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Short Communication

Laterality briefed: Laterality modulates performance in a numerosity-congruity task

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ABSTRACT

It is widely agreed that irrelevant numerical values are automatically activated. However, automatic and intentional activations may give rise to different numerical representations. We examined processing of symbolic and non-symbolic (i.e., numerosity) representations asking whether they differ in automatic and intentional processing. Participants were presented with two-dimensional displays containing repetitions of a digit and were asked to report, in different blocks, whether the digit or numerosity was smaller or larger than 5. Incongruent trials differed either in laterality between the relevant and irrelevant dimensions (i.e., the location of both dimensions in reference to the midpoint 5) or in numerical distance between dimensions. Congruency affected performance regardless of symbolic or non-symbolic presentation. For incongruent trials, laterality (not distance) affected performance, again regardless of presentation. This implies that automaticity does not mean similar processing of relevant and irrelevant dimensions. Specifically, the relevant dimension is processed elaborately whereas the irrelevant dimension is processed crudely.

1. Introduction

One aspect of skilled performance is automaticity, indicated by processing of a stimulus even when it is irrelevant to the task at hand (MacLeod, 1991; Tzelgov, Henik, & Leiser, 1990). Is the irrelevant stimulus processed to the same degree as the relevant stimulus? We examined this question in the area of numerical cognition.

It is widely agreed that processing of numerical values associated with digits is robust, independent of task requirements, and occurs automatically, even when the numerical value is irrelevant to the task at hand (e.g., Dehaene, Bossini, & Giraux, 1993; Henik & Tzelgov, 1982; Pavese & Umiltà, 1998, 1999). This has been demonstrated repeatedly by a variety of effects, amongst them: distance, priming, and laterality. Whereas most of these effects have been studied using numerical values, it remains unclear whether they are present when processing another aspect of magnitude—numerosity. Recently, we (Naparstek & Henik, 2010) have shown that in a comparative judgment task, numerosities behave similarly to numerical values. Specifically, both numerical value and numerosity were automatically activated when irrelevant to the task at hand. The current study examines the interaction between distance and laterality for numerosity.

The distance effect manifests as a decrease in reaction time (RT) as the distance between the values-to-be-compared increases (Moyer & Landauer, 1967). It has been described in a variety of numerical and non-numerical comparisons (e.g., Cohen Kadosh, Cohen Kadosh, & Henik, 2008). Interestingly, the distance effect appears not only when the numerical dimension is the relevant dimension (intentional processing) but also when it is irrelevant to the task at hand, suggesting automatic activation of numerical values (Henik & Tzelgov, 1982). The second effect, priming, occurs when participants are asked to

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react to a target preceded by a number prime. The priming effect is opposite in direction to the distance effect. Specifically, RTs increase as the distance between the target and prime increases (Dehaene et al., 1998; Den Heyer & Briand, 1986; Reynvoet & Brysbaert, 1999, 2004). Finally, laterality refers to the location of the digits-to-be-compared in reference to the midpoint 5. Accordingly, the pair 4-6 is a bilateral pair whereas 2-4 and 6-8 are unilateral pairs. Bilateral pairs have a larger effect on performance than unilateral pairs. This occurs when the numerical values are irrelevant (Tzelgov, Meyer, & Henik, 1992) and even when no comparison to 5 is required (Cohen Kadosh, 2008). Following the two-stage model by Banks and colleagues (Banks, Fujii, & Kayra-Stuart, 1976), Tzelgov and colleagues (1992) suggested that distance and laterality represent different levels of processing of numerical information. Specifically, laterality affects performance as a result of crude categorization (i.e., '*large*' '*small*') whereas distance affects performance as a result of a more elaborated categorization.

