Spatial Components in the Mental Representations of Numeric and Symbolic Magnitudes: Extending the SNARC Effect

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Abstract

With English-language readers as participants, in an experiment requiring pair-wise comparative judgments of numerical magnitude, typical SNARC effects were obtained. With comparisons of the remembered size of animals, SNARC depended on the direction of the instruction. In both cases the continua are organized from left to right corresponding to the direction of reading. On the other hand, with Hebrew- and Arabic-language readers, exactly the same configuration of findings was obtained except that the spatial direction in each domain was reversed; the mental continua are organized from right to left corresponding again to the direction of reading.

Keywords: mental number line; SNARC effect; spatial representation; direction of reading; symbolic comparisons; number processing.

Introduction

There is substantial evidence in support of the claim that psychologically, numbers are represented on a mental number line, with both spatial and extensive components. The most striking, indeed landmark, demonstration of a spatial component in the mental representation of the number line was obtained by Dehaene, Bossini, and Giraux (1993) in the context of a parity judgment task. They found that responses with the left hand were faster than those with the right hand when the numbers were relatively small (e.g., 1 and 2). On the other hand, when the numbers were relatively large (e.g., 8 and 9), responses were faster with the right hand than with the left hand. The authors argued than small numbers are represented on the left end of the number line and become positively associated with the leftward responses. Similarly, because relatively large numbers are located on the right of the number line they tend to preferentially elicit rightward responses. Dehaene et al. labeled their effect the Spatial Numerical Association of Response Codes (SNARC), capturing the association of the spatial component of the mental representation of numbers and the hand of the response.

The Present Experiments: Overview

In one set of experiments, we employ English-language readers (i.e., people who read from left to right). In the next, we employ Israeli and Palestinian participants who read from right to left, with a view toward determining if the form of SNARC effect is language - direction of reading - dependent. In each case, in one set of conditions, we require comparisons of numerical magnitude, and in another, we require comparisons of the remembered sizes of animals, with a view toward determining whether SNARC effects also occur with symbolic, non-numerical continua.

Experiment 1: Robust SNARC Effects in Numerical Comparisons – English Readers

A further purpose of this experiment was to determine how the instructions are presented might influence the SNARC effect. In particular, using a within-participants design, in one condition the instructions randomly varied from trial to trial (randomized) and in the other condition they remained constant over a block of trials (blocked). As well, an additional purpose was to determine if the SNARC effect in any way depended on the direction of the comparison. For comparisons involving pairs of positive and negative numbers, Shaki and Petrusic (2005) had previously found approximately comparable SNARC effects with the two possible forms of the instructions.

Method

Twelve Carleton university students participated in a single 45-min. session for course credit. They indicated which was either the larger or the smaller of three relatively small digit pairs (0-1, 1-2, 2-3) and three relatively large digit pairs (6-7, 7-8, 8-9). Each pair in the design was presented in each of the two possible left-right position orders, resulting in 12 digit pairs. The two forms of the comparative instructions occurred equally often and were constant over a block in one condition (blocked) and inter-mixed, occurring equally often and in random order in a second condition (randomized). This factorial combination of the 12 stimulus pairs by two instructions by two conditions was replicated ten times.

Results

As the plots in Figure 1 show, RTs are faster with left hand responses than with right hand responses for the small number pairs and faster with the right hand than with the left hand for the relatively large number pairs. The interaction involving stimulus pair and hand, which defines the SNARC effect with these paired comparisons is statistically reliable ($F(5, 55) = 7.69$). Importantly, as is also evident in the plots in Figure 1, the obtained SNARC effects did not depend on the direction of the instruction nor whether the instructions were blocked or randomized.

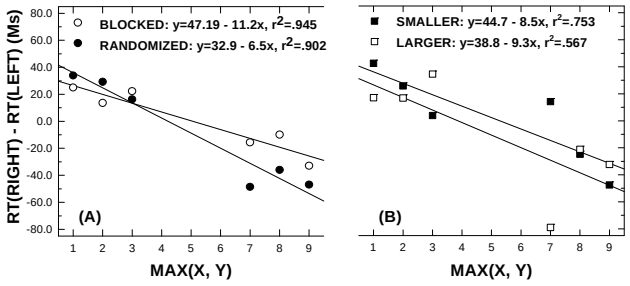

Figure 1. Mean RTs with the left hand subtracted from mean RTs with right hand (SNARC index) as a function of stimulus pair for the blocked and randomized conditions in Panel A and for each instruction in Panel B as a function of stimulus pair in Experiment 1.

Repeated measures regression analyses, as outlined in Lorch and Myers (1990), were conducted separately with each instruction and with each condition (blocked vs. randomized). In each case, standardized beta regression coefficients were obtained for each participant with the SNARC index (RT(Right)-RT(Left)) as the dependent variable and pair magnitude as the predictor. The hypothesis (two-tailed) that the mean of these weights differed from zero was then tested using the *t*-distribution. With both instructions and each instruction condition, the mean of the standardized regression coefficients were significantly less than zero affirming the clear and robust occurrence of SNARC effects.

