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THE EFFECT OF THE PRESENCE VERSUS ABSENCE OF CONCURRENT TASKS  
AND CONTROLLED ATTENTION SHARING ON SUBJECTIVE TIME ESTIMATES

by

Chris N. Kladopoulos

A dissertation submitted to the Graduate Faculty in  
Psychology in partial fulfillment of the requirements for the  
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## Abstract

THE EFFECT OF THE PRESENCE VERSUS ABSENCE OF CONCURRENT TASKS  
AND CONTROLLED ATTENTION SHARING ON SUBJECTIVE TIME ESTIMATES

by

Chris N. Kladopoulos

Adviser: Professor Nancy S. Hemmes

The effect of concurrent memory tasks on prospective time estimates was investigated. In order to deter participants from using self-paced counting to scale duration, they were required to perform a word-reading task during the temporal stimulus. In each experiment, participants estimated the duration of 40- and 60-s stimuli. In Experiment 1, the presence versus absence of three concurrent memory tasks (estimating the number of words, recalling words and recognizing words) was manipulated. Time estimates were shortened by the word-reading task, compared to a no-task-control condition. Under the word-reading task, time estimates were unaffected by the presence versus absence of the memory tasks. Measures of word recall and word recognition were greater when participants were instructed to perform those tasks prior to stimulus presentation (prospectively) versus following stimulus presentation (retrospectively). Estimates of the number of words presented were lower when participants performed the tasks

prospectively versus retrospectively. In Experiment 2, participants performed a word-reading task, while instruction to focus on timing or on a word-memory task was manipulated. Results showed that time estimates were longer, and more accurate, when participants were instructed to focus on timing versus word memorization. Measures of word recall and word recognition were greater when participants were instructed to focus on word memorization rather than on timing. In both experiments, time estimates were positively correlated with estimates of the number of words presented during the interval. Results suggest the mediation of time estimates by estimates of the number of words presented and interference between timing and memorizing words.

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## **The Effect of the Presence versus Absence of Concurrent Tasks and Controlled Attention Sharing on Subjective Time Estimates**

Under a prospective temporal estimation task, a concurrent task refers to a task that is required of the participant during an estimated interval. Concurrent tasks have included sorting cards (Allen, 1980; Hicks, Miller, & Kinsbourne, 1976), reading numbers (Rakitin, et al. 1998), solving anagrams (Sawyer, Meyer, & Huser, 1994), performing the Stroop (1935) color-word test (Zakay, 1989), engaging in a physical activity (Druyan, Dani, & Hadadi, 1995), performing mental arithmetic (Wilsoncroft & Stone, 1975), memorizing word lists (Miller, Hicks, & Willette, 1978), and timing the duration of two or more simultaneously presented stimuli (Brown, Stubbs, & West, 1992). Several prospective timing studies have demonstrated shorter time estimates, and greater variability in estimates, under conditions in which participants were engaged in a task during presentation of a temporal stimulus than when not engaged in such a task (e.g., Allen, 1980; Brown, 1985; Brown, 1997; Burnside, 1971; Dewolf & Duncan, 1959; Harton, 1942; Hicks et al., 1976; Smith, 1969; Vroon, 1970).

The shortening of time estimates under a concurrent task has often been interpreted in terms of an attention model (e.g., Allen, 1980; Block & Zakay, 1997; Brown, 1985,

1997; Curton & Lordahl, 1974; Harton, 1938; Macar, Grondin, & Casini, 1994; Thomas & Weaver, 1975; Zakay, 1993; Zakay & Block, 1996). The model is based on two assumptions: (a) Time estimation requires continuous measurement of the passage of time during an interval, and (b) there is competition in the allocation of processing resources for timing and for performing a concurrent task (Brown, 1985; Harton, 1938; Hicks et al., 1976; Macar, 1992; Macar et al., 1994; Zakay, 1989).

Consistent with an attention model, researchers have suggested that there are different systems for timing and performing a concurrent task. These systems are a cognitive timer and an information processor, respectively (Macar et al., 1994; Michon, 1972, 1985; Michon & Jackson, 1985; Thomas & Weaver, 1975; Zakay, 1993). According to the model, there is a single and limited pool of attentional resources available to the two processors. Thus, there is an inverse relation between the amount of attentional resources allocated to the information processor and the cognitive timer. It is assumed that time estimates are mediated by similar psychological processes in the presence and absence of a concurrent task, because time estimates are governed by the output of the cognitive timer under both conditions.

Alternatively, the obtained difference between time estimates in the presence and absence of a concurrent task may result from timing based on different psychological processes. These processes can be understood by examining the role of chronometric counting in prospective time estimates. Chronometric counting refers to subdividing an interval of time into smaller units of time to measure the duration of a stimulus event (Creelman, 1962; Getty, 1976; Grondin, Meilleur-Wells, & LaChance, 1999; Wilkening, Levin, & Druyan, 1987). The smaller units of time are marked by stimulus events that can either be generated by the participant in a self-paced manner (e.g., "one-one thousand, two-one thousand", etc.) or generated by the environment (e.g., Harton, 1938; Killeen & Weiss, 1987; Zakay, Nitzan, & Glicksohn, 1983). For example, using a temporal discrimination task, Grondin et al. (1999) showed that the use of explicit counting strategies resulted in more accurate timing than the absence of explicit counting for intervals greater than 1.8 s. In the absence of a concurrent task, participants may use self-paced counting to produce a time estimate. In the presence of a concurrent task, participants may be prevented from engaging in this form of counting. Therefore, the difference between time estimates in the presence and

absence of a concurrent task may reflect timing without self-paced counting, and with self-paced counting, respectively.

One method for examining the effects of a concurrent task on time estimates while interfering with self-paced counting under all conditions is to manipulate level of concurrent task difficulty. Consistent with an attention model, several of these studies showed an inverse relation between level of task difficulty and time estimates (e.g., Allen, 1980; Block, 1982; Brown, 1985; Hicks et al., 1976; Sawyer et al., 1994; Zakay et al., 1983). In these studies, the concurrent task used was one in which participants controlled the rate of presentation of task-related stimuli. An inverse relation between task difficulty and rate of performing the concurrent task has been used to verify differences in level of concurrent-task difficulty (e.g., Allen, 1980; Hicks et al., 1976; McKay, 1977; Zakay, 1993; Zakay et al., 1983).

Few attempts have been made to manipulate task difficulty while holding the rate of presentation of task-related stimuli constant (Brown et al., 1992; Macar et al., 1994; Predebon, 1996). Thus, an inverse relation between task difficulty and time estimates was often confounded with an inverse relation between task difficulty and the

number of stimuli presented (e.g., Allen, 1980; Hicks et al., 1976; Zakay, 1989). For example, in Allen's (1980) study, participants were instructed to estimate the duration of a card-sorting task. Playing cards were sorted either into a single pile, according to color, or according to suit (0, 1, and 2 bits of information, respectively). Consistent with the attention model, time estimates varied inversely with the number of bits of information processed. However, the number of cards sorted also varied inversely with the number of bits of information processed. Thus, the number of bits of information processed and the number of cards sorted were confounded.

In the present study, the effect of concurrent tasks on time estimates was examined in two experiments while controlling for differences in timing strategies and for the number of stimuli presented. In Experiment 1, participants read words aloud to interfere with self-paced counting while the presence versus absence of three additional concurrent tasks (estimating the number of words presented, word recall and word recognition) was manipulated. Time estimates were compared to those of a condition in which participants estimated time while performing no concurrent task.

The effect of controlled attention sharing on time estimates and memory measures was examined in Experiment 2. Participants performed the reading and word-memory tasks on all trials while an instruction to focus on timing or on word memory was manipulated across trials. The purpose of this manipulation was to examine the effects of instructions to distribute attention between tasks on time estimates under conditions in which participants were deterred from using self-paced counting and the number of stimuli (words) presented was held constant.

### **Experiment 1**

In Experiment 1, the effect of the presence versus absence of concurrent memory tasks on subjective time estimates was examined. Measures of estimated number of words and word memory were obtained when participants were instructed to perform the concurrent tasks either prospectively or retrospectively. The rate of presentation of words was held constant in the present study. To control for the possibility that time estimates represent timing based on self-paced counting, estimates were obtained by interfering with self-paced counting in the presence and absence of the concurrent tasks. This manipulation was designed to allow for a reevaluation of the attention model of timing.

Under two conditions, participants were instructed to perform a word-reading task intended to interfere with self-paced counting on all trials, and under one condition participants were instructed to perform three additional concurrent tasks (estimating the number of words presented, recalling words and recognition of words). Time estimates were compared between conditions, and to those of other participants did not perform the word-reading task.

Only participants in the memory condition produced memory responses during each trial of the session, and were instructed to memorize words prior to stimulus presentation (prospectively). To obtain memory measures for participants under the other conditions, those participants produced memory responses following their last time estimate with no prior knowledge of the memory tasks (retrospectively). The purpose of obtaining memory measures across conditions was to evaluate the relation between timing and concurrent task performance. Based on the assumption that there is a limit in the availability of attentional resources for the various tasks, the attention model predicts bidirectional interference between timing and performing the memory tasks. An inverse relation between time estimates and memory measures across conditions would indicate such interference. According to

the model, shorter time estimates are predicted in the presence than in the absence of the memory tasks. Measures of estimated number of words, word recall, and word recognition are expected to be greater for participants who performed the concurrent tasks prospectively than for those who performed the same tasks retrospectively. Several studies that measured both time estimates and concurrent task performance have produced results consistent with these predictions (e.g., Allen, 1980; Brown, 1985; Hicks et al., 1976; Zakay, 1993). In the present study, correlations between dependent measures were obtained across trials for each participant who performed the timing and memory tasks prospectively. According to an attention model, in a given trial as more attentional resources are allocated to the timing task, fewer resources are available for the concurrent tasks and vice versa. Thus, a negative correlation between time estimates and each of the concurrent task measures (estimated number of words, and the word memory measures) is predicted.

Alternatively, some studies that have manipulated the presence and absence of a concurrent task have tested a set of hypotheses that are based on a context-change model of timing (Block, 1978; Block & Reed, 1978; Block, George, & Reed, 1980; Poynter & Homa, 1983). The context-change

model is an extension of Ornstein's (1969) storage-size model. According to the context-change model, temporal estimates are based on, and directly related to, the number of discrete stimulus events that occur during the interval (Block et al., 1980; Brown, 1985; Fraisse, 1963; Hicks et al., 1976; Vroom, 1970). The segmentation model of Poynter (1983) makes the same prediction. The segmentation model also predicts that time estimates are directly related to the discreteness of stimulus events (defined by the magnitude of sensory change between successively presented stimuli and the interval of empty time between stimuli), and the ease by which events can be organized in memory (Poynter, 1989; Poynter & Homa, 1983).

Evidence that participants base time estimates on stimulus events during an interval was shown by Hemmes, Kladoopoulos, and Brown (2001) in a prospective timing study in which number reading served as the concurrent task. In that study, several participants reported using an estimate of the number of stimulus values presented to make their time estimate during the interval. In the present study, the context-change model predicts shorter time estimates and lower estimated number of words in the presence than in the absence of the concurrent tasks. Similarly, the model predicts that each participant would show a positive

correlation across trials between time estimates and estimated number of words. The context-change model makes no prediction about the relation between time estimates and measures of word recall and word recognition, because the memory of specific stimulus events is not considered necessary for estimating the number of changes in stimulus context. However, if time estimates are mediated by the number of discrete stimulus events independent of the memory of those events, then word memory may interfere with estimating the number of words, as specified by the attention model.

### **Method**

#### *Participants*

Seventy-four undergraduate psychology students participated to satisfy an academic requirement. Prior to each session, participants were asked to remove their watches, and to turn off their cellular phones, and beepers.

#### *Apparatus and Setting*

A microcomputer (Gateway 286, 16 MHz) with a VGA color monitor was used to run experimental sessions and to collect data. A standard keyboard served as the manipulandum. For word recognition tests, two keys (the / and < key) were covered with tape that read "yes" and "no",

respectively. Beside the computer was a tape recorder used to record the vocalizations of participants during the experiment. No sources of temporal information were available in the room.

#### *Procedure*

Participants were divided equally into three conditions (condition time [T], condition read and time [RT], and condition read, time, and memory [RTM]) using random assignment. Each participant was seated facing the computer monitor with the keyboard located directly in front of the computer monitor. All trials began with the presentation of the following message on the monitor "press the spacebar when ready." In each trial, a sample stimulus (green square, 4cm<sup>2</sup>) was presented in the center of the monitor. The sample stimulus was presented for either 40 or 60 s.

During each trial, words were presented sequentially in the center of the green square. Twenty and thirty words were presented during the 40- and 60-s duration, respectively. For each stimulus duration the number of words presented in a trial was constant across trials. No words were presented more than once for each participant.

### *Session Structure*

The arrangement of instructions for each trial of the three conditions is shown in Table 1. Each participant was presented with five trials during a single session in Experiment 1. The session consisted of one practice trial followed by four test trials. For each trial, each participant was presented with instructions prior to the temporal stimulus (preinstructions). For each test trial, each participant was presented with additional instructions following presentation of the temporal stimulus (postinstructions).

### *Training*

Prior to the preinstructions for the practice trial, participants were presented with a set of general instructions (Appendix A) on the computer monitor. Participants of each condition were instructed to time the duration of the green square. Participants of conditions RT and RTM received additional instructions. Participants of both conditions were instructed to read each word out loud as it was presented, and that their voices would be recorded during the session. Participants of condition RTM were also instructed that following their time estimate, they would be asked to estimate the number of words presented, recall the words presented, and perform a word-

recognition test. The practice trial began after each participant correctly repeated the instructions verbally to the experimenter.

Following the general instructions, the participants of each condition were exposed to one practice trial specified in the first line of Table 1. Prior to presentation of the sample stimulus, participants of each condition were instructed that the green square to be presented was an example of the stimulus they would be shown in each trial. Participants were not instructed to time the duration of the sample stimulus during the practice trial. Participants of conditions RT and RTM were instructed to read each word presented within the green square out loud as they were presented. For participants of condition T, no instruction to read the words out loud was provided. The experimenter was present during the general instructions and practice trial.

#### *Testing*

The practice trial was immediately followed by four test trials (Trials 1 - 4 of Experiment 1 in Table 1). For each condition, preinstructions and postinstructions were identical on all trials; however, after completion of Trial 4, participants of conditions T and RT were given

additional postinstructions as described below. For each condition, the experimenter was absent during test trials.

*Condition T.* The preinstruction for participants of condition T was to time the duration of the green square. Following each presentation of the sample stimulus, the postinstructions directed these participants to type a time estimate (in seconds) using the number pad on the keyboard, and to press the enter key following their estimate. For the first three test trials, following this response, participants were prompted to press the space bar to begin the next trial.

Following their temporal estimate on the fourth test trial, participants of condition T were presented with three memory tasks: Upon pressing the enter key following a time estimate, participants were instructed to provide their estimate of the number of words presented using the number pad on the keyboard, and to press the enter key following their estimate. Following this response, participants were instructed to recall the words presented in the green square by typing them in any order using the keyboard, and to press the enter key after typing each word. Participants were instructed to press the enter key without typing a word when finished. Following the recall test, participants performed a forced-choice recognition

test. Participants were shown the words presented during the sample stimulus intermixed with an equal number of distractor words (not presented in either practice or test trials). The participants were instructed to indicate whether each word was presented in the trial by pressing either the yes or no key. Each word in the recognition test was presented individually on the computer monitor and remained visible until the participant pressed one of the two response keys. There were no time limits for participants to perform the memory tasks.

