MODELLING SNARC BY USING POLARITY CODES TO ADJUST DRIFT RATES

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Abstract

Forty participants compared pairs of adjacent positive and negative numbers which were associated with temperature values by using the comparative instructions "Colder?" and "Warmer?". In this experiment, the stimulus pairs were presented horizontally and responses were made using left and right manual key presses. The presence of a significant four-way interaction between absolute digit magnitude, digit sign, the form of the comparative instruction, and the side of response provided a very challenging set of constraints for RT modelling. Nonetheless, a good fit to these data could be obtained within a random walk model framework by using adjustments to the drift rates based on both correspondences between polarity codes (Proctor & Cho, 2006) and the nature of the semantic congruency of the pairs with the comparative instructions (Leth-Steensen & Marley, 2000).

A number of response time (RT) phenomenon invariably occur when people make comparisons involving pairs of numerical magnitudes. For instance, comparison RT is known to be inversely related to the numerical *distance* between the digits, such that comparing the pair (1, 9) is faster than comparing the pair (1, 2). Two other very robust effects obtained in number comparison studies (e.g., Banks, Fujii, & Kayra-Stuart, 1976) are the *semantic congruity effect* (SCE; which refers to the fact that numerically smaller pairs are responded to more quickly when choosing the smaller number in the pair and numerically larger pairs are responded to faster when choosing the larger number in the pair), and the *min effect* whereby RTs become slower as the numbers being compared increase in size even with the ordinal distance held constant (which has been taken to indicate that the subjective distance between adjacent digits decreases with digit size as might be prescribed by Weber's Law). Finally, the *SNARC* (Spatial-Numerical Association of Response Codes) effect also extends to paired comparisons of numbers (Shaki & Petrusic, 2005). This effect concerns the manner in which the difference in RT between and left and right responses is moderated by number magnitude (i.e., smaller numbers are responded to faster on the left and larger numbers on the right) and has been hypothesized to be reflective of the existence of a mental number line.

With respect to negative numbers, the cognitive literature on the processing of them is quite sparse. However, there are a few studies which have examined the SNARC effect for negative numbers. Such studies are helpful for understanding how negative numbers are processed. A key question of interest is whether the magnitude of negative values is processed according to their absolute value (i.e., polarity is ignored) or according to their numerical value, such that, the more negative a number gets, the smaller in magnitude it becomes (namely, whether the mental number line extends past zero).

Shaki and Petrusic (2005) recently investigated the SNARC effect for negative numbers using paired comparisons of positive and negative digits with pairs constructed by pairing each digit with its adjacent digit. Therefore, much like single digits, the pairs ranged from small (e.g., -9, -8) to large (e.g., 8, 9). On each trial, participants were required to choose either the larger or the smaller number according to their number-line-based numerical magnitude. Their participants completed both a blocked condition containing only positive-number pairs or negative-number pairs, as well as a mixed condition in which trials randomly alternated between positive and negative pairs within a single block. In the blocked condition, a SNARC effect was found for types of pairs that was dependent on the absolute value of the numbers (i.e., its direction was reversed for the negative and positive pairs). Hence, it was as if polarity was ignored and the left-right direction of response was either facilitated or interfered with by the absolute magnitude of the pairs. However, when negative pairs were intermixed with positive pairs, the direction of the SNARC effect for negative pairs was now dependent on the numerical number-line-based values in that for negative pairs left responses generally became faster compared to right ones as the pairs became more negative, but right responses generally became faster as the pairs became more positive.

In contrast, Shaki and Petrusic (2005) also found an SCE that extended across the whole range of positive and negative values in both their blocked and mixed pair conditions. Correspondingly, in Shaki and Petrusic (2005), the negative pairs were invariably responded to faster with the “Smaller” instruction and the positive pairs with the “Larger” instruction. Hence, this complete dissociation of the nature of the SCE and the SNARC effects in their blocked condition provides a rather puzzling paradox, namely, that *within the same trial* subjective smallness was associated with numerically smaller (i.e., negative) values in regards to the SCE but with absolutely smaller (i.e., 1s and 2s regardless of sign) in regards to the SNARC effect.

The current study essentially represents a replication of Shaki and Petrusic (2005), except for the fact that the positive and negative number pairs have explicitly been associated here with positive and negative temperature values by using “Colder” and “Warmer” as the relevant comparative instructions. For this work, the concern will mainly be with the results for the blocked positive- and negative-pair condition.

