

## **The effect of processing load and task difficulty on duration discrimination in temporal memory**

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**Abstract:** It remained to be identified that increasing processing load would result in higher variance in temporal information process. The roles of memory and task difficulty in duration discrimination were investigated in auditory and visual modality in this study. Participants were asked to judge whether or not comparison duration was standard duration under four loading conditions. Results revealed that increases in standard duration in memory within blocks led to more discrimination errors, but increases in modality did not. More importantly, this memory loading effect on duration discrimination varied with the difficulty levels. Results confirmed central roles of memory and task difficulty in temporal information processing. Finally, the modality effect was significant, with discrimination being better with auditory signals than visual ones in each of the four loading conditions, which was attributed to the mechanism of modality.

**Keywords:** processing load, task difficulty, sensory modality, memory, duration cognition.

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### **INTRODUCTION**

Temporal cognition is a central issue in psychological research. Several psychological models or theories have been adopted to explain how temporal information can be processed in humans [1-4] such as clock model, cognitive model, attentional model, optimal timing, scalar timing model. It remains to be identified that increasing processing load in temporal information processing would lead to higher discrimination error. Generally speaking, the focus of divergence of opinions is on the internal and external factors. Internal factors focus on cognitive processes such as demands on memory and attentional capacity or resources sharing, while external factors emphasize on the influence of external environmental stimulus such as structure and patterning of sensory events on perception, attention and memory [5,6] Presently, attention and memory are two main internal cognitive components, which are argued to interpret processing loading effect.

Attention plays an important role in temporal information processing. Research on the attentional model assumes that attention is a limited-capacity system, and sharing of attentional resources between temporal and nontemporal tasks would affect temporal cognition. Thus, less attention resources are available to each of two or more tasks to be processed simultaneously. If more attention resources are available for temporal tasks, then time is perceived as being longer and better discrimination performance is

attained. Most empirical studies on human timing were conducted under a typical dual-task paradigm where more attentional demands are available for non-temporal tasks to show the central role of attention in temporal information processing [7-15]. For example [6], investigated the role of attention in temporal reproduction in two experiments. Participants were asked to reproduce the durations of melodies (from folk tunes) with either a coherent or an incoherent event structure in experiment 1; in experiment 2, participants reproduced the durations of auditory prose passages represented in a series of mental workload and event structure. The Experiments were conducted under two loading conditions: control (timing only) and detection (timing and target detection). Results revealed that reproductions were shorter and more inaccurate for the detection condition than for the control condition, which is argued to show the central role of attention in temporal processing.

Generally speaking, research on effect of attention on temporal information processing asks participants to allocate a certain amount of attention to each of two or more tasks to be processed simultaneously before each trial. Since attentional resources are limited and unequally distributed, there is competition between tasks, which leads to differences in task performance. Doubts about the role of attention were proposed. A task was first kept for a moment, then, a subsequent task is performed, so the difference in task performance results from memory not attention. Thus, a new

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psychological theory is developed to explain temporal processing.

Scalar expectancy theory (SET) was originally proposed by [16] as an explanation of the performance of animals on timing behaviour tasks. In the present decade, however, SET has been a popular model for explaining human timing [1,17,18]. There are essentially three components in SET: a clock, consisting of a pacemaker and an accumulator; a memory mechanism, consisting of work and reference memory; and decision. And timing behaviour in humans depends on an interaction of processes between these three components [19,20]. There are two fundamental features in SET. One is that the mean representation of time when a series of temporal judgments are made equals real time; the other is that the variability of temporal judgment or estimation increases linearly with mean representation of time, which constitutes the basic scalar property: the ratio of variability to mean time is constant as Weber's law [5, 1].

To examine specifically the mechanism and characteristics of the different parts of SET, studies investigated the operating mechanism and features of the three components by manipulating successfully each of them separately while keeping the others constant [17,18, 20-23]. The results supported the hypothesis on three parts of SET framework commendably.