For each set of words presented within a trial, there was a fixed set of distractor words used for the recognition test. Distractor words were randomly selected without replacement from the same pool of words (described below) as those selected for presentation during the sample stimulus. For each trial, the order in which words were presented during the recognition test was determined using randomized blocks of four words. For each block, two words were presented during the sample stimulus, and two words were distractor words. For each set of words presented in a trial during the recognition test, the order of presenting words was identical across participants.

*Condition RT.* The preinstructions for participants of condition RT were to read each word out loud as it was

presented, and to estimate the duration of the green square. The postinstructions for Trials 1-4 were identical to those used for the corresponding trials of condition T. After entering their temporal estimate on the fourth trial, participants of condition RT performed the same three memory tasks as those of condition T.

*Condition RTM.* Participants of condition RTM also received preinstructions to read each word out loud as it was presented and to estimate the duration of the green square. In addition, they were instructed to memorize the words. On each trial, following presentation of the sample stimulus, the postinstructions for these participants were identical to those of trial four for participants of conditions T and RT. For Trials 1-3, following a response to the last word presented in the recognition test, the preinstructions for the next test trial were presented.

Immediately following the test session, the experimenter asked all participants from each condition to verbally report what strategy they used to make their time estimates.

#### *Word Stimuli*

The words presented in each trial were randomly selected without replacement from a set of 720 English nouns that were of the highest average number for measures

of concreteness, imagery, categorizability, meaningfulness, familiarity, number of attributes, and pleasantness (Toglia & Battig, 1978). No plural words were used. The first word presented in a trial appeared simultaneously with the onset of the sample stimulus. The last word presented in a trial disappeared simultaneously with the offset of the sample stimulus. The word presentation time was variable:  $M = 1700$  ms, range 1000 - 2400 ms. The interword interval was also variable:  $M = 300$  ms, range 100 - 500 ms.

The words presented during the 40-s trials were subsets of the words presented during the 60-s trials. The thirty words from each of the 60-s trials were divided into three sets of 10 words (sets A, B, and C). Sets A, B, and C consisted of the first 10, second 10, and third 10 words that were presented during a 60-s trial. The three subsets of words that were used for the 40-s trials were composed of sets AB, AC, and BC. Four participants in each condition were randomly assigned to one of the three subsets of words that were used throughout the experiment.

For each sample duration, the same four word sets were used for all participants within a condition. For each condition, the order of presentation of the word sets used across the four test trials was counterbalanced across participants using incomplete Latin squares ( $n = 12$

participants per square). For a given sample duration, the same set of Latin squares was used for each condition.

### *Experimental Design*

Of the 74 participants, 24 participants were assigned to each condition. Two participants from condition T were replaced when their performance on the word-reading test did not meet criterion (see below). Using random assignment, half of the participants from each condition were presented with the sample stimulus for 40 s on all trials, and the other half of the participants were presented with the sample stimulus for 60 s. The effects of condition (T, RT, and RTM) and stimulus duration (40 and 60 s) were examined using a 3 x 2 between groups factorial arrangement with 12 participants in each of the six combinations of condition and duration.

### *Data Analysis*

For each combination of condition and duration, time estimates were directly obtained on each trial, and the mean time estimate was calculated across the four test trials for each participant. Mean time estimates were used for all analyses involving the condition and duration factors. For participants of condition RTM, estimated number of words, and word-memory measures were also obtained on each trial, and the mean of each measure was

calculated across trials for each participant. For participants of conditions T and RT, the memory measures were recorded on the final test trial.

For the recall test, a correctly recalled word was defined as one in which the word typed was one of those presented within the sample stimulus in a given trial. A typed word was scored correct only if there were no spelling errors. For each trial, the proportion of words recalled (number of words recalled in a trial divided by the number of words presented in a trial) was the measure used for data analysis.

For the recognition test, a "yes" or a "no" response in the presence of a word that was presented during the sample stimulus was recorded as a hit or miss, respectively. A "yes" or a "no" response in the presence of a word that had not been presented during the sample stimulus was scored as a false alarm or correct rejection, respectively. For each trial, the total word recognition score was the sum of the hit and correct rejection scores. For each trial, proportion of word recognition was calculated by dividing the total word recognition score by the total number of words presented during the recognition test.

For each trial with a recognition test, hit and false alarm scores were converted to proportion hit (PH) and proportion false alarm (PFA) by dividing each by the number of words presented during the sample stimulus. These measures were used to calculate a measure of sensitivity ( $A'$ ),

$$A' = .5 + [(PH - PFA) (1 + PH - PFA) / 4PH (1 - PFA)], \quad (1)$$

that is based on signal detection theory (Grier, 1971; Fetterman, Dreyfus, & Stubbs, 1993). The  $A'$  measure is a nonparametric version of the commonly used  $d'$  measure and requires no assumptions about the shape of the population distribution. By calculating an index of sensitivity based on yes responses only,  $A'$  of word recognition is a measure that is independent of response bias. The  $A'$  measure is scaled from 0.5 to 1.0 such that 0.5 represents chance performance and 1.0 represents perfect discrimination.

For statistical tests that involve the condition factor, analyses of the four memory measures were limited to the fourth test trial of each condition, because participants of conditions T and RT performed the memory tasks only on the last test trial. For condition RTM, the four test trials were used for analyses of the duration

factor and for correlations between dependent measures across trials.

For data analysis involving estimated number of words, a rejection criterion was implemented. Trials in which estimates were greater than four times the number of words presented in a trial (estimates greater than 80 and 120 words for each 40- and 60-s trial, respectively) were excluded from data analysis. This rejection criterion was used because some participants met this criterion and may have been basing their estimates on the sum of the number of words presented across the four test trials. Trials in which estimated number of words was zero were also excluded from data analysis. A zero estimate of word number was recorded when a participant typed zero, or pressed enter prior to entering a number, when prompted to estimate the number of words. Zero estimates of word number may have resulted from a failure to attend to, or a misunderstanding of, the postinstruction for an estimate of word number. The percent of data rejected for analysis of estimated number of words was 11.1. The percent of data rejected due to zero estimates of word number was 5.6 and the percent of data lost due to large estimates of word number was 5.5. For analysis of the condition factor, estimated number of words for three participants from each of conditions T and

RT and two participants from condition RTM were excluded from data analysis. For analysis of estimated number of words across the four test trials of condition RTM, the percentage of trials rejected was 5.2.

The recorded vocal responses under the word-reading task were analyzed to ensure that participants performed the concurrent task on all trials. Participants were replaced with other participants if more than one word presented was not read aloud for two or more trials. Two participants from condition T were replaced.

An alpha level of .05 was used for all statistical tests with one exception. For multiple t-tests within a session, the alpha level for each of a set of comparisons was determined using Holm's (1979) procedure.

## ***Results***

### *Time Estimates*

Mean time estimate is shown for each condition and duration to the left of the vertical dashed lines in Figure 1. Participants of condition T produced time estimates that most closely approximated veridical time. With the exception of the 40-s duration of condition RT, time estimates obtained under conditions in which participants pronounced words out loud (conditions RT and RTM) were statistically shorter than those of condition T.

Time estimates were examined using a condition x duration analysis of variance (ANOVA). The results of the ANOVA are shown in Table 2. There was a significant effect of condition. The effect of duration and the condition x duration interaction were not significant. The condition factor was further analyzed using Tukey's post hoc tests ( $p < .05$ ). Results showed that mean time estimates were significantly longer for condition T than condition RTM. There was no significant difference in time estimates between conditions T and RT. Mean time estimates under the two conditions requiring the reading task (conditions RT and RTM) did not differ significantly.

Despite the nonsignificant condition x duration interaction, planned comparisons of time estimates between conditions were conducted for each of the two durations. One-way ANOVAs of time estimates comparing conditions T and RT, and conditions RT and RTM were conducted for the 40- and 60-s durations. Results showed that time estimates were significantly longer for condition T than condition RT for the 60-s duration,  $F(1, 22) = 4.45$ ,  $p = .046$ , but did not differ significantly for the 40-s duration,  $F(1, 22) < 1$ . Time estimates did not differ significantly between conditions RT and RTM for either the 40-s,  $F(1, 22) = 3.24$ ,  $p = .085$ , or 60-s,  $F(1, 22) < 1$ , sample duration.

To examine the accuracy of time estimates across conditions, time estimates for each condition and duration were compared to veridical time using two tailed t-tests. For condition T, there was no significant difference between time estimates and the sample duration for the 40- and 60-s durations [maximum  $t(11) < 1$ ]. Comparisons between time estimates and veridical time showed a pattern of results for conditions RT and RTM that differed from condition T. Temporal estimates were significantly shorter than the sample duration for the 60-s duration of condition RT,  $t(11) = 4.52$ ,  $p < .01$ , and for the 40-s,  $t(11) = 2.28$ ,  $p < .05$ , and 60-s,  $t(11) = 4.24$ ,  $p < .01$ , durations of condition RTM. There was no significant difference between time estimates and veridical time for the 40-s duration of condition RT which yielded a nonsignificant overestimate,  $t(11) < 1$ .

#### *Memory Measures*

Examination of the condition factor was limited to the fourth test trial, though only participants of condition RTM had three prior trials with the word-memory tasks. To test for the presence of practice effects, estimated number of words, proportion of words recalled, proportion of word recognition, and A' of word recognition were analyzed for condition RTM using trial x duration ANOVAs. For each

dependent measure, neither the effect of trial [maximum  $F(3, 66) = 1.18, p = .324$ ] nor the trial x duration interaction [maximum  $F(3, 66) = 2.21, p = .095$ ] was significant.

*Estimated Number of Words.* Mean estimated number of words is shown for each condition and duration to the left of the vertical dashed lines in Figure 2. A condition x duration ANOVA of estimated number of words is shown in Table 2. Results showed significant effects of condition and duration. Estimated number of words was significantly greater for the 60-s duration than the 40-s duration. The condition x duration interaction was not significant. Post-hoc comparisons of estimated number of words between conditions were conducted using Tukey's procedure ( $p < .05$ ). Results showed that estimated number of words was significantly lower for condition RTM than conditions T and RT. There was no significant difference in estimated number of words between conditions T and RT.

*Word Recall.* Mean proportion of words recalled is shown for each condition and duration to the left of the vertical dashed lines in Figure 3. A condition x duration ANOVA showed a significant effect of condition (Table 2). The effect of duration was not significant nor was the condition x duration interaction. The effect of condition

was further analyzed using Tukey's post hoc tests ( $p < .05$ ). Results showed that the proportion of words recalled was significantly lower for condition T than conditions RT and RTM. Proportion of words recalled was significantly greater for condition RTM than condition RT.

*Word Recognition.* Mean proportion of word recognition is shown for each condition and duration to the left of the vertical dashed lines in Figure 4. A condition x duration ANOVA of proportion of word recognition showed a significant effect of condition (Table 2). The effect of duration was not significant nor was the condition x duration interaction. Pairwise comparisons between conditions (Tukey's procedure,  $p < .05$ ) showed that proportion of word recognition was significantly lower for condition T than conditions RT and RTM. Proportion of word recognition did not differ significantly between conditions RT and RTM.

Performance under the recognition test was also examined in terms of the sensitivity measure ( $A'$ ). Mean  $A'$  of word recognition is shown for each condition and duration to the left of the vertical dashed lines in Figure 5. A condition x duration ANOVA of  $A'$  of word recognition showed results that were identical to those of proportion of word recognition (Appendix B).

### *Condition RT versus Condition RTM*

The manipulation of the presence versus absence of a concurrent task, when self-paced counting was deterred under both conditions, was analyzed using condition (RT and RTM) x duration ANOVAs of each dependent measure.

Condition T was omitted from this analysis. The results of the analysis are presented in Table 3. For each dependent measure, the effect of condition replicated the post hoc comparisons between conditions RT and RTM in the ANOVAs that included condition T with one exception. Proportion word recognition was significantly greater for condition RTM than condition RT. For each dependent measure, the effect of duration and the duration x condition interaction also replicated the findings of the ANOVAs that included condition T. Analysis of A' of word recognition showed no significant effect of condition (Appendix C). A' of word recognition was significantly greater for the 40-s duration than the 60-s duration. The duration x condition interaction was not significant.

### *Correlation Analysis*

The five dependent measures were subjected to a correlation analysis to test predictions of the attention and context-change models. The correlation analysis was limited to condition RTM, because only these participants

produced memory measures for four test trials (maximum  $n = 12$  per correlation). For each participant, each correlation was based on pairs of values among the four dependent measures from the four test trials. For each correlation measure, a session in which a correlation for a given participant was undefined owing to absence of variability in one of the two measures used for the correlation was excluded from analysis. Based on this criterion, for correlation analysis involving proportion of words recalled, the data of one participant were excluded for the 60-s duration. For correlation analysis involving estimated number of words, two participants' data were excluded for the 40-s duration.

Table 4 shows median correlation coefficients between time estimates and estimated number of words, between time estimates and proportion of words recalled, and between times estimates and proportion of word recognition. There was a significant positive correlation between time estimates and estimated number of words for the 60-s duration ( $p = .016$ , sign test), but not for the 40-s duration ( $p = .205$ , sign test). The correlations between time estimates and proportion of words recalled, and between time estimates and proportion of word recognition were predominantly negative; however, none of the

correlation measures differed significantly from zero [minimum  $p = .121$ , sign tests].

Correlation coefficients among the memory measures were calculated to examine the degree of covariation in performance across trials between the three memory tasks. Table 5 shows median correlation coefficients between estimated number of words and proportion of words recalled, between estimated number of words and proportion of word recognition, and between proportion of words recalled and proportion of word recognition. There was a significant negative correlation between estimated number of words and proportion of words recalled for the 60-s duration ( $p = .005$ , sign test), but not for the 40-s duration ( $p = .117$ , sign test). The correlation between estimated number of words and proportion of word recognition was not significantly different from zero for either duration [minimum  $p = .044$ , sign tests] nor was the correlation between proportion of words recalled and proportion of word recognition [minimum  $p = .08$ , sign tests].

#### *Reported Timing Strategies*

The timing strategies that participants reported using to estimate the duration of the sample stimulus were analyzed for each condition. For condition T, 21 of 24 participants (88%) reported using self-paced counting to

estimate the sample duration. For conditions RT and RTM, 4 of 24 participants (17%) and 5 of 24 participants (21%), respectively, reported using self-paced counting to estimate the sample duration. The proportion of participants who reported using self-paced counting varied significantly across conditions,  $\chi^2(2, N = 72) = 31.19, p < .001$ . The proportion of participants who reported using self-paced counting was significantly greater for condition T than condition RT,  $\chi^2(1, N = 48) = 24.12, p < .001$ , and condition RTM,  $\chi^2(1, N = 48) = 21.48, p < .001$ . Conditions RT and RTM showed no significant difference in proportion of participants who reported using self-paced counting,  $\chi^2(1, N = 48) < 1$ . For these two conditions, 54% of participants reported using an estimate of the number of words presented to estimate the sample duration (50% and 58% of participants for conditions RT and RTM, respectively). One participant from condition T reported using the number of words presented to estimate the sample duration. The remaining participants from conditions RT and RTM reported that they estimated time by "feeling" how long the sample stimulus was presented (33% and 21% of participants for conditions RT and RTM, respectively).