Method

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

Stimuli and Apparatus. Stimulus pairs were constructed from digits that can be categorized in terms of a relatively small positive set (1, 2), (2, 3), (3, 4); a large positive set (6, 7), (7, 8), (8, 9); a small absolute-valued negative set (-4, -3), (-3, -2), (-2, -1); and large absolute-valued negative set (-9, -8) (-8, -7), (-7, -6). Each pair was presented randomly in each of the two possible left-right position orders an equal amount of times. Pairs were presented in a condition in which all trials within a block involved either only positive or only negative pairs (i.e., a blocked condition) as well as in a condition in which negative and positive pairs alternated randomly within a block (i.e., a mixed condition). The two “Warmer” and “Colder” instructions were always held constant within a block for each of these conditions. The 12 stimulus pairs by 2 orders by 2 instructions by 2 conditions were each presented eight times. The order of conditions and blocked instructions were counterbalanced so that eight possible orderings of instructions and conditions were possible.

On each trial, one member of the comparison pair appeared to the left of centre and the other appeared to the right of centre in the approximate upper third of the screen. The comparative instruction word appeared under the stimuli in the approximate centre of the screen. The instructions and stimuli were printed in black (Arial font, size 36) on a white background on a 17 inch (43 cm) View Sonic monitor. The experiment was programmed and executed using SuperLab 2 software on a PC with Pentium III microprocessor.

Procedure. Participants were tested individually seated at a desk, approximately 90 cm from the computer monitor. Participants were told that the presentation of the word “Warmer” or “Colder” would serve as a warning for the next trial and indicated whether or not they would be required to choose the warmer or the colder of the pair of temperatures which then appeared 500 ms later. Participants indicated their decision by pressing the “A” key with the index finger of the left hand to choose the temperature on the left or the “L” key with the index finger of the right hand to choose the temperature on the right. The instruction and temperatures remained on the screen until participants indicated their decision. The next trial followed 500 ms later. Participants were encouraged to respond accurately but also quickly.

Results

The data were the correct RTs obtained from 40 participants in, as mentioned earlier, the blocked pair-polarity conditions only. For each cell of the design, correct RT medians across trials for each participant were computed (where any median values that exceeded the cell mean for all participants plus 3 SDs were replaced with the mean plus 3 SDS for that cell). Finally, each participant’s median correct RTs for the three pairs in each of the large-negative, small-negative, small-positive, and large-positive pair sets were averaged together.

The key result of interest was the presence of a significant four-way Absolute Digit Magnitude × Digit Polarity × Instruction Type × Response Side interaction, $F(1,39) = 12.636$, $p < .01$. One view of this four-way interaction is shown in Figure 1 which displays the right minus left mean correct RT differences at each level of the other three factors. Interestingly, a SNARC effect that is dependent on the absolute magnitude of the digit pairs (i.e., faster right-hand responses for absolutely larger pairs) is clearly evident for negative pairs with the colder instruction and positive pairs with the warmer instruction (in concurrence with the results obtained by Shaki & Petrusic, 2005, for their negative and positive blocked-condition pairs in general) but not for comparisons involving either negative pairs with the warmer instruction or positive pairs with the colder instruction (which was not found by Shaki & Petrusic, 2005). Another view of this four-way interaction is provided in Figure 2 which shows averaged median RTs for each of the left and right response sides separately. Importantly, a clear SCE (i.e., faster “Colder” responses for negative pairs and faster “Warmer” responses for positive pairs) is evident in this figure that is dependent on the full negative and positive number line (as in Shaki & Petrusic, 2005). An additional notable aspect of this effect, though, is that its size is moderated across absolute small and large pair sizes by the left and right side of response, such that the SCE is enhanced for smaller stimulus pairs in comparison to larger ones for left-handed responses but enhanced for larger stimulus pairs in comparison to smaller ones for right-handed responses.

