AUTOMATIC ACTIVATION OF NUMERICAL MAGNITUDE? EVIDENCE FROM JOINT DERIVATION OF SNARC AND SIZE CONGRUITY EFFECTS

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ABSTRACT

A widely held assumption in the realm of numerical cognition states that the meaning (i.e., numerical magnitude) of numerals is automatically activated just whenever numerals are exposed for any purpose. Two markers of automatic activation have been the SNARC and the size congruity effect. In this study, we derived both effects on a common set of numerals for the same group of observers. We found the effects to be independent. These results invite a revision of the traditional interpretations of the SNARC as a marker of automatic activation.

Mathematics marks the realm of human abstraction at its highest purest form. It is the discipline concerned with the logically implied conclusions drawn from any set of axioms or postulates. Mathematics is abstract because mathematical statements can be drawn about virtually anything or no-thing; it is formal because the validity of mathematical statements or derivations is grounded in the internal structure of the statements, not in any external meaning or state of affairs. It is this meaning-less content-less nature of the mathematical enterprise that is so well captured by Bertrand Russell's famous epigram: pure mathematics is the subject that we do not know what we are talking about, or whether what we say is true (see Nagel & Newman, 2001, for a fine discussion and demonstrations of this point). In other (famous) words, mathematics is a "game of signs and rules" (Stevens, 1951, p. 1). It is these "signs" that form the topic of the present study. We were interested in exploring the psychological nature of the "signs" that enable the game of mathematics.

Every game has its pawns and moves, and numerals comprise the pawns of the formal game of mathematics. Emancipated from the confines of empirical phenomena (if not of man's mind), numerals, like the rest of mathematics, are purely logical entities. Numerals are formal, dimension-less tools of the game of mathematics. This quality of numerals highlights the following factuality. In stark contrast with their abstract nature in mathematics stands the brutal fact that, in the empirical world, every numeral comes fully dressed in a multitude of physical dimensions. Every numeral that you have ever seen, heard, or touched came in a certain size, loudness, or texture. The truism is sometimes overlooked that, in the empirical world, a number is not a pure mathematical entity but rather a sensory stimulus. Had it not had sensory qualia, none of us humans would have ever been able to encounter a number. So, apart from its formal-logical properties, a numeral always is an "ink mark on a piece of paper" (Stevens, 1951, p. 22), or numerals can merely be "scratches on paper" (Guilford, 1954, p. 5). Inevitably, the physical appearance of a numeral (e.g., its size, color, shape, location) form as inalienable properties as do its arithmetic properties.

The issue at focus is the relationship between physical and arithmetic properties of a numeral. Do the physical properties of those "ink marks" and "scratches" affect their abstract mathematical meaning? Does the physical size of the "scratch" influence the semantic meaning

(i.e., numerical magnitude) that it conveys? Conversely, Does the semantics of the numeral affect the perception of its purely physical (non-semantic) attributes? Does the numerical magnitude of a numeral influence the perception of its physical size? Are the arithmetic properties of a numeral activated in an automatic fashion whenever a numeral is exposed for view just for any purpose?

Pertinent research shows that they probably are. Consider a task in which a pair of digits is compared on *physical size*. The task focuses on a non-semantic attribute of the digits, yet the irrelevant numerical values facilitate (in congruent pairs such as 8 6) or impair (in incongruent pairs such as 8 6) performance. This size congruity effect (SCE) has evolved into an important marker of the potency of numerical activation (Fitousi & Algom, 2006; Henik & Tzelgov, 1982). The SCE is not limited to comparisons of pairs of numerals. It is also present when people estimate the physical size of single numerals (Algom, Dekel, & Pansky, 1996; see also, Choplin & Logan, 2005). Thus, people are slower to perceive the physical size of a small number presented in a large format (3) or that of a large number presented in a small format (7) than vice versa. In this study, we applied the single-digit version of the SCE.

Recently, another phenomenon is linked to mode of numerical magnitude activation. The phenomenon taps an association between side of responding with lateralized keys and numerical magnitude -- *regardless* of the task that is performed with those keys (on the presented numerals). Consider the task of parity judgments in which the participants decide whether the presented number is odd or even. When asked to indicate the parity of small numbers, people respond faster with a left-hand key than with a right-hand key (irrespective of the odd-even assignment of response keys). In contrast, people respond faster with a right-hand key than with a left-hand key to indicate the parity of larger numbers. The effect, the Spatial-Numerical Association of Response Codes (the SNARC effect, Dehaene, Bossini, & Giraux, 1993), suggests the involvement of magnitude, although magnitude is not strictly required to determine parity. Consequently, the SNARC effect has been taken to support the notion of automatic activation of meaning (i.e., numerical magnitude) whenever numerals are presented for view just for any task. It is this explanation of the SNARC effect that we tested in the present study.