### *Coefficient of Variation*

Evidence for Weber timing was evaluated by calculating the Weber fraction for time estimation (coefficient of variation, CV) for each participant. The CV is defined as the standard deviation of time estimates divided by the mean time estimate. Mean CVs of conditions T, RT, and RTM were .10, .25, and .19, for the 40-s duration, respectively, and .12, .22, and .22, for the 60-s duration, respectively. A condition x duration ANOVA of CVs showed a significant effect of condition,  $F(2, 66) = 8.74, p < .001$ . The effect of duration was not significant,  $F(1, 66) < 1$ , nor was the condition x duration interaction,  $F(2, 66) < 1$ . Tukey's post-hoc test ( $p < .05$ ) showed that CVs were significantly lower for condition T than conditions RT and RTM. There was no significant difference in CV between conditions RT and RTM.

### ***Discussion***

#### *Time Estimates*

The results of Experiment 1 showed that estimates of duration were shortened, relative to condition T, by the word-reading task for the 60-s duration of condition RT and the 40- and 60-s durations of condition RTM. The obtained shortening of time estimates under the word-reading task is consistent with several studies that have examined the

effect of the presence versus absence of a concurrent task using various concurrent tasks, stimulus durations, and time estimation procedures (e.g., Allen, 1980; Brown, 1985, 1997; Burnside, 1971; Dewolf & Duncan, 1959; Harton, 1942; Hicks et al., 1976; Smith, 1969; Vroon, 1970).

The lack of a shortening of time estimates under the 40-s duration of condition RT was not predicted. Analysis of individual participant time estimates showed that the mean time estimate across participants for this condition was not accounted for by an extreme overestimate on the part of a single participant. Five of 12 participants from this condition produced time estimates that exceeded the sample duration. No studies that examined concurrent task effects while interfering with self-paced counting and holding the number of presented stimuli constant used the same combination of duration and task as the 40-s duration of condition RT in the present study (Brown et al., 1992; Macar, 1992; McClain, 1983; Predebon, 1996). However, under one manipulation, McClain (1983) instructed participants to read words for 120 s. Results were similar to those of the 40-s duration of condition RT in that mean time estimates exceeded the sample duration when 15 and 30 words were presented.

Under the three conditions in which subjective shortening was present, proportion of time estimates (PTE), calculated by dividing the mean subjective duration by the sample duration, ranged from .62 to .78. These proportions were similar to those obtained by Hicks et al. (1976) when participants sorted playing cards by suit for 42 s (PTE = .74), Predebon (1996) for estimates of a 60-s sample duration under letter discrimination and word identification tasks (PTE = .48 to .84), Smith (1969) for estimates of 15- to 60-s sample durations using an analogy solving task (PTE = .69 to .89), Vroon (1970) for estimates of a 60-s sample duration under the method of comparison (PTE = .78 to .83), and Zakay et al. (1983) for estimates of a 14-s sample duration under three word processing tasks (PTE = .54 to .66). Under conditions in which the word-reading task was required, time estimates did not differ between the presence (condition RTM) and absence (condition RT) of the word-memory tasks. This finding is inconsistent with the attention model.

#### *Memory Measures*

Despite the invariance in time estimates between participants of conditions RT and RTM, memory measures differed between the conditions. Estimated number of words was greater for condition RT than for condition RTM, but

proportion of words recalled and proportion of word recognition were greater for condition RTM than for condition RT. The A' measure for word recognition was unaffected by the instruction to memorize words. This finding suggests that participants showed no differential sensitivity to the recognition task between conditions RT and RTM.

When self-paced counting was deterred, the difference in the direction of the effect of prospective versus retrospective instruction to perform the memory tasks on estimated number of words and the word-memory measures (measures of recall and recognition) can be discussed in terms of an attention model. There was competition in the allocation of attentional resources between the processing of stimulus number and the processing of stimulus information required for the recall and recognition tasks. However, there was no evidence of an inverse relation between time estimates and memory measures across prospective and retrospective instructions to perform the memory tasks. The nonsignificant difference in time estimates in the presence and absence of the word-memory tasks (conditions RTM vs. RT), despite significant differences between those conditions in the three memory

measures, is inconsistent with both the attention and context-change models.

Measures of word-recall and word-recognition were greater in the presence than in the absence of the word-reading task (conditions RT and RTM vs. condition T). Measures of word-recall and word-recognition were greatest for participants who were preinstructed to perform the memory tasks (condition RTM). The finding that these measures were greatest for condition RTM was not unexpected. This result is consistent with an attention model, because prospective memory tasks were used for this condition, and retrospective memory tasks were used for conditions T and RT. For the retrospective memory conditions, the finding that word-memory measures were greater in the presence (condition RT) than in the absence (condition T) of the word-reading task suggests that the reading task alone was sufficient to improve memory performance. The finding of a greater A' measure under condition RT than condition T indicates that the word-reading task increased sensitivity to the recognition of words.

#### *Correlation Analysis*

Attention and context-change models were further evaluated by examining the correlations between dependent

measures for condition RTM. An attention model predicts an inverse relation between time estimates and memory measures, and a context-change model predicts a positive relation between time estimates and estimated number of words. Consistent with the context-change model, time estimates were positively correlated with estimated number of words for the 60-s duration. This correlation suggests either that the number of words presented mediated time estimates or visa versa, or that both time estimates and estimated number of words were mediated by the same source of stimulus control. The negative correlation between estimated number of words and proportion of words recalled for the 60-s duration is consistent with the attention model. This correlation may reflect within-subject competition across trials in the allocation of attentional resources to counting words (owing to the requirement to estimate the number of words presented) and to memorizing words. A plausible interpretation of the positive correlation between time estimates and estimated number of words, and the negative correlation between estimated number of words and proportion of words recalled is provided by a combination of attention and context-change models. Time judgments were mediated by estimates of word number, and there was competition in the allocation of

attentional resources between counting words and memorizing words.

### *Timing Strategies*

The pattern of time estimates across conditions, and differences across conditions in comparisons between time estimates and stimulus duration, may be related to the method of timing that participants reported using during debriefing. For condition T, most participants reported using self-paced counting to estimate the sample duration. For conditions RT and RTM, relatively few participants reported using this method to estimate the sample duration. The difference in reported timing strategies in the presence versus absence of the word-reading task may imply that time estimates were mediated by different sources of stimulus control under the two conditions.

Unlike the obtained difference in reported timing strategy in the presence and absence of the word-reading task, participants of the two conditions that required the task (conditions RT and RTM) reported using similar timing strategies. In line with the context-change model, many of these participants reported using an estimate of the number of words presented to produce their time estimate. Several of these participants (33% and 38% of participants of conditions RT and RTM, respectively) reported counting the

number of words presented in a trial, then multiplying that value by an estimate of the number of seconds between words. The remaining participants reported "feeling" how long the sample stimulus was presented. The differences in reported timing strategy between condition T and conditions RT and RTM, and the similarities in reported timing strategy between conditions RT and RTM, are consistent with the pattern of time estimates across conditions. This finding suggests that time estimates may be influenced by timing strategy.

#### *Weber Fraction*

In line with time estimates and reported timing strategies, Weber fractions (CV) of condition T ( $M = .11$ ) differed from both conditions RT ( $M = .24$ ) and RTM ( $M = .21$ ); however, Weber fractions did not differ between condition RT and condition RTM. The values of the Weber fraction obtained in the presence and absence of the concurrent tasks were comparable to those of other studies such as Brown (1997) for estimates of 2 and 5 s using mental arithmetic tasks (CV no task = .13, CVs task = .24 to .26), Druyan et al. (1995, Experiment 1) for estimates of 60 and 79 s using various physical activities (CVs = .18 to .44), Macar et al. (1994) for estimates of 12 and 18 s using word identification tasks (CVs = .16 to .18), Rakitin

et al. (1998) for estimates of 8 to 21 s using a single digit reading task (CVs = .12 to .14), Wearden and McShane (1988) for estimates of 0.5 to 1.3 s with no concurrent task (CVs = .11 to .14), and Zakay et al. (1983) for estimates of 14 s using three word processing tasks (CV no task = .15, CVs task = .27 to .35).

A comparison of the Weber fraction across conditions permitted an examination of the effect of the concurrent tasks on timing processes. Ivry and Hazeltine (1995) proposed that a difference between experimental conditions in the slope of the function relating the standard deviation of time estimate to the sample duration suggests the operation of different timing mechanisms (Gibbon, 1991; Gibbon & Church, 1984; Gibbon & Church, 1990; Kladopoulos, Brown, & Hemmes, 1998). In the present study, a similar interpretation can describe the obtained difference in CVs between the presence versus absence of the word-reading task, because CV is the multiplicative constant (slope) of the function that depicts the linear relation between the standard deviation of time estimates and the mean time estimate ( $SD = CV \times T$ ). Hemmes et al. (2001) expanded this interpretation and argued that a difference in the Weber fraction for time between task and no-task conditions reflects different dimensions of time much the way

different Weber fractions have been shown across different sensory modalities (Fetterman & Killeen, 1995; Geldard, 1962; Spetch & Sinha, 1989).

### **Experiment 2**

An alternate approach to examining the effect of attentional factors on timing performance is instructing participants to focus their attention on performing either a timing task or a concurrent task. In Experiment 2, this manipulation was conducted while interfering with self-paced counting via a word-reading task, and while holding the stimulus presentation rate constant. Researchers have generally shown that time estimates are shorter when participants are instructed to place emphasis on performing a concurrent task than when instructed to place emphasis on performing a timing task (Curton & Lordahl, 1974; Macar et al., 1994; McKay, 1977; Zakay, 1989). These researchers have argued that when participants place emphasis on performing a concurrent task, fewer attentional resources are available for timing.

The effect of attentional focus on time estimates has not been examined while interfering with self-paced counting. When self-paced counting is not deterred, instruction to focus on a timing task is likely to result in a bias toward using this strategy to scale duration.

However, instruction to focus on a concurrent task may result in interference with using self-paced counting to scale duration. Thus, differences in time estimates resulting from an instruction manipulation may reflect different forms of timing under the two conditions. This interpretation is contrary to an attention-based interpretation that would describe the effect of an instruction manipulation on time estimates in terms of a single temporal-processing system. In Experiment 2, participants were instructed to perform a word-reading task during presentation of the sample stimulus, while instruction to place emphasis on either timing or memorizing words was manipulated.

### **Method**

#### *Participants*

The participants of Experiment 1 also participated in Experiment 2.

#### *Apparatus and Setting*

The apparatus and setting were identical to those of Experiment 1.

#### *Design and Procedure*

Experiment 2 was run 15 minutes after participants completed Experiment 1. The design of Experiment 2 is summarized in Table 1. Experiment 2 consisted of two test

sessions, with a break of 15 minutes between sessions. There were four trials per session. Participants who were presented with a 40-s sample stimulus in Experiment 1 were presented with a 60-s sample stimulus in Experiment 2, and vice versa. The words appearing during the temporal stimulus were selected from the same pool of 720 words used in Experiment 1, but different words were used in Experiment 2. Words were presented only once.

The first test session is described under Trials 5-8 of Experiment 2 in Table 1. For this session, the general instructions and procedures for each participant were identical to those used for condition RTM of Experiment 1 (Appendix A). The purpose of this session was for participants of the three conditions from Experiment 1 to have experience performing the timing and memory tasks before the second test session.

The second test session (attention to timing vs. attention to memorizing words) is described under Trials 9-12 of Experiment 2 in Table 1. In Session 2, the general instructions were identical to those of Session 1 with the exception that participants were also told that prior to each presentation of the sample stimulus, they would be instructed to focus on either the timing task or the word-memory task (see Appendix D for instructions). In this

session, preinstruction to place emphasis on performing the timing or word-memory task was manipulated across trials. The procedures for this session were identical to those of Session 1, with the exception that an added instruction immediately preceded each presentation of the sample stimulus.

For Trial 9, half of the participants from each condition and duration of Experiment 1 were instructed that it was most important to produce an accurate time estimate. The other half of the participants from each condition and duration of Experiment 1 were instructed that it was most important to remember as many words as possible. For each participant, instruction to place emphasis on the timing task or the word-memory task was determined using a block randomization procedure with two participants from each condition and duration per block.

For the Trial 10, the participants who were instructed to place emphasis on the timing task in the first trial were instructed to place emphasis on the word-memory task. Similarly, the participants who were instructed to place emphasis on the word-memory task in the first trial were instructed to place emphasis on the timing task. The alternation of instruction type across trials continued for a total of four trials. Immediately following the second

test session, the experimenter again asked the participants to report verbally the strategy they used to make their time estimates when they were instructed to focus on the timing task and when they were instructed to focus on the word-memory task. The effect of duration (40- and 60 s) and instruction (focus on time or word memory) was examined using a 2 x 2 mixed factorial arrangement with 36 participants in each level of duration.

#### *Data Analysis*

For each trial, the method of calculating the five dependent measures (time estimates, estimated number of words, proportion of words recalled, proportion of word recognition, and A' of word recognition) was identical to that of Experiment 1. For Session 1, the data for each measure were pooled across the four test trials for each participant. For Session 2, the data for each measure were pooled across two trials separately for instruction to focus on timing and word memory. For both test sessions, trials in which participants produced time estimates of zero were excluded from data analysis. Zero time estimates were produced in a trial by either typing zero on the number pad, or by pressing the enter key prior to producing a time estimate. The percentage of trials excluded from analysis of time estimates for sessions 1 and 2 combined

was 0.7. For analysis of estimated number of words, estimates of zero were excluded from data analysis. The percentage of trials excluded from analysis of estimated number of words for Session 1 and Session 2 was 3.8 and 2.4, respectively. For Session 2, the percentage of trials excluded from analysis of estimated number of words for instruction to focus of timing and word memory was 1.4 and 3.4, respectively.

The same correlation analysis used for condition RTM of Experiment 1 was used for each session of Experiment 2. Each correlation was calculated by using the four test trials within a session for each participant. For Session 2, the method for calculating correlation coefficients included using trials under both levels of the instruction factor, because there were only two trials for each level of instruction.

## **Results**

### *Session 1: RTM Training*

Mean time estimate for Session 1 is shown for the two durations between the vertical dashed lines in Figure 1. To test for differences in time estimates based on the assignment of participants to the experimental conditions in Experiment 1, a condition x duration ANOVA of time estimates was conducted. Results of the analysis are shown

in Table 6. Time estimates were significantly longer for the 60-s duration than the 40-s duration. There was no significant effect of condition, nor a significant condition x duration interaction.

Mean estimated number of words, proportion of words recalled, proportion of word recognition, and A' of word recognition are shown between the vertical dashed lines in Figures 2-5. Condition (based on assignment of participants in Experiment 1) x duration ANOVAs of estimated number of words, proportion of words recalled, and proportion of word recognition, were conducted. The results of the analyses are shown in Table 6. Results showed no significant effects of condition. Estimated number of words and proportion of word recognition were significantly greater for the 60-s duration than the 40-s duration. The effect of duration was not significant for proportion of words recalled. For each measure, there was no significant condition x duration interaction. As a result of the nonsignificant effects of condition, and the nonsignificant condition x duration interactions, the data for each dependent measure were pooled across condition for subsequent analyses (N = 36 per duration). A condition x duration ANOVA of A' of word recognition produced results that were identical to those of proportion of word

recognition (Appendix E). Therefore,  $A'$  of word recognition data were also pooled across condition for subsequent analysis.

