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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 each other's perceived size (see stimuli and experimental design in Fig. 1). Participants performed a forced-choice parity judgment task on the target digits, and were instructed to ignore the animal prime images. Critically, all prime images were of equal retinal size, thus, any effects of primes on responses to targets could be attributed to conceptual knowledge of the animals' sizes only.

The experiment consisted of 64 trials in total; 16 trials for each experimental condition of congruency (congruent/incongruent) and numerical value (big/small).

2.1.3. Procedure

Participants were tested in a dimly-illuminated room. They were seated 57 cm from the computer monitor. Participants were instructed to maintain fixation at the center of the screen throughout the experiment. Each trial began with the appearance of a central fixation cross (0.8°) for 1000 ms. After a blank interval of 1000 ms, a prime stimulus appeared for 1000 ms. Following an additional blank interval of 500 ms, a target digit appeared for 3000 ms or until the participant's response (see Fig. 1B for a complete trial sequence). Participants were instructed to respond to the target's parity value as fast as possible, while avoiding false responses (press 'M' key for an even digit and 'Z' key for an odd digit). A blank screen appeared at the end of each trial for 1000 ms. Each participant conducted 8 practice trials before the experiment began.

2.2. Results

Trials in which the participants responded very fast (⩽100 ms) or very slow (⩾1500 ms) were excluded from the analysis (less than 1 percent of the data). Trials in which participants responded incorrectly were also excluded from the analysis (2.5 percent of the data).

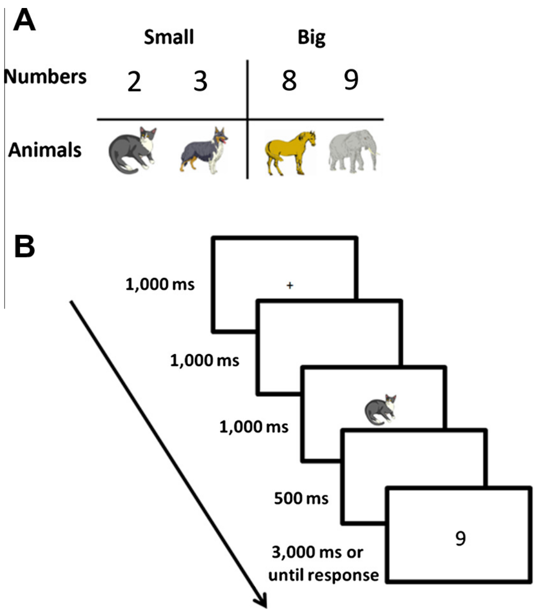

Fig. 1. (A) Stimuli and (B) trial sequence in Experiment 1.

Fig. 2 presents participants' RT as a function of target numerical value and prime-target congruency. A two-way analysis of variance (ANOVA) was conducted with target numerical value (small, big) and prime-target congruency (congruent, incongruent) as factors. There was a statistically significant main effect of congruency [$F(1, 10) = 6.1$, $p < .05$, $\eta p^2 = .38$], which stemmed from faster RTs for targets preceded by congruent than by incongruent primes. All other effects failed to reach statistical significance (all Fs < 1.7).

2.3. Discussion

In this experiment we demonstrated that processing a number's value is influenced by the conceptual size of an object appearing immediately before it. Specifically, the conceptual size of an animal prime image influenced a parity judgment of a subsequent number target. One shortcoming of the current design is that it tests the relations between conceptual and numerical value on a rather limited set of stimuli. Namely, the priming effect was seen for small and big size values, each containing only two animal exemplars, and tested with a relatively small number of experimental trials. To allow further validation and generalization of our results, we conducted an additional experiment in which we used a wider range of numbers and conceptual sizes, and a larger variety of animal images within each conceptual size category. Expanding the range of size categories also allowed us to examine the extent to which conceptual size representation is flexible, and whether it changes as a function of task context (see below). To strengthen our experimental power, we additionally increased the number of trials within each condition in Experiment 2.

3. Experiment 2

3.1. Method

3.1.1. Participants

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

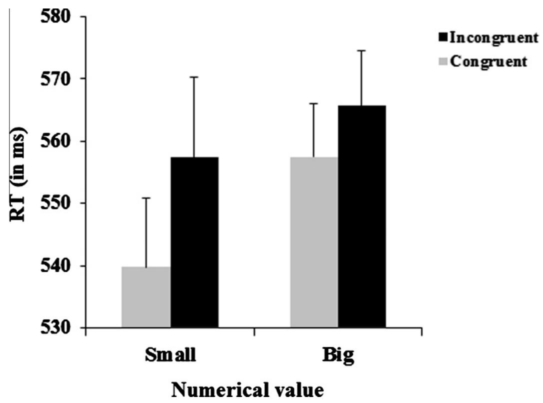

Fig. 2. RT as a function of numerical value and congruency. Error bars represent standard errors (as computed in within-subjects designs; see, e.g., Morey, 2008).

