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Brief article

Size before numbers: Conceptual size primes numerical value

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ABSTRACT

The present work examined the influence of conceptual object size on numerical processing. In two experiments, pictures of conceptually large or small animals of equal retinal size served as prime stimuli appearing before numerically big or small integer targets. Participants were instructed to perform an unbiased parity judgment task on the target integers. When the prime's conceptual size was congruent with the target's numerical value, participants' reaction time was faster than when the two were incongruent with each other. This influence of conceptual object size on numerical value perception suggests that both types of magnitudes share similar mental representations. Our results are in accord with recent theories (e.g., Cantlon, Platt, & Brannon, 2009; Henik, Leibovich, Naparstek, Diesendruck, & Rubinsten, 2012) that emphasize the evolutionary importance of evaluation and perception of sizes to the development of the numerical system.

1. Introduction

Numerical cognition is an essential part of our everyday life. Research from the last few decades investigating the nature of the numerical cognitive system has been accumulating. In the present study we examined the relations between number and size perception. Specifically, we asked whether numerical value perception is affected by the *conceptual size* of real-world objects. We hypothesized that despite the seemingly different types of knowledge, numerical perception may rely on similar underlying cognitive mechanisms as conceptual size perception does. Our hypothesis is supported by recent models arguing that the number representational system has evolved from a more primitive system that evaluates sizes (Henik, Leibovich, Naparstek, Diesendruck, & Rubinsten, 2012).

Ample research has suggested that humans possess a core numerical system that allows us to perceive, to manipulate, and to compare discrete quantities (e.g., Ansari, 2008; Butterworth, 2010; Dehaene, 2009; Piazza, 2010). One of the first studies to investigate numeral cognition was conducted by Moyer and Landauer (1967), who asked adults to compare two Arabic numerals while measuring their reaction times (RT). The results of Moyer and Landauer suggested that RT was influenced by the numerical distance between the two numbers. Namely, RT for comparative judgments increased with a decrease in numerical distance (e.g., the comparison of 6 & 7 was slower than 2 & 7). Dehaene (1997) explained this distance effect by the existence of a mental number line (MNL). According to Dehaene, we convert quantities and numbers into analog magnitudes and place them on a mental number line. As the representations become closer on the mental number line it becomes more difficult to distinguish between them.

In a follow-up work, Moyer (1973) presented participants with pairs of animal names and asked them to choose the larger animal. The animal names were previously ranked by the participants according to their relative sizes in real life. Similar to the findings of Moyer and Landauer (1967), RT was negatively correlated with the

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difference in the animals' conceptual size (e.g., comparing ANT & BEE was slower than ANT & HOG). It was argued that participants compared animal names by making an "internal psychological judgment" after first converting the names into analog representations that preserved the animal sizes. The results of Moyer and of Moyer and Landauer may imply that the mental number line is not restricted to numerals and that any size is converted into an analog magnitude.

Later studies further investigated the relationship between numerical values and physical sizes. Henik and Tzelgov (1982) presented participants with pairs of Arabic numerals that could differ in their numerical value or in their physical size. Participants were asked to judge which of the two numerals was physically larger while ignoring the numerical values, or to judge the numerical values of the digits while ignoring the digits' physical sizes. The experiment contained three conditions: an incongruent condition (e.g., the numerically larger numeral was physically smaller), a congruent condition (e.g., the numerically larger numeral was also physically larger), or a neutral condition (e.g., only the physical size of the digits differed while the numerical value remained constant, or vice versa). The pattern of results indicated a size congruity effect, that is, shorter RTs for congruent than for incongruent trials (see also Besner & Coltheart, 1979; Dehaene, 1992; Schwarz & Heinze, 1998; Tzelgov, Meyer, & Henik, 1992). These findings suggest that numerical value—a symbolic representation of size or quantity—interacts with physical size—a non-symbolic value representing continuous magnitudes.

Physical size was also found to be associated with conceptual size, as was demonstrated in an early study by Paivio (1975). The author presented participants with two object pictures in different physical sizes and asked them to choose the conceptually larger object while ignoring physical size relations. The conceptual sizes of the objects were previously judged and given size values by an independent group of participants. Results showed that responses to pictures were significantly slower when physical size relations conflicted with conceptual size relations than when the two were congruent with each other see also Konkle & Oliva (2012), for a complementary finding of an interference of conceptual size with physical size judgments. Similar results to those of Paivio were obtained when using animal names presented in varying physical sizes (Rubinsten & Henik, 2002). Taken together, these findings imply that during processing of an object (presented as a picture or as a word), its physical and conceptual sizes are being processed in a relatively automatic fashion (see also Sereno, O'Donnell, & Sereno, 2009).

Based on these findings and on convergence of findings from fields such as cognitive development, comparative cognition and neurobiology, Cantlon, Platt, and Brannon (2009) postulated the existence of the 'Approximate Number System' (ANS). According to the authors, "the processes underlying different quantitative judgments might have evolved from a single magnitude system. Under this scenario, a system that once computed one magnitude (e.g., size) could have been hi-jacked to perform judgments along a new dimension (e.g., number)" (p. 89). Recently, Henik et al. (2012) have similarly suggested that a system which has evolved to perceive and evaluate non-countable, continuous dimensions like size or amount of substance may have formed the basis from which the numerical system and numerical abilities were developed.

Note that in the studies investigating distance and size congruency effects, task requirements typically involved an explicit evaluation of size (whether physical, conceptual, or numerical). It is possible, thus, that the reported effects occurred at some level involving a response initiation (e.g., response selection, motor preparation, or response execution) rather than at a perceptual or a conceptual level. Indeed, it has been previously demonstrated, using functional magnetic resonance imaging and event-related potentials measures, that such tasks involve primary motor cortical activation (Cohen Kadosh et al., 2007), supporting the role of response conflict in the congruency effects obtained. By using an unbiased task that does not require an explicit response to size magnitude, one could rule out response conflict as a possible factor in the size congruency effect. Consequently, a stronger argument for the automatic processing of object size could be made.

The goal of the present research was, therefore, to examine the influence of conceptual size of real-world images on numeral perception, using a priming paradigm and an unbiased numerical parity judgment task. In two sets of experiments, participants viewed a prime animal image followed by a target number. The participants were instructed to ignore the animal image and to determine as fast as possible if the numeral target was odd or even. The concepts of odd and even are not applicable to animals, only to numbers. Critically, the parity judgment task is strictly orthogonal to numerical magnitude; hence, response bias was avoided. We hypothesized that if the system that processes conceptual object size interacts with the system that processes numbers, a size congruency effect should be observed. Namely, RT would be faster for large numbers that are primed by large animals than for the same numbers primed by small animals (and vise versa for small numbers). Such results would comply with recent theories suggesting that a primitive size evaluation mechanism may have affected the development of a number processing mechanism (Cantlon et al., 2009; Henik et al., 2012).

2. Experiment 1

2.1. Method

2.1.1. Participants

Eleven participants from Ben-Gurion University of the Negev participated in the experiment for course credit.

2.1.2. Apparatus and stimuli

Prime stimuli depicted images of animals ($6.5^\circ \times 6.5^\circ$) that were either conceptually small (a cat or a dog) or big (a horse or an elephant). Target stimuli consisted of digits (4.4° in height) that either depicted small (2 or 3) or big (8 or 9) numerical values, accordingly. Prime and target stimuli were therefore congruent or incongruent with respect to