VERTICAL SNARC WITH POSITIVE AND NEGATIVE NUMBERS

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Abstract

Participants compared the magnitudes of pairs of vertically presented digits, viewed as temperatures, ranging from (-7,-6) through to (6,7). On half the trials the larger digit was selected and the smaller on the other half. Taken together, the findings show: 1) SNARC occurs in the vertical dimension for both positive and negative numbers; 2) the direction of the SNARC effect is not fixed but depends on the instruction; 3) the mental number line extends past zero to include negative numbers, and 4) SNARC was more robust when a thermometer was included. As well, semantic congruity effects were obtained: selection of the smaller of a pair of negative digits was faster than with the instruction "larger" and selection of the larger of a pair of positive digits was faster than with the instruction "smaller". These findings did not depend on whether the positive and negative pairs were intermixed or whether they were presented in separate blocks.

The mental number line serves as the underlying mental representation of digits. On this view, a digit is represented as point on this line corresponding to its magnitude, i.e., an analogue representation. In addition to their representations as locations on an underlying analogue continuum, digits have spatial components in their mental representations. In particular, relatively small digits (e.g. 1, 2) are viewed as points on the left end of the mental number line and relatively large digits (e.g., 8, 9) are viewed as located on the right side of the mental number line. The SNARC effect (Spatial Numerical Association of Response Codes) provides the basis for inferring this representation of digits. For example in a numerical magnitude comparison task, leftward responses are faster than rightward responses with relatively small digits. However, when the digits are relatively large, rightward responses are faster than leftward responses. Thus, SNARC effects with the typically horizontally presented digits are clear and well established. However, SNARC effects remain to be investigated with numbers presented in the vertical dimension. Accordingly, in the present experiment pairs of positive and pairs of negative digits were presented, aligned vertically in each pair. In one condition, the positive and negative pairs were presented in separate blocks and in another they were intermixed.

Shaki and Petrusic (2005) found a SNARC effect for negative digits when participants were required to choose the "smaller" or "larger" of a pair. They found a SNARC effect that corresponds to spatial arrangement of the mental number line when negative and positive digits were mixed together in a block, but a SNARC effect consistent with the absolute magnitude of the digit, when negative and positive digits were presented in separate blocks. Some studies have shown that the SNARC effect can occur vertically as well as horizontally (Ito & Hatta, 2004). However, it is unclear if it can occur vertically for negative digits. This experiment explores this possibility in the context of temperature. It is possible that unlike the results of Shaki and Petrusic (2005), the results of the present experiment will show that, even when negative numbers are presented exclusively within a block they may still elicit a SNARC effect consistent with the spatial arrangement of the mental number line. The reason for this is that a context of temperature may elicit an orientation of negative numbers that would not seem to be important to participants otherwise.

Method

Participants. Thirty-three Carleton University students participated in a single session lasting approximately 45 minutes, in exchange for course credit.

Stimuli and Design. The digits 1-9, excluding 5, were used to construct stimulus pairs that were categorized as relatively small positive (1, 2), (2, 3), (3, 4); large positive (6, 7), (7, 8), (8, 9. These pairs were then coded as 1, 2, 3, 4, 5, 6, respectively, defining the positive set of temperatures. The small negative pairs were defined by the pairs (-9, -8), (-8, -7), and (-7, -6), and (-4, -3), (-3, -2), (-2, -1) as large negative . The negative temperature pairs were then coded as (-6, -5, -4, -3, -2, -1), respectively and these pairs defined the negative set of temperatures.

The temperature pairs were presented in the vertical plane. One number was presented up from the centre point and one was presented down from the centre point in "Arial Black" font, size 24. There was no obvious centre point indicated on the thermometer and no indication of whether the scale was Fahrenheit or Celsius. Written instructions were not used. Instead participants were expected to determine the instruction based on the colour of the stimuli. Blue pairs indicated that participants were required to choose the colder temperature and red pairs indicated that participants were required to choose the warmer temperature of the pair. For the second half of the experiment a picture of a thermometer, created in PowerPoint, appeared to the left of the digit pair and remained on the screen for each trial. The twelve stimulus pairs by two orders by two instructions by two conditions (blocked, intermixed), by two thermometer conditions (present or not) were presented six times.

Procedure. Participants used a standard computer keyboard and were instructed to press the upper "Y" key to choose the upper digit on the screen or to press the lower "B" key to choose the lower digit. The keys were covered with silver tape. The monitor used was a 19-inch (48.3 cm) NEC monitor. The experiment was programmed and executed using SuperLab 4 software on a PC with Pentium IV microprocessor.

