ROVING VERSUS FIXED STANDARD IN NUMERICAL COMPARISONS: THE DISTANCE EFFECT REVISITED

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Abstract

A classic marker of (automatic) numerical processing is the distance effect: The time to select the larger member of a pair of numerals decreases as the numerical distance between the numbers increases. The most popular procedure for testing the distance effect is a task in which the participant decides whether the presented number is smaller or larger than a predetermined fixed standard (usually 5). The problem with this arrangement is that each number always maps into the same fixed response. Consequently the observer can bypass the numerical comparison, using the number-response association instead. We show that indeed the distance effect is reduced or eliminated all together when testing comparison with a fixed standard. A novel "roving standard" procedure in which a momentary standard varies from trial to trial forces the observer to make the comparison and thus can remove the confound with the traditional method.

Seldom do we appreciate the important role that numbers play in our everyday life. A number stands for our height, another for our IQ, a third indicates the balance in our checking account, a fourth our telephone—and the list is virtually inexhaustible. The ease with which we use numbers, especially single-digit numbers, is extraordinary. Given the privileged status of numbers in people's cognitive milieu, the first study to probe speeded numerical processing (Moyer & Landauer, 1967) already yielded surprising results. Moyer and Landauer asked people to indicate the larger member of a pair of numerals. They found that the larger the numerical difference between the two digits, the shorter the time needed to decide which is the larger. Regardless of years of experience or the ease with which numbers are used, it takes longer to decide that 8 is larger than 6 than to decide that 8 is larger than 2. This *distance effect* has since been reproduced in numerous studies in a variety of comparison tasks (see, e.g., Dehaene, Dupoux, & Mehler, 1990; Foltz, Poltrock, & Potts, 1984; Garner, Podgorny, & Frasca, 1982; Hinrichs, Yurko, & Hu, 1981; Link, 1990; Poltrock & Schwartz, 1984).

Comparing numbers on magnitude is one of the most prevalent operations with numbers in everyday life. People compare numbers denoting the size of their income, their height, weight, or grades in class. Virtually hundreds of such comparisons are performed in the course of a given day. Numerical comparison also comprises the most popularly studied task in the laboratory. A distance effect governs all such comparisons.

In the laboratory, Dehaene (1989) distinguished between two classes of numerical comparisons. In one task, a number is compared with a fixed standard (usually 5). In the other task, pairs of numbers, varying from trial to trial, are compared on magnitude. Dehaene termed these tasks "classification" and "selection," respectively. We argue that, due to a serious confound, the distance effect should emerge systematically only in selection but not in classification.

Given a fixed standard, the constant stimulus-response association created permits to bypass the numerical comparison altogether. For example, using the fixed standard of 5, the number 3 is always responded with the same lateralized key, "smaller." The participant can bypass the comparison operation entirely and use instead the shortcut heuristics of the fixed bond between the number and the response key. In order to eliminate this confound, we developed a new design, the roving standard paradigm. In this method, the standard varies from trial to trial in an unpredictable fashion. As a result a given number is sometimes large and sometimes small depending on the momentary standard. For example, the number 8 is large if preceded by the momentary standard 7, but it is small if preceded by the momentary standard 9. In other words, the roving standard procedure pries apart the constant link between a number and a fixed response and forces the participants to perform the arithmetic operation on each trial.

In the present study we used the traditional version of the classification task. The fixed standard of 5 was determined in advance and the participant's task was to indicate whether the presented number was larger or smaller than the predetermined standard. Our hypothesis was as follows. A distance effect is expected only if the comparison operation is actually performed. However, given the fixed link between a numeral and a response key, the sought comparison is not performed on each and every trial. In particular, the comparison is bypassed during the last set of trials in the block. Therefore, we predict the presence of an overall distance effect but the absence of the distance effect during the last trials in the block.

Method

Participants

Sixteen Tel-Aviv University students, undergraduates from the Psychology Department, participated in partial fulfillment of course requirement.

Apparatus and Design

The stimulus set included all the numbers between 2-8 (except for 5 which served as the standard). The stimuli were generated by an IBM compatible microcomputer (PC 486) and displayed on a 600 x 800 pixel VGA color monitor. The stimuli appeared black on the grayish background of the monitor. The stimuli were displayed (in Arial font) at around the center of the screen. To avoid adaptation, we introduced a trial-to-trial spatial uncertainty of up to 15 pixels around the target location. The height of the numbers was 12 mm and the width was 10 mm. The 6 numbers appeared 3 times each in a random order, making for 18 trials in all.

The task for the participant was to indicate, while timed, whether the presented number was larger or smaller than 5. The presentation of the stimuli was response terminated. The mode of responding was manual, pressing one key for "larger than 5" (key A on the computer board) and another key for "smaller than 5" (key L on the computer board) decisions. After responding, the next stimulus was presented following a 500 ms interval.

Results

Figure 1 gives the results. We calculated the mean RT for each value of numerical distance from the standard of 5. Clearly, the overall data in Figure 1 exhibit the typical distance effect. The smaller the numerical distance, the longer it takes to decide whether the presented number is larger or smaller than 5. Is this distance function based on all trials presented? Would it remain intact during the latter trials as well?