According to SET, memory plays an important role in temporal processes. Working memory (short-term memory) is required in temporal judgment or estimation, but it has a severely limited-capacity system just like attention [24-27]. Here, the term capacity limit refers to the phenomenon that task performance declines rapidly with an increase in tasks to be remembered. Many studies showed that, by manipulating the number of standard durations in memory demand, the temporal performance accuracy reduced significantly with an increase in memory loading [18, 28-31]. For instance, [5] investigated the role of memory in duration judgment. Participants kept the standard intervals marked by two 20-ms sensory signals (either visual or auditory) for a while under four loading conditions (the number of standard intervals and modality types increased from loading condition 1 to 4), then were presented with a series of comparison intervals around standard interval (e.g. the comparison intervals were 200, 220, 240, 260, 280 and 300 ms when the standard duration was 250 ms) and asked to judge whether they were longer or shorter than the standard interval. The results revealed that more discrimination errors were committed as the level of memory load increased within blocks of the same modality, which supported the hypothesis that memory is a major source of variance in temporal information processing.

Under a typical dual-task paradigm, attention is a major factor affecting temporal processing. When the

presence of two or more task to be processed simultaneously forces individuals to allocate attentional resources between them, task performance declines quickly as less attention is available for each one [31]. Nevertheless, when two or more tasks are presented separately and successively, attention is clearly not sufficient to explain the timing changes in performance under multiple loading conditions. Because tasks are processed separately and successively not simultaneously, there should be no attentional resource distribution and competition between tasks at the processing stage. Therefore, the difference of performance will need an alternative theoretical explanation: memory. For example, processing more than one task in temporal reference memory results in some kind of interference between the different tasks, another possibility is that processing multiple tasks in temporal reference memory needs some resource-limited rehearsal, thus, the second task interferes with the rehearsal process for the first one [18]. SET emphasizes that memory is a main factor affecting temporal processing, so the popular explanation of these findings depends on memory capacity.

Most previous studies on the processing loading effect have been conducted to illuminate the critical role of internal cognitive components on temporal information processing, regardless of external factors, especially in regard to the complexity of stimuli. Moreover, some experimental evidence finds increasing memory load can't influence the duration discrimination [17,32]. Recently, studies show that task difficulty is an important factor in temporal judgment. Here, task difficulty refers to the difference between standard stimulus and comparison stimulus. If the difference is less, standard stimulus is more difficult to distinguish from comparison stimuli, and more discrimination errors are committed [33] found that memory loading effect (the number-of-standard effect) on discrimination varied with the difficulty of task when stimuli to be judged were presented in the left visual field, with duration judgment being better in the 4-standard than in the 2-standard at the most difficulty level, and with discrimination being better in the 2-standard than in the 4-standard condition at easy and middle difficulty levels.

Additionally, external factors such as number of modality, processing mechanism, strategy, individual trait, can also affect temporal cognition. [34] reported that characteristics of stimuli, number of modality, and gender can influence time succession threshold. A study on the cognitive characteristics of Min-duration estimation found that the duration of cognition was affected by different processing and retrieval mechanisms [35]. A review on individual differences in temporal information processing in humans indicated that the processing of temporal information can be influenced by various subject-related factors, such as

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age, gender, developmental disorders, auditory experience [36]; see also [37-40] found that there were more discrimination errors in the intervals marked by long signals (e.g. 500ms) than by short signals (e.g. 10ms).

Studies on modality effect found that the duration judgment marked by auditory signals was significantly better than by visual ones [41, 42]. However, [5] reported in an experimental study on memory loading effect that neither sensitivity nor the perceived duration was influenced by mixing two marker types within one block. In other words, there was no significant modality effect. Researchers in support of modality effect argued that the difference of duration cognition in modality types is attributed to multiple factors, out of which modality features (e.g. timing and threshold), experimental materials (familiarity), memory, experimental design seem to be important [41-45].

