**Separate mechanisms for magnitude and order processing
in the SNARC effect: The strange case of musical note
values.**

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Valter Prpic¹, Antonia Fumarola¹, Matteo De Tommaso^{1,2}, Riccardo Luccio¹, Mauro Murgia^{1,3} & Tiziano Agostini¹

¹Department of Life Sciences, University of Trieste, Italy

²Center for Mind/Brain Sciences, University of Trento, Italy

³Department of Pedagogy, Psychology, Philosophy, University of Cagliari, Italy

*Corresponding author:

Dr. Valter Prpic

Department of Life Sciences, University of Trieste

Via Weiss 21, 37131 Trieste (Italy)

Email: valter.prpic@gmail.com

Abstract

The SNARC effect is considered an evidence of the association between numbers and space, with faster left key-press responses to small numbers and faster right key-press responses to large numbers. We examined whether visually presented note values produce a SNARC-like effect. Differently from numbers, note values are represented as a decreasing left-to-right progression, allowing us to disambiguate the contribution of order and magnitude in determining the direction of the effect. Musicians with formal education performed a note value comparison in Experiment 1 (direct task), a line orientation judgment in Experiment 2 (indirect task), and a detection task in Experiment 3 (indirect task). When note values were task relevant (direct task), participants responded faster to large note values with the left key-press, and vice versa. Conversely, when note values were task irrelevant (indirect tasks), the direction of this association was reversed. This evidence suggests the existence of separate mechanisms underlying the SNARC effect. Namely, an Order-Related Mechanism (ORM) and a Magnitude-Related Mechanism (MRM), that are revealed by different task demands. Indeed, according to a new model we proposed, ordinal and magnitude related information seem to be preferentially involved in direct and indirect tasks, respectively.

Keywords: SNARC; note value; order; magnitude; duration.

INTRODUCTION

The SNARC effect (Dehaene, Bossini & Giraux, 1993) is a well known psychological phenomenon, consisting in faster left key-press responses to relatively small numbers (e.g., 1) and faster right key-press responses to relatively large numbers (e.g., 9). To account for this effect, authors suggested that a representation of number magnitude is automatically accessed during parity judgments of Arabic digits, and that this representation can be connected to a spatially oriented mental number line (MNL) (Restle, 1970). Therefore, the SNARC effect would be the result of a direct correspondence between this mental representation (i.e., MNL) and the execution of responses in the external space (for alternative accounts see Proctor and Cho, 2006; Gevers, Verguts, Reynvoet, Caessens, & Fias, 2006). Moreover, Dehaene et al. (1993) hypothesized that the left-to-right direction of the SNARC effect is directly related to the direction of writing in the Western culture (see also Zebian, 2005; Shaki, Fischer & Petrusic, 2009).

However, the SNARC effect showed to be highly influenced by task demands and not to be strictly related to a left-to-right oriented MNL representation (Bächtold, Baumüller & Brugger, 1998). Indeed, Bächtold et al. (1998) revealed that, when participants were instructed to imagine numbers placed on a ruler, a normal left-to-right SNARC effect emerged. Whereas, when task demands required to think about numbers as represented on a clock-face, the direction of the effect was reversed.

The SNARC effect was firstly assessed by using a task where number magnitude was relevant, namely a number comparison (Dehaene, Dupoux & Mehler, 1990), and secondly with a task where number magnitude was irrelevant, namely a parity judgment (Dehaene et

al., 1993). From now on, we will call these two task categories respectively "direct task" and "indirect task", since magnitude information is directly and indirectly involved in task instructions. Overall, the use of both direct and indirect tasks seems a good practice to investigate the SNARC effect, since the first one allows evaluating the spatial coding of internal information, whereas the second one focuses on the evaluation of the automaticity of this process.

A longstanding issue: The processing of order and magnitude.

Gevers, Reynvoet & Fias (2003; 2004) demonstrated that, not only numbers but even non-numerical ordinal sequences (i.e., letters of the alphabet, months of the year and days of the week) are spatially organized. From this evidence, number magnitudes and ordinal sequences seem to be involved in similar processes and to share a common representational system. This claim is supported by Marshuetz, Smith, Jonides, DeGutis & Chenevert's (2000) study, in which common brain areas were engaged in processing both non-numerical ordinal attributes and numbers. However, other studies in related domains brought new evidence contrasting the idea that order and magnitude are processed by the same mechanism (Badets, Boutin & Heuer, 2015; Rubinsten, Dana, Lavro & Berger, 2013; Vogel, Remark, & Ansari, 2015; Viarouge & de Hevia, 2013). Nevertheless, in the domain of SNARC there is still no clear evidence about common or separate mechanisms for processing order and magnitude.

The order-magnitude ambiguity is due to the fact that several stimuli show both properties of magnitudes and ordinal sequences at the same time. For instance, digits clearly represent number magnitude, but they possess also ordinal properties that are

independent from magnitude. In the case of numbers, as for other stimuli that have been previously investigated, the usual representational sequence starts from the smallest magnitude (e.g., 1) and progressively increases to larger magnitudes. Indeed, people usually start counting from number "1" as the initial point of the sequence, and usually find it more difficult to start counting from a larger magnitude and progressively decreasing to smaller magnitudes (see also Ben-Meir, Ganor-Stern & Tzelgov, 2012; Müller & Schwarz, 2008). Therefore, the increasing progression from the smallest to the largest magnitudes is considered as the "correct" or the "usual one", while the opposite decreasing progression is considered "odd" or "unusual". Thus, the first progression represents also the typical orientation of the mental number line (Restle, 1970).

In the case of numbers there is a natural confounding, since the SNARC effect can be due both to the ordinal sequence and to the magnitude of the stimuli. However, in some cases both ordinal property and magnitude of stimuli can independently determine SNARC-like effects. For instance, SNARC-like effects for letters, months and days (Gevers et al., 2003; 2004) are clearly due to the over-learned ordinal sequence of the stimuli, since magnitude is not a property of these categories of stimuli. Similarly, it has been shown that even newly acquired arbitrary sequences of words can produce a reliable SNARC-like effect (Previtali, de Hevia, & Girelli, 2010). Thus, ordinal features of the stimuli can be sufficient to account for a great number of the SNARC-like effects revealed in literature.