As noted above, these effects have been reported repeatedly for digits. We recently asked if numerosity is endowed with similar characteristics (Naparstek & Henik, 2010). Participants were presented with a two-dimensional display containing repetitions of a single digit and were asked to indicate, in separate blocks, whether the numerical value or the numerosity was smaller or larger than 5. Stimuli could be congruent (numerosity and numerical value were the same) or incongruent (numerosity and numerical value were different). We found a congruency effect for both numerical value and numerosity. This means that both dimensions modulated performance even when irrelevant to the task. Following Pavese and Umiltà (1998, 1999), we examined the effect of numerical distance between relevant and irrelevant dimensions (henceforth referred to as relevant–irrelevant distance) within incongruent trials. Interestingly, we found that RT increased as the relevant–irrelevant distance increased, resembling a priming effect (Van Opstal, Gevers, De Moor, & Verguts, 2008). Specifically, incongruent trials with a small relevant–irrelevant distance (e.g., three 4s) were processed faster than incongruent trials with a large relevant–irrelevant distance (e.g., nine 4s). In our study (Naparstek & Henik, 2010), stimuli with small relevant–irrelevant distance (i.e., distances 1 and 2) were always unilateral, whereas stimuli with large relevant–irrelevant distance (i.e., distance 5) were always bilateral. Thus, it remains unclear whether the obtained pattern of responses was a result of laterality or distance. Previous studies asked whether laterality of only one dimension—relevant (Tzelgov & colleagues, 1992) or irrelevant (Cohen Kadosh, 2008)—modulated performance. Accordingly, the current study was designed in order to test whether: (1) the relation between the relevant and irrelevant dimension is affected by the laterality or the distance between the dimensions, and if yes, then (2) whether this modulation differs between intentional and automatic processing of numerosity (i.e., whether numerosity is the relevant or irrelevant dimension, accordingly). Participants carried out a comparative judgment task similar to the one described above (Naparstek & Henik, 2010). In Experiment 1, laterality was manipulated and relevant–irrelevant distance was controlled, whereas in Experiment 2, both laterality and relevant–irrelevant distance were manipulated.

2. Experiment 1

2.1. Method

2.1.1. Participants

Thirteen undergraduates (9 females, mean age: 26 ± 1.4 yrs) at Ben-Gurion University of the Negev participated in the experiment for course credits. All participants had normal or corrected-to-normal eye sight.

2.1.2. Stimuli

Participants were presented with a circular display containing 18 equidistant points on a black background. At a viewing distance of 57 cm, the circle's diameter subtended a visual angle of approximately 4°. A given array was created by placing a red digit in one to nine random locations on the circumference. Remaining locations were filled with fillers—repetitions of a same green letter. Two red targets could never appear in adjacent locations. Stimuli included single digits (1, 3, 4, 6, 7 and 9) and upper case Latin letters (A, C, D, G, K, L, M, and P) [1] in Courier New font size 14. The experiment was programmed using E-prime and was run on an Intel Pentium 4 computer.

Participants responded to two blocks: a numerosity-relevant block (henceforth, numerosity block) and a numerical-value-relevant block (henceforth, numerical value block). In each block, half of the trials were congruent–numerosity and numerical value were the same (e.g., three 3s: 333, or six 6s: 666666), and half were incongruent–numerosity and numerical value were different (e.g., six 3s: 333333, or nine 6s: 666666666). All incongruent trials had a relevant–irrelevant distance of 3. However, these trials differed in laterality between the relevant and irrelevant dimension in relation to the reference 5. The stimuli 1-4 (i.e., one 4: 4, or four 1s: 1111) and 6-9 (i.e., six 9s: 999999, or nine 6s: 666666666) served as unilateral stimuli and the stimuli 3-6 (i.e., three 6s: 666, or six 3s: 333333) and 4-7 (i.e., four 7s: 7777, or seven 4s: 4444444) served as bilateral stimuli (see Table 1).

2.1.3. Design

Two independent variables were manipulated within participants: block (numerosity, numerical value) and congruency (congruent, incongruent). For incongruent trials only, we manipulated laterality (unilateral, bilateral).

[1] These letters were chosen randomly; letters that visually resemble numbers were excluded.