To that end, in the present study, participants judged the physical size (large, small) of numerals presented singly for view. The judgments of size were made manually by pressing one of a pair of lateralized keys. The participants performed these physical judgments twice with a different key assignment. In one block, the participants indicated large physical size by pressing a left-hand key and small physical size by pressing a right-hand key. In another block, they responded through the reverse key assignment. This design permitted to derive the SCE -- by comparing performance for a given number in small and large physical format. The design also permitted the derivation of the SNARC effect -- by comparing performance for a given number stimulus with left- and right-hand responses. If the SNARC effect taps activation of numerical information, then the effect is expected to interact with the SCE that registers the inadvertent involvement of numerical magnitude in tasks of physical size. In particular, a larger SNARC effect is expected to emerge for congruent (small numbers in small physical size and large numbers in large physical size) than for incongruent stimuli.

Method

Participants

Twenty-two Carleton University undergraduates participated in a single experimental session to satisfy course requirements. All the participants reported normal or corrected to normal vision.

Stimuli and apparatus

The stimulus set comprised all the digits between 1-9 except 5. The digits appeared printed in Times New Roman, bold, in either small or large font size (30 and 40 pixels, respectively). Each of the 16 stimuli (8 digits x 2 sizes) was presented five times, preceded by sixteen practice trials (unbeknownst to the participants). Order of presentation was random and different for each subject. Graphics production, presentation of the stimuli, event sequencing and timing, and the recording of responses (reaction times, RTs, and errors) were governed by a Pentium III computer running under SuperLab control.

Design and Procedure

Participants were tested individually in a dimly lit room, seated approximately 60 cm from the center of the screen. The participant's task was to decide if the font size of the digit is small or large (while ignoring numerical value). The responses were made by pressing one of the marked keys ('A' in the left, and 'L' in the right). In one block, the participants indicated small font size by pressing the left-hand key and large font size by pressing the right-hand key. In the other block, they responded by the reverse key assignment. Half of the participants first performed in the former block and half first performed in the latter block. The stimuli were response terminated, and a new stimulus was presented following a 1000 ms interval. Participants were encouraged to respond quickly, but accurately.

Results

Figure 1 shows the mean RTs (correct responses) for each digit to the two values of physical size. For small digits (1-4), the participants responded faster when the numeral appeared in small size than when it appeared in large size, whereas for larger digits (6-9) the opposite pattern held ($F(7, 147) = 2.682$, $P < 0.022$). Numerical magnitude, irrelevant to the physical task at hand, greatly influenced the judgments of physical size. Clearly, an appreciable SCE appeared.

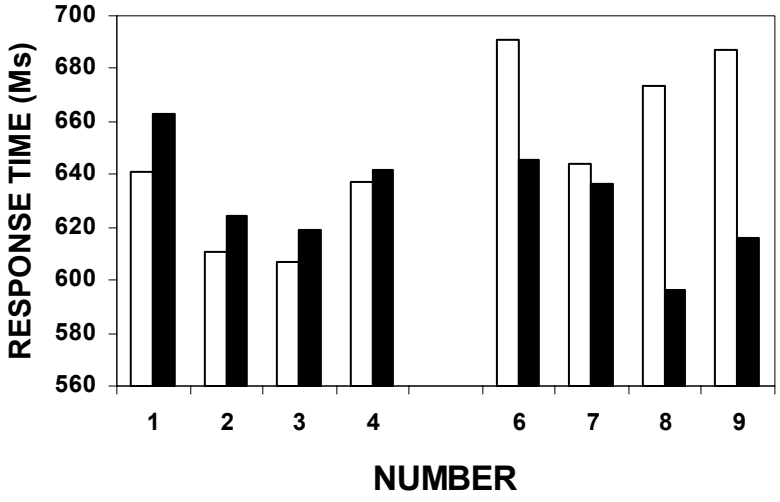

Figure 1: Mean RTs to small (white columns) and large (black columns) font size for each of the 8 digits presented.

