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How to cook a SNARC: Number placement in text rapidly changes spatial–numerical associations

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ABSTRACT

Most theoreticians believe that reading habits explain why Western adults associate small numbers with left space and large numbers with right space (the SNARC effect). We challenge this belief by documenting, in both English and Hebrew, that SNARC changes during reading: small and large numbers in our texts appeared near the left or right ends of the lines, positioned either spatially congruent or incongruent with reading habits. In English, the congruent group showed reliable SNARC before and after reading and the incongruent group's SNARC was significantly reduced. In Hebrew the incongruent reading condition even induced a reverse SNARC. These results show that SNARC is a fleeting aspect of number representation that captures multiple spatial associations.

1. Introduction

Numerical cognition is a key aspect of intellectual development and a foundation of human culture. It is therefore of great interest to understand a surprising aspect of numerical cognition: why do most people respond to small numbers (e.g., 1 or 2) more quickly on their left side and to larger numbers (e.g., 8 or 9) more quickly on their right side? This Spatial–Numerical Association of Response Codes, or SNARC, holds across a wide range of tasks (see Wood, Nuerk, Willmes, & Fischer, 2008, for a meta-analysis of over 100 experiments). The most frequently used method for measuring SNARC is the speeded parity task where single digits from 1 to 9 are randomly shown and must be classified as odd or even by pressing left or right keys. Changing the response rule (even number – left key or even number – right key) half-way through the experiment allows researchers to calculate, for each person, the average left-hand reaction time (RT) and the average right-hand RT for each number. Regressing the difference score RT right minus RT left against number magnitude typically leads to a linear regression equation with a negative slope coefficient. In a *t*-test the average slope coefficient of a group of participants is usually reliably smaller than zero.

SNARC is interpreted as reflecting a characteristic of the cognitive representation of numbers, much like the size effect (better performance with small compared to large numbers) and the distance effect (better discrimination between numerically distant compared to similar numbers). However, in contrast to these latter effects, which are robust and hardly affected by training (e.g., Zbrodoff & Logan, 2005), the SNARC can easily be reversed by instruction (Bächtold, Baumüller, & Brugger, 1998) or by contextual manipulations such as number range (Dehaene, Bossini, & Giraux, 1993, Experiment 3), sequential ordering of a memory set (Lindemann, Abolafia, Pratt, & Bekkering, 2008) or an interleaved task with conflicting spatial mapping (Notebaert, Gevers, Verguts, & Fias, 2006; Shaki & Fischer, 2008; Fischer, Shaki, & Cruise, 2009). Despite this flexibility, spatial associations are still considered as a core aspect of number meaning (e.g., De Hevia, Vallar, & Girelli, 2008).

The origin of SNARC has been attributed to a "spill-over" of directional reading habits ever since Dehaene et al. (1993) inferred the presence of a reverse SNARC (small numbers – right side) in Iranian adults who normally read and write from right to left: the longer these Persian-French bi-literates had spent in France, the stronger they presented the Western large-right/small-left SNARC. Note, however, that this argument relied on extrapolating beyond the available data, as no SNARC scores from people living in Iran were available. A subsequent study with Lebanese participants who were still immersed in their Arabic culture (Zebian, 2005) found that naming the side of the larger number in a pair was faster when it was on the left compared to the right side of a display. This seems to support the prediction of a reverse SNARC in right–left reading cultures, but naming latencies were not sensitive to SNARC in a Western control group, thus leaving unclear whether this study actually probed the spatial mapping of numbers. Shaki, Fischer, and Petrusic (2009) were the first to document a clear reverse SNARC with mono-literate right to left reading Palestinians in the typical parity task; but their Israeli participants,

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who also read from right to left, showed no SNARC. The authors concluded that reading habits cannot be the only determinant of SNARC, and that number-specific spatial associations must contribute to SNARC as well: Palestinians read numbers from right to left, consistent with their text reading; whereas Israelis read numbers from left to right, thus counteracting the word-related reading habit and nulling the overall SNARC.

This brief review shows a recent change of opinion in the literature about the origin of SNARC: instead of attributing it to a spillover of directional processing habits from reading, researchers are beginning to see multiple contributions to the SNARC, ranging from short-lived trial-based effects (e.g., Fischer et al., 2009) over intermediate working memory associations (e.g., Bächtold et al., 1998; Lindemann et al., 2008) to longer-term habitual strategies (e.g., Dehaene et al., 1993; Berch, Foley, Hill, & Ryan, 1999).