The four dependent measures were subjected to a correlation analysis to examine the reliability of the correlation pattern obtained in Experiment 1 with three times the sample size. The median of each correlation coefficient for Session 1 of Experiment 2 is shown in Tables 4 and 5. There was a significant positive correlation between time estimates and estimated number of words (Table 4) for both the 40- and 60-s durations [maximum  $p < .001$ , sign tests]. The correlations between time estimates and the word-memory measures (proportion of words recalled and proportion of word recognition) did not differ significantly from zero [minimum  $p = .054$ , sign tests] nor did the correlations between estimated number of words and the word-memory measures (Table 5 [minimum  $p = .03$ , sign tests]). For the 60-s sample duration, there was a significant positive correlation between proportion of words recalled and proportion of word recognition ( $p = .001$ , sign test). This correlation did not differ significantly from zero for the 40-s duration ( $p = .128$ , sign test).

Table 7 contains comparisons between correlation measures using the Wilcoxon signed ranks procedure. This analysis was conducted to determine whether the obtained positive correlation between time estimates and estimated number of words, differed from correlations between these variables and the other memory measures. This allowed us to examine the relative contribution of counting words and memorizing words in determining time estimates. The analysis showed that for both durations, the correlation between time estimates and estimated number of words was significantly greater than the correlations between time estimates and each of the word-memory measures. The correlation between time estimates and estimated number of words was also significantly greater than the correlations between estimated number of words and each of the word-memory measures.

*Session 2: Attention to Timing versus Attention to Word Memory*

Mean time estimate, estimated number of words, proportion of words recalled, proportion of word recognition, and A' of word recognition are shown for instruction to focus on timing and word memory (Session 2) to the right of the vertical dashed lines in Figures 1-5, respectively. An instruction x duration ANOVA of time

estimates was conducted. Results of the analysis are shown in Table 8. Time estimates were significantly longer when participants were instructed to focus on the timing task than when instructed to focus on the word-memory task. Time estimates were significantly longer for the 60-s duration than the 40-s duration. The instruction x duration interaction was not significant.

For each level of instruction and duration, time estimates were compared to veridical time to determine whether subjective shortening occurred. Time estimates were shorter than veridical time for each level of instruction and duration [minimum  $t(35) = 3.07, p < .01$ ].

Instruction x duration ANOVAs of memory measures are shown in Table 8. Results showed that estimated number of words did not differ significantly between instruction to focus on the timing task and instruction to focus on the word-memory task (Figure 2). Estimated number of words was significantly greater for the 60-s duration than the 40-s duration. There was a significant instruction x duration interaction. Analysis of the instruction factor for each duration showed that estimated number of words was significantly greater when participants were instructed to focus on word memory than when instructed to focus on timing for the 40-s sample duration,  $F(1, 34) = 5.81, p =$

.022. There was no significant effect of the instruction factor on estimated number of words for the 60-s sample duration,  $F(1, 35) = 1.99, p = .166$ .

The obtained effects of the instruction factor on time estimates differed from the effects of this factor on proportion of words recalled (Figure 3), and proportion of word recognition (Figure 4). An instruction x duration ANOVA of proportion of words recalled showed that proportions were significantly greater when participants were instructed to focus on the word-memory task than when instructed to focus on the timing task (Table 8). The effect of duration was not significant nor was the instruction x duration interaction.

Similar results were obtained for the recognition test as those shown for the recall test. An instruction x duration ANOVA showed that proportion of word recognition was significantly greater when participants were instructed to focus on the word-memory task than when instructed to focus on the timing task (Table 8). The effect of duration and the instruction x duration interaction were not significant. Analysis of A' of word recognition produced results that were identical to proportion of word recognition (Appendix F).

Correlation analyses between dependent measures are shown for Session 2 of Experiment 2 in Tables 4 and 5. There was a significant positive correlation between time estimates and estimated number of words (Table 4) for the 60-s sample duration ( $p < .001$ , sign test). The correlation did not differ significantly from zero for the 40-s sample duration ( $p = .08$ , sign test). The correlations between time estimates and word-memory measures were not significantly different from zero [minimum  $p = .066$ , sign tests] nor were the correlations between estimated number of words and word-memory measures [Table 5; minimum  $p = .051$ , sign tests]. There was a significant positive correlation between proportion of words recalled and proportion of word recognition for the 40- and 60-s durations [maximum  $p = .017$ , sign test].

Wilcoxon signed ranks tests among correlation coefficients are shown in Table 7. Results showed that the correlation between time estimates and estimated number of words was significantly greater than the correlation between time estimates and proportion word recognition for the 60-s duration. These correlations did not differ significantly for the 40-s duration. The correlation between time estimates and estimated number of words did not differ significantly from the correlation between time

estimates and proportion of words recalled for either duration. The correlation between time estimates and estimated number of words was significantly greater than the correlation between estimated number of words and each of the word-memory measures for the 60-s duration. These correlations did not differ significantly for the 40-s duration.

Participants' reported strategy when instructed to focus on timing and word memory was examined. When participants were instructed to focus on timing, they reported basing their time estimates on either self-paced counting, the number of words presented, or "feeling" the duration of the sample stimulus (30.6%, 44.4%, and 25% of participants, respectively).

When participants were instructed to focus on the word memory, 42% of participants reported the use of a timing strategy. Five of these participants reported using self-paced counting, 17 reported using the number of words presented, and eight reported "feeling" the duration of the sample stimulus. Under this condition, most participants (85%) reported using a mnemonic technique to facilitate the recall and recognition of words. Reported mnemonic techniques included rote memory, forming sentences with successively presented words in a trial, organizing the

presented words into different categories (e.g., words related to cooking), and forming associations between presented words and information from personal memory. All participants that made no report of using a timing strategy reported using a mnemonic technique.

### **Discussion**

When participants performed a word-reading task, instructing participants to focus on timing or word memory affected each of the dependent measures. Time estimates were longer when participants were instructed to focus on timing than when instructed to focus on word memory. In the present study, the difference in the proportion of time estimated (PTE; see discussion Experiment 1) between the focus on time (PTE = .80) and the focus on memory (PTE = .72) conditions is consistent with those of other studies that manipulated attentional focus. For example, Macar et al. (1994) obtained PTE values for focus on time and focus on a concurrent task of .78 and .72, respectively. Zakay (1989, Experiment 3) obtained PTE values for focus on time and focus on a concurrent task of .75 and .67, respectively. In a study with children, Zakay (1992) obtained PTE values for focus on time or focus on a toy that were greater than those obtained in the present study (.92 and .81, respectively).

Measures of word recall and word recognition were greater when participants were instructed to focus on memorizing words than when instructed to focus on timing. The opposing effect of the instruction factor on time estimates and these word-memory measures is consistent with an attention model. For estimated number of words, the results differed among the two durations. In line with an attention model, under the 40-s duration, estimates of word number were significantly greater when participants were instructed to focus on word memory than when instructed to focus on time. Under the 60-s duration, estimates of word number did not differ across the instruction factor.

Although the inverse relations between time estimates and measures of word-recall and word-recognition across the instruction manipulation are consistent with an attention model, correlation analysis between dependent measures did not support hypotheses based on the model. During both RTM training and the instruction manipulation (Sessions 1 and 2, respectively), there were no significant correlations between time estimates and word-memory measures. According to an attention model, an inverse relation between time estimates and memory measures is predicted.

In both sessions, there was a positive correlation between time estimates and estimated number of words. This

correlation is consistent with the results of Experiment 1 (60-s duration), and with the context-change model. The similarity in the correlation pattern between Session 2 of Experiment 2 and both Experiment 1 and Session 1 of Experiment 2 indicates that the correlation pattern in Session 2 of Experiment 2 was unaffected by using data from both levels of instruction. Moreover, for both sample durations of Session 1, the correlation between time estimates and estimated number of words differed from the correlations between time estimates and word-memory measures. For one sample duration in Session 2, the correlation between time estimates and estimated number of words differed from the correlation between time estimates and proportion of word recognition. The obtained correlations between time estimates and memory measures suggest that time estimates were differentially affected by estimates of stimulus number and by memory of the specific stimuli presented. Thus, the results of Experiment 2 do not consistently support either the attentional or the context change model.

The obtained effects of the instruction factor on the dependent measures may reflect differences across level of instruction in the strategies that participants reported using to perform the timing and word-memory tasks. When

participants were instructed that the most important task was to produce an accurate time estimate, they all reported using one of the forementioned timing strategies. When participants were instructed that the most important task was to remember as many words as possible, most participants reported using one of the forementioned strategies for memorizing words.

The difference in reported strategies across levels of the instruction factor was consistent with the obtained differences in time estimates and measures of word-memory across levels of this factor. This finding further indicates the necessity to determine whether the effect of instruction on time estimates and concurrent-task measures is strategy dependent. In the present study, the obtained post-hoc reports are not to be taken as direct measures of the effect of strategy on dependent measures. In addition, these findings do not suggest that participants solely used mnemonic strategies or timing strategies when they reported using one of the strategy types.

#### ***General Discussion***

The present study examined the effect of concurrent memory tasks on time estimates. To isolate task effects from their concomitant effects on timing strategy and the confounded variable of number of stimulus changes,

participants were deterred from using self-paced counting to scale duration by instructing them to read words aloud, and the number of presented words was held constant. The presence versus absence of memory tasks (Experiment 1), and instruction to focus on timing versus word memory (Experiment 2) were manipulated. Results showed that time estimates, estimated number of words, proportion of words recalled, and proportion of word recognition were each affected by one or both of these factors. Some of these effects were consistent with the attention model of timing and other effects were consistent with the context-change model. The following text provides a review of the two timing models and relates these models to the results of the present study.

#### *Attention Model of Timing*

According to attention models of timing, there is competition in allocating processing resources for timing and performing a concurrent task. As more attentional resources are required by a concurrent task, fewer resources are available for processing temporal information. Based on this assumption, it was predicted that time estimates would be shorter in the presence than in the absence of the word-reading task (conditions RT and RTM vs. condition T) in Experiment 1. Results were

consistent with this prediction. In addition, word-memory measures were greater in the presence of the word-reading task. The obtained difference in the direction of the effect of word reading on time estimates and word-memory measures is consistent with previous timing research that examined bidirectional interference effects (e.g., Allen, 1980; Brown, 1985, 1997; Burnside, 1971; Dewolf & Duncan, 1959; Harton, 1942; Hicks et al., 1976; Smith, 1969; Vroon, 1970).

It was also predicted that time estimates would be shorter in the presence than in the absence of the word-memory tasks (condition RTM vs. condition RT), and there would be an inverse relation between time estimates and each memory measure across conditions. Despite an obtained difference between conditions in each of the memory measures, time estimates did not differ between the two conditions. This finding was inconsistent with an attention model. There was an inverse relation between estimated number of words and the word-memory measures. Estimated number of words was lower for condition RTM than condition RT, and word-memory measures were greater for condition RTM than condition RT. In terms of an attention model, these findings suggest interference between counting words and memorizing words.

The effect of condition on time estimates was similar to the effect of this factor on the Weber fraction for time (Gibbon & Church, 1990; Treisman, 1963) and reported timing strategies. CVs of condition T differed from those of both conditions RT and RTM, and CVs did not differ between conditions RT and RTM. The possibility that differences across conditions in CV reflect differences in the function of internal timing mechanisms was supported by analysis of reported timing strategies. Participants of condition T primarily reported using self-paced counting to scale duration, and relatively few of the participants of conditions RT and RTM reported using this strategy. The uniformity in the effect of condition across time estimates, CVs, and reported timing strategies suggests that the timing mechanisms used to mediate temporal judgments under condition T differed from those used under the other two conditions (Hemmes et al., 2001).

In Experiment 2, based on an attention model, time estimates were expected to be longer when participants were instructed to focus on timing than when instructed to focus on word memory. Memory measures were expected to be lower when participants were instructed to focus on timing than when instructed to focus on word memory. The results conformed to this prediction. The different direction of

the effect of instruction on time estimates and word-memory measures is in line with studies that examined attentional focus when self-paced counting was not deterred and implies bidirectional interference between the two types of tasks (e.g., Macar et al., 1994; McKay, 1977; Zakay, 1989). Consistent with these results, participants primarily reported using one of several timing strategies when instructed to focus on the timing task, and one of several word-memory strategies when instructed to focus on the word-memory task. Thus, in both experiments, differences in reported strategy corresponded to differences in time estimate.

Brown (1997) used the Baddeley and Hitch (1974) working-memory model to describe bidirectional interference effects between temporal and concurrent tasks. Baddeley and Hitch proposed a separate working space for verbal information (phonological loop) and for visual-spatial information (visual-spatial sketchpad), with the allocation of attentional resources to each controlled by a central executive. Each component contains a limited pool of processing resources. Brown (1997) argued that timing primarily involves the central executive, and that the phonological loop in working memory is the locus of resources used for self-paced counting, because this form

of timing is verbally based. According to the working memory model, a concurrent task that requires resources of the phonological loop (reading, memorizing or counting words) will interfere with self-paced counting. Conversely, allocation of resources for self-paced counting will interfere with performance of verbally based concurrent tasks.

The different direction of the effect of instruction on time estimates and word-memory measures in Experiment 2 may reflect the different proportion of resources allocated by the phonological loop for timing via self-paced counting and for word memory. The reduction in resources available for self-paced counting under a concurrent task could result in a shift to an alternative timing strategy such as those reported by participants in the present study. Moreover, the reduction of  $A'$  of word recognition under the focus-on-timing condition is in line with the attention model in that sensitivity to the recognition task varied directly with the amount of attentional resources allocated to word memory.

In both experiments, the correlations across trials between time estimates and memory measures that were obtained for each participant were inconsistent with an attention model that would predict negative correlations

between these measures owing to competition in the proportion of attentional resources allocated to the timing and word-memory tasks. There were no negative correlations between time estimates and the memory measures.

*The Role of Task-Related Stimuli on Prospective Time Estimates*

According to the context-change model, temporal estimates are based on the number of stimulus events, or the number of changes in stimulus context that occur during an interval (e.g., Block et al., 1980; Poynter, 1983). Therefore, in Experiments 1 and 2, direct relations between time estimates and estimated number of words across conditions (T, RT, and RTM) and instructions (focus on timing vs. word memory) were predicted, respectively.

In Experiment 1, the effect of word reading on time estimates and estimated number of words was similar. Both measures were lower for condition RTM than condition T, and both measures were lower for condition RT than condition T under the 60-s duration. These findings are consistent with the context-change model. However, time estimates did not differ between conditions RT and RTM, although estimated number of words was lower for condition RTM than condition RT. This finding indicates control by stimulus number rather than time, but does not support the model.

Moreover, time estimates were either inversely related (40-s duration) or unrelated (60-s duration) to estimated number of words across the instruction factor in Experiment 2. This finding was also inconsistent with the model.

The positive correlation between time estimates and estimated number of words that was obtained in both experiments was consistent with the context-change model. Although the correlation is not sufficient to support a hypothesis of temporal control by the number of stimulus events, it may reflect such control. The correlation may also reflect control of temporal and numeric judgments by a common mechanism. Nevertheless, a positive relation between time estimates and estimates of the number of presented stimuli has seldom been demonstrated in prospective timing studies, particularly under the condition in which the rate of presentation of stimuli is controlled by the experimenter. Most studies investigating concurrent task effects either did not obtain a measure of estimated number of stimuli, did not correlate estimated number of stimuli and time estimates, or showed no relation between estimated number of stimuli and time estimates (Macar, 1992).