Conversely, SNARC-like effects for non-symbolic quantities, such as luminance, size and duration of stimuli (Fumarola, Prpic, Da Pos, Murgia, Umiltà, & Agostini, 2014; Ren, Nicholls, Ma, & Chen, 2011; Vallesi, Binns, & Shallice, 2008; Vallesi, McIntosh, & Stuss, 2011), are presumably due to the magnitude of the stimuli, since there is not a standard

ordinal sequence for representing these categories of stimuli (as instead it occurs for numbers or letters). This evidence supports the ATOM (i.e., A Theory of Magnitude) model proposed by Walsh, which assumes the existence of a common mechanism for processing different kinds of magnitudes, such as numbers, space and time (Walsh, 2003; Buetti & Walsh, 2009).

Even though a large number of researchers have dedicated their studies to the SNARC effect, there are still some relevant open questions regarding the mechanisms determining this phenomenon: 1) Is the SNARC effect due to the ordinal sequence of the stimuli or to their magnitude? 2) Do the magnitude and the ordinal properties of the stimuli differently affect the SNARC effect? Similar questions were raised also by Gevers & Lammertyn (2005) that, in their review "The hunt for SNARC", addressed the following issue: *"The question can be asked if non-numerical ordinal information and numerical information share the same processing mechanisms or, alternatively, use different mechanisms with similar properties."* (p. 12). In the present work, we will try to address these questions by investigating the spatial association for musical note values.

The representation of musical note values.

Note values have a comparable role for music as numbers do for mathematics. Indeed, they represent the relative duration of a sound and have many similarities with digits. Note values are usually expressed by graphic symbols and their specific values are indicated by the color or the shape of the note's head, by the presence or the absence of a stem, and by the presence or the absence of flags on the stem (Figure 1). Note values can also be expressed as numerical values, representing the notes' duration as the number of

beats inside a bar. In music, a bar (or measure) represents a unit of time defined by a given number of beats. Each measure satisfies a specified time signature. Therefore, if the measure is written in 4/4 time, a whole note will be enough to complete a bar. Alternatively, it could be completed by two half notes, or four quarter notes, and so on, with all the possible combinations.

Figure 1 about here

The typical sequential order for representing note values start from the whole note and is followed by progressively smaller note values in a hierarchical order (e.g., half note, quarter note, eighth note, and so on). Therefore, the usual order for representing numbers and note values is reversed¹. Indeed, as represented in Figure 2, numbers' sequence progressively increases in magnitude (from the smallest to the largest number), whereas note values decrease in magnitude (from the largest to the smallest value). The typical way to represent musical note values is a key feature that will allow us to disambiguate between order and magnitude processing.

Figure 2 about here

The present study.

The aim of the present work is to verify whether note values produce a spatial correspondence effect having the same direction of numbers (left key-press advantage for

Footnote ¹

small magnitudes and vice versa) or the opposite one (left key-press advantage for large magnitudes and vice versa). In the first case (left key-press advantage for small magnitudes and vice versa), the cause of this effect should be ascribed to the magnitude of the stimuli. We will call this hypothesis "magnitude prediction" from now on. Conversely, in the second case (left key-press advantage for large magnitudes and vice versa), the cause of this effect should be ascribed to the typical order used to represent note values. We will call this hypothesis "order prediction" from now on. The magnitude prediction hypothesis is supported by a large number of studies investigating the STEARC effect (i.e., Spatial-Temporal Association of Response Codes), that revealed a spatial-temporal association with short durations linked to the left space and long durations linked to the right space (Bonato, Zorzi & Umiltà, 2012; Bono, Grazia, Casarotti, Priftis, Gava, Umiltà & Zorzi, 2012; Casasanto & Boroditsky, 2008; Fabbri, Cancellieri & Natale, 2012; Fabbri, Cellini, Martoni, Tonetti & Natale, 2013; Ishihara, Keller, Rossetti & Prinz, 2008; Vallesi et al., 2008; Vallesi et al., 2011). Conversely, the order prediction hypothesis is supported by the evidence revealed by Gevers et al. (2003; 2004) about letters of the alphabet, months of the year and days of the week, and by Previtali et al. (2010) about newly acquired ordinal sequences.

Therefore, the direction of the SNARC-like effect for note values should attempt to disambiguate between the properties determining the SNARC-like effects (magnitude and ordinal sequence of the stimuli). Indeed, due to the particular nature of note value representation, there will be a conflicting situation between magnitude and sequential order of the stimuli, allowing us to better understand their role in SNARC-like effects. To address this issue, we asked three groups of musicians with formal education to perform respectively a direct comparison of note value in Experiment 1, and to perform two indirect

tasks, namely a line orientation judgment in Experiment 2 and a simple detection task in Experiment 3.

EXPERIMENT 1

In Experiment 1 we aimed to assess whether note values produce a spatial correspondence effect when values are relevant for performing the task (direct task). Thus, we created a situation in which participants had to perform a direct comparison of note values using a fixed middle reference value, in order to evaluate the spatial coding of internal information. In particular, we were interested in verifying whether the direction of this spatial association fits the magnitude prediction hypothesis or the order prediction hypothesis. Namely, if the SNARC-like effect for note values is due to the magnitude, there should be an advantage for left key-press responses to small note values (i.e., eighteenth note and sixteenth note) and for right key-press responses to large note values (i.e., whole note and half note). Conversely, if the effect is due to the typical ordinal sequence used for representing note values, there should be an advantage for left key-press responses to large note values (i.e., whole note and half note) and for right key-press responses to small note values (i.e., eighteenth note and sixteenth note).

Method

Participants. Sixteen students from an Italian State Conservatory of Music took part in Experiment 1. They were all right-handed and used to the left-to-right writing direction. They had an overall mean of 5.8 (SD = 1.4) years of music experience and formal education

at the conservatory, and a mean age of 20.3 (SD = 3.4). Thirteen of the participants were female and three were male.