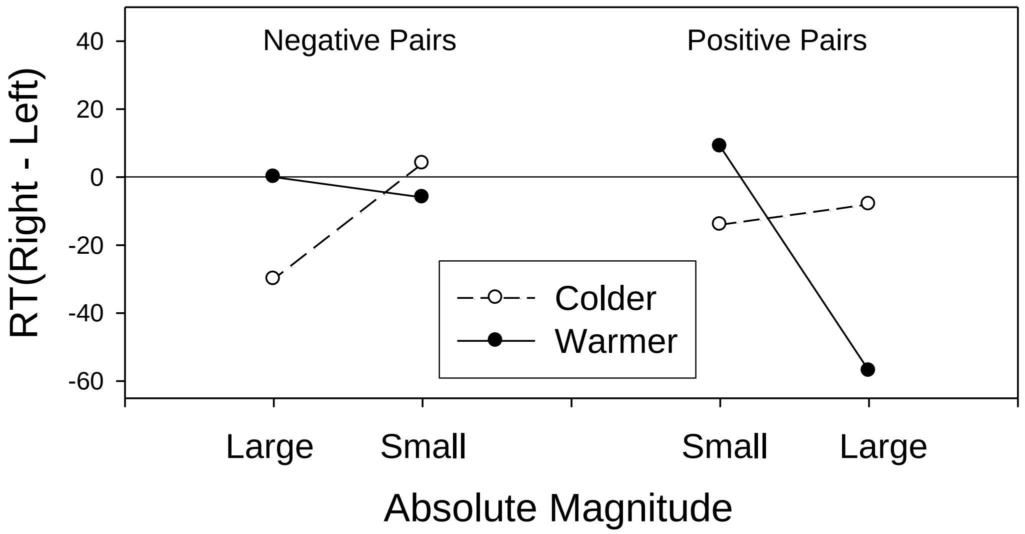

Figure 1. Right- minus left-side correct RT differences as a function of pair polarity, absolute pair size, and the form of the comparative instruction.

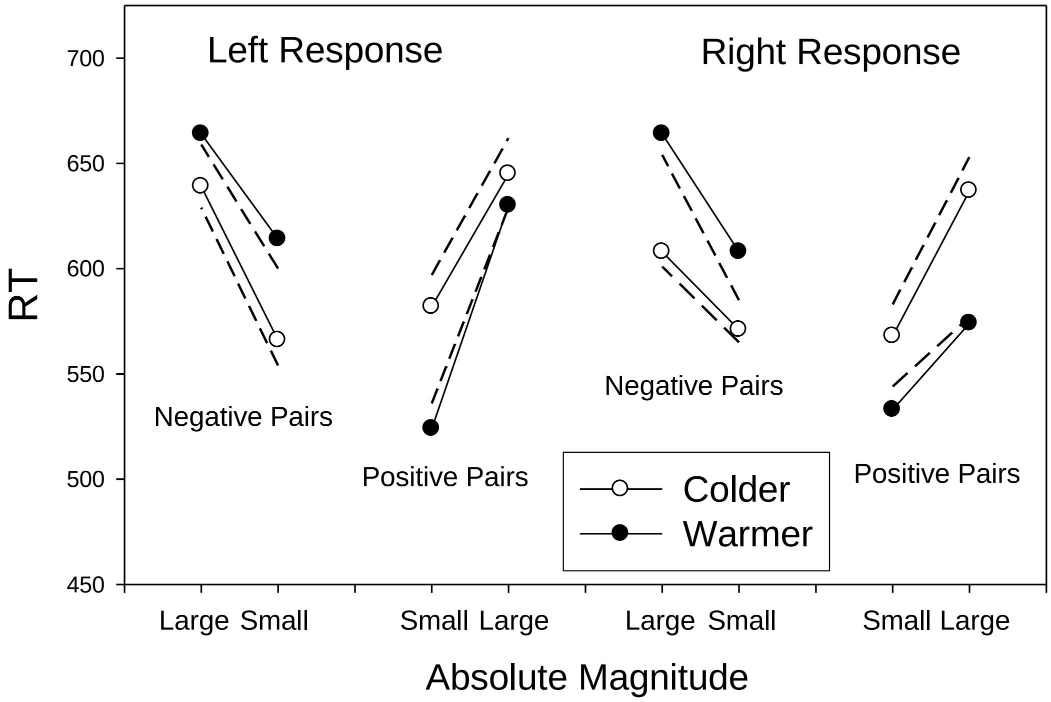

Figure 2. Mean of the correct RT medians as a function of response side, pair polarity, absolute pair size, and the form of the comparative instruction. Dashed lines represent simulation results.

Discussion

The results of the present experiment provide some rather interesting constraints for theorizing. Not only was responding generally faster when the direction of the instruction was congruent with the polarity of the digit pairs but a SNARC effect was evident only for such cases as well. However, the fact that this absolute magnitude-based SNARC effect was then nullified when the form of the instruction was incongruent with pair polarity, indicates that incongruent instructions also seem to be invoking a representational directional orientation that runs counter to that associated with absolute magnitude. Such results strongly suggest that multiple frames of reference are being invoked simultaneously and in parallel by these stimuli and instructions, all of which can then affect responding.