For the second half of the experiment, participants repeated the first half, except that on all trials, a picture of a thermometer appeared on the screen, vertically beside the temperatures. We reasoned that as in the study of Bächtold, Baumüller, and Brugger (1998), where the direction of SNARC depended on whether participants imagined a clock face or a ruler, adding a contextual feature such as a thermometer might strengthen the influence of mental number line such that the SNARC effect is intensified or somehow altered. Accordingly, in one phase of the experiment, the number pairs were accompanied by a graphic of a thermometer.

Results

Prior to analysis, data were eliminated from three participants because their response accuracy was below 90%. Therefore, the data used in the analysis were from 33 participants.

Response time. Medians for each cell, from each participant were averaged. Cells that exceeded the averaged median plus three standard deviations were replaced with the averaged median plus three standard deviations for that condition. An ANOVA was then conducted with mean correct RTs as the dependent variable and the six magnitude pairs, two polarities of the number pair (negative, positive), the two instructions (colder, warmer), two levels of thermometer picture (present or not) and the direction of response as the within participant factors. Significance levels for analysis of variance (ANOVA) were based on the Huyn-Feldt adjusted degrees of freedom, although the degrees of freedom and error mean squares provided are those specified by the design. The level of significance used for all tests was $\alpha = 0.05$.

The ANOVA, revealed various main effects and interactions. The ANOVA showed that participants responded faster when the instruction was "warmer" (M = 949.124 ms), compared to "colder" (M = 978.899 ms), F (1, 32) = 8.822, MSE = 159174.064. Participants also responded faster to positive pairs (M = 922.521 ms), compared to negative pairs, (M = 1005.502 ms), F (1,

32) = 108.009, *MSE* = 100983.243. Additionally, participants were faster in the blocked condition (*M* = 811.424 ms) compared to the mixed condition (*M* = 1116.599 ms), *F* (1, 32) = 274.484, *MSE* = 537445.928. Interestingly, participants were significantly faster to respond when there was a picture of a thermometer on the screen (*M* = 919.491 ms) compared to when there wasn't, (*M* = 1008.532 ms), *F* (1, 32) = 53.284, *MSE* = 235684.582.

A *semantic congruity effect* was evident from the significant interaction of instruction and polarity, *F* (1, 32) = 75.315, *MSE* = 154154.466. As seen in Figure 1, generally, for both the blocked and mixed conditions, when the pairs were negative, responses were faster for the instruction "colder" compared to "warmer", but when the pairs were positive, responses were faster for the instruction "warmer" compared to "colder