Considering that the knowledge of note values is early assimilated and its use is widespread among all musicians, we did not take into consideration the specific instrument played as an important variable. As the only exception, we excluded percussionists as they use also different music marks in addition to the more common note writing, while we considered without distinctions other instrument players (e.g., pianists, violinists, flutists, guitarists) across the experiments. All the participants of this study had at least five years of formal musical education at the Conservatory, thus they were perfectly familiar with musical notation and able to read and play a musical score.

All participants had normal or corrected-to-normal vision and were naive about the purpose and the hypothesis being tested. Informed consent was obtained prior to participation in the experiments, that was conducted in accordance with the ethical standards established by the Declaration of Helsinki.

Apparatus and stimuli. The experiment was created and controlled by the E-Prime software, version 2.0. Stimuli were displayed on a 15.6 inch screen, with a 1280 x 800 pixels resolution. The PC was a Dell notebook with Intel Core i3 (RAM: 2 Gb). The Operating System was Windows 7 64-bit Edition. A five button Serial Response Box, connected to the pc by means of a serial port, was used for collecting responses.

Stimuli consisted of four pictures representing four musical notes (those represented in Figure 2), with different duration values (i.e., whole note, half note, eighteenth note and sixteenth note), presented in the middle of the screen against a dim yellow background. The "quarter note" was the middle point reference for the duration value judgment and,

consequently, was excluded from the stimuli. No stave or other cues appeared on the screen, so we presented just one isolated musical note at a time.

Procedure. The experiment took place in a quiet room, without environmental distractions. Participants were positioned in front of the PC. The midlines of the screen and the response box were aligned with the midline of the participant's body. The viewing distance was approximately 60 cm. Participants were instructed to move as little as possible and were asked to position their left index finger on the leftmost key and their right index finger on the rightmost key of the response box.

Each trial started with a fixation cross presented for 300 ms, followed by an inter-stimulus interval (ISI) of 130 ms. Then the target note appeared at fixation point, until a response occurred. Participants were asked to decide whether the presented note value was larger or smaller than the "quarter note", used as middle point reference, by pressing the leftmost or the rightmost keys. The experiment was divided into two sessions. In the first one, participants were asked to press the leftmost key, with their left hand, when the note's value on the screen was larger than a "quarter note" and the rightmost key, with their right hand, when the note's value was smaller than a "quarter note". In the second session, the assignment was reversed (leftmost key for smaller note values, and rightmost key for larger note values, compared to a quarter note). The order of the two sessions was counterbalanced among participants. Since participants were all Italian speakers and students from the Italian State Conservatory of Music, we used the Italian terminology to indicate note value in the instructions. Thus, the middle point reference used in the experiment was indicated as "semiminima". Each of the two sessions started with 8 practice trials (not considered for data analysis). Then, each of the 4 note values was presented 20

times in random order. This resulted in a total of 80 trials in each session. The inter-trial interval (ITI) was 1500 ms.

Participants were allowed to take a short break between the two sessions, otherwise they could continue with the experiment. Both speed and accuracy were stressed in the instructions.

Data analysis and results

Experimental variables were manipulated within a repeated-measures design for regression analysis (Fias, Brysbaert, Geypens, & D'Ydewalle, 1996; Lorch & Myers, 1990). The predictor variable was the note value, whereas the criterion variable was the difference between reaction time (RT) of the right hand and RT of the left hand: $dRT = RT(\text{right hand}) - RT(\text{left hand})$. Positive dRTs indicated faster responses with the left key-press, whereas negative dRTs indicate faster responses with the right key-press. In the first step, for each participant the median RT of the correct responses was computed for each note value, separately for left- and right-hand responses. On the basis of these medians, dRT was computed by subtracting the median RT of left-hand responses from the median RT of right-hand responses. In the second step, a regression equation was computed for each participant with the note value as the predictor variable. In the third step, a one-sample t-test was performed to verify whether beta regression weights of the group deviated significantly from zero.

The analysis of dRT revealed that the regression slopes were significantly different from zero, $t(15) = -2.745$, $p < .05$ (Figure 3). This result shows a relative left key-press

advantage in processing large note values (i.e., whole note and half note) and a relative right key-press advantage for small note values (i.e., eighth note and sixteenth note).

Figure 3 about here

Discussion

In Experiment 1 we aimed to assess whether the internal representation of note values, symbolizing note duration, is spatially organized. More importantly, we were interested in verifying whether the direction of this spatial association fits the magnitude prediction hypothesis or the order prediction hypothesis.

The results of this experiment showed that note values are spatially coded, revealing a significant SNARC-like effect. The direction of this association fits our order prediction hypothesis and is consistent with the evidence obtained for other ordinal sequences - such as letters of the alphabet, months of the year and days of the week - by Gevers et al. (2003; 2004). However, the direct comparison of note values do not inform us about the automaticity of this spatial representation. In order to deeply investigate this phenomenon, we ran a second experiment where note values were irrelevant for performing the task.

EXPERIMENT 2

In Experiment 2 we aimed to assess whether note values produce a spatial correspondence effect, when note values are irrelevant for performing the task (indirect

task). Similarly to Fias, Lauwereyns & Lammertyn (2001), we adopted a line orientation judgment task, since these authors showed that this task is effectively influenced by irrelevant stimuli (i.e., numbers), producing a SNARC effect. Therefore, we expected to obtain similar results with note values, revealing the automaticity of this spatial representation. Similarly to Experiment 1, we were particularly interested in the direction of this spatial association (magnitude prediction or order prediction hypotheses). If data of Experiment 2 confirm those of Experiment 1 (order prediction hypothesis), we conclude that the order of the stimuli has a dominant role in producing this SNARC-like effect, independently of the task. Conversely, if data of Experiment 2 are consistent with the magnitude prediction hypothesis (advantage for left key-press responses to small note values and for right key-press responses to large note values), we conclude that either magnitude or order processing prevails, depending on task demands.