3.1.2. Apparatus, stimuli and procedure

Apparatus and stimuli were identical to those of the first experiment except for the following: three size categories were used, each containing three prime stimuli (i.e., three different animal images) of equal retinal size but of different conceptual size—small (turtle, butterfly, snail), medium (lamb, dog, deer) or big (elephant, bear, camel). Target stimuli consisted of digits that depicted, respectively, small (1 or 2), medium (4 or 5) or big (8 or 9) numerical values. Prime and target stimuli formed congruent (e.g., small animal and a small number), moderately incongruent (e.g., small animal and a medium number) or highly incongruent (e.g., small animal and a big number) conditions (see stimuli and experimental conditions in Fig. 3).

There were 72 trials in each numerical value condition (small, medium, big), adding up to a total of 216 trials altogether. The experimental procedure was identical to that of the first experiment.

3.2. Results and discussion

Trials in which participants responded very fast (⩽100 ms) or very slow (⩾1500 ms) were excluded from the analysis (less than 1 percent of the data). Trials in which participants responded incorrectly (2%) were also excluded from the analysis. Fig. 4 presents participants' RT as a function of target numerical value and prime-target congruency.

Since the design was not factorial (medium sized numbers formed only moderately incongruent conditions, but not highly incongruent conditions), we conducted two separate ANOVAs. In the first analysis we excluded the medium size stimuli, such that it included only extreme size values, that is, small and big numbers paired with small and big animals (forming either congruent or highly incongruent conditions). This analysis resembled the analysis performed in Experiment 1. The second analysis included all three number and animal (i.e., conceptual) size categories, allowing the comparison of the congruent and the moderately incongruent conditions of all size categories. Consequently, we could generalize our results to a wider range of size representations. In addition, by comparing the results of this analysis with the results of Experiment 1, we could explore the nature of the mapping between conceptual size and numerical value; for example, whether a specific conceptual size represented an absolute numerical value, or, alternatively, whether the two size dimensions interacted in a flexible manner, depending on task demands and on contextual factors.

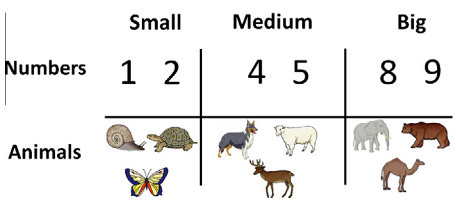

Fig. 3. Stimuli in Experiment 2.

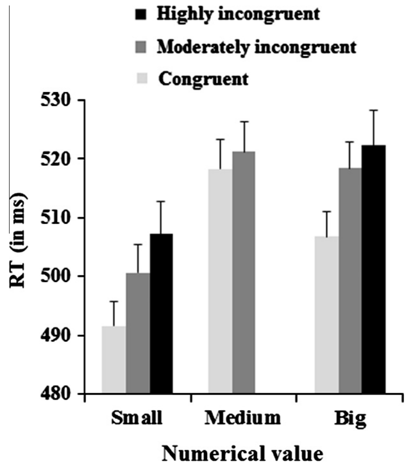

Fig. 4. RT as a function of numerical value and congruency. Error bars represent standard errors (as computed in within-subjects designs; see, e.g., Morey, 2008).

3.2.1. Small and big numbers and conceptual sizes

We conducted a two-way ANOVA with target numerical value (small or big) and prime-target congruency (congruent or highly incongruent) as factors. There was a significant main effect of size [$F(1, 28) = 15.2$, $p < .01$, $\eta p^2 = .35$], which stemmed from faster RTs for small than for big number targets. Most importantly, a statistically significant main effect of congruency was obtained [$F(1, 28) = 7.0$, $p < .05$, $\eta p^2 = .2$], indicating that participants' responses were faster for targets preceded by congruent than by highly incongruent primes. These findings replicated the results of Experiment 1. Note, however, that while similar animal objects were used to define the 'big' conceptual size category in the two experiments, different objects were used in the 'small' category of the two experiments (e.g., cat/dog vs. turtle/butterfly/snail in Experiments 1 and 2, respectively). In fact, some of the objects defining the 'small' category in Experiment 1 were included in the 'medium' category in Experiment 2 (e.g., dog) due to the expansion of the size scale in the latter. The fact that different 'small' conceptual sizes elicited similar congruency effects in both experiments suggests that the relations between conceptual size and numerical value may be somewhat flexible and context-dependent (see further elaboration on this point below).

