Larger stimuli are judged to last longer

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Representing magnitude information in various dimensions, including space, quantity, and time, is an important function of the human brain. Many previous studies reported that numerical and spatial magnitudes could be mutually influenced through a "mental number line". In this study, we address the question of whether magnitudes in nontemporal dimensions and magnitudes in time are represented independently or not. Observers judged the duration of the stimuli while four types of nontemporal magnitude information, including number of dots, size of open squares, luminance of solid squares, and numeric value of digits, were manipulated in Stroop-like paradigms. Results revealed that stimuli with larger magnitudes in these nontemporal dimensions were judged to be temporally longer. This observation supports the idea that magnitudes in temporal and nontemporal dimensions are not independent and implies the existence of generalized and abstract components in the magnitude representations.

Keywords: time perception, magnitude, Stroop effect

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Introduction

Magnitude information such as the number of apples in a basket, the size of a room, or the time it takes us to commute is a fundamental property influencing our decision making and behavior in daily life (Gallistel & Gelman, 2000). Given that magnitudes exist in many dimensions (e.g., length, size, weight, intensity, etc.), it is important to understand whether magnitude information in different dimensions is represented independently. A number of studies have demonstrated that numerical magnitude can be represented in a spatial manner on a "mental number line" (Dehaene, Bossini, & Giraux, 1993; Hubbard, Piazza, Pinel, & Dehaene, 2005) and that, in turn, number can influence performance on spatial cognitive tasks (Calabria & Rossetti, 2005; Doricchi, Guariglia, Gasparini, & Tomaiuolo, 2005; Fischer, Castel, Dodd, & Pratt, 2003; Kaufmann et al., 2005).

In addition to the close relationship between spatial size and number, new evidence also suggests a shared representation between symbolic and nonsymbolic quantities (Fias, Lammertyn, Reynvoet, Dupont, & Orban, 2003); between physical and numerical magnitudes for action (Andres, Davare, Pesenti, Olivier, & Seron, 2004); among number, size, and luminance (Pinel, Piazza, Le Bihan, & Dehaene, 2004); and between semantic and physical quantities (Cohen Kadosh & Henik, 2006). However, among diverse magnitude information, much less attention has been given to the temporal dimension. Although time is traditionally believed to be a fundamentally different perceptual dimension from space or quantity, there is growing evidence pointing to a relationship between magnitudes in time and nontemporal dimensions. For example, velocity of motion is found to influence time perception. Brown (1995) has shown that faster speeds lengthened perceived time to a greater degree than slower speeds. Judgments of duration are also found to be related with the intensity of visual stimuli. The later the increment of intensity occurs during the stimulus presentation, the judged duration tends to be shorter (Casini & Macar, 1997). In addition, the experience of time may be compressed together with space in scale-model environments (DeLong, 1981). Numerosity (Dormal, Seron, &

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Pesenti, 2006) and mental calculation (Brown, 1997) can interfere with duration judgment. Especially, the pattern of discrimination sensitivity to absolute (the size effect) and relative (the distance effect) difference is very similar in space, time, and quantity (Grondin, 2001; Pinel et al., 2004). These studies all implied the possible relationship between nontemporal, quantifiable dimensions and temporal information; however, existing studies either addressed the issue indirectly or suffer from potential confounding factors such as complexity, familiarity, and velocity of imputed motion (Jones & Huang, 1982; Schiffman & Bobko, 1974, 1977). More direct evidence is still needed to understand the mental representation of temporal magnitudes and its relation to magnitudes in nontemporal dimensions.

In this study, we investigated whether judgments of temporal durations can be influenced by magnitude information in nontemporal dimensions, such as quantity, size, luminance, and abstract magnitude information. A Stroop-like interference paradigm was adopted in duration comparison tasks to test whether interactions exist between magnitudes in time and nontemporal dimensions.

Method

Participants

Twenty-four healthy right-handed participants (12 men, 12 women) took part in all of the tasks of this study. Their age ranged from 20 to 29 years (M = 23.17 years). All have normal or corrected-to-normal vision. Written informed consent and ethical approval were obtained before the experiment.