Method

Participants. Eighteen students from the same music conservatory as Experiment 1 took part in Experiment 2. They were all right-handed and used to the left-to-right writing direction. They had an overall mean of 7.3 (SD = 2.2) years of music experience and formal education at the conservatory, and a mean age of 22.3 (SD = 4.1). Eleven of the participants were female and seven were male.

Apparatus and stimuli. Apparatus and stimuli were the same as in Experiment 1, with the only exception that a horizontal or vertical line was superimposed to the notes' images. Lines were drawn in black and crossed the notes' middle point head, coming out

from both sides (left/right or up/down) of approximately three-fourths of the note's length (Figure 4).

Figure 4 about here

Procedure. The procedure was similar to that described in the previous experiment. The only difference was that participants were asked to judge whether the superimposed line was horizontally or vertically oriented, by pressing the leftmost and the rightmost keys, while note values were irrelevant for performing the task. The experiment was divided into two sessions. In the first one, participants were asked to press the leftmost key (with their left hand), when the line was horizontally oriented, and the rightmost key (with their right hand), when the line was vertically oriented. In the second session, the assignment was reversed (leftmost key for vertically oriented lines, and rightmost key for horizontally oriented lines).

Data analysis and results

Data analyses were the same as in Experiment 1. The analysis of dRT revealed that the regression slopes were significantly different from zero, $t(17) = 3.06$; $p < .01$ (Figure 5). The result shows a relative left key-press advantage in processing small note values (i.e., eighth note and sixteenth note) and a relative right key-press advantage for large note values (i.e., whole note and half note). The direction of this association was reversed compared to that revealed by the direct task (Experiment 1).

Figure 5 about here

Discussion

The aim of Experiment 2 was to assess whether note values automatically produce a spatial correspondence effect. By using a line orientation judgment task (Fias et al., 2001), we found a SNARC-like effect for note values. In Experiment 2 the direction of the spatial association for note values was the opposite of that found in Experiment 1. Indeed, when performing a direct note value comparison (Experiment 1), participants showed a left key-press advantage in processing large note values and a right key-press advantage in processing small note values, supporting the order prediction hypothesis. In contrast, when performing a line orientation judgment (Experiment 2), participants showed a left key-press advantage in processing small note values and a right key-press advantage in processing large note values, supporting the magnitude prediction hypothesis. These results suggest that while in direct tasks the order of the stimuli seems to prevail, in indirect tasks the magnitude of the stimuli seem to have a dominant role. It is interesting to observe that while in Experiment 1 the effect seems to be mainly due to the smaller note values (eighth and sixteenth notes), in Experiment 2 it seems to be mainly due to larger note values (whole and half notes). This further evidence not only suggests that there is a reversion of the direction of the effect, but also a reversion of the stimuli that mainly determine the effect.

Given that the results of Experiment 2 contrasted with those of Experiment 1, we decided to perform a third experiment. Indeed, several kinds of indirect tasks have been

used in literature, and we aimed to extend the validity of the results of Experiment 2 using a different type of indirect task.

EXPERIMENT 3

In Experiment 3, we aimed to confirm the direction of the SNARC-like effect for note values obtained in Experiment 2, by using a detection task (Fischer, Castel, Dodd & Pratt, 2003; van Galen & Reitsma, 2008). This task was firstly used with numbers by Fischer et al. (2003), who demonstrated that the mere perception of numbers causes a spatial shift of attention (also called attentional SNARC effect). Namely, participants were faster in responding to a target appearing on the left of the screen after that a small number was presented in the centre as a prime. Conversely, participants were faster in responding to a target appearing on the right of the screen after that a large number was presented as a prime. We hypothesized that a similar phenomenon can occur also for note values, providing further empirical support for the automaticity of the spatial association found in Experiment 2. Moreover, we expected that the direction of this spatial association would be the same as that found in Experiment 2. Indeed, in both line orientation judgment (Experiment 2) and detection task (Fischer et al., 2003) no direct processing of the magnitude was required. Therefore, we expected that data would fit the magnitude prediction hypothesis and, thus, that participants would automatically access the magnitude information of the stimuli, despite the opposite order of stimuli representation. Indeed, while numbers certainly induce automatic shift of attention (Fisher et al., 2003), ordinal information (i.e., letters, days and months) failed to produce a similar phenomena in a

simple detection task. Conversely, the attentional SNARC for letters, days and months was revealed only when participants were forced to process the stimuli and perform an order-relevant decision. Evidence suggests that there are processing mechanisms specific to numbers that do not automatically generalize to other ordinal sequences (Dodd, Van der Stigchel, Leghari, Fung, & Kingstone, 2008). Thus, we expect that if note values are processed similarly to numbers, Experiment 3 should reveal an attentional SNARC-like effect with the direction consistent with the magnitude prediction hypothesis. Conversely, the absence of an attentional SNARC-like effect would suggest that note values are processed similarly to other non-numerical ordinal sequences.

Method

Participants. Eighteen students from the same music conservatory took part in Experiment 3. They were all right-handed and used to the left-to-right writing direction. They had an overall mean of 8.4 (SD = 3.3) years of music experience and formal education at the conservatory, and a mean age of 23.1 (SD = 4.2). Ten of the participants were female and eight were male.

Apparatus and stimuli. Apparatus and stimuli were the same as in Experiment 1.

Procedure. The experimental procedure was adapted from Fischer et al. (2003) and van Galen & Reitsma (2008), by using the same note values images as in Experiment 1. As regards the stimuli presentation, each trial started with a white fixation cross displayed for 400 ms at the centre of the screen, between two dark grey boxes. Then, an image representing one of the note values appeared for 300 ms instead of the fixation cross. After a short or long delay (400 ms and 750 ms, respectively), one of the two dark grey squares

were replaced by a lighter grey square, that disappeared in 2000 ms or after participants responded. The reason for a variable delay was to discourage participants from guessing the timing of the target appearance. Moreover, the delay values were chosen as representing the upper (750 ms) and the lower level (400 ms) where a SNARC effect was previously found (Fisher et al., 2003). Participants were asked to respond, by pressing the central key on the response box, at the appearance of the target light gray square. Note values were task irrelevant, as no instructions related to note values were given to perform the task. Note images were presented as a prime, with the intent to shift participants' attention to the left or right side of the screen. The inter-trial interval (ITI) was 1500 ms.