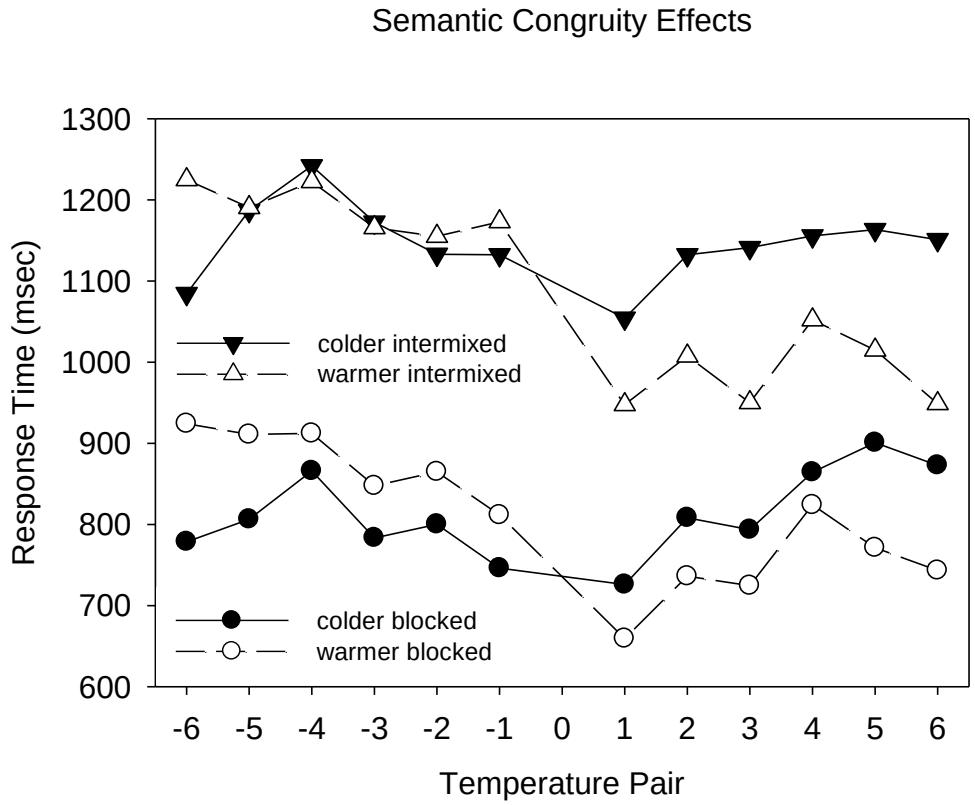

Figure 1. Mean response times collapsed across thermometer presentation, for each instruction and condition, as a function of each stimulus pair. The x-axis represents the order of temperatures with -6 representing the most negative pair (-9, -8) progressing to 6 representing the most positive (9, 8).

SNARC effects. There was a significant interaction between instruction, polarity and response button (top, bottom), *F* (1, 32) = 12.651, *MSE* = 82938.179 thus indicating an instruction dependent SNARC effect, although only when data were collapsed across magnitude, mix condition and thermometer condition. When the instruction was "colder", upward responses were faster than downward responses when the pairs were negative but downward responses were faster than upward responses when the pairs were positive. When the instruction was "warmer", the opposite pattern occurred. When the pairs were negative, downward responses were faster than upward responses, but when the pairs were positive, upward responses were faster than downward responses. Additionally, there was a significant three-way interaction for instruction, magnitude and response button, *F* (5, 160) = 5.008, *MSE* = 33911.521 also confirming the *instruction-dependent SNARC effect*. When the instruction was "colder", upward

response times were faster than downward responses, for numerically smaller pairs, but for numerically larger pairs, downward responses were faster than upward responses. However, when the instruction was "warmer" this pattern reversed. Downward responses were faster than upward responses when the pairs were numerically smaller, but upward responses gradually became faster than downward responses as the pairs increased in numerical value; i.e., an instruction dependent SNARC effect..

Full range regression analyses

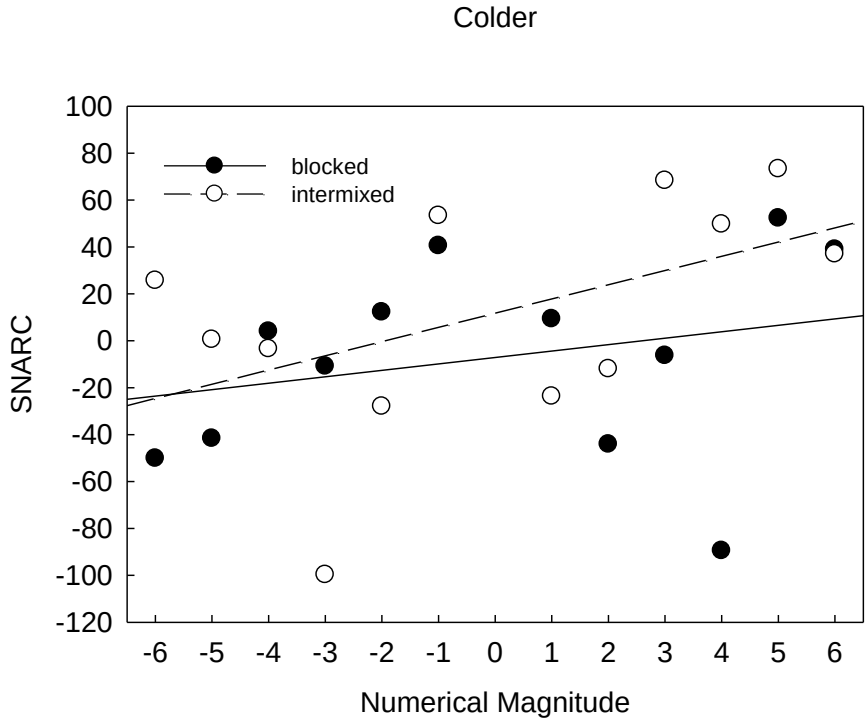

Figure 2. Mean downward response times subtracted from median upward response times as a function of each stimulus pair, for the instruction "colder", with a thermometer present, in the blocked and the intermixed conditions.

After combining the data over order, the SNARC index (Mean Upward RT – Mean Downward RT) was regressed across the entire range of temperatures, separately with each instruction (colder, warmer). As is evident in plots provided in Figure 2 for the instruction "colder", SNARC was significant in the intermixed condition, M =.131, SD = .356, t (32) = 2.102, R^2 = .246 but not in the blocked condition M = .061, SD = .323, t (32) = 1.077, R^2 = .070. Although not shown, very comparable regression plots were obtained when the thermometer was not present.