In the present study we aim to provide further evidence for number-specific spatial–numerical associations that are relatively independent of directional reading habits. Our participants read a few short paragraphs in their native language, with numbers embedded at the start or end positions of each line. By manipulating the spatial positions of small and large numbers in otherwise identical texts, and by holding reading direction constant, we can then measure the contribution of position-specific spatial–numerical associations to SNARC by comparing pre-test and post-test SNARC effect sizes. If the spatial positions of the numbers matter, then SNARC should be reduced after reading compared to before reading, but only when number positions are incongruent with the participants' directional reading habits. In other words, encountering large numbers on the left side within a text is inconsistent with the mapping of large numbers to right space, and should therefore reduce the SNARC. Finding support for this clear-cut prediction would constitute powerful evidence against the influence of normal reading habits on the SNARC because the experimental treatment itself consists of normal reading in both the congruent and incongruent conditions. Thus, to the extent that our position manipulation modulates SNARC it effectively overrules the influence of reading direction on SNARC.

2. Methods

2.1. Participants

Twenty-two Scottish students (16 females; average age 22 years, range 18–57; four left-handers) completed the experiment in English, and another 22 students of the University Center of Samaria (21 females; average age 22 years, range 20–24; 2 left-handers) completed the experiment in Hebrew.

2.2. Apparatus

A Pentium 4 PC was used to present stimuli in black on white on a CRT monitor and responses were recorded on a keyboard, using commercial software.

2.3. Materials

Twenty paragraphs of fictional cooking instructions were written in English. They contained 58–123 words (Courier New, size 12) on 7–12 lines of up to 64 char length. The Hebrew translations contained 55–124 words on 6–12 lines of up to 64 char length. Importantly, each recipe contained eight single numbers: the SNARC-congruent paragraphs[1] had numbers 1–4 distributed on the left side (range: char positions 1–16) and 6–9 on the right side (range: char positions 44–64) and the SNARC-incongruent condition had the reverse positioning. A sample recipe is shown in Appendix A. Each recipe was followed by two questions about quantities of ingredients from both sides of the last display.

2.4. Design and procedure

Participants gave informed consent and completed a parity pre-test with both response rules (even-left, even-right) in counterbalanced order. The numbers 1–9 (except 5) were randomly presented ten times each in the screen center for speeded parity judgments on the keyboard. Reaction time (RT, from number onset to key-press) and accuracy were recorded. Participants were then randomly assigned to either the SNARC-congruent or SNARC-incongruent reading condition; they read 20 recipes in randomized order and answered two comprehension questions verbally after each recipe. Upon completion of reading (after about 20 min) participants completed the parity post-test with both response rules (even-left, even-right) again in counterbalanced order.

3. Results

Parity data were trimmed for errors and outliers, leaving 94% for analysis in the English data set and 98% of data in the Hebrew data set. The spatial mapping of numbers was studied with the usual regression analyses: each participant's SNARC effect was computed by finding, for each number separately in the pre- and post-test, the mean difference in response time (dRT, right-hand minus left-hand RT), and then regressing dRT against number. The slopes of best-fitting individual regressions were assessed with *t*-tests to test our predictions. The slope size expresses the strength of the SNARC, and a negative sign conveys its normal left–right directionality. Our main results are depicted in Fig. 1.

Consider first the results from English readers. Participants who read SNARC-incongruent paragraphs showed a reliable SNARC before reading (-11.2 ms/number, $t(10) = 3.89$, $p = .003$) but no SNARC effect after reading (-1.6 ms/number, $t(10) = 0.95$). This was a statistically reliable change, $t(10) = 2.53$, $p = .03$. Those who read SNARC-congruent paragraphs showed reliable SNARC both before and after reading (-9.2 and -8.1 ms/number, respectively, both $t(10) > 4.01$, $p < .002$), with no reliable change, $p = .74$. These results were confirmed per analysis of variance by a reliable interaction between Congruency and Time of test (pre-test vs. post-test), $F(1, 10) = 5.75$, $p = .04$.

Consider now the results from Hebrew readers. Participants who read SNARC-incongruent paragraphs had no reliable SNARC before reading (-0.90 ms/number, $t(10) = 0.26$, $p = .803$) but a reversed SNARC effect after reading (+8.42 ms/number, $t(10) = 3.09$, $p = .011$). This was a statistically reliable change, $t(10) = 2.72$, $p = .022$. Those who read SNARC-congruent paragraphs showed no reliable SNARC either before or after reading (3.45 and 0.69 ms/number, respectively, both $t(10) < 2.07$, $p > .06$), and thus no reliable change, $p = .43$. These results were again confirmed by a significant interaction between Congruency and Time of test, $F(1, 10) = 4.76$, $p = .05$.

4. Discussion

This study explored possible origins of the systematic link between numbers and space known as SNARC. We measured SNARC before and after adults read a set of texts with numbers placed either congruently or incongruently with respect to the predominant Western spatial–numerical association. This allowed us to contrast effects of long-standing reading habits and short-term

[1] We use this culture-centric label to convey the fact that SNARC is not normally found in Hebrew readers.