The experiment was divided into two sessions. In the first session, participants were asked to press the central key with their right index finger when the target square appeared, while, in the second session, participants responded with their left index finger. Speed was stressed in the instructions. The order of the sessions was counterbalanced among participants. Each of the two sessions started with 8 practice trials and then each note value was presented 20 times in random order. This resulted in a total of 80 trials in each session. Participants were allowed to take a short break between the two sessions, otherwise they continued with the experiment. The experimental setting and the participants' position were the same as those described in the previous experiments.

Data analysis and results

Data were analyzed with the same method used in the previous experiments. Outlier RTs below 150 ms were removed from the data (2.4%), according to previous literature (van Galen & Reitsma, 2008). The predictor variable was the note value, whereas the criterion

variable was the difference between the median reaction time (RT) of the right target and of the left target: $dRT = RT(\text{right target}) - RT(\text{left target})$. Positive dRTs indicated faster responses to the left target, whereas negative dRTs indicated faster responses to the right target.

The analysis of dRT revealed that the regression slopes were significantly different from zero in the short delay condition (400 ms), $t(17) = 1.79$; $p < .05$ (one-tailed, see Figure 6), whereas in the long delay condition (750 ms) data were not significant, $t(17) = -0.04$, $p = .97$ (Figure 6). Thus, in the short delay condition, there was a relative left target advantage after the presentation of small note values (i.e., eighth note and sixteenth note), and a relative right target advantage after the presentation of large note values (i.e., whole note and half note).

Figure 6 about here

DISCUSSION

The aim of Experiment 3 was to confirm the direction of the SNARC-like effect for note values obtained in Experiment 2, by using a detection task (Fischer et al., 2003; van Galen & Reitsma, 2008). Data revealed that for short delays the note images primed spatial attention, producing a leftward bias for small note values (eighth and sixteenth notes) and a rightward bias for large note values (whole and half notes). This evidence revealed that the spatial association effect for note values is not limited to motor responses, but it

extends to perceptual encoding processes. These data provide further empirical evidence supporting the magnitude prediction hypothesis, when note values are task irrelevant.

Moreover, evidence provided by Dodd et al. (2008) suggests that, in Experiment 3, note values were processed similarly to numbers, producing an automatic spatial shift of attention.

GENERAL DISCUSSION

The aim of this work was to disambiguate a natural confounding aspect of the SNARC effect, namely the covariance of order and magnitude in numbers. Due to the specific characteristics of musical note values, we were able to separately investigate the role of order and magnitude in determining the spatial association for note values. In particular, we aimed at verifying whether the direction of this SNARC-like effect was consistent either with the order prediction hypothesis or with the magnitude prediction hypothesis.

The results revealed an intriguing reversal of this SNARC-like effect across the experiments, depending on task requests. By using a note value comparison task (Experiment 1), data supported the order prediction hypothesis. Indeed, when participants were required to directly judge the magnitude of note values (direct task), they seemed more likely to process the order rather than the magnitude of the stimuli. Conversely, when participants were required to perform a task in which note values were irrelevant (indirect task), namely a line orientation task (Experiment 2), they seemed to access the semantic information of the stimuli and automatically process their magnitude (i.e., note duration), rather than the order. Indeed, in this case, the data supported the magnitude prediction

hypothesis. Further support to this hypothesis was provided through a different indirect task, namely a detection task (Experiment 3).

The results of Experiment 1 suggest that when note values are directly assessed they are processed similarly to other non-numerical ordinal sequences, such as letters of the alphabet, months of the year and days of the week (Gevers et al., 2003; 2004). The results of Experiment 2 and 3 suggest that when note values are not directly assessed they are processed similarly to other non-symbolic quantities, such as luminance and size (Fumarola et al., 2014; Ren et al. 2011). In particular, this evidence is in line with previous findings regarding the STEARC effect, i.e. , the association of short durations with left space, and of long durations with right space (Bono et al., 2012; Casasanto & Boroditsky, 2008; Fabbri et al., 2012; Fabbri et al., 2013; Ishihara et al., 2008; Vallesi et al., 2008; Vallesi et al., 2011). Moreover, from a broader perspective, our findings extend previous evidence about the spatial association in the domain of music (Rusconi et al., 2006; Lidji et al., 2007).

The opposite directions revealed by the SNARC-like effect for note values suggest the existence of separate mechanisms, concerning both magnitude and order representation, involved in the SNARC-like effects. These mechanisms are revealed by the different task demands of the three experiments. In Experiment 1, participants most likely compared the ordinal position of targets with that of the middle point reference. Thus, the magnitude information of note values seems to be irrelevant and the ordinal properties of the stimuli are sufficient *per se*, to complete the task. Conversely, in Experiments 2 and 3, the tasks did not explicitly require participants to compare note values with a reference stimulus. Thus, given the absence of an explicit comparison, we suggest that participants did not focus on the order but they automatically processed the magnitude of the stimuli. The idea of

different mechanisms involved in direct and indirect tasks is in line with the account of Gevers, Verguts, Reynvoet, Caessens, & Fias (2006) on the SNARC effect. Indeed, they show that the SNARC effect is continuous for the parity judgment task (indirect task) but categorical for the magnitude comparison task (direct task), suggesting a dual nature of this phenomenon.

Our interpretation of these results is also supported by the study of Bächtold et al. (1998). In this study participants were required to imagine numbers either on a ruler or on a clock-face. In the clock-face condition the typical numerical representation was manipulated, reversing the natural order of the sequence of stimuli (large numbers on the left, small numbers on the right). Similarly to our Experiment 1, results showed that when a direct comparison with a middle reference standard is required, the direction of the SNARC effect is influenced by the ordinal properties of the stimuli and not by their magnitude. Apart from this exception, in the case of numbers the dissociation between order and magnitude processing never emerged, since both order and magnitude representations share the same direction. Nevertheless, there is an important difference between note values and numbers in the clock-face condition. Indeed, in the note value representation the order-magnitude reversion is a natural feature of the stimuli, while in the clock-face condition it is artificially triggered by the experimental procedure. For this reason, the task required a more robust involvement of the participants' working memory (WM), as revealed by slower RTs in the clock-face compared to the ruler condition.