*Evidence of the Processing of Temporal and Numeric Information.* The ability for human subjects to

simultaneously process temporal and numeric information was demonstrated by Kladopoulos, Hemmes, and Brown (1998). The study was a systematic replication of a study by Roberts and Mitchell (1994) who worked with pigeons. Under a prospective psychophysical timing procedure, participants were presented with stimuli that consisted of a single white square that flashed at a constant rate. The stimuli varied across trials in the duration between the first and last flash and in the number of flashes. For each trial, either the word "time" or "number" was presented indicating that participants were to judge the stimulus as long or short in duration, or to judge the stimulus as many or few in number, respectively. The instruction to discriminate based on time or number was presented either prospectively or retrospectively in a trial. For each stimulus presented, a correct response for time (long or short) was an incorrect response for number of stimuli (many or few). The time(s)/number combinations used in testing were 10/16, 11/15, 12/14, 13/13, 14/12, 15/11, and 16/10.

Figure 6 shows proportion of long (duration) and many (number of stimuli) responses as a function of the time between the first and last flash and the number of flashes, respectively. The obtained psychometric functions indicate that participants processed both dimensions. Estimates of

stimulus number showed a steeper psychometric function than estimates of elapsed time. Demonstration of psychophysical scaling of time and number under the retrospective discrimination task indicates that information about both dimensions was available in memory when the retrospective instruction appeared. If participants can independently store temporal and numerical information, then it may be possible for them to use estimates of the number of stimulus events to make temporal judgments under a concurrent task. This possibility is in line with the context-change model, and would account for the positive correlation between time estimates and estimated number of words, and the reported timing strategies under the word-reading task, in the present study.

Further similarity in the processing of elapsed time and the number of stimulus events was provided by Kladoopoulos, Brown, and Hemmes (2001), in a replication of Hemmes et al. (2001). In Hemmes et al., participants made estimates of the duration of a green square that was presented for one of seven values of stimulus duration ranging from 2 to 23 s. The presence versus absence of a concurrent task (reading 3 - 5 digit numbers) was manipulated. Results showed that time estimates were generally shorter under task than no-task trials. The

psychophysical function depicting subjective time estimate as a function of stimulus duration showed that the task function was flatter than the no-task function. The flattening of the psychophysical timing function under a concurrent task has been demonstrated by other studies (e.g., Brown et al., 1992; Burnside, 1971; Sawyer et al., 1994).

Kladopoulos, Brown, and Hemmes (2001) was a replication of Hemmes et al. (2001) with the exception that participants were instructed to estimate the number of stimuli (numbers) presented within the sample stimulus rather than the duration of the sample stimulus. Estimated number of stimuli is presented as a function of number of stimuli in Figure 7. For both the task and no-task trials, estimated number of stimuli varied directly with the number of stimuli presented. Estimated number of stimuli was analyzed with a task x number of stimuli ANOVA. The results of the ANOVA are presented in Appendix G. Results showed no significant effect of task. The effect of number of stimuli was significant. The number of stimuli x task interaction was also significant indicating that estimated number of stimuli was increasingly smaller under task than no-task trials as a function of the number of stimuli presented. This pattern of results was in line with those

obtained by Hemmes et al. (2001) when time estimates served as the dependent measure. The similarity between the two studies in the effect of a concurrent task on time estimates and estimated number of stimuli is consistent with the context-change model.

The mediation of temporal estimates by number of discrete stimulus events is a hypothesis often used to describe results from retrospective timing studies. Under a retrospective timing paradigm, participants are unaware that they must make a temporal judgment until after the temporal interval has elapsed. Under this paradigm, a direct relation between time estimates and the number of stimulus events that occur during an interval has often been demonstrated (e.g., Block, 1978, 1992; Cahoon & Edmunds, 1980; Zakay, 1993).

The use of self-paced counting under a retrospective timing paradigm is unlikely, because participants are unaware they must attend to elapsed time. According to Block (1978), under this paradigm, time estimates are based on the recollection of events that have occurred during the interval (Ornstein, 1969; Poynter, 1983). Consistent with Block's (1978) interpretation, in the present study several participants reported basing their time estimates on the number of words presented in a trial, when self-paced

counting was deterred. Studies have shown that prospective time estimates in the presence of a concurrent task, and retrospective time estimates, are both shorter than prospective time estimates in the absence of a concurrent task (Block & Zakay, 1997; Brown, 1985; Brown & Stubbs, 1992; Hicks et al., 1976; Predebon, 1996; Zakay, 1993).

#### *The Role of an Internal Clock*

Although a cognitive timer is often a component of attention models of timing, findings consistent with a context-change model may also indicate the role of a cognitive timer. In the present study, some participants who reported using an estimate of the number of words presented to produce a time estimate also reported estimating the interword interval. These participants reported calculating a time estimate by multiplying the estimated number of words by the estimated interword interval. The estimation of an interword interval may be based on the function of a cognitive timer (Gibbon & Church, 1990; Treisman, 1963). When self-paced counting is used to estimate time, the intercount interval may also be based on a cognitive timer.

A study by Wearden (1991) provided evidence of the timing of interstimulus intervals in humans. Wearden required participants to time a 6-s interval using self-

paced counting. Participants were required to subdivide the interval into a specified number of units by varying their rate of counting. Results showed that the mean and standard deviation of the intercount interval were directly related across count rate. Thus, the Weber fraction for time was constant across count rate. This finding suggests that the timing of the intercount interval is based on Weber timing properties.

#### *Future Research*

In light of the obtained results that suggest the mediation of temporal judgments by self-paced counting and by counting externally presented stimuli, a determination of the factors that control selective attention to the stimuli used to produce temporal judgments is required. Future research should include an examination of the effect of concurrent tasks and timing strategy on time estimates while systematically instructing participants to use different timing strategies. A manipulation of timing strategy would allow further evaluation of predictions based on different timing models of the effect of concurrent tasks on prospective time estimates.

In each experiment of the present study, the number of participants who reported using a given timing or mnemonic strategy differed, because participants were under no

constraints in choosing a timing strategy. The present study was also limited to between-subject comparisons of dependent measures between reported timing strategies. A more systematic analysis of timing strategy would result from instructing participants to use a specific strategy under a no-task condition, and in the presence of concurrent tasks. This manipulation could be conducted within and between participants. To examine the effect of concurrent tasks on timing responses that occur during an interval, self-paced counting and the counting of stimulus events could be recorded by instructing participants to respond in an observable and measurable manner such as counting out loud or repeatedly pressing a response key (Wearden, 1991).

### *Conclusion*

The present study examined the effect of the presence versus absence of concurrent tasks (Experiment 1) and attentional focus (Experiment 2) on time estimates and concurrent-task measures. Under each manipulation, self-paced counting was deterred, and the number of presented stimuli was held constant. Self-paced counting was deterred to reduce the number of possible differences in dependent measures owing to corresponding differences in the method of timing used by participants, and the number

of presented stimuli was held constant to prevent participants from controlling the speed of performing the concurrent tasks. Unlike the results of most prospective timing studies that examined the presence versus absence of a concurrent task and attentional focus without implementing these controls, the results of the present study only partially supported an attention model, and in some cases supported a context-change model. The findings suggest a consideration of the role of timing strategy, and how choice of timing strategy is determined, when examining the effects of concurrent tasks on time estimates.

## Appendix A

## Instructions for Each Condition of Experiment 1

*Instructions for Condition T*

On each trial you will be presented with a GREEN SQUARE at the center of the screen for a specific amount of time that we will call the TARGET TIME. When the GREEN SQUARE disappears, you will be asked to ESTIMATE THE DURATION OF THE GREEN SQUARE using the number pad on the keyboard.

On ALL trials, words will flash at the center of the GREEN SQUARE.

Remember that your task is to ESTIMATE THE DURATION OF THE GREEN SQUARE using the number pad on the keyboard.

DO YOU HAVE ANY QUESTIONS?

If you don't, then

Press the spacebar when ready

*Instructions for Condition RT*

On each trial you will be presented with a GREEN SQUARE at the center of the screen for a specific amount of time that we will call the TARGET TIME. When the GREEN SQUARE disappears, you will be asked to ESTIMATE THE DURATION OF THE GREEN SQUARE using the number pad on the keyboard.

On ALL trials, words will flash at the center of the

GREEN SQUARE. You should READ ALOUD each word when it appears. Your voice will be recorded during the session.

For practice, read aloud the following words:

antique                      psychology                      molecule

Remember that your task is to ESTIMATE THE DURATION OF THE GREEN SQUARE using the number pad on the keyboard.

Remember to READ ALOUD all of the words that appear in the GREEN SQUARE.

DO YOU HAVE ANY QUESTIONS?

If you don't, then

Press the spacebar when ready

*Instructions for Condition RTM*

On each trial you will be presented with a GREEN SQUARE at the center of the screen for a specific amount of time that we will call the TARGET TIME. When the GREEN SQUARE disappears, you will be asked to ESTIMATE THE DURATION OF THE GREEN SQUARE using the number pad on the keyboard.

On ALL trials, words will flash at the center of the GREEN SQUARE. You should READ ALOUD each word when it appears. Your voice will be recorded during the session.

For practice, read aloud the following words:

antique                      psychology                      molecule

Remember that your task is to ESTIMATE THE DURATION OF THE GREEN SQUARE using the number pad on the keyboard.

After you ESTIMATE THE DURATION OF THE GREEN SQUARE, you will be given some memory tasks.

You will be asked to ESTIMATE THE NUMBER OF WORDS PRESENTED IN THE GREEN SQUARE using the number pad on the keyboard.

You will be asked to TYPE EACH OF THE WORDS YOU REMEMBER READING OUT LOUD.

You will be asked to IDENTIFY THE WORDS THAT YOU READ from a list of words that will be presented to you by pressing the key labeled "YES" or "NO".

Remember to READ ALOUD all of the words that appear in the GREEN SQUARE.

DO YOU HAVE ANY QUESTIONS?

If you don't, then

Press the spacebar when ready

## Appendix B

Condition (T, RT, and RTM) x Duration (40 and 60 s) ANOVA  
of A' of Word Recognition for Experiment 1

Source	<i>df</i>	<i>F</i>	<i>p</i>
Condition (C)	2	44.32***	<.001
Duration (D)	1	0.17	.681
D x C	2	1.97	.148
error	66	(.012)	

Note. Values in parentheses represent mean square errors.

\*\*\* $p < .001$ .

## Appendix C

Condition (RT, and RTM) x Duration (40 and 60 s) ANOVA of  
A' of Word Recognition for Experiment 1

Source	<i>df</i>	<i>F</i>	<i>p</i>
Condition (C)	1	1.68	.201
Duration (D)	1	7.27**	.01
D x C	1	2.21	.144
error	44	(.003)	

Note. Values in parentheses represent mean square errors.

\*\**p* < .01.

## Appendix D

## Instructions for Session 2 of Experiment 2

On each trial you will be presented with a GREEN SQUARE at the center of the screen for a specific amount of time that we will call the TARGET TIME. When the GREEN SQUARE disappears, you will be asked to ESTIMATE THE DURATION OF THE GREEN SQUARE using the number pad on the keyboard.

On ALL trials, words will flash at the center of the GREEN SQUARE. You should READ ALOUD each word when it appears. Your voice will be recorded during the session.

For practice, read aloud the following words:

antique                      psychology                      molecule

Remember that your task is to ESTIMATE THE DURATION OF THE GREEN SQUARE using the number pad on the keyboard.

After you ESTIMATE THE DURATION OF THE GREEN SQUARE, you will be given some memory tasks.

You will be asked to ESTIMATE THE NUMBER OF WORDS PRESENTED IN THE GREEN SQUARE using the number pad on the keyboard.

You will be asked to TYPE EACH OF THE WORDS YOU REMEMBER READING OUT LOUD.

You will be asked to IDENTIFY THE WORDS THAT YOU READ from a list of words that will be presented to you by

pressing the key labeled "YES" or "NO".

In this session, you will be presented with one additional instruction before the GREEN SQUARE is presented.

On some trials, you will be instructed that IT IS MOST IMPORTANT THAT YOU PRODUCE AN ACCURATE TIME ESTIMATE. On these trials, your task is to place emphasis on TIMING THE GREEN SQUARE.

On other trials, you will be instructed that IT IS MOST IMPORTANT THAT YOU REMEMBER AS MANY WORDS AS POSSIBLE. In this case, your task is to place emphasis on MEMORIZING THE WORDS presented.

Remember to READ ALOUD all of the words that appear in the GREEN SQUARE.

DO YOU HAVE ANY QUESTIONS?

If you don't, then

Press the spacebar when ready

## Appendix E

Condition (T, RT, and RTM) x Duration (40 and 60 s) ANOVA  
of A' of Word Recognition for Session 1 of Experiment 2

Source	<i>df</i>	<i>F</i>	<i>p</i>
Condition (C)	2	0.07	.932
Duration (D)	1	6.12*	.016
C x D	2	0.02	.978
error	66	(.002)	

Note. Values in parentheses represent mean square errors.

\* $p < .05$ .

## Appendix F

Instruction (Focus on Time vs. Word Memory) x Duration (40 and 60 s) ANOVA of A' of Word Recognition for Session 2 of

## Experiment 2

Source	<i>df</i>	<i>F</i>	<i>p</i>
Between subjects			
Duration (D)	1	3.00	<.087
error	70	(.002)	
Within subjects			
Focus (F)	1	13.58***	<.001
F x D	1	0.14	.714
error	70	(.002)	

Note. Values in parentheses represent mean square errors.

\*\*\* $p < .001$ .

## Appendix G

Results of Task x Number of Stimuli ANOVA  
of Estimated Number of Stimuli

Source	df	F	p
Between subjects			
Task (T)	1	2.43	.139
error	16	(1.35)	
Within subjects			
Number of Stimuli (N)	11	286.60***	<.001
N x T	11	3.34***	<.001
error	176	(0.16)	

Note. Values in parentheses represent mean square errors.

\*\*\* $p < .001$ .

Table 1

*Summary of Experimental Design for Experiments 1 and 2*

<u>Trial</u>	<u>Instruction</u>	<u>Condition</u>		
		<u>Time</u>	<u>Read-Time</u>	<u>Read-Time-Memory</u>
Experiment 1				
Practice	Pre	----	R	R
1 - 3	Pre	T	R T	R T M
	Post	T	T	T M
4	Pre	T	R T	R T M
	Post	T M	T M	T M
Experiment 2 (Session 1)				
5 - 8	Pre	R T M	R T M	R T M
	Post	T M	T M	T M
Experiment 2 (Session 2)				
9 - 12	Pre	R T M	R T M	R T M
		Focus on Time or Memory	Focus on Time or Memory	Focus on Time or Memory
	Post	T M	T M	T

Note. T = estimate time, R = read words, M = memory tasks (estimating the number of words, word recall, and word recognition), Pre = preinstruction, Post = postinstruction.

