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RESEARCH****Research Report****Numerical magnitude modulates temporal comparison: An ERP study****Bin Xuan^{a,b}, Xiang-Chuan Chen^a, Sheng He^c, Da-Ren Zhang^{a,*}**^aDivision of Bio-X Interdisciplinary Sciences, Hefei National Laboratory for Physical Sciences at Microscale and Department of Neurobiology and Biophysics, School of Life Science, University of Science and Technology of China, Hefei, Anhui 230027, PR China^bDepartment of Psychology, Anhui Normal University, Wuhu, Anhui 241000, PR China^cDepartment of Psychology, University of Minnesota, 75 East River Road, Minneapolis, MN 55455, USA

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ABSTRACT

Time is believed to be a part of the generalized magnitude system just like space and quantity. Previous research suggests that time perception can be affected by magnitude in some non-temporal dimensions. Here we address two questions. First, could the influence be caused by an abstract magnitude component without perceptual variables? Second, what are the underlying mechanisms of the influence? Participants compared a pair of durations defined by two Arabic digits in a hundreds of milliseconds range. They performed more accurately when the shorter durations were defined by lower numeric value digits (small digits) and the longer durations were defined by higher value digits (large digits) than they did in the reversed condition. Event-Related Potential (ERP) results showed that the CNVs corresponding to the first duration (CNV1), to the second duration (CNV2) and the N1 were all enhanced when durations marked by small digits than that marked by large ones. Combining the electrophysiological data with the behavioral results, we suggest that digits can modulate performance of temporal comparison at the relatively early stage of perceptual processing. One possible explanation of the current results is that selective temporal attention and subsequent expectation may be involved in this modulation.

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1. Introduction

Time is a fundamental dimension of our existence. Processing of temporal information is crucial to many aspects of our daily lives, from our sleep–wake cycle to speech recognition, music perception and skilled motor control, even just waiting an upcoming event (Buhusi and Meck, 2005). We can experience time across a wide range of intervals, but often represent and estimate it subjectively with limited precision, especially in a hundreds of milliseconds range, for its susceptibility to many environmental factors and cognitive processes.

Time is traditionally believed to be a fundamentally different perceptual dimension from space or quantity. However, increasing evidence indicates that perceiving temporal magnitude may not be an independent or specialized neural process, but has close relationships with perceiving other magnitude dimensions in the generalized magnitude system (Walsh, 2003). Take “the Tau effect” as an example, when three points on observer’s forearm were stimulated in succession to define two spatial and temporal information, Helson found that the judgments of relative positions were high correlated with the relative intervals. If the temporal interval between

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stimulating the second and third points was greater than that between the first and second, observers were inclined to report that the tactile spatial distance between the second and third points was greater than that between the first and second, though in fact it might be equal or less (Helson, 1930). Similarly, the judgments of temporal intervals between two stimuli were also reported to depend on their spatial relations (Cohen et al., 1953). It was even observed that the experience of time is compressed together with space in scale-model environments (DeLong, 1981), which reflects the psychologically interdependence between magnitude information in spatial and temporal dimensions. Electrophysiological, neuropsychological and further behavioral studies all implicate the possible spatial-related timing mechanisms (Basso et al., 1996; Buonomano and Merzenich, 1995; Grondin, 1998; Johnston et al., 2006). On the other hand, the relationships between perceiving time and magnitude in other dimensions were also observed. Dormal et al. found that judging the duration of dot sequences is influenced by the irrelevant number of dots (Dormal et al., 2006). Our previous study also suggest the error rates of temporal judgment could be significantly affected by the magnitudes in non-temporal dimensions, including number of dots, size of open squares, luminance of solid squares, and numeric value of digits (Xuan et al., 2007). In addition, quite a few research also demonstrated that number, another part of the proposed generalized magnitude system, and space are also close related. Dehaene et al. made the pioneer studies of this domain. They put forward “number sense” — a domain-specific, biologically-determined ability (Dehaene et al., 1998), but they also indicated that numbers can be represented and manipulated on a “mental number line” (Dehaene et al., 1993). This analogical spatial representation robustly influences the performance of many spatial cognitive tasks, such as magnitude comparison (Pinel et al., 2004), target detection (Fischer et al., 2003), line and number bisection (Doricchi et al., 2005; Fischer, 2001) etc.