Other recent evidence revealed the important role of WM in the SNARC effect. Van Dijck, & Fias (2011) revealed that information stored in WM gets spatially coded based on its ordinal position in the sequence (items from the beginning of a WM sequence are

associated to the left space, and vice versa). However, a further investigation (Ginsburg, van Dijck, Previtali, Fias, & Gevers, 2014) revealed that this "position effect" is observed only when the retrieval of the memorized sequence is required, while a typical SNARC effect emerged when numbers were maintained in WM without retrieval. Authors concluded that the activation of the canonical order of numbers in WM is a prerequisite for the SNARC effect and that this order can be overruled when the retrieval of a new sequence is required, resulting in an ordinal position effect instead of a SNARC effect.

In our study, neither maintenance nor retrieval of new ordinal sequences in WM was required. However, we cannot exclude the role of WM in our results, especially in Experiment 1. Indeed, in this case the task may require to keep the four musical symbols in WM, and their position in WM may have enhanced the preference for order processing. However, in Experiments 2 and 3 the symbols do not have to be explicitly maintained in WM, thus the effect of the position is not salient, and the processing of magnitude prevails.

Separate mechanisms for order and magnitude processing: A new model.

On the basis of our results and of previous literature, we hypothesize the existence of two separate mechanisms underlying the SNARC-like effects: a more general order-related mechanism (ORM) and a specific magnitude-related mechanism (MRM). Both mechanisms are strictly connected and hardly dissociable when simultaneously active, thus their existence can be revealed only when one mechanism overcomes the other in specific situations. The functioning of these mechanisms is summarized in the model reported in Figure 7. This model does not have the ambition to explain the functioning of the SNARC-

like effects, but aims at disambiguating the role of magnitude- and order-related information in determining these effects, depending on task requests.

Figure 7 about here

As regards the functioning of the ORM, we hypothesize that every ordinal sequence of stimuli is spatially coded associating the starting point of the sequence with one of the cardinal poles (left/right, down/up), and that the subsequent elements are organized in the direction of the opposite pole, maintaining the order of the sequence. For example, in the case of letters, "A" may be the starting point of a sequence and would be associated with one pole, while "B", "C" and "D" would be respectively organized in the direction of the opposite pole, which would be associated with the last letter of the stimuli sequence. The association of stimuli with the poles is not fixed and can be modified temporarily or permanently by several factors, such as task instructions, as in the case of the clock-face condition (Bächtold et al., 1998), position in working memory (Van Dijck & Fias, 2011), and cultural factors, as in the case of writing direction (Zebian, 2005; Shaki et al., 2009). This general mechanism is independent of the kind of stimuli. Indeed, even sequences of stimuli providing magnitude information are processed by the ORM. In this case, the magnitude of the stimuli is irrelevant *per se*, but the relevant point is that the magnitude provides ordinal information as well. Thus, at this level all the stimuli are processed in the same way, independently of their meaning (semantic information). For this purpose, important evidence was provided by Previtali et al. (2010), who demonstrated that newly acquired

sequences are mapped in the representational space and that, at least in western culture, this spatial representation is preferentially oriented from left-to-right.

Differently from the ORM, the MRM applies only to stimuli that provide meaningful information about quantities. As regards the functioning of the MRM, we hypothesize that smaller magnitudes are associated with one cardinal pole and larger magnitudes with the opposite pole, maintaining the internal order of the stimuli. This mechanism is supported by the ATOM model (Walsh, 2003; Bueti & Walsh, 2009) that predicts that any spatially or action-coded magnitude should reveal a relationship between magnitude and space. Thus, the SQARC effect (i.e., Spatial-Quantity Association of Response Codes) proposed by Walsh (2003) seems to be based on this mechanism. Importantly, according to our model, while the ORM can be activated without involving the MRM (as in the case of letters, month, and days), the activation of the MRM involves always the co-activation of the ORM, since all magnitudes intrinsically own also ordinal properties. These ordinal properties can be more or less salient, depending on the kind of stimuli and on observers' experience. In the case of numbers ordinal properties are extremely salient, since they are commonly experienced in daily life, therefore numbers can be considered an over-learned sequence. Conversely, most non-symbolic magnitudes (e.g. luminance, size) have ordinal properties, but these properties are less salient since they are less commonly experienced in daily life.

The idea of polarity coding for ORM and MRM draws inspiration from the Polarity Correspondence Principles proposed by Proctor & Cho (2006). These authors proposed a general principle to account for various binary classification tasks. More specifically, they suggested that both stimuli and response alternatives are coded as positive (+) and negative (-) polarities along several dimensions, and that the polarity correspondence is sufficient to

produce mapping effects. Furthermore, the coding of both stimuli and responses to opposite poles does not seem to be fixed and can be modified by task instructions (see also Cho & Proctor, 2007; Lakens, 2011).

According to our model, depending on task demands the ORM and MRM mechanisms are differently involved. In particular, direct tasks seem to activate the ORM preferentially, while indirect tasks seem to activate the MRM. Indeed, in Experiment 1 (direct task), we found empirical evidence suggesting a predominant role of the ORM; in Experiments 2 and 3 (indirect tasks), we found empirical evidence suggesting a predominant role of the MRM.

In the case of direct tasks, the reference stimulus defines a middle point in the sequence that fosters the activation of the ORM and induces one to categorize stimuli as positioned before or after the reference point in the ordinal sequence (e.g., Gevers et al., 2003). Even when a magnitude comparison is required (e.g., our Experiment 1), this task can be easily performed just by using the ordinal properties of the stimuli, while a semantic access to stimuli magnitude is not necessary. For this reason, it is difficult to assess the involvement of the MRM in this kind of tasks.