Table 2

Condition (T, RT, and RTM) x Duration (40 and 60 s) ANOVAs of Time Estimates, Estimated Number of Words, Proportion of Words Recalled, and Proportion of Word Recognition for Experiment 1

Source	<u>Time estimates</u>			<u>Estimated number of words</u>		
	df	F	p	df	F	p
Condition (C)	2	3.42*	.039	2	4.48*	.016
Duration (D)	1	2.80	.099	1	8.83**	.004
C x D	2	2.36	.102	2	0.10	.903
error	66	(281.46)		58	(191.11)	

Source	<u>Proportion word recall</u>			<u>Proportion word recognition</u>		
	df	F	p	df	F	p
Condition (C)	2	24.03***	<.001	2	51.00***	<.001
Duration (D)	1	0.18	.672	1	0.81	.371
C x D	2	1.72	.188	2	2.28	.110
error	66	(.01)		66	(.01)	

Note. Values in parentheses represent mean square errors.

\* $p < .05$ . \*\* $p < .01$ . \*\*\* $p < .001$ .

Table 3

*Condition (RT and RTM) x Duration (40 and 60 s) ANOVAs of Time Estimates, Estimated Number of Words, Proportion of Words Recalled, and Proportion of Word Recognition for Experiment 1*

Source	<u>Time estimates</u>			<u>Estimated number of words</u>		
	<i>df</i>	<i>F</i>	<i>p</i>	<i>df</i>	<i>F</i>	<i>p</i>
Condition (C)	1	1.03	.315	1	6.41*	.015
Duration (D)	1	0.92	.342	1	5.07*	.03
C x D	1	0.03	.857	1	0.17	.685
error	44	(253.41)		39	(230.75)	

Source	<u>Proportion word recall</u>			<u>Proportion word recognition</u>		
	<i>df</i>	<i>F</i>	<i>p</i>	<i>df</i>	<i>F</i>	<i>p</i>
Condition (C)	1	18.00***	<.001	1	4.24*	.045
Duration (D)	1	1.17	.285	1	3.40	.072
C x D	1	1.44	.237	1	0.72	.401
error	44	(.007)		44	(.008)	

Note. Values in parentheses represent mean square errors.

\* $p < .05$ . \*\*\* $p < .001$ .

Table 4

*Median Correlation Coefficient Between Time Estimates and Estimated Number of Words, Between Time Estimates and Proportion of Words Recalled, and Between Time Estimates and Proportion of Word Recognition for Experiment 1 and Sessions 1 and 2 of Experiment 2*

	Experiment 1	
	40-s duration	60-s duration
TE versus NW	.26	.60*
TE versus PRCL	.05	-.39
TE versus PRGN	-.10	-.26
	Experiment 2 (Session 1)	
TE versus NW	.68*	.71*
TE versus PRCL	-.29	.02
TE versus PRGN	.13	-.28
	Experiment 2 (Session 2)	
TE versus NW	.45	.61*
TE versus PRCL	-.30	-.17
TE versus PRGN	-.15	-.10

Note. TE = time estimate, NW = estimated number of words, PRCL = proportion of words recalled, and PRGN = proportion of word recognition.

\* indicates a significant correlation.

Table 5

*Median Correlation Coefficient Between Estimated Number of Words and Proportion of Words Recalled, Between Estimated Number of Words and Proportion of Word Recognition, and Between Proportion of Words Recalled and Proportion of Word Recognition for Experiment 1 and Sessions 1 and 2 of Experiment 2*

Experiment 1		
	40-s duration	60-s duration
NW versus PRCL	-.36	-.44*
NW versus PRGN	-.36	-.36
PRCL versus PRGN	.32	.53
Experiment 2 (Session 1)		
NW versus PRCL	-.06	-.46
NW versus PRGN	.22	-.38
PRCL versus PRGN	.05	.46*
Experiment 2 (Session 2)		
NW versus PRCL	-.37	-.34
NW versus PRGN	.08	-.37
PRCL versus PRGN	.59*	.53*

Note. TE = time estimate, NW = estimated number of words, PRCL = proportion of words recalled, and PRGN = proportion of word recognition.

\* Indicates a significant effect.

Table 6

Condition (T, RT, and RTM) x Duration (40 and 60 s) ANOVAs of Time Estimates, Estimated Number of Words, Proportion of Words Recalled, and Proportion of Word Recognition for Session 1 of Experiment 2

Source	<u>Time estimates</u>			<u>Estimated number of words</u>		
	df	F	p	df	F	p
Condition (C)	2	0.25	.778	2	1.19	.310
Duration (D)	1	14.46***	<.001	1	16.79***	.001
C x D	2	3.09	.052	2	1.89	.159
error	66	(292.48)		66	(48.60)	

Source	<u>Proportion word recall</u>			<u>Proportion word recognition</u>		
	df	F	p	df	F	p
Condition (C)	2	1.16	.320	2	0.12	.888
Duration (D)	1	3.10	.083	1	6.37*	.014
C x D	2	0.65	.526	2	0.08	.928
error	66	(.005)		66	(.005)	

Note. Values in parentheses represent mean square errors.

\* $p < .05$ . \*\*\* $p < .001$ .

Table 7

*Paired Comparisons (Wilcoxon Signed Ranks Procedure) Among the Correlation Matrix Between Time Estimates, Estimated Number of Words, Proportion of Words Recalled, and Proportion of Word Recognition for Sessions 1 and 2 of Experiment 2*

Comparison	<u>40-s duration</u>		<u>60-s duration</u>	
	<i>df</i>	<i>t<sub>w</sub></i>	<i>df</i>	<i>t<sub>w</sub></i>
Experiment 2 (Session 1)				
TE-NW versus TE-PRCL	28	3.15*	29	3.10*
TE-NW versus TE-PRGN	29	3.03*	30	3.64*
TE-NW versus NW-PRCL	28	2.82*	29	3.95*
TE-NW versus NW-PRGN	29	2.80*	30	3.49*
PRCL-PRGN versus TE-PRCL	29	0.92	32	2.22
PRCL-PRGN versus TE-PRGN	29	0.10	32	3.40*
Experiment 2 (Session 2)				
TE-NW versus TE-PRCL	24	2.03	28	2.28
TE-NW versus TE-PRGN	28	1.85	28	3.84*
TE-NW versus NW-PRCL	25	2.35	28	3.86*
TE-NW versus NW-PRGN	29	0.94	29	3.92*
PRCL-PRGN versus TE-PRCL	30	3.43*	33	2.28

Table continues

PRCL-PRGN versus TE-PRGN 30 3.17\* 33 2.96\*

Note. TE = time estimate, NW = estimated number of words, PRCL = proportion of words recalled, and PRGN = proportion of word recognition.

\* Indicates a significant effect.

Table 8

*Instruction (Focus on Timing vs. Word Memory) x Duration (40 and 60 s) ANOVAs of Time Estimates, Estimated Number of Words, Proportion of Words Recalled, and Proportion of Word Recognition for Session 2 of Experiment 2*

Source	<u>Time estimates</u>			<u>Estimated number of words</u>		
	df	F	p	df	F	p
Between subjects						
Duration (D)	1	13.24***	<.001	1	39.76***	<.001
error	70	(547.83)		70	(86.18)	
Within subjects						
Focus (F)	1	15.53***	<.001	1	0.11	.740
F x D	1	0.03	.870	1	4.98*	.029
error	70	(31.4)		70	(10.41)	
Source	<u>Proportion word recall</u>			<u>Proportion word recognition</u>		
	df	F	p	df	F	p
Between subjects						
Duration (D)	1	3.32	.073	1	1.94	.167
error	70	(.01)		70	(.008)	
Within subjects						
Focus (F)	1	48.73***	<.001	1	37.98***	<.001
F x D	1	0.05	.826	1	0.68	.012
error	70	(.003)		70	(.002)	

Table continues

Note. Values in parentheses represent mean square errors.

\* $p < .05$ . \*\*\* $p < .001$ .

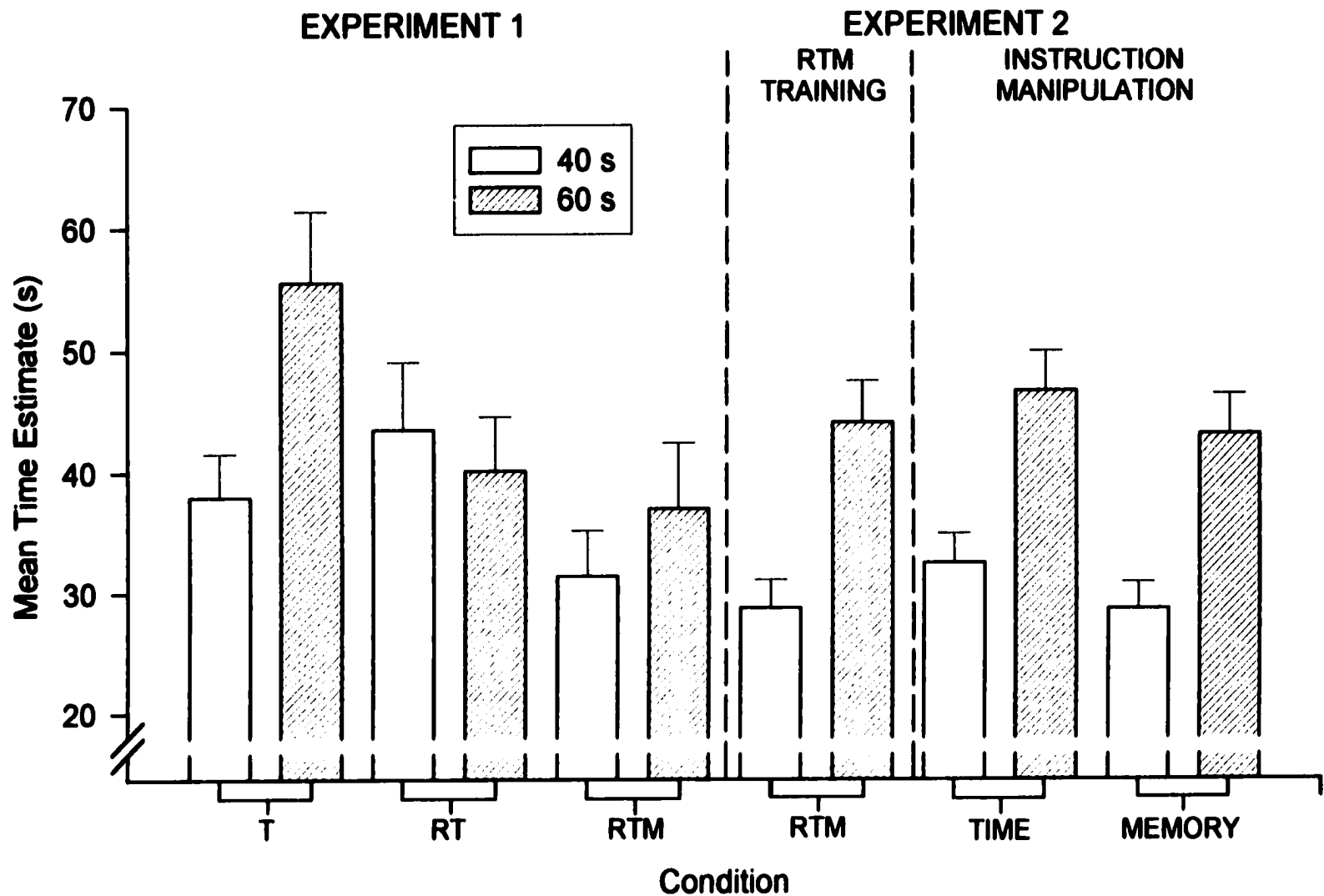


Figure 1. Mean time estimate (+SE) as a function of condition for Experiment 1 (left of vertical dashed lines), and sessions 1 and 2 of Experiment 2 (between, and to the right of the vertical dashed lines, respectively).

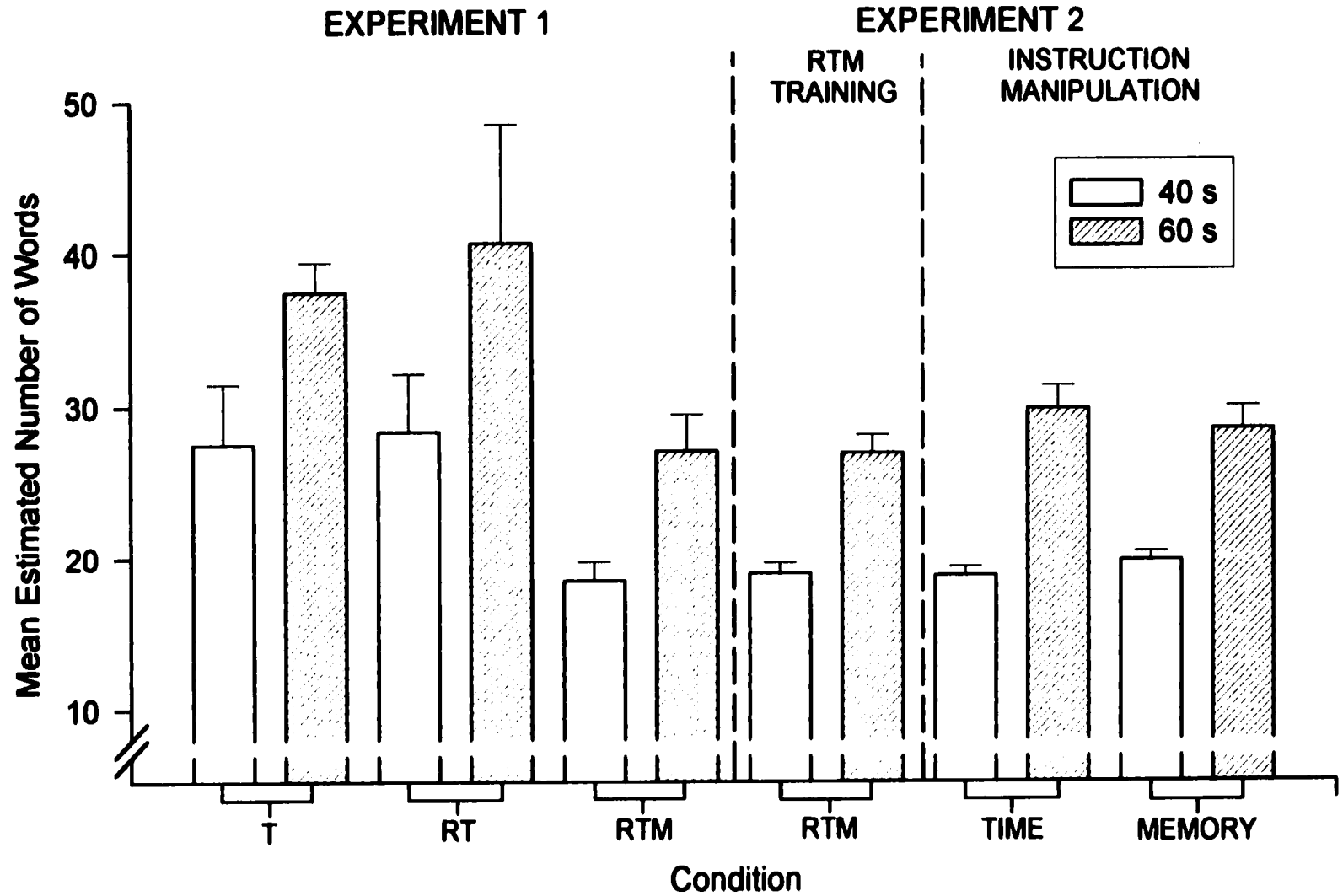


Figure 2. Mean estimated number of words (+SE) as a function of condition for Experiment 1 (left of vertical dashed lines), and sessions 1 and 2 of Experiment 2 (between, and to the right of the vertical dashed lines, respectively).