3.2.2. Small, medium, and big numbers and conceptual sizes

In our second analysis, we conducted a two-way ANOVA with target numerical value (small, medium or big) and prime-target congruency (congruent or moderately incongruent) as factors. There was a significant main effect of size [$F(2, 56) = 16.1$, $p < .01$, $\eta p^2 = .26$]. An inspection of the results revealed that this effect stemmed from faster RTs for small numerical value targets than for the averaged RT of medium and big numerical targets [$F(1, 28) = 41.3$, $p < .01$, $\eta p^2 = .59$] (there was no difference in RTs between medium and large numerical targets [$F(1, 28) = 2.1$, $p = .15$, *ns*]). Critically, a statistically significant main effect of congruency was once again observed [$F(1, 28) = 5.9$, $p < .05$,

$\eta p^2 = .17$], revealing faster RTs for number targets that were preceded by congruent than by moderately incongruent primes. Our results replicated once again the results of Experiment 1 using of a wider range of size values, further establishing the interaction between conceptual size and number processing.

An additional aspect of the results concerns the nature of mapping between the two size parameters. As noted earlier, the conceptual size scale (as well as the numerical size scale) varied between Experiments 1 and 2. As a result, object images (e.g., a dog) that were congruent with small numbers (e.g., 2, 3) in Experiment 1 were perceived as incongruent with the small numbers (e.g., 1, 2) in Experiment 2. These findings strongly suggest that object conceptual size is perceived and judged on a relative rather than on an absolute scale. Namely, a dog is perceived as 'big' when it is compared to a snail, yet it is perceived as 'small' when it is compared to an elephant. Note that relative scaling is also inherent to number representation, in which, for instance, the digit 9 may be perceived as big relative to 1, but as small relative to 100 or 1000. Taken together, the results of Experiments 1 and 2 strongly imply that mapping of conceptual and numerical magnitudes may be flexible and scale-dependent.

4. General discussion

In two experiments we demonstrated that processing a number's value is influenced by an object's conceptual size. Specifically, the conceptual size of an animal prime image influenced a parity judgment of a number target. Critically, since the parity judgment task was orthogonal to the conceptual size of the prime and to the numerical value of the target, the interaction obtained between conceptual size processing and number processing could not be an outcome of a simple response bias. Rather, the interaction between the two magnitude parameters most likely occurred on a pure perceptual or conceptual level. Our findings, therefore, suggest that conceptual size representation may activate the mental number line.

Previous studies have documented the effects of physical size on numerical value processing (e.g., Besner & Coltheart, 1979; Dehaene, 1992; Henik & Tzelgov, 1982; Schwarz & Heinze, 1998; Tzelgov et al., 1992). Herein, we further elaborated this finding by demonstrating that not only physical properties but also high-level conceptual knowledge of real-world object size may be processed automatically and may affect numeral value perception. We demonstrated that conceptual size modulates processing of numbers even when the two magnitudes are generated by separate stimuli and when the former is strictly irrelevant to task demands.

An interesting question concerns the nature of the mapping between conceptual size and numerical magnitude. Several researchers have recently argued that objects are represented by a canonical visual size representation (Konkle & Oliva, 2011). Namely, that knowledge about objects includes information about the 'true', absolute real-world size of stimuli, regardless of task demands or of contextual factors. Here we show that, at least when presented in the context of numerical values, conceptual size may be represented on a relative, rather than on an absolute, scale. Namely, the association between conceptual size and numerical value may be flexible and task dependent.

Object size is a non-countable dimension that has no exact value. In contrast, integers have a precise value. Demonstrating an interaction between an approximate size representation and an exact number representation may support recent suggestions regarding a core system that was originally designed to compute continuous magnitudes, which, with evolutionary development, was exploited in the development of the numerical system (Cantlon et al., 2009; Henik et al., 2012).

A central question emerging from the above suggestions concerns the mechanism by which the numerical system has evolved. We suggest that the shift from evaluation and perception of continuous, non-countable properties to the fully developed numerical system may have been mediated by the use of conceptual sizes. Conceptual sizes are necessary for an organism's survival. They help determine predators from prey and rivals from possible mates. Conceptual sizes might be perceived as evolutionarily early measurement units of continuous values. That is, they convey long-term semantic knowledge of an object's size, regardless of the object's actual retinal size; similar to numerals that denote (symbolically) long-term knowledge of specific quantities and/or amounts. From an evolutionary perspective, therefore, conceptual size may have served as a possible bridge between continuous and numerical magnitude representations.

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