Conversely, in the case of indirect tasks, both MRM and ORM can be activated. However, if there is a conflict between them due to the opposite progression between order and magnitude (such as in the case of note values), then MRM prevails (our Experiments 2 and 3). In the case of non-numerical ordinal stimuli (e.g., letters), since there is no magnitude, we can expect only a weak activation of the ORM (e.g., Dodd et al., 2008;

Gevers et al., 2003; Van Opstal et al., 2009). For an overview regarding how our results and those of previous studies fit our model, see Table 1.

Table 1 about here

A good metaphor to explain how these two mechanisms work is provided by the levels of measurement proposed by Stevens (1946). Indeed, the ORM would work at the level of ordinal scale, since stimuli are processed according to rank order information (1st, 2nd, 3rd, etc.), ignoring information about the relative degree of difference between the stimuli. Conversely, the MRM would work at the level of interval scale, since stimuli are processed according to the degree of difference between them. As it happens for the levels of measurement, the upper levels (e.g., interval scale) always preserve the characteristics of lower levels (e.g., ordinal scale), thus, when the MRM is activated, the ORM is simultaneously involved, since ordinal information is always coexisting. Therefore, we consider the MRM as a higher level mechanism compared to the ORM.

Conclusions

To sum up, from previous literature we knew that SNARC-like effects were related both to ordinal and magnitude properties of stimuli. However, the role of these two properties determining SNARC-like effects was not sufficiently clear. To better explore this topic, we investigated the SNARC-like effect for musical note values, allowing us to

separately study the effects of order and magnitude. According to the results of our three experiments, these properties seem to be processed by two separate mechanisms - called Order-Related Mechanism (ORM) and Magnitude-Related Mechanism (MRM) - that are revealed by different task demands. Indeed, ORM and MRM seem to be preferentially involved in direct and indirect tasks, respectively.

Our evidence and the resulting theoretical explanation are due to the particular nature of note value representation. Further studies should test our model using other kinds of stimuli and adopting different paradigms, in order to extend its validity. In our opinion and from a theoretical point of view, most of these accounts for SNARC-like effects focus only on a part of the story. For instance, the ATOM model (Walsh, 2003; Bueti & Walsh, 2009) focuses just on the role of magnitude, while other accounts, such as the working memory account of van Dijck and Fias (2011), focus just on the ordinal position of the stimuli. Our model tries to consider both aspects, combining in a single account an explanation for the processing of both magnitude and order in SNARC-like effects.

References

- Bächtold, D., Baumüller, M., & Brugger, P. (1998). Stimulus-response compatibility in representational space. *Neuropsychologia*, 36(8), 731-735.
- Badets, A., Boutin, A., & Heuer, H. (2015). Mental representations of magnitude and order: A dissociation by sensorimotor learning. *Acta psychologica*, 157, 164-175.
- Ben-Meir, S., Ganor-Stern, D., & Tzelgov, J. (2012). Numerical and physical magnitudes are mapped into time. *The Quarterly Journal of Experimental Psychology*, 65(12), 2309-2320.
- Bonato, M., Zorzi, M., & Umiltà, C. (2012). When time is space: evidence for a mental time line. *Neuroscience & Biobehavioral Reviews*, 36(10), 2257-2273.
- Bono, D., Grazia, M., Casarotti, M., Priftis, K., Gava, L., Umiltà, C., & Zorzi, M. (2012). Priming the mental time line. *Journal of Experimental Psychology: Human Perception and Performance*, 38(4), 838.
- Bueti, D., & Walsh, V. (2009). The parietal cortex and the representation of time, space, number and other magnitudes. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 364(1525), 1831-1840.
- Casasanto, D., & Boroditsky, L. (2008). Time in the mind: Using space to think about time. *Cognition*, 106, 579–593.

- Cho, Y. S., & Proctor, R. W. (2007). When is an odd number not odd? Influence of task rule on the MARC effect for numeric classification. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 33(5), 832.
- Craik, F. I., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of verbal learning and verbal behavior*, 11(6), 671-684.
- Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*, 122 (3), 371–396.
- Dehaene, S., Dupoux, E., & Mehler, J. (1990). Is numerical comparison digital? Analogical and symbolic effects in two-digit number comparison. *Journal of Experimental Psychology: Human Perception and Performance*, 16(3), 626–641.
- Dodd, M. D., Van der Stigchel, S., Leghari, M. A., Fung, G., & Kingstone, A. (2008). Attentional SNARC: There's something special about numbers (let us count the ways). *Cognition*, 108(3), 810-818.
- Fabbri, M., Cancellieri, J., & Natale, V. (2012). The A Theory of Magnitude (ATOM) model in temporal perception and reproduction tasks. *Acta Psychologica*, 139, 111–123.
- Fabbri, M., Cellini, N., Martoni, M., Tonetti, L., & Natale, V. (2013). The Mechanisms of Space-Time Association: Comparing Motor and Perceptual Contributions in Time Reproduction. *Cognitive science*, 37(7), 1228-1250.
- Fias, W., Brysbaert, M., Geypens, F., & d'Ydewalle (1996). The importance of magnitude information in numerical processing: Evidence from the SNARC effect. *Mathematical Cognition*, 2 (1), 95–110.

- Fias, W., Lauwereyns, J., & Lammertyn, J. (2001). Irrelevant digits affect feature-based attention depending on the overlap of neural circuits. *Cognitive Brain Research*, 12(3), 415-423.
- Fischer, M. H., Castel, A. D., Dodd, M. D., & Pratt, J. (2003). Perceiving numbers causes spatial shifts of attention. *Nature neuroscience*, 6(6), 555-556.
- 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.
- Gevers, W., & Lammertyn, J. (2005). The hunt for SNARC. *Psychology Science*, 47(1), 10-21.
- Gevers, W., Reynvoet, B., & Fias, W. (2003). The mental representation of ordinal sequences is spatially organized. *Cognition*, 87(3), B87–B95.
- Gevers, W., Reynvoet, B., & Fias, W. (2004). The mental representation of ordinal sequences is spatially organized: evidence from days of the week. *Cortex*, 40(1), 171-172.
- 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.
- Ginsburg, V., van Dijck, J. P., Previtali, P., Fias, W., & Gevers, W. (2014). The impact of verbal working memory on number–space associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 40(4), 976.
- Ishihara, M., Keller, P. E., Rossetti, Y., & Prinz, W. (2008). Horizontal spatial representations of time: Evidence for the STEARC effect. *Cortex*, 44, 454–461.