Some psychological models or theories mentioned early demonstrate the effect of the processing load on temporal cognition from different perspectives, however, there exists divergence of opinions between them. The main difference is that whether or not single model (e.g. attention and memory) can explain processing loading effect effectively. According to our reviews, we suppose that processing loading effect is influenced by not only internal cognitive processes but also external factors. In the present study, we will investigate the role of memory and task difficulty in temporal memory by using the strategy—increasing memory load—adopted by [5]. Most previous research explores possible effects of increasing memory load in the memory component of the SET. Although few studies have been conducted to examine indirectly the critical role of task difficulty in temporal memory loading effect [33,17] more direct evidence for the critical of task difficulty on temporal memory loading effect remains to be identified, especially in regard to the influence of memory processes and task difficulty on temporal memory loading effect. According to our hypothesis, we predict that increasing memory load within the same modality would lead to more discrimination errors, and this memory loading effect on duration discrimination varied with the difficulty levels; but mixing the number of modality-type durations would not affect temporal discrimination. And we also predict the modality effect was significant, with discrimination being better with auditory signals than visual ones. Finally, we anticipate that memory and task difficulty would affect temporal memory loading effect together.

## **METHOD**

### **Participants**

Twenty 21- to 36-year-old volunteer students (10 men, 10 women) with normal visual and auditory acuity at Southwest University, Chongqing, China,

participated in the study. The students (mean age = 20.3 years) were paid 4\$ (RMB. 30¥) after the experiment.

### **Stimuli and Apparatus**

Two TCL B6000 (compatible) computers controlled whole experimental processes. The durations to be discriminated were produced by computer. The visual stimuli were marked by circular white flicker (diameter = 1cm); and the auditory stimuli were 500Hz tones with an intensity of about 60 dB, which were presented binaurally through headphones (DEGEN, DE925). The program used to control the experiment and record data was written in E-prime language (Psychology Software Tools, Inc. Learning Research and Development Center, University of Pittsburgh) with millisecond accuracy for timing of stimuli and responses. The participants finished experiment through manipulating keyboard.

### **PROCEDURE**

There were four independent variables in the experiment: the type of standard duration, the type of modality, memory loading condition, and the level of difficulty. There were two standard durations: 300 and 900ms. The type of modality was visual (V) and auditory (A). According to our pilot experiment, we established three levels of task difficulty: plus and minus 10, 20, or 30% of the standard duration value. In other words, for the 300ms standard duration, the three levels of difficulty were 270 and 330ms, 240 and 360ms, and 210ms and 390ms, respectively. For the 900ms standard duration, the difficulty values were 810 and 990ms, 720 and 1080ms, and 630 and 1170ms. There were four loading conditions [5], 1) one of the four kinds of trials per session, entailing four experimental conditions (one for each of the four sessions); 2) the modalities (from the four kinds of trials) randomize within one session, yielding two experimental conditions (two sessions at 300ms, two at 900ms); 3) the two standard durations (from the four kinds of trials) randomize within one session, yielding two experimental conditions (two sessions at A, two at V); and 4) all kinds of trials randomize within one session (i.e., one experimental condition repeats in four sessions).

There were four sessions for each loading condition, a total of 16 sessions. Each session lasted 8-10 min and involved 6 blocks. Each block included 8 trials. In loading condition 1: there were 1 repetition of each of the six comparison durations (from three levels of difficulty) and 2 repetitions of each of two standard durations in a random order within one block; in loading condition 2 and 3: there was 1 repetition of each of the comparison duration of each level of difficulty and 1 repetition of each of two standard durations in a random order within one block; in loading condition 4: there was 1 repetition of each modality and each

comparison duration of each level of difficulty and each of two standard duration in a random order within one block (Latin square arrangement).