Experiment 2: Symbolic Comparisons – English Readers

SNARC effects have been obtained with continua other than numbers. Indeed, recently SNARC effects have also been obtained with well-defined, highly over-learned linear orderings. Most notably, Gevers, Reynvoet, and Fias (2003) have shown that when participants are required to categorize a month of the year as coming before or after July, RTs are faster with the leftward than rightward responses with the earlier months in the year and conversely for the months later in the year. Similar effects were obtained in categorical judgements of whether a letter of the alphabet came before or after the letter "M". Each of these experiments nicely shows that mental representations with spatial components are not unique to numbers. However, it remains to be determined if stimuli varying on other varieties of continua might also have spatial components in their mental representations. Accordingly we seek to determine if SNARC effects, paralleling those with well-defined, highly over-learned, linear orderings might be obtained with comparisons of the remembered size of animals (i.e., symbolic comparisons).

Method

Twenty-four Carleton University students participated for course credit in a single 45-min. session. On each trial they determined which was the larger of three pairs of relatively small animals (ant-bee, bee-mouse, mouse-rat) and three pairs of relatively large animals (dog-pig, pig-cow, cow-elephant) on half of the trials and which was the smaller on the other half. Each pair in the design was presented in each of the two possible left-right position orders, resulting in 12 animal names pairs. The two forms of the comparative instructions ("Smaller" "Larger") occurred equally often and were randomly changed from trial to trial. This factorial combination (the 12 stimulus pairs by two instructions) was replicated six times, preceded by a single replication of practice trials.

Results

In contrast to SNARC effects with number comparisons, the interaction between stimulus pair and hand of response was not statistically reliable ($F(5, 115) = 2.31$). Rather, the three-way interaction, involving stimulus pair, hand of response, and instruction was reliable ($F(5, 115) = 4.11$). Indeed, as is evident in the plots in Figure 2, SNARC-like effects, paralleling those evident with

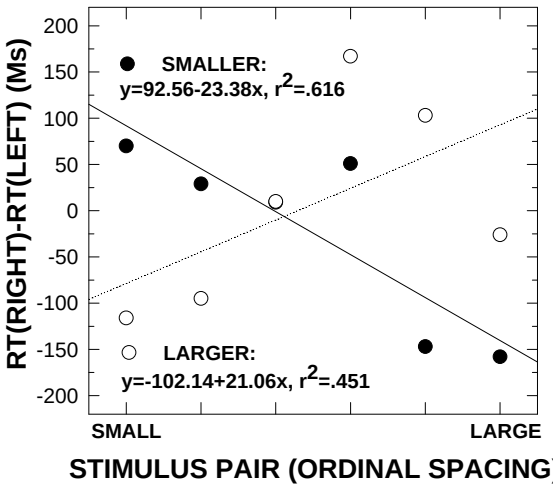

Figure 2. Mean RTs with the left hand subtracted from mean RTs with right hand (SNARC index) as a function of stimulus pair with each instruction for the animal-size symbolic comparisons for the English-language (left-to-right) readers in Experiment 2.

numbers, are obtained with the instruction "Smaller". However, reverse SNARC-like effects occur with the instruction "Larger". With the instruction "Smaller", the small animals are represented on the left of the continuum and the large animals on the right. On the other hand, with the instruction "Larger", the large animals are represented on the left and animal size decreases rightward on the dimension. In other words, the instruction serves as a leftward reference point. This instruction-dependent ordering is left to right corresponding to the direction of reading.

The mean of the standardized regression coefficients (M = -0.47, SD = 0.39) differed reliably from zero ($t(23) = -5.85$, $p < 0.0001$), thereby establishing a spatial component with the mental representation of the remembered size of animals with the instruction "Smaller". Indeed, for 21 of the 24 participants, the slope of the regression line was *negative*. On the other hand, with the instruction "Larger", the slope was *positive* for 15 of the 24 participants, and the mean of the standardized regression coefficients (M = 0,14, SD = 0.38) was marginally significantly different from zero ($t(23) = 1.75$, $p > 0.093$, two-tailed).

Language-Dependent SNARC Effects:

Dehaene et al. (Experiment 7) tried to establish that the direction of the mental number line depends on the direction of reading by obtaining SNARC effects with Iranians who had lived in France as immigrants for varying amounts of time. They showed that Iranians who had only recently arrived in France, and thus were familiar with only right-to-left reading, showed a highly attenuated SNARC effect (which became less attenuated with the more time spent in France).

Method

Seven Israelis and 5 Palestinians (19- to 26-years old) participated in two 30-min. sessions. All participants read Hebrew or/and Arabic only, and reported minimal exposure to any left-to-right language. The same digit pairs as in Experiment 1 (0-1, 1-2, 2-3, 6-7, 7-8, 8-9) and the same animal pairs (ant-bee, bee-mouse, mouse-rat, dog-pig, pig-cow, cow-elephant) as in Experiment 2 were used. The two forms of the comparative instructions occurred equally often and were presented randomly from trial to trial. This factorial combination (the 12 stimulus pairs by two instructions by two conditions) was replicated six times, preceded by a single replication of practice trials. The order of the two numbers- and animals-sessions was counterbalanced.