As is evident in the plots provided in Figure 3, when the instruction was "warmer" the direction of SNARC reversed such that upward responses were faster than downward for the higher temperature pairs but downward responses were faster than upward responses for relatively lower temperature pairs; i.e. an instruction dependent SNARC effect and this was clearly evident when the thermometer was present and when it was not.

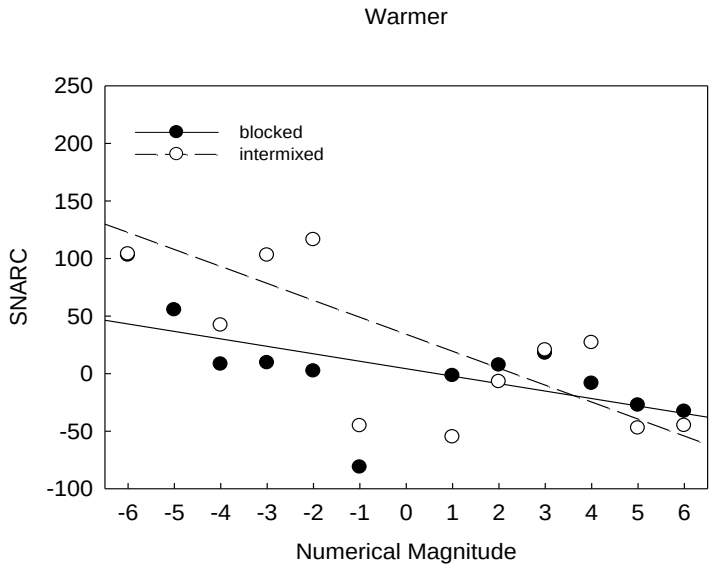

Figure 3. Mean downward response time subtracted from median upward response times as a function of each stimulus pair, for the instruction "warmer", without a thermometer present, in the blocked and the intermixed conditions.

The regression analysis across both negative and positive numbers, when the thermometer was not present showed significant SNARC in the intermixed condition, M = -.189, SD = .351, t (32) = -3.085, R^2 = .548, but not in the blocked condition, M = -.121, SD = .395, t (32) = -1.764, p =.09, R^2 = .069. As can be seen in Figure 3, generally, downward responses were faster than upward responses for the numerically smallest pairs but upward responses were faster than downward responses for the relatively larger pairs. Taken together, these findings are clear that the processing the numbers was not in terms of their absolute value but their value on the whole number line.

Error Rates The overall error rate was low at 3.97 %. As expected there were fewer errors in the blocked condition (3.05 %) compared to the intermixed condition (4.89 %). The correlation between response time and mean error rate was r = .370, p <. 001, based on the 96 cells representing, magnitude, instruction, polarity, condition, and thermometer. Lower accuracy was associated with longer response times, so there was no speed-accuracy trade-off.

Discussion

This experiment produced several important findings including: 1) SNARC occurs in the vertical dimension, not only for positive digits but negative as well; 2) The direction of SNARC is not fixed but depends on instruction; 3) The mental number line extends past zero to include negative numbers; 4) SNARC was more robust when a thermometer was included.

Previously, SNARC effects in the vertical dimension were found with positive numbers that were consistent with a mental number line ordered from bottom to top, as small numbers were responded to faster in a downward direction and larger numbers were responded to faster in an upward direction as shown by Ito and Hatta (2004). The present findings nicely extend the number line in the vertical dimension to include the negative numbers as well, with the vertical number line extending upward from the negative numbers..

When the instruction was "warmer" the highest temperature pairs were responded to faster in an upward direction compared to downward and the lowest temperature pairs were responded to

faster in a downward direction compared to upward. However, when the instruction was "colder" the reverse occurred; the lower temperature pairs were now responded to faster in an upward direction compared to downward but higher temperature pairs were responded to faster in a downward direction compared to upward. The present results do in fact support a hypothesis of a full mental number line as it seems clear that as pairs became more negative, participants judged them as smaller.

Additionally, the obtained a semantic congruity effect was entirely consistent with the full mental number line hypothesis. If participants processed numbers according to absolute value the semantic congruity effect would look the same for both positive and negative numbers. Instead when the instruction was "colder", responses for negative numbers were faster than for positive numbers, but when the instruction was "warmer", responses for positive numbers were faster than for smaller numbers. These results are consistent with a hypothesis that the mental number line is flexible in that can change dimensions from horizontal to vertical and that the direction is reversible depending on context. Another way to interpret the results from all of the experiments taken together is that participants always order "the least" on the left or on the bottom and "the most" to the right or on top.

Acknowledgements

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