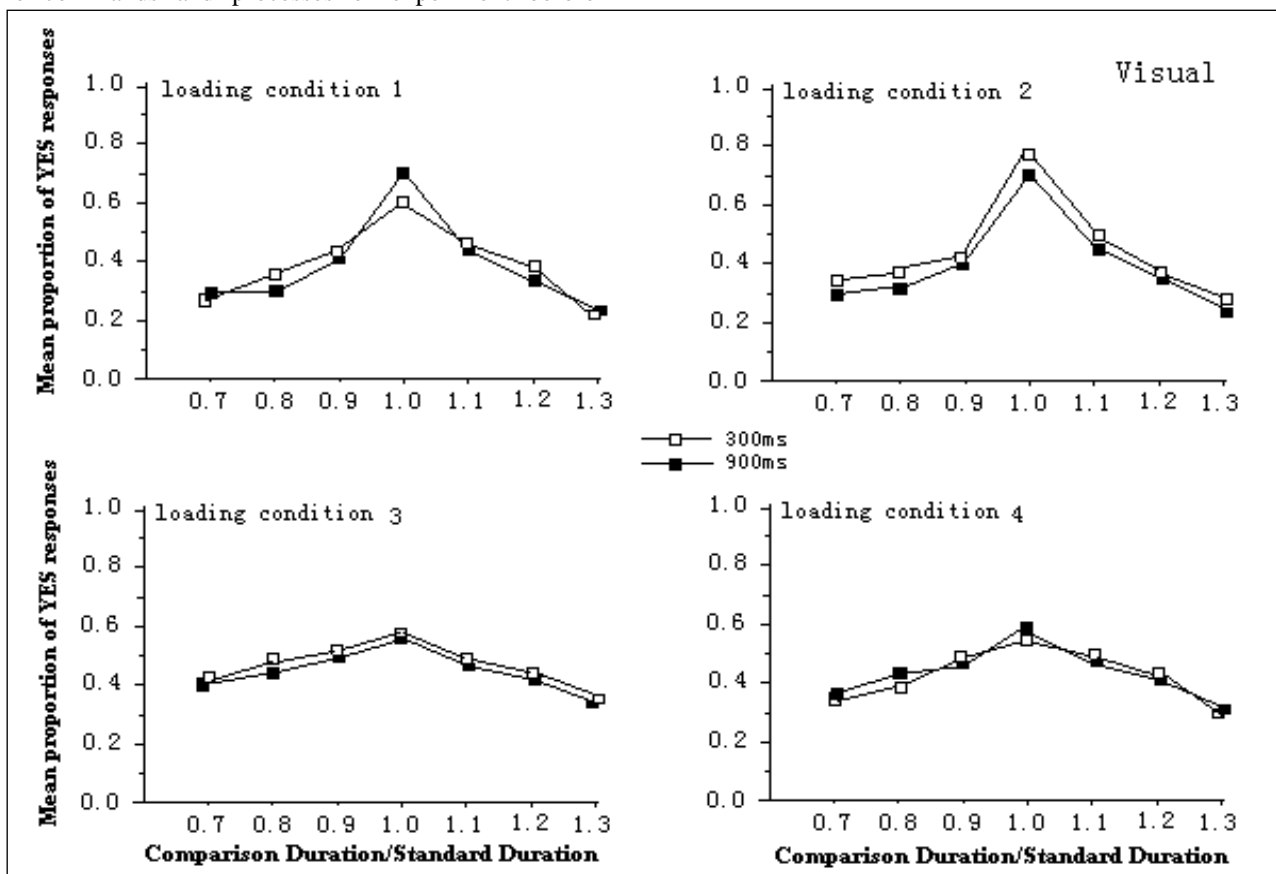
Single-stimulus method was used [5, 17]): each trial was presented with only one duration presentation. All the participants were conducted through the four sessions of each of the four loading conditions one after another. And the sequence effect was eliminated in modality and standard duration. The participants were presented with standard duration and asked to remember its lasting time, then presented with a series of comparison durations (including standard duration). After comparison duration presentation, participants were asked to judge whether or not the comparison stimuli had the standard duration, making a “1” (Yes) or “0” (No) response on the keyboard. A 1.5-s feedback signal indicated whether the judgment was right is presented 200-ms after the response, followed by a 500ms inter-trial interval. There was 20-30min rest between loading conditions.

Participants practiced for a while, until they knew the commands and processes of experiment before

experiment. And they were told whether different standard durations and types of modality would be presented before each session.