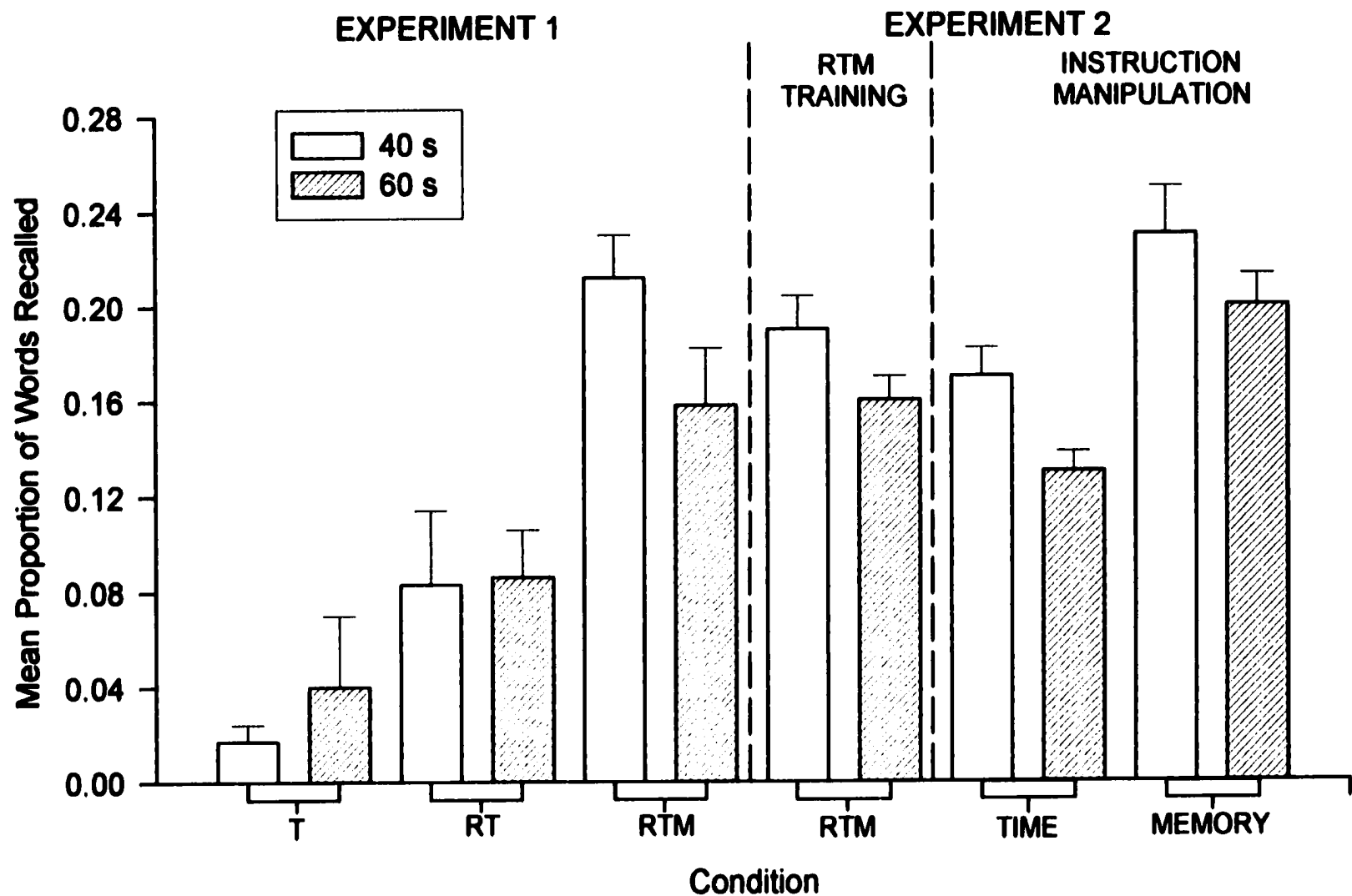


Figure 3. Mean proportion of words recalled (+SE) as a function of condition for Experiment 1 (left of vertical dashed lines), and sessions 1 and 2 of Experiment 2 (between, and to the right of the vertical dashed lines, respectively).

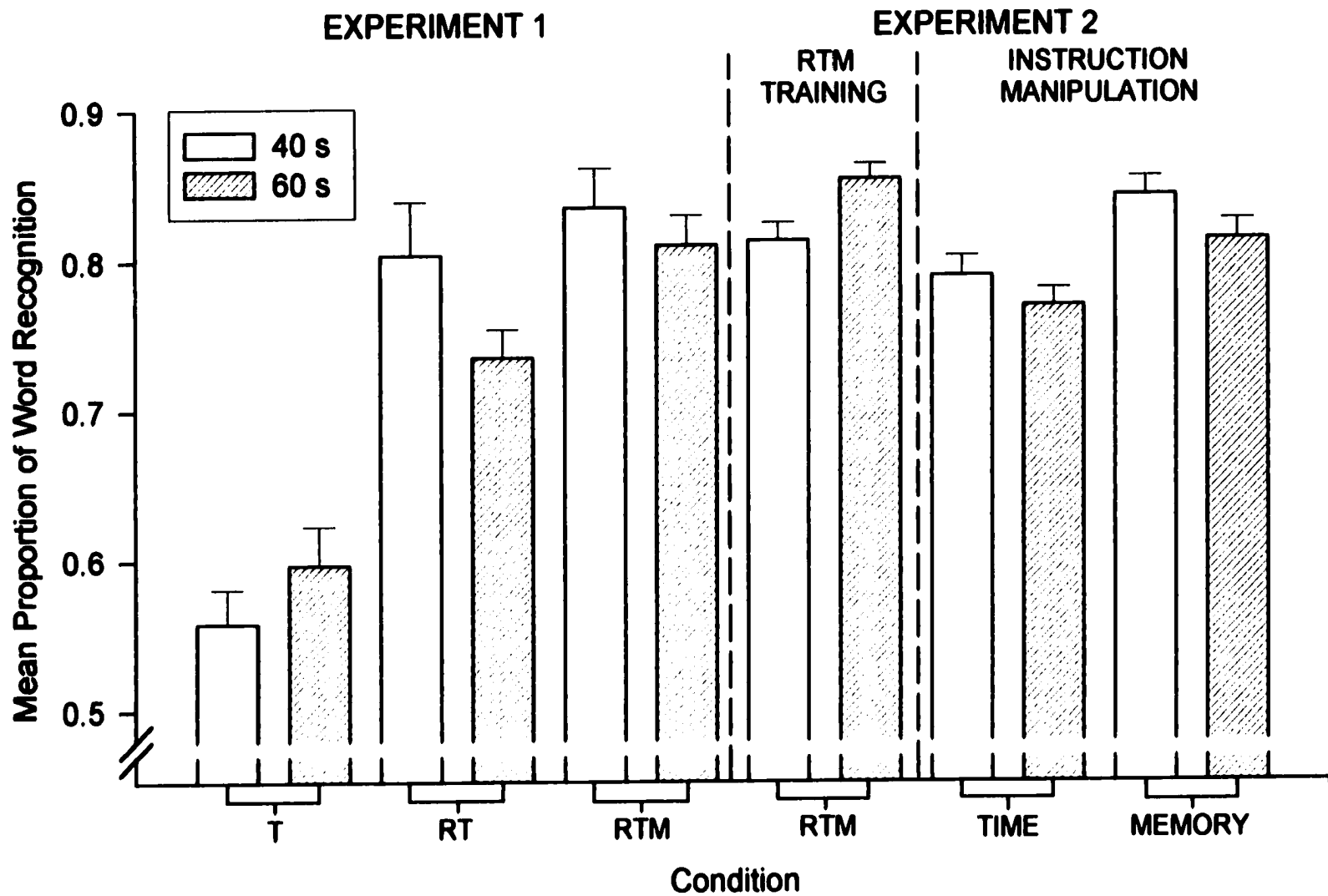


Figure 4. Mean proportion of word recognition (+SE) as a function of condition for Experiment 1 (left of vertical dashed lines), and sessions 1 and 2 of Experiment 2 (between, and to the right of the vertical dashed lines, respectively).

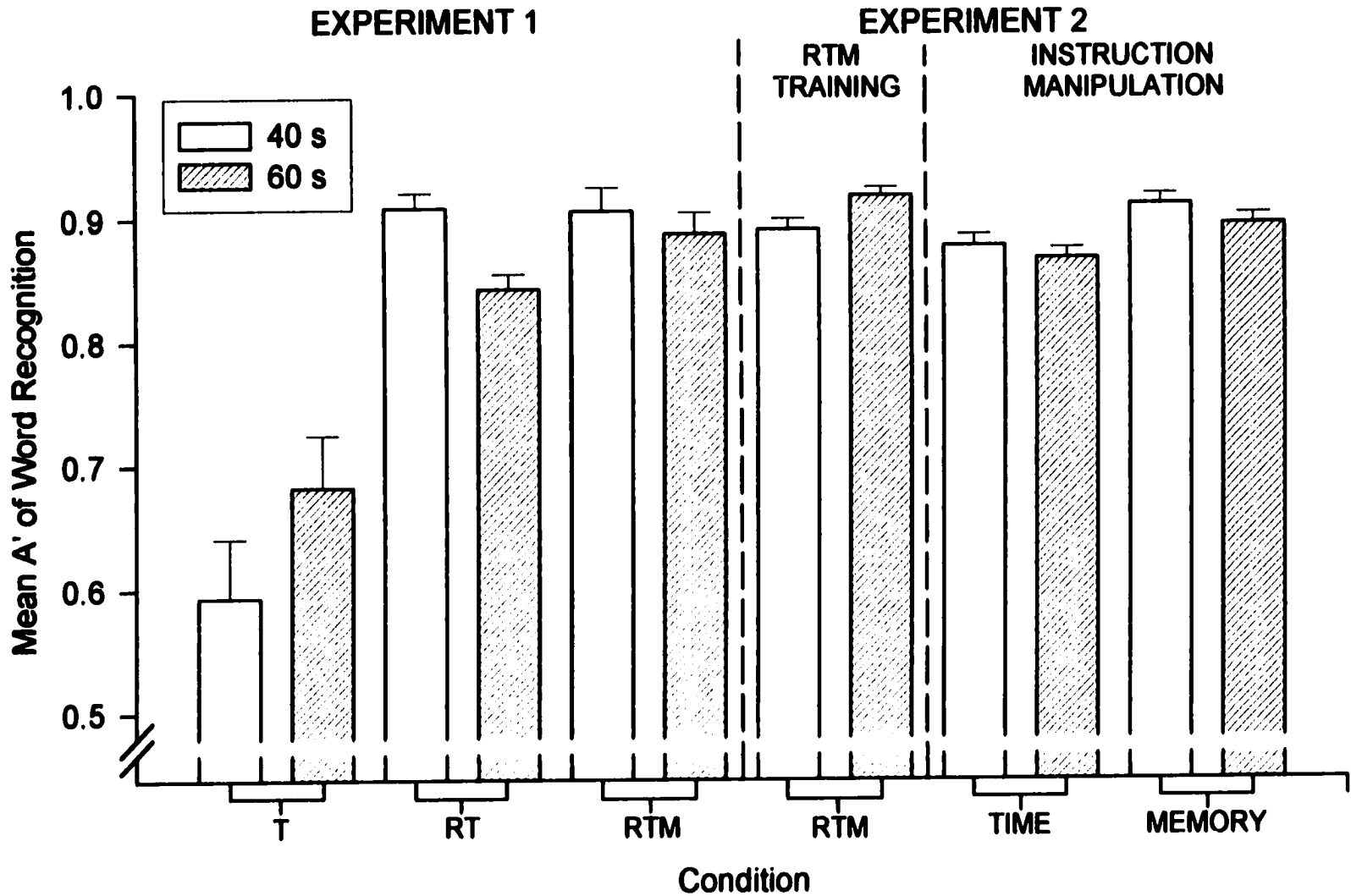


Figure 5. Mean A' of word recognition (+SE) as a function of condition for Experiment 1 (left of vertical dashed lines), and sessions 1 and 2 of Experiment 2 (between, and to the right of the vertical dashed lines, respectively).

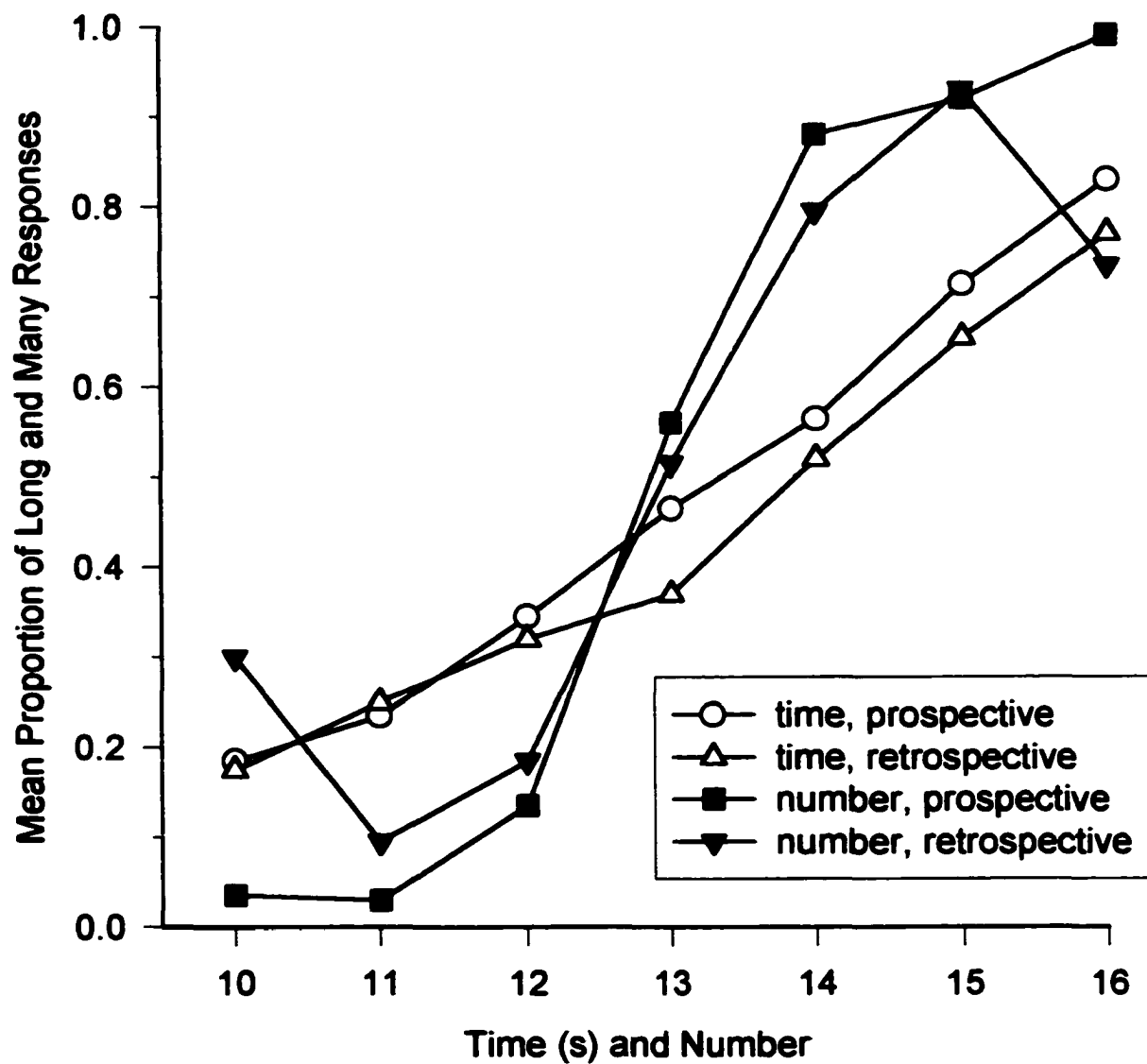


Figure 6. Mean proportion of long responses (time) and many responses (number of stimuli) as a function of stimulus duration and number of stimuli for the prospective and retrospective discrimination conditions.