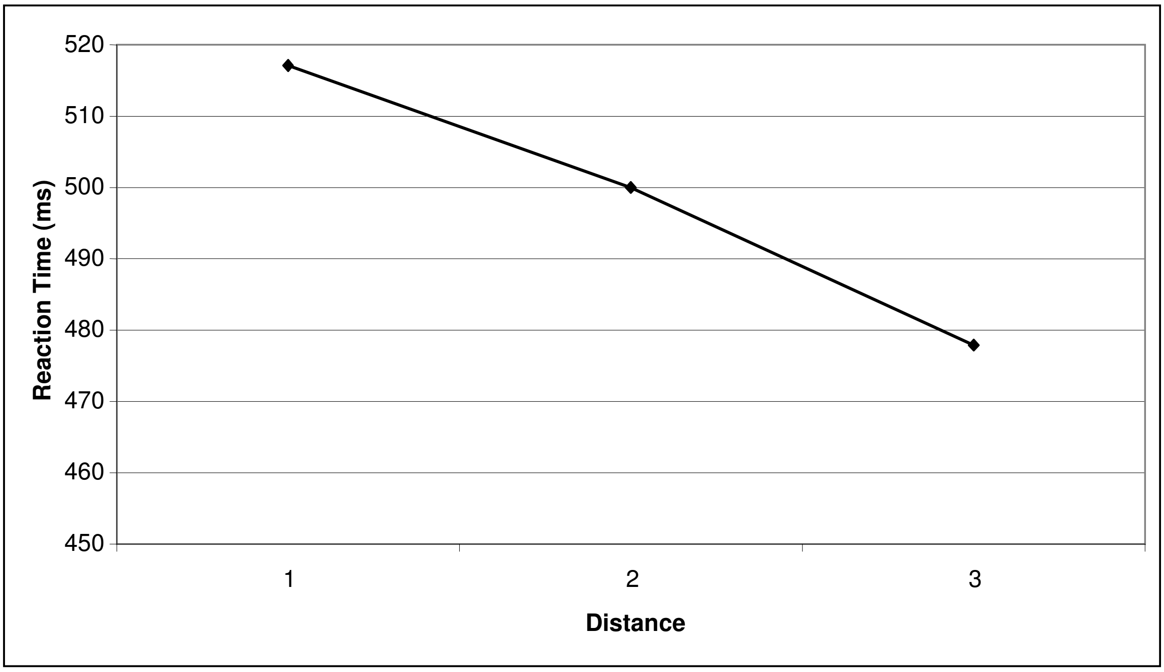

Figure 1: The overall distance function: The RT to decide that a number is larger or smaller than 5 as a function of numerical distance.

In order to answer the last questions we calculated the distance effect solely for the last 4 trials for each participant. The results for this subset of the data are presented in Figure 2.

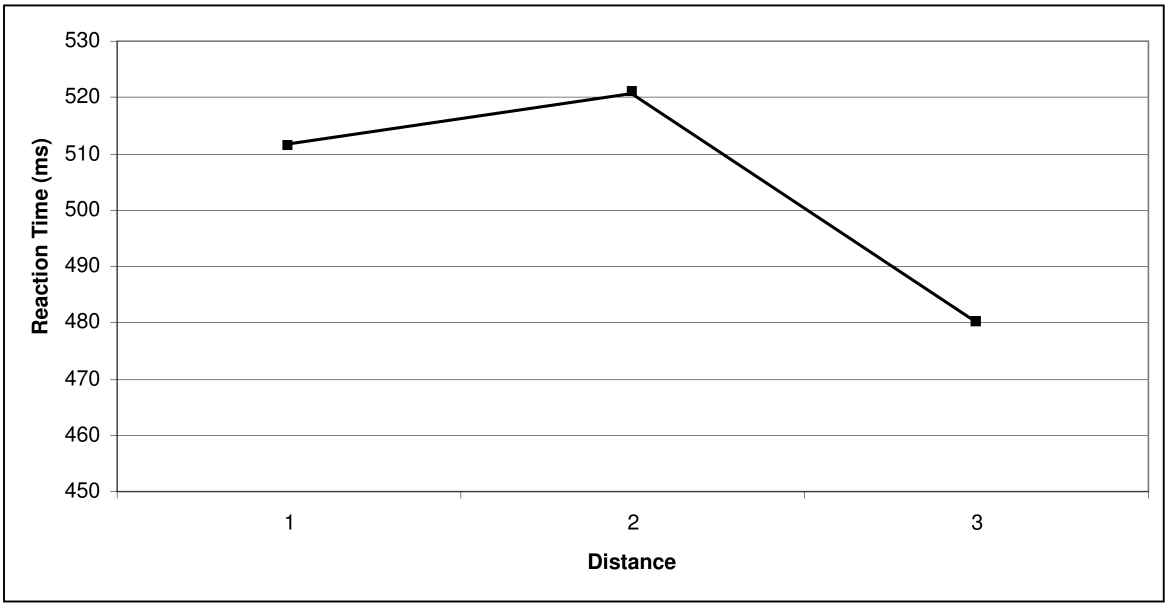

Figure 2: The distance effect for the subset of the last 4 trials: The RT to decide that a number is larger or smaller than 5 as a function of numerical distance.

Clearly, a distance effect is absent for this subset of trials. We conclude that the overall distance effect is based only on the first part of the trials and that, subsequently, people bypass the numerical comparison. As a result, the distance effect vanishes in the latter part of the experiment.

Discussion

Our results show that, in the traditional classification task, numerical comparison is not performed on every trial (only in the first ones). The distance effect by which RTs are expected to be shorter as the numerical distance increases is expected only if the comparison operation is actually performed. Because the distance effect vanished in the last few trials of the classification task, the underlying comparison was probably absent on these trials. The evaporation of the initial distance effect in the last trials reflects the absence of an authentic algorithmic operation.

We argue that this absence pinpoints a serious problem with the fixed standard classification task. This task does not strictly force the participants to perform the vital numerical comparison. The participants can complete the task via the fixed stimulus-response mapping, bypassing the mental operation of comparison altogether. In the novel method of a roving standard which we develop the vital comparison is enforced on all trials.

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