Based on the mentioned evidence, Walsh proposed a common magnitude concept. The magnitude concept is rooted in people’s need for information about the nature of the external world, and it is often represented as “how many, how much, how long, how far and how fast” with shared metric, processing resources and behavioral goals (Walsh, 2003). However, there still remain disagreements on the relationship between time and magnitude in other dimensions until recently (Lewis and Walsh, 2005). First, some research indicates that short time on the scale of tens to hundreds of milliseconds may not be encoded explicitly as a metric (Burr and Morrone, 2006). Second, it is still a question whether there is an abstract and generalized magnitude component influence time perception. Specifically, the magnitude component is irrelevant to any perceptual variable, such as complexity, luminance, velocity of imputed motion or spatial attention shift (Cohen et al., 1953; Jones and Huang, 1982; Schiffman and Bobko, 1974; Schiffman and Bobko, 1977). To avoid these possible interferential factors, in the present study, Arabic digits were selected to mark durations in a temporal comparison task, and the control stimuli were also used to match any confounding physical parameter. Our first concern focused on whether the subjective time perception is affected by

abstract symbols bearing magnitude meanings such as Arabic digits, and whether the influence is independent of perceptual variables.

If digits did modulate the subjective time perception, the underlying mechanisms of the modulation naturally became our next concern. Lots of studies have indicated that time perception is intimately related to the level of attention (Grondin, 2001; Macar et al., 1994; Perbal et al., 2003; Pouthas and Perbal, 2004; Seigniny et al., 2003). Both the accuracy (Coull et al., 2004) and the length (Tse et al., 2004) of subjective time perception can be influenced by attention resource deployment. What is more, Nobre, Coull and their colleagues simultaneously explored two fundamental cognitive functions: selective attention and processing of time. They gave a great impetus to the study of orienting attention to time. Similar to attention in spatial domain, a series of delicate experiments demonstrate that attention in the temporal domain can be directed to certain time point of an upcoming event intentionally, which is named as selective temporal attention (Coull and Nobre, 1998). With a modified Posner’s paradigm (Posner, 1980), it was found that subjects can make use of valid temporal cues to correctly predict specific time points in high proportion, effectively improve the performance of target detection and accuracy of predictable temporal information (Correa et al., 2006b; Nobre, 2001).

In the mentioned studies, cues were originally meaningless. The meanings of cues were set up through the proportion of correct predictions. However, digits themselves can convey meanings of magnitude. Fischer et al. investigated the use of digits as cues for the detection of lateralized spatial targets. They found that digits can direct spatial attention to the left or right of visual space (Fischer et al., 2003). Similarly, we suspected that digits might play a role of “temporal cue” in the present experiment. That is, digits may direct subjects to deploy attention to a certain time point according to their numerical magnitude. Small digits orient attention to early points in time, and large digits orient attention to late points in time. Based on this hypothesis, if small digits marked shorter duration, large digits marked longer duration, then subjects would establish valid time attention to expect the target — the ending of duration. That is, subjects would expect target arrived earlier with small digits and later with large digits, and it was consistent with this kind of experimental condition; In contrast, if large digits marked shorter duration and small digits marked longer duration, time attention would be invalid. That is, subjects generate a reversed expectation induced by digits as compared with this kind of experimental condition. The valid or invalid time attention would influence the accuracy of temporal comparison. To further validate the hypothesis, we use Event-Related Potential (ERP) to monitor the brain activity. ERP investigation is appropriate to track on-line the dynamic modulation processing of time perception for the high temporal resolution (Macar and Vidal, 2004). If temporal attention did mediate the influence, we can expect that the related ERP components, such as CNV were modulated by digits, since some previous studies indicated that CNV component was related with time attention and the expectation of the upcoming event (Griffin et al., 2002; Miniussi et al., 1999). The combined behavioral performance and the related

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