Materials

Visual stimuli were presented on a computer screen for observers to make duration or temporal interval judgments (shorter vs. longer). Stimuli contained four types of task-irrelevant magnitude information in nontemporal dimensions (Figure 1). The first type of stimulus was a dot array composed of one, two, eight, or nine dots, and each dot was 0.5° in diameter. The second type of stimulus was open squares that were 0.8° × 0.8°, 1.2° × 1.2°, 3.0° × 3.0°, or 3.4° × 3.4° in size. The third type was solid squares of the same size but with the following luminance values: 2.03, 4.15, 69.55, or 142.49 cd/m^2. The fourth one was digits: 1, 2, 8, or 9, with a size of 1.5° × 2°. The labels "small" and "large" were assigned based on the number of dots, size of open squares, luminance of solid squares, and digit value, respectively, in each pair.

The durations paired in the experiment were 600/750, 650/812, 700/875, and 750/937 ms (all conforming to the shorter/the longer ratio of 1/1.25).

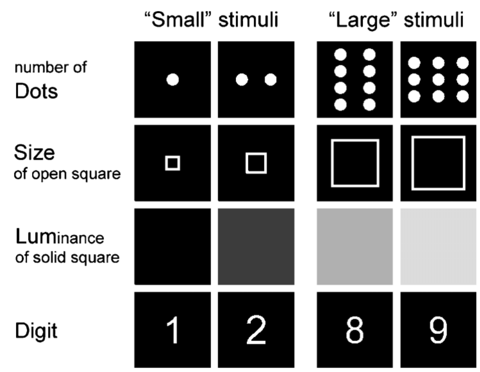

Figure 1. Four types of stimuli. Dot array: one, two, eight, or nine dots. Open squares: 0.8° × 0.8°, 1.2° × 1.2°, 3.0° × 3.0°, or 3.4° × 3.4° in size. Solid squares: 2.03, 4.15, 69.55, or 142.49 cd/m^2 in luminance. Digits: 1, 2, 8, or 9.

Procedure

Participants performed three duration judgment tasks between a pair of durations or intervals (Figure 2, Tasks A–C): Task A: which one of the two stimuli was presented for a longer (or shorter) duration; Task B: which one of the two intervals was longer (or shorter); Task C: which one of the two masks was displayed longer (or shorter). The shorter or longer durations defined by "small" or "large" stimuli generated two types of experimental conditions—congruent and incongruent. The congruent condition refers to the case in which a "small" stimulus was presented for a shorter time and a "large" stimulus was presented for a longer time (Figure 2, Task A) or to that in which a shorter interval was defined by two adjacent stimuli with a "small" difference in magnitudes and a longer interval was defined by two adjacent stimuli with "large" difference in magnitudes. Absolute magnitudes in the beginning and ending of intervals were balanced (Figure 2, Tasks B and C). The incongruent condition refers to the "small"/longer and "large"/shorter stimulus configurations.

Participants were told in advance that the visual pattern in the stimuli was irrelevant to the temporal judgment tasks. They were instructed to make their responses as quickly and accurately as possible. If the former time is longer (or shorter), press "J"; if the latter is longer (or shorter), press "K". The response keys were balanced within participants.

Results

A 2 × 2 (Magnitude ["small" and "large"] × Duration [shorter and longer]) repeated measures ANOVA was performed on the response error rate data across all