## RESULTS

Figure 1 shows that the scalar property—the mean proportion of YES responses (judgment of a comparison duration as the standard duration)—in timing of short durations in auditory and visual modality plotted according to a ratio of comparison/standard duration. The results suggest that the maximum mean proportion of YES responses occurred when the comparison duration was standard duration; while the minimum mean proportion of YES responses appears at the easy level of task difficulty, which shows that the more the difference between comparison and standard duration is, the easier the discriminations is. Additionally, the superimposed features in function change with the different loading conditions in auditory and visual modality, with the scalar property being more significant with auditory durations than with visual ones.



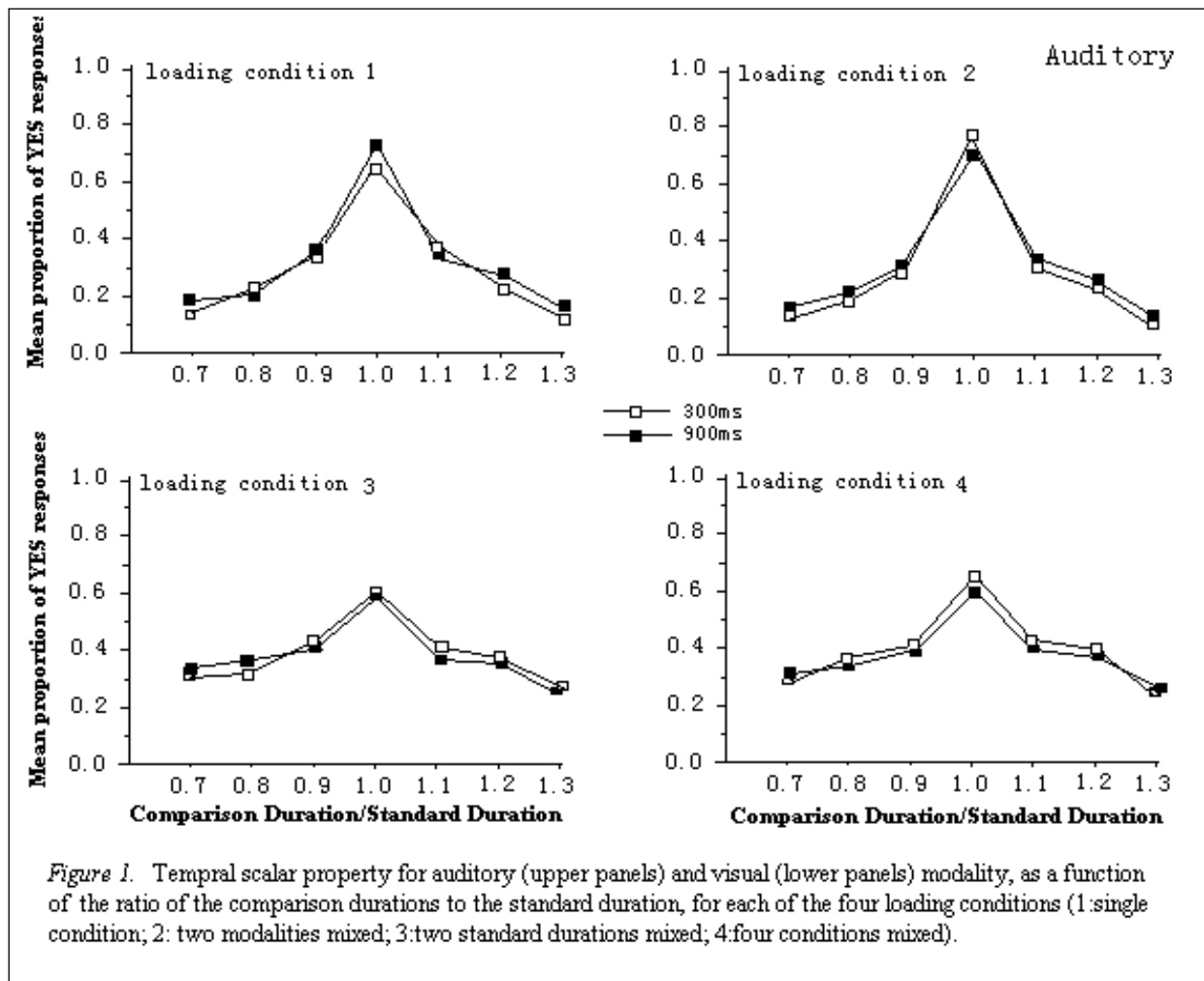


Figure 1. Temporal scalar property for auditory (upper panels) and visual (lower panels) modality, as a function of the ratio of the comparison durations to the standard duration, for each of the four loading conditions (1: single condition; 2: two modalities mixed; 3: two standard durations mixed; 4: four conditions mixed).