Simulation Work

A fairly recent and novel account for the SNARC effect furthered by Proctor and Cho (2006) assumes that asymmetric categorical aspects of dimensional attributes associated with both the stimuli (e.g., small or large) and the responses (e.g., left and right) can be discretely coded in terms of either a negative (-) or positive (+) polarity, and also that responses in binary decisional tasks are faster when such polarities are in correspondence. More importantly with respect to our results, Proctor and Cho (2006) developed a strong case for the fact that that in any particular experimental situation, polarity coding can occur for multiple stimulus and response dimensions including those that are both relevant and irrelevant to the decision task. This account also assumes that the speed of responding can then depend on the degree to which the *aggregation* of the polarities associated with the various stimulus-related dimensions is in correspondence with the polarities associated with the response-related dimensions.

Hence, a polarity coding scheme for the stimulus pairs associated with each of the 16 cell means in Figure 2 was derived. First, pairs responded to with the “Colder” and “Warmer” instructions were coded as – and + polarity, respectively. Second, negative and positive number pairs were (naturally) coded as – and + polarity, respectively. Third, pairs that were small and large in absolute magnitude were coded as – and + polarity, respectively, Fourth, positive and negative pairs were polarity coded separately according to the dimensional congruence between their magnitudes (within either the positive or number negative ranges given the blocked fashion in which each of these ranges were presented here) and the form of the comparative instruction being used. For example, the large absolute-valued negative number pairs were coded as + here for the colder instruction but as – here for the warmer instruction. Fifth, pairs presented in number-line congruent and incongruent orders were coded as – and + polarity, respectively.

In order to determine how well these specific sets of polarity codes could account for the 16 RT data points, Proctor and Cho’s (2006) suggestion that polarity code correspondence could be affecting the accumulation of evidence within a noisy sequential sampling decision model was invoked. To simulate the decision process in such a manner, a random walk model framework was developed in which all + stimulus-based polarity codes enhanced (i.e., added to) the drift rate towards response criterion boundaries corresponding to right-sided responses and all – stimulus-based polarity codes enhanced the drift rate towards criterion boundaries corresponding to left-sided responses (or, analogously, subtracted from drift rates pointing towards left- and right-sided boundaries, respectively).

To model the number comparison task more generally, it was first assumed that absolute-valued small number pairs had a mean drift rate of 1 towards the correct response criterion boundary. Then, a determination of the values of the drift rate for the absolute-valued large number pairs, the response criterion, the standard deviation of the trial-to-trial variability in drift rate (this was the only type of variability used), and the size of the drift rate adjustments associated with corresponding polar codes for each of the polarity-coded stimulus dimensions by choosing those values that provided the best r^2 fit to the data (determined by regressing model steps and the RT data after 1000 simulated trials per data point with each set of parameter values that was explored – note also that any simulated trial taking more than 50 model steps was regarded as an outlier). Importantly, note that in this simulation work, the contributions of the polarity code correspondences were specifically allowed to vary across the coded dimensions in accordance with the supposition by Proctor and Cho (2006) that it needn't be the case that all polarity codes should necessarily be assumed to exert equal weight in the decision process.

On the basis of some initial simulation results, it was determined that providing a good fit to these data also necessitated incorporating two more aspects. One of them involved assuming that model residual times (i.e., the intercept term) were faster by a constant amount for all right-sided responses. The other involved adding a parameter that proportionally slowed the polarity-correspondence-adjusted drift rates for semantically incongruent decisions (as in Leth-Steensen & Marley, 2000). For the final model (see the dashed lines in Figure 2 for the fits), $r^2 = .92$ ($r = .96$) with intercept (residual) values of 239 and 224 ms for left and right responses, respectively, and a slope value of 34 ms/step (where the remaining model parameters used to provide this fit are given in Table 1).

Table 1. Random Walk Model Parameters.

Resp. Crit.	Lg. Drift Mult.	Drift Var.	Instruct.	Polarity	Abs. Mag.	Dim. Mag.
8	.85	.35	0	.0050	.0125	.0150

Order	SC Drift Mult.	Residual Time	Right-Side Adv.	Slope
.0150	.875	239	15	34

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