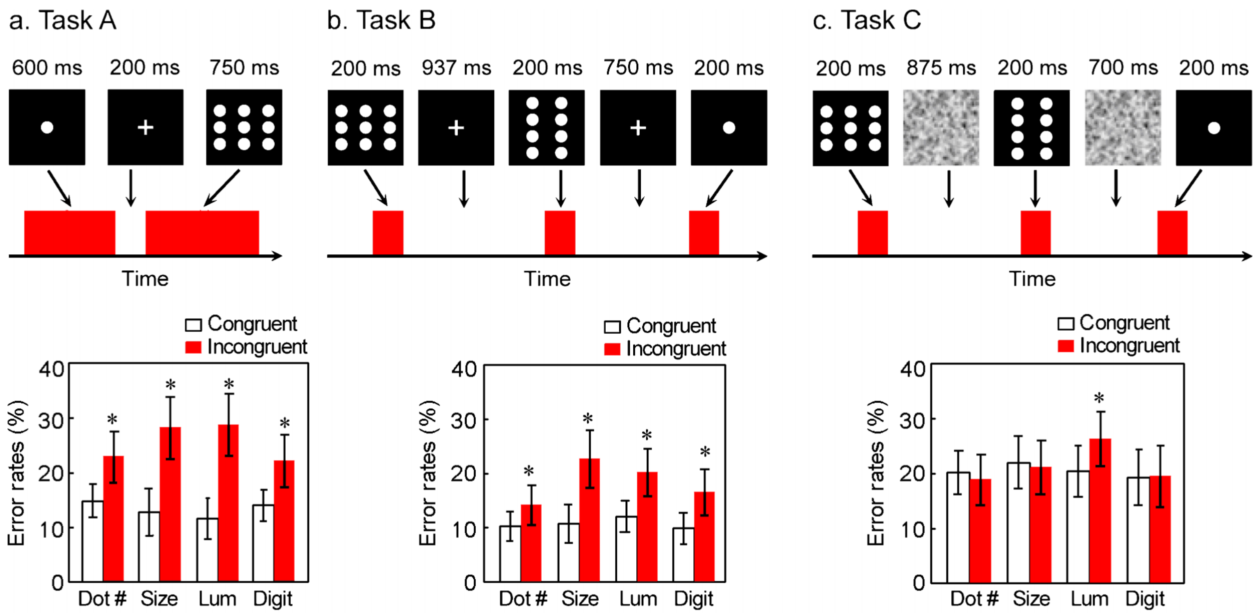

Figure 2. Task paradigms and behavioral performance. (a) A sample trial for the congruent condition in Task A, in which a one-dot stimulus ("small" stimulus) was presented for 600 ms (shorter duration) and a nine-dot stimulus ("large" stimulus) was presented for 750 ms (longer duration). The incongruent condition referred to the "small"/longer and "large"/shorter stimulus configurations. (b) A sample trial for the incongruent condition in Task B. Three stimuli were presented for 200 ms, respectively, defining two intervals among them. The magnitude difference between the first (nine-dot) and the second (eight-dot) stimuli was small ("1"), but the first interval was longer (937 ms); the difference between the second (eight-dot) and the third (one-dot) stimuli was large ("7"), and the second interval was shorter (750 ms). The congruent condition referred to the "small"/shorter and "large"/longer stimulus configurations. (c) A sample trial for the incongruent condition in Task C. The trial procedure was the same as that of Task B, except that a mask of random noise pattern was presented instead of a fixation cross. Participants made fewer errors in the congruent condition than in the incongruent condition for all of the four types of stimuli in both Task A and Task B. This congruency effect was absent (except for the luminance condition) in Task C. Dot # = number of dots; Size = size of open square; Lum = luminance of solid square. Error bars: 95% confidence interval. *$p < .005$.

participants. The statistical results showed no main effect of magnitude in all of the conditions in Task A, $F(1, 23) < 0.54$, $p > .46$, Task B, $F(1, 23) < 3.77$, $p > .06$, and Task C, $F(1, 23) < 1.60$, $p > .20$. The main effect of duration was present for the digits condition in Task A, $F(1, 23) = 5.35$, $p < .03$, and for the quantity, size, and luminance conditions in Task C, $F(1, 23) > 4.34$, $p < .05$. However, significant Magnitude × Duration interactions were observed for the four types of stimuli in both Task A, $F(1, 23) > 13.55$, $p < .002$, and Task B, $F(1, 23) > 11.27$, $p < .003$, but not in Task C, $F(1, 23) < 0.93$, $p > .34$, except for the luminance condition, $F(1, 23) = 9.97$, $p < .005$. In Task B, the interactions between duration and magnitude were not from the absolute magnitudes of the two stimuli defining the beginning and the ending of intervals, $F(1, 23) < 1.84$, $p > .18$, but from the difference in magnitudes defined by two adjacent stimuli.

To compare between the congruent and the incongruent conditions, we combined all of the data for the two conditions (congruent: "small"/shorter and "large"/longer; incongruent: "small"/longer and "large"/shorter), respectively (Figure 2). The results showed that participants performed better in the congruent condition than in the incongruent condition for all four types of stimuli in both Task A, $t(23) > 3.68$, $p < .002$, and Task B, $t(23) > 3.35$, $p < .003$. The congruency effect was absent in Task C, $t(23) < 0.97$, $p > .34$, except for the luminance condition, $t(23) = 3.16$, $p = .004$.