Lakens, D. (2011). High skies and oceans deep: polarity benefits or mental simulation?.

Frontiers in psychology, 2.

Lidji, P., Kolinsky, R., Lochy, A., & Morais, J. (2007). Spatial Associations for Musical Stimuli: A Piano in the Head? *Journal of Experimental Psychology: Human Perception and Performance*, 33 (5), 1189–1207.

Lorch, R. F., & Myers, J. L. (1990). Regression analyses of repeated measures data in cognition research. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 16, 149– 157.

Marshuetz, C., Smith, E. E., Jonides, J., DeGutis, J., & Chenevert, T. L. (2000). Order information in working memory: fMRI evidence for parietal and prefrontal mechanisms. *Journal of Cognitive Neuroscience*, 12(Suppl. 2), 130–144.

Müller, D., & Schwarz, W. (2008). “1–2–3”: Is there a temporal number line? Evidence from a serial comparison task. *Experimental Psychology*, 55, 143–150.

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.

Proctor, R. W., & Cho, Y. S. (2006). Polarity correspondence: A general principle for performance of speeded binary classification tasks. *Psychological bulletin*, 132(3), 416.

Ren, P., Nicholls, M.E.R., Ma, Y.Y., & Chen, L. (2011). Size matters: non-numerical magnitude affects the spatial coding of response. *PLoS ONE* 6 (8), e23553.

- Restle, F. (1970). Speed of adding and comparing numbers. *Journal of Experimental Psychology*, 95, 437–444.
- Rubinsten, O., Dana, S., Lavro, D., & Berger, A. (2013). Processing ordinality and quantity: ERP evidence of separate mechanisms. *Brain and cognition*, 82(2), 201–212.
- Rusconi, E., Kwan, B., Giordano, B. L., Umiltà, C., & Butterworth, B. (2006). Spatial representation of pitch height: The SMARC effect. *Cognition*, 99, 113–129.
- 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.
- Shaki, S., & Petrusic, W. M. (2005). On the mental representation of negative numbers: Context-dependent SNARC effects with comparative judgments. *Psychonomic Bulletin & Review*, 12(5), 931–937.
- Stevens, S. S. (1946). On the theory of scales of measurement. *Science* 7 June 1946: Vol. 103 no. 2684 pp. 677–680
- 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, 501–527.
- Vallesi, A., McIntosh, A.R., & Stuss, D.T. (2011). How time modulates spatial responses. *Cortex* 47, 148–156.
- van Dijck, J. P., & Fias, W. (2011). A working memory account for spatial–numerical associations. *Cognition*, 119(1), 114–119.

- van Galen, M. S., & Reitsma, P. (2008). Developing access to number magnitude: A study of the SNARC effect in 7-to 9-year-olds. *Journal of Experimental Child Psychology*, 101(2), 99-113.
- Van Opstal, F., Fias, W., Peigneux, P., & Verguts, T. (2009). The neural representation of extensively trained ordered sequences. *Neuroimage*, 47(1), 367-375.
- Vogel, S. E., Remark, A., & Ansari, D. (2015). Differential processing of symbolic numerical magnitude and order in first-grade children. *Journal of experimental child psychology*, 129, 26-39.
- Viarouge, A., & de Hevia, M. D. (2013). The role of numerical magnitude and order in the illusory perception of size and brightness. *Frontiers in psychology*, 4.
- Walsh, V. (2003). A theory of magnitude: common cortical metrics of time, space and quantity. *Trends in cognitive sciences*, 7(11), 483-488.
- 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), 1-2.

Note	Name	Beats	Note value hierarchy
Whole note	4

Half note	2
Quarter note	1
Eighth note	1/2
Sixteenth note	1/4	

Figure 1. Note values

Figure 2. Numbers and note values sequence representation

Figure 3. Mean differences of the median RT right hand – RT left hand as a function of note value in Experiment 1. Positive differences indicate faster left-hand responses; negative differences indicate faster right-hand responses. Error bars represent standard errors of the mean.

Figure 4. Stimuli in Experiment 2

Figure 5. Mean differences of the median RT right hand – RT left hand as a function of note value in Experiment 2. Positive differences indicate faster left-hand responses; negative differences indicate faster right-hand responses. Error bars represent standard errors of the mean.

Figure 6. Mean differences of the median RT right target – RT left target as a function of note value in Experiment 3 with 400ms and 750ms delay. Positive differences indicate faster left-hand responses; negative differences indicate faster right-hand responses. Error bars represent standard errors of the mean.

Figure 7. A new model accounting for both order and magnitude properties in the SNARC-like effects

Stimuli	Task	Mechanism	Effect	Examples
NUMBERS	Direct	ORM	Negative-sloped SNARC effect	Dehaene et al. (1990)
	Indirect	MRM	Negative-sloped SNARC effect	Dehaene et al. (1993)
LETTERS	Direct	ORM	Negative-sloped SNARC-like effect	Gevers et al. (2003)
	Indirect	ORM	Absent or weak negative-sloped SNARC-like effect	Dodd et al. (2008); Gevers et al. (2003)
NOTE VALUES	Direct	ORM	Positive-sloped SNARC-like effect	Experiment 1
	Indirect	MRM	Negative-sloped SNARC-like effect	Experiments 2 & 3

Table 1. Overview of SNARC-like effects according to our model.

Footnote: ¹ To confirm this, we interviewed 10 musicians with formal music education and all of them reported the sequence of note values starting from the whole note followed by progressively smaller note values.