Results

For the numerical comparisons, an ANOVA with stimulus pair, instruction, and hand as within-participant factors revealed a significant linear-by-linear component of the Hand by Pair interaction ($F(1, 11) = 10.27$), affirming a reliable SNARC effect. As is evident from the plots in Figure 3, rightward responses were faster than leftward responses with relatively small numbers and conversely with relatively large numbers. Thus, the mental number line extends leftward for these Israeli/Arab participants, with small numbers at the right (i.e., a reverse SNARC effect). Moreover, this number line, as with English-language readers, is not dependent on instructions. As well, the mean of the standardized regression coefficients is positive and significantly different from zero with both instructions, confirming reliable reverse SNARC effects for these right-to-left readers.

For the symbolic comparisons, an ANOVA with the same within-participant factors as the numerical comparisons revealed a significant linear-by-linear-by-linear component of the Pair by Hand by Instruction three-way interaction ($F(1, 11) = 13.19$). As is clear from the plots in Figure 4, the animal mental size line is also instruction dependent for these Israeli/Arab participants. Moreover, the direction of the animal mental size line is the opposite of that obtained with English-language participants. The mean standardized regression coefficient for the instruction "Smaller" is 0.254 which is significantly different from zero and for the instruction "Larger" the mean coefficient is -0.300 which also significantly differs from zero. Thus, these regression analyses converge perfectly with the outcomes of the corresponding ANOVA, confirming an instruction-dependent SNARC effect that is the opposite of that obtained with our Canadian participants.

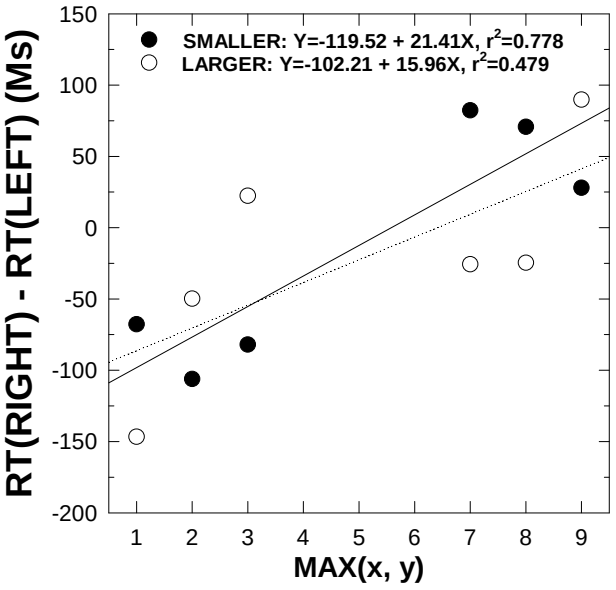

Figure 3. Mean RTs with the left hand subtracted from mean RTs with right hand (SNARC index) as a function of stimulus pair with each instruction for the numerical magnitude comparisons of Experiment 3.

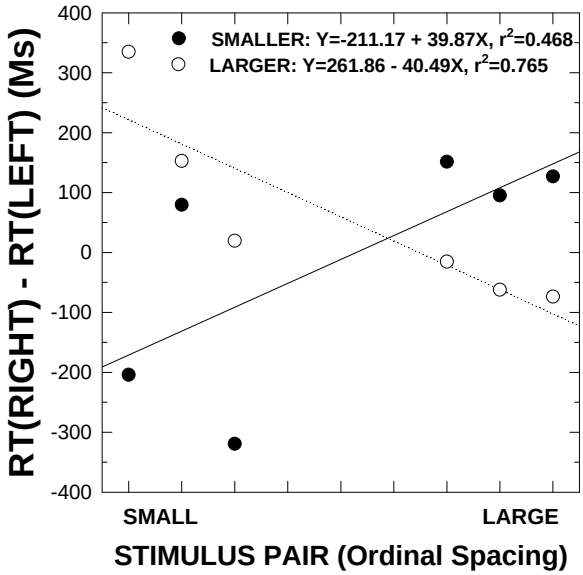

Figure 4. Mean RTs with the left hand subtracted from mean RTs with right hand (SNARC index) as a function of stimulus pair with each instruction for the animal size, symbolic comparisons for the Hebrew- and Arabic-language (right-to-left) readers of Experiment 3.

Summary and Conclusions

SNARC effects in number comparisons for both English-language and Hebrew-/Arabic-language readers are not dependent on the direction of the comparison in contrast to SNARC effects arising from symbolic comparisons of remembered animal size. SNARC effects for both number and symbolic comparisons are language dependent. The mental line for both numbers and for remembered size extends rightward from the reference point activated by the required instruction for English-language participants and leftward for Hebrew-/Arabic-language participants. Our current work is directed at determining how we might make SNARC effects with symbolic comparisons instruction independent (i.e., more like numbers).

Acknowledgements

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