & Regolin, L. (2020). Numerical magnitude, rather than individual bias, explains spatial numerical association in newborn chicks. eLife, 9, e54662. https://doi.org/10.7554/eLife.54662

Sellaro, R., Treccani, B., Job, R., & Cubelli, R. (2015). Spatial coding of object typical size: Evidence for a SNARC-like effect. Psychological Research, 79(6), 950–962. https://doi.org/10.1007/s00426-014-0636-7

Seron, X., Pesenti, M., Noël, M.-P., Deloche, G., & Cornet, J.-A. (1992). Images of numbers, or "when 98 is upper left and 6 sky blue". Cognition, 44(1), 159–196. https://doi.org/10.1016/0010-0277(92)90053-K

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. (2014). Random walks on the mental number line. Experimental Brain Research, 232(1), 43–49. https://doi.org/10.1007/s00221-013-3718-7

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

Simon, J. R. (1969). Reactions toward the source of stimulation. Journal of Experimental Psychology, 81, 174–176. https://doi.org/10.1037/h0027448

Toomarian, E. Y., & Hubbard, E. M. (2018). On the genesis of spatial-numerical associations: Evolutionary and cultural factors co-construct the mental number line. Neuroscience and Biobehavioral Reviews, 90, 184–199. https://doi.org/10.1016/j.neubiorev.2018.04.010

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

Vicovaro, M., & Dalmaso, M. (2021). Is 'heavy' up or down? Testing the vertical spatial representation of weight. Psychological Research, 85(3), 1183–1200. https://doi.org/10.1007/s00426-020-01309-0

Walsh, V. (2003). A theory of magnitude: Common cortical metrics of time, space and quantity. Trends in Cognitive Sciences, 7(11), 483–488. https://doi.org/10.1016/j.tics.2003.09.002

Winter, B., & Matlock, T. (s.d.). More is up… and right: Random number generation along two axes. 7.

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

Zhao, T., He, X., Zhao, X., Huang, J., Zhang, W., Wu, S., & Chen, Q. (2018). The influence of time units on the flexibility of the spatial numerical association of response codes effect. British Journal of Psychology, 109(2), 299–320. https://doi.org/10.1111/bjop.12273

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. https://doi.org/10.1037/xhp0000336