Table 1 shows that the mean accuracy—a probability of the frequency of the correct judgment (the comparison duration was not standard duration)—in each experimental condition. In general, the mean accuracy varied with the different levels of task difficulty and loading conditions. It was very easy to

make a judgment at the easy difficulty level regardless of intensity of processing load. Moreover, there was a significant difference between auditory and visual modality, but there was little difference between two standard durations for each experimental condition.

Table-1: Mean accuracy (and standard deviation) for each experimental condition

modality	standard duration	difficulty level	loading condition			
			1	2	3	4
auditory	300	1	.64 (.06)	.64 (.04)	.56 (.04)	.53 (.04)
		2	.77 (.09)	.78 (.04)	.71 (.05)	.70 (.05)
		3	.74 (.09)	.75 (.05)	.74 (.05)	.74 (.05)
	900	1	.65 (.06)	.61 (.05)	.58 (.02)	.54 (.03)
		2	.78 (.08)	.76 (.04)	.71 (.03)	.71 (.03)
		3	.74 (.06)	.75 (.05)	.74 (.03)	.73 (.05)
visual	300	1	.59 (.06)	.54 (.06)	.51 (.05)	.46 (.05)
		2	.69 (.07)	.70 (.04)	.66 (.04)	.68 (.04)
		3	.69 (.07)	.64 (.05)	.67 (.04)	.72 (.03)
	900	1	.59 (.06)	.56 (.03)	.52 (.04)	.47 (.04)
		2	.71 (.07)	.71 (.03)	.68 (.04)	.69 (.03)
		3	.68 (.08)	.70 (.07)	.68 (.05)	.67 (.03)



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A  $2 \times 2 \times 4 \times 3$  ANOVA with repeated measures on mean accuracy revealed that there was a significant modality effect,  $F(1, 19) = 164.303, p < .01$ ; however, the type of standard duration effect was not significant,  $F(1, 19) = 1.096, p = .308$ . The results also revealed that there was a significant difficulty level effect,  $F(2, 18) = 2180.63, p < .01$ , and the processing loading effect was significant,  $F(3, 17) = 14.147, p < .000$ . Most importantly, there was a significant processing load and task difficulty interaction effect,  $F(6, 14) = 18.921, p < .01$ , and the modality, processing load and task difficulty interaction is significant,  $F(6, 14) = 8.133, p < .01$ . None of the other main effect or interaction was significant.

Because the modality effect was involved in the significant interaction effect, we conducted a  $2 \times 4 \times 3$  ANOVA with repeated measures on each modality. The results revealed that there existed significant processing loading effect and difficulty level effect both auditory and visual condition, but there was not a significant standard duration effect. Most importantly, the processing load and task difficulty interaction was significant regardless of type of modality.

To examine the effects of variability in different processing loading conditions, we made an analysis of variance in four loading conditions. Firstly, a  $2 \times 2 \times 2 \times 3$  ANOVA with repeated measures on loading conditions 1 and 2 was investigated. The results uncovered that there was a significant modality main effect,  $F(1, 19) = 118.207, p < .01$ , and significant task difficulty main effect,  $F(2, 18) = 392.068, p < .01$ ; there was no significant processing loading effect,  $F(1, 19) = 1.427, p = .247$ , but there was a significant interaction between processing loads and task difficulty levels. None of the main effect and interaction was significant. Secondly, a  $2 \times 2 \times 3 \times 3$  ANOVA with repeated measures on loading conditions 1, 2 and 3 was compared revealed that the findings replicated the loading conditions 1 and 2 except that processing loading main effect was significant,  $F(2, 18) = 15.144, p < .01$