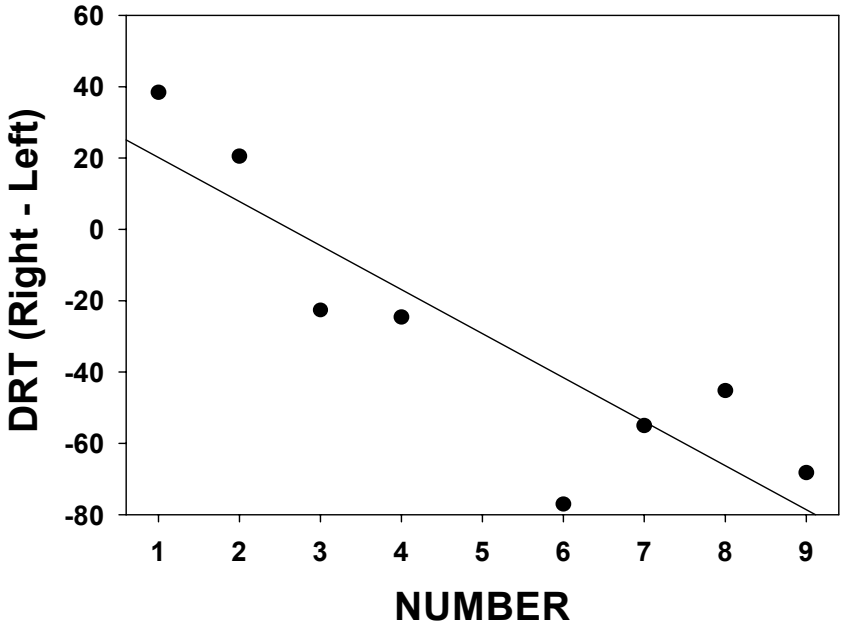

Figure 2: The difference in mean RT (in milliseconds) between responses with the right and the left hands (DRT) plotted against number.

In Figure 2, we calculated for each digit the mean difference in reaction time between the responses made with the right- and the left-hand keys (DRT). This difference is plotted in Figure 2 against number (i.e., numerical magnitude). For small numbers, the left-hand responses were faster than the right-hand responses, but the reverse pattern held for large numbers ($F(7, 147) = 3.175$, $P < 0.007$). The presence of the SNARC effect is documented by the negative slope of the regression line.

Therefore, both the SNARC effect and the SCE appeared in the present data. Are they associated? Figure 3 provides the answer. We calculated the SNARC effect separately for congruent (numerical and physical size match) and incongruent (numerical and physical size mismatch) stimuli. The slopes of the two SNARC functions are remarkably similar, their vertical difference reproduces the SCE. Clearly, the two effects are *not* related, a conclusion corroborated by the lack of the three way interaction, Number x Size x Hand ($F<1$). Basically, the SNARC effect was the same for congruent and incongruent stimuli.

The SNARC effect concerns a seemingly innocuous variable -- the lateral assignment of the responses used to indicate physically large and small numerals. People are faster to respond to the physical size of small numbers with a left-hand key and to the physical size of large numbers with a right-hand key. Magnitude activation is implicated by the sheer influence of numerical value as well as by its direction. The hypothetical number line is laid out from left to right, hence small values are associated with the left side of space and large values with the right side of space. However, the effect of magnitude on judgments of physical size expresses itself in another, much more direct way. People judge the physical size of numerals faster when that size corresponds with the respective numerical magnitude than in cases in which physical size conflicts with numerical magnitude. This effect of irrelevant magnitude is known as the SCE. The present dissociation of the effects of SNARC and SCE suggests to us that the traditional explanation of the former in terms of automatic activation of numerical value cannot be the valid or the exclusive account.

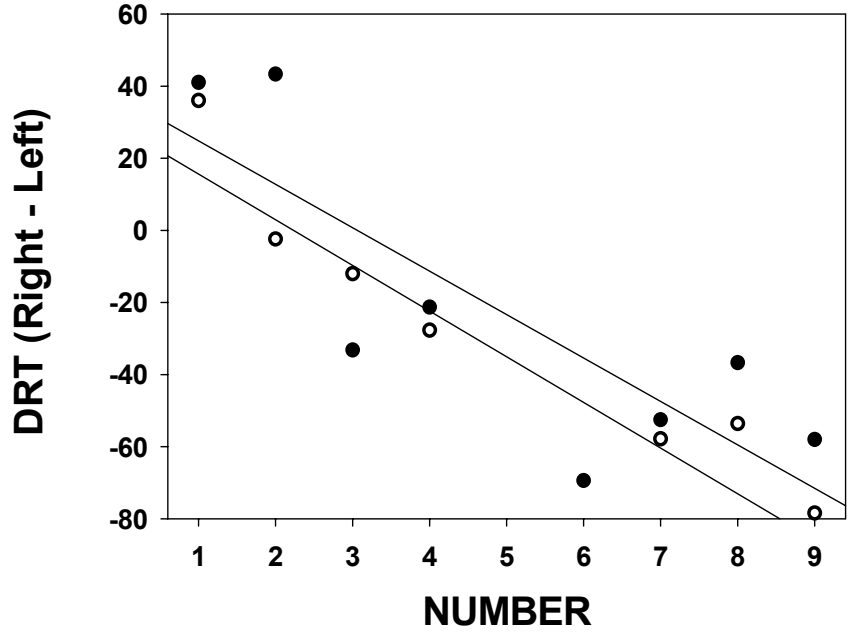

Figure 3: Two SNARC functions as in Figure 2, separately for congruent (lower curve) and incongruent (upper curve) stimuli.

Conclusion

If the SCE taps the pervasive activation of numerical magnitude (even in cases in which this information is irrelevant to the task at hand and can hurt performance), then the SNARC effect does not tap the same process. The present results invite an alternative explanation of the SNARC effect that does not appeal to the notion of automatic activation of magnitude. We submit that the SNARC effect reflects a heavily overlearned stimulus-response mapping. People's responses reflect the real-world arrangement by which the numbers 1-2 are typically located at the left and the larger numbers are typically located further to the right.

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