Discussion

Time is an elementary and ubiquitous dimension of our existence. In this study, we focused on time perception and its relations to nontemporal magnitudes. By using Stroop-like paradigms, the results revealed that the error rates of temporal judgment could be significantly affected by the magnitudes in nontemporal dimensions, including number of dots, size of open squares, luminance of solid squares, and numeric value of digits, and directly demonstrated the relationship of magnitudes between time and nontemporal dimensions. Despite the fact that the magnitudes were in four different categories with different forms and physical attributes, they showed very similar interference effects with temporal judgments. Additionally, the current stimulus design avoided potential confounding factors of complexity (Schiffman & Bobko, 1974), familiarity (Schiffman & Bobko, 1977), and velocity of imputed motion (Jones & Huang, 1982).

In addition, the error rates of temporal judgment can be affected not only by absolute magnitudes of the mentioned nontemporal dimensions in Task A but also by relative magnitudes from the difference between two adjacent stimuli in Task B. Given that magnitude in a nontemporal dimension is irrelevant to the experimental task, participants did not intentionally evaluate the magnitude values of the stimuli, nor did they compute the magnitude difference between the two stimuli. Thus, the results suggest that the magnitude information of a stimulus is processed somewhat automatically (Dehaene & Akhavein, 1995; Schwarz & Heinze, 1998; Schwarz & Ischebeck, 2003; Tzelgov, Meyer, & Henik, 1992). In contrast, the lack of an interference effect in Task C, except for the luminance condition, suggests that the interference of magnitude information is dependent on attending to the visual marker containing magnitude information. The random noise pattern blocked the maintenance and utilization of the magnitude information contained in the dot's number, size, and digits; hence, the participants relied more on the masks themselves to make their responses rather than on the endings and beginnings of the two stimuli. Inconsistent observations were reported in previous studies on interactions between luminance and other magnitudes (Cohen Kadosh & Henik, 2006; Pinel et al., 2004). Here, we show that luminance changes did exert effects on the duration judgment in all tasks including Task C, suggesting a potential quantifiable component in representing luminance as well as temporal magnitudes. For the luminance condition, because luminance difference could be perceived with little attentional resources (Irwin, Colcombe, Kramer, & Hahn, 2000; Theeuwes, 1995), the effect of luminance on duration judgment was not blocked by the random noise pattern.

It has been suggested that humans possess an innate "number sense" to quickly understand, approximate, and manipulate various quantitative forms and their interrelations with an analogical representation (Dehaene, Dehaene-Lambertz, & Cohen, 1998; Feigenson, Dehaene, & Spelke, 2004; Plodowski, Swainson, Jackson, Rorden, & Jackson, 2003). The mutual interactions between space and quantity extend the concept of "number sense" (Schwarz & Heinze, 1998; Schwarz & Ischebeck, 2003). Walsh (2003) also proposed "a generalized magnitude system" to summarize the common property of magnitudes in space, time, and quantity, and these magnitudes can be often represented as "how many, how much, how long, how far", and so forth. He suggested that the inferior parietal cortex is responsible for encoding the magnitudes in the external world that are used in action. Such a proposal is consistent with previous brain imaging studies. The inferior parietal cortex is found to be involved in magnitude processing in different dimensions such as digits and spatial size (Pinel et al., 2004), as well as time and intensity (Maquet et al., 1996). Thus, a common neural substrate seems to be indicated for the magnitude encoding of different dimensions. However, evidence supporting "a generalized magnitude system" has primarily come from the studies that only examined the numerosity and magnitudes in spatial dimensions. This study extends this line of research to more dimensions, especially the temporal dimension, which provides expanded and direct support for the existence of a generalized magnitude system, and will constrain any theory about magnitude representation in the human brain.

Conclusions

In this study, we reported Stroop interference effects from four types of nontemporal magnitudes on temporal comparison tasks. This observation implies a generalized and abstract component in the magnitude representations and provides significantly expanded support for the existence of a generalized magnitude system.

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