Because there was a processing load and task difficulty interaction in different loading conditions, it was necessary to identify the processing loading effect for each task difficulty level. A  $2 \times 2 \times 4$  ANOVA with repeated measures on each difficulty level uncovered that, at the most difficulty level, the modality main effect was significant,  $F(1, 19) = 130.993, p < .01$  and, the processing loading main effect was significant,  $F(3, 17) = 48.519, p < .01$ ; at the middle difficulty level, modality main effect was significant,  $F(1, 19) = 84.14, p < .01$ , and processing loading main effect was significant,  $F(3, 17) = 11.105, p < .01$ ; the modality effect was significant,  $F(1, 19) = 85.248, p < .01$  and, processing loading effect was not significant,  $F(3, 17) =$

.118,  $p = .948$ . None of the other effects were significant.

## DISCUSSION

The purpose of the study was to investigate the role of memory and task difficulty in temporal memory to determine to what extent the memory processes influenced duration discrimination in the different modalities. The experimental results showed that there existed significant modality effects in discrimination, and more importantly, the memory loading effect in discrimination varied with task difficulty levels, which indicated that memory was not only source of variance affected temporal information processing.

### Temporal scalar property

Scalar feature in timing is SET's basic characteristic, which shows that when the variability of temporal judgment is reported on the same relative scale, it should superimpose in function. The scalar property was observed in part from the data in the present experiment. It was clearer in two standard durations than one, which was partly consistent with previous findings [17] reported in a series of experiments that when the feedbacks were given, the temporal generalization gradient superimposed in the 5-standard condition, while not in the 1 and 3 standards [5] found that the functions superimposed in one standard duration rather than two durations. The probabilities of the differences were attributed to various factors. One is memory. In SET, memory process consists of two components: working memory and reference memory. The mechanisms of the two sorts of temporal memory might still be identified [46]. Second is individual personality. Personality is a hot issue recently. As mentioned earlier, many subject-related factors can affect temporal information processing. The distinctiveness of temporal memory might be more obvious. Thirdly, the nature of stimuli is also important. The difficulty levels and the scalar sizes might influence temporal generalization gradient [33]; [17]. Finally, maybe the most interesting factor is the number of repeated presentations of standard [17] conducted a number of computer simulations of temporal generalization performance in AVE (average) and SAM (sampling), in order to explore the effect of the number of presentations of the standard theoretically. The results revealed that the effect of standard durations varied with the repeated presentations of the item.

### Type of standard duration

Attention is a critical variance in processing load of temporal duration under the dual-task paradigm, while applying the separate-stimulus procedure in the context of duration memory loading research, with no competition in attentional resources, so attention can't explain available temporal memory loading effect. But

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there exist other theoretical probabilities: one is the stimuli order to be processed [18], another is attentional lasting time for each stimulus. In this experiment, the stimuli order to be presented was controlled seriously. The results uncovered there was no significant standard duration effect for each experimental condition. In other words, the task performance was not influenced by the type of standard durations (e.g. 300ms and 900ms). This finding is consistent with previous studies on this issue [40],[18] In general, the duration discrimination was not affected by the processing lasting time, which indicated that attention played no critical role in temporal memory load in the present study.

### **Type of modalities**

The results showed that there was a significant modality effect both 300ms and 900ms standard duration, with the discrimination being better in auditory than in visual modality, which is consistent with the results obtained in other literatures [47, 40, 42, 44, 45]. Another fact related with modality effect should be emphasized. The difference in modalities changed with processing load and task difficulty level, with a larger difference at the most difficulty level and more processing loading condition. The findings were explained from various perspectives. For example, one is the nature of modalities itself, maybe most importantly. According to Weber' fraction, the differential threshold in auditory modality (1/30) is lower than in visual one (1/60), thus, for the same differential stimuli (e. g. 30ms or 60ms in this experiment), the discrimination with auditory modality is much better than with visual one. Of course, if the auditory and visual modality placed on a fair position such as the same differential threshold (the studies on modality effect were not involved in this aspect), probably, the modality effect would disappear. Memory is another important explanation [49] suggested that the modality difference in the discrimination of short durations would in part rely on the efficiency of temporal memory process; [48] also showed that time memory seems to have a close relationship with auditory system (see also [5]. Finally, subjective experience is also a possible reason. The sensitivity and the consolidation of representation of memory in auditory modality would increase by long time training. For instance, the philharmonic amateurs and the individuals who learn the foreign language with difficulty, after training, might achieve a higher performance with auditory modality than visual one. Certainly, a lack of evidence supports the contribution of these factors. Further research should investigate their role.

### **Processing load and task difficulty**

Just as mentioned previously, the temporal processing loading effect is influenced both by internal cognitive processes and external factors [3] suggested that temporal information processing was determined

by various factors such as event structure, attentional resource, coding, strategy, motion, and not explained effectively from only one perspective. The data from this experiment uncovered that, under the different processing loading conditions, there was a significant processing loading effect within the same modality but no modality effect within the same standard duration, which agrees with many findings [28,18,5,6,8], however, this effect was affected by task difficulty levels simultaneously. [5,48] found that there was also no multiple-modality effect. The results were explained in terms of SET. This model emphasizes that multiple-duration effect depends on memory. For the limited capacity of duration working memory, enhancing the number of standard durations increases the number of representations of durations in memory, thus, the loading effect on memory process results in more discrimination errors. And yet, failure to observe the multiple-modality effect can be interpreted by the transfer for the same duration. The same duration shares the same representation, and different durations require different representations of durations. Therefore, sharing the same representation would be the reason why increasing the load of modality did not influence discrimination accuracy significantly.

Nevertheless, the results also revealed that the processing loading effect changed with task difficulty levels within the same modality, with processing loading effect being larger at the highest difficulty level than at the middle or easy difficulty level. More wondrously, the processing loading effect disappeared at the easy difficulty level. The literature on this issue also supported this finding [17, 33, 6]. This phenomenon can be attributed to nature of stimulus. When the difference between standard and comparison stimulus was much larger (e. g. 300ms vs 390ms), the participant perceived this difference easily, and gave a correct judgment. Even though the processing load increased, the discrimination errors can't decline rapidly, thus, the processing loading effect exhibited faintly; on the contrary, when the difference was minimal, the discrimination accuracy reduced quickly even if there was a no processing load. So the loading effect showed clearly.

The effect of processing load on interval discrimination is one of the focus questions in temporal memory literatures. Generally speaking, the loading effect is argued to depend on various theoretical models of psychological timing, for example, framework version of SET. But SET only emphasizes the central role of internal cognitive process regardless of the regulative role of external factors, therefore, SET, just as attention, is obviously not sufficient to explain the performance variability resulted from increasing memory load. This study indicated that, we can't eliminate the role of memory because the memory load effect changed with the processing load; however, we

can't also emphasize the role of memory excessively because the processing loading effect disappeared at the easy difficulty level. Thus, the critical role of memory in processing loading effect was restrained from task difficulty levels [17] examined the role of reference memory through three experiments in which participants were presented with 1-, 3- and 5-standard duration, then asked to judge whether or not the comparison was standard duration. In addition to task difficulty levels, the three experiments were similar. The results revealed that the performance in timing was not influenced by the number of standard durations.

This study investigated memory loading effect by the effect of memory (manipulating processing loading conditions) and the nature of stimuli (task difficulty). The results confirmed that the importance of memory and task difficulty in duration discrimination, which indicated that there was no sense if we only used the internal cognitive processes rather than external factors to explain the effect of temporal memory load [3] showed that temporal information processing was affected by various factors. It is difficult for a single model to explain the performances in timing behaviour in humans [6] found that the mental workload and event structure influenced time judgments separately and in combination.

The findings of this study supported the fact that temporal cognition is a complex process influenced by multiple different factors. Further research should explore the effect of sorts of factors on temporal processing synthetically to determine their function. A future important task is that, for researchers, a new model of psychological time should be developed to understand the characteristic, nature and mechanism of human temporal information processing.

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