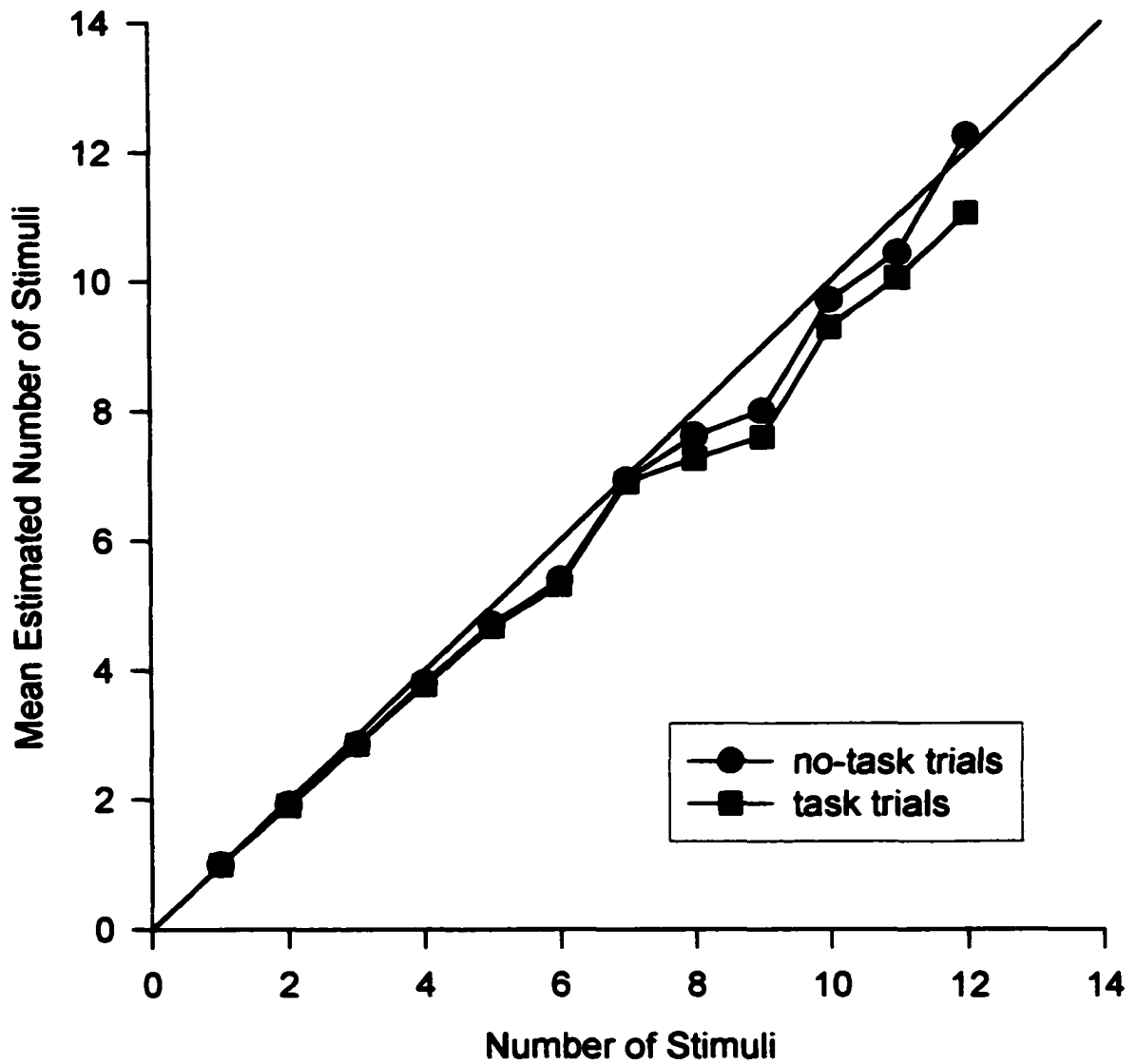


Figure 7. Mean estimated number of stimuli as a function of number of stimuli for the task and no-task trials. The solid line represents veridical counting.

### Bibliography

- Allen, D. A. (1980). Filling time versus affective response to an activity that fills time: Independent effects on time judgment? *Perceptual & Motor Skills*, 51, 723-727.
- Baddeley, A. D., & Hitch, G. (1974). Working Memory. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47-89). New York: Academic Press.
- Block, R. A. (1978). Remembered duration: Effects of event and sequence complexity. *Memory & Cognition*, 6, 320-326.
- Block, R. A. (1982). Temporal judgments and contextual change. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 8, 530-544.
- Block, R. A. (1992). Prospective and retrospective duration judgment: The role of information processing and memory. In F. Macar, V. Pouthas, & W. Friedman (Eds.), *Time, action, and cognition: Toward bridging the gap* (pp. 141-152). Dordrecht: Kluwer.
- Block, R. A., George, E., & Reed, M. A. (1980). A watched pot sometimes boils: A study of duration experience. *Acta Psychologica*, 46, 81-94.

- Block, R. A., & Reed, M. A. (1978). Remembered duration: Evidence for a contextual change hypothesis. *Journal of Experimental Psychology: Human Learning and Memory*, 4, 656-665.
- Block, R. A., & Zakay, D. (1997). Prospective and retrospective duration judgments: A meta-analytic review. *Psychonomic Bulletin & Review*, 4, 184-197.
- Brown, S. W. (1985). Time perception and attention: The effects of prospective versus retrospective paradigms and task demands on perceived duration. *Perception & Psychophysics*, 38, 115-124.
- Brown, S. W. (1997). Attentional resources in timing: Interference effects in concurrent temporal and nontemporal working memory tasks. *Perception & Psychophysics*, 59, 1118-1140.
- Brown, S. W., & Stubbs, D. A. (1992). Attention and interference in prospective and retrospective timing. *Perception*, 21, 545-557.
- Brown, S. W., Stubbs, D. A., & West, A. N. (1992). Attention, multiple timing, and psychophysical scaling of temporal judgments. In F. Macar, V. Pouthas, & W. J. Friedman (Eds.), *Time, action and cognition: Towards bridging the gap* (pp. 129-140). Dordrecht: Kluwer Academic Publishers.

- Burnside, W. (1971). Judgment of short time intervals while performing mathematical tasks. *Perception & Psychophysics*, 9, 404-406.
- Cahoon, D., & Edmunds, E. M. (1980). The watched pot still won't boil: Expectancy as a variable in estimating the passage of time. *Bulletin of the Psychonomic Society*, 16, 115-116.
- Creelman, C. D. (1962). Human discrimination of auditory duration. *The Journal of the Acoustical Society of America*, 34, 582-593.
- Curton, E. D., & Lordahl, D. S. (1974). Effects of attentional focus and arousal on time estimation. *Journal of Experimental Psychology*, 103, 861-867.
- Dewolf, R. K. S., & Duncan, C. P. (1959). Time estimation as a function of level of behavior of successive tasks. *Journal of Experimental Psychology*, 58, 153-158.
- Druyan, S., Dani, A., & Hadadi, G. (1995). Effect of complexity of a physical task on estimation of time to complete. *Perceptual & Motor Skills*, 81, 707-722.
- Fetterman, J. G., Dreyfus, L. R., & Stubbs, D. A. (1993). Discrimination of duration ratios by pigeons (*Columba livia*) and humans (*Homo sapiens*). *Journal of Comparative Psychology*, 107, 3-11.

- Fetterman, J. G., & Killeen, P. R. (1995). Categorical scaling of time: Implications for clock-counter models. *Journal of Experimental Psychology: Animal Behavior Processes*, 21, 43-63.
- Fraisse, P. (1963). *The psychology of time*. New York: Harper & Row.
- Geldard, F. A. (1962). *Fundamentals of psychology*. New York: Wiley.
- Getty, D. J. (1976). Counting processes in human timing. *Perception & Psychophysics*, 20, 191-197.
- Gibbon, J. (1991). Origins of scalar timing. *Learning & Memory*, 22, 3-38.
- Gibbon, J., & Church, R. M. (1984). Sources of variance in an information processing theory of timing. In H. L. Roitblat, T. G. Bever, & H. S. Terrace (Eds.), *Animal cognition* (pp. 465-488). Hillsdale, NJ: Erlbaum.
- Gibbon, J., & Church, R. M. (1990). Representation of time. *Cognition*, 37, 23-54.
- Grier, J. B. (1971). Nonparametric indexes for sensitivity and bias: Computing formulas. *Psychological Bulletin*, 75, 424-429.

- Grondin, S., Meilleur-Wells, G., & LaChance, R. (1999).  
When to start explicit counting in a time-intervals  
discrimination task: A critical point in the timing  
process of humans. *Journal of Experimental  
Psychology: Human Perception and Performance*, 25, 993-  
1004.
- Harton, J. J. (1938). The influence of the difficulty of  
activity on the estimation of time. *Journal of  
Experimental Psychology*, 23, 270-289.
- Harton, J. J. (1942). Time estimation in relation to goal  
organization and difficulty of tasks. *The Journal of  
General Psychology*, 27, 63-69.
- Hemmes, N. S., Kladopoulos, C. N., & Brown, B. L. (2001).  
*Clock processes governing timing with and without a  
concurrent nontemporal task*. Manuscript submitted for  
publication.
- Hicks, R. E., Miller, G. W., & Kinsbourne, M. (1976).  
Prospective and retrospective judgments of time as a  
function of amount of information processed. *American  
Journal of Psychology*, 89, 719-730.
- Holm, S. (1979). A simple sequentially rejective multiple  
test procedure. *Scandinavian Journal of Statistics*,  
6, 65-70.

- Ivry, R. B. & Hazeltine, R. E. (1995). Perception and production of temporal intervals across a range of durations: Evidence of a common timing mechanism. *Journal of Experimental Psychology: Human perception and performance*, 21, 3-18.
- Killeen, P. R. & Weiss, N. A. (1987). Optimal timing and the Weber function. *Psychological Review*, 94, 455-468.
- Kladopoulos, C. N., Brown, B. L., Hemmes, N. S., & Cabeza de Vaca, S. (1998). The start-stop procedure: Estimation of temporal intervals by human subjects. *Perception & Psychophysics*, 60, 438-450.
- Kladopoulos, C. N., Brown, B. L., & Hemmes, N. S. (2001). *The effect of the presence versus absence of a concurrent task on prospective estimates of the number of presented stimuli*. Unpublished manuscript.
- Kladopoulos, C. N., Hemmes, N. S., & Brown, B. L. (1998). *Simultaneous processing of temporal and numerical information in human subjects*. Unpublished manuscript.
- Macar, F. (1992). Temporal judgments on intervals containing stimuli of varying quantity, complexity, and periodicity. *Acta Psychologica*, 92, 297-308.

- Macar, F., Grondin, S., & Casini, L. (1994). Controlled attention sharing influences time perception. *Memory & Cognition*, 22, 673-686.
- McKay, T. D. (1977). Time estimation: Effects of attentional focus and a comparison of interval conditions. *Perceptual & Motor Skills*, 75, 581-586.
- Michon, J. A. (1972). Processing of temporal information and the cognitive theory of time experience. In J. T. Fraser, F. C. Haber, & G. H. Muller (Eds.), *The study of time* (pp. 242-258). Heidelberg: Springer-Verlag.
- Michon, J. A. (1985). The complete time experimenter. In J. A. Michon & J. L. Jackson (Eds.), *Time, mind, and behavior* (pp. 20-52). Heidelberg: Springer-Verlag.
- Michon, J. A., & Jackson, J. L. (1985). Introduction: The psychology of time. In J. A. Michon & J. L. Jackson (Eds.), *Time, mind, and behavior* (pp. 2-17). Berlin: Springer-Verlag.
- Miller, W., Hicks, R. E., & Willette, M. (1978). Effects of concurrent verbal rehearsal and temporal set upon judgments of temporal duration. *Acta Psychologica*, 42, 173-179.
- Ornstein, R. E. (1969). *On the experience of time*. Middlesex, England: Penguin Books.

- Poynter, W. D. (1983). Duration judgment and the segmentation of experience. *Memory & Cognition*, 11, 77-82.
- Poynter, W. D. (1989). Judging the duration of time intervals: A process of remembering segments of experience. In I. Levin & D. Zakay (Eds.), *Time and human cognition: A life span perspective* (pp. 305-331). B. V. (North Holland): Elsevier Science Publishers.
- Poynter, W. D., & Homa, D. (1983). Duration judgment and the experience of change. *Perception & Psychophysics*, 33, 548-560.
- Predebon, J. (1996). The effects of active and passive processing on interval events in prospective and retrospective time estimates. *Acta Psychologica*, 94, 41-58.
- Rakitin, B. C., Gibbon, J., Penney, T. B., Malapani, C., Hinton, S. C., & Meck, W. M. (1998). Scalar expectancy theory and peak-interval timing in humans. *Journal of Experimental Psychology: Animal Behavior Processes*, 24, 15-33.

- Roberts, W. A., & Mitchell, S. (1994). Can a pigeon simultaneously process temporal and numerical information? *Journal of Experimental Psychology: Animal Behavior Processes*, 20, 66-78.
- Sawyer, T. F., Meyers, P. J., & Huser, S. J. (1994). Contrasting task demands alter the perceived duration of brief time intervals. *Perception & Psychophysics*, 56, 649-657.
- Smith, N. C. (1969). The effect on time estimation of increasing the complexity of a cognitive task. *The Journal of General Psychology*, 81, 231-235.
- Spetch, M. L., & Sinha, S. S. (1989). Proactive effects in pigeons' memory for event duration: Evidence for analogical retention. *Journal of Experimental Psychology: Animal Behavior Processes*, 15, 347-357.
- Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, 18, 643-662.
- Thomas, E. A. C., & Weaver, W. B. (1975). Cognitive processing and time perception. *Perception & Psychophysics*, 17, 363-367.
- Toglia, M. P., & Battig, W. F. (1978). *Handbook of semantic word norms*. New Jersey: Erlbaum.

- Treisman, M. (1963). Temporal discrimination and the indifference interval: Implications for a model of the "internal clock." *Psychological Monographs*, 77 (13, Whole No. 576).
- Vroon, P. A. (1970). Effects of presented and processed information on duration experience. *Acta Psychologica*, 34, 115-121.
- Wearden, J. H. (1991). Do humans possess an internal clock with scalar timing properties? *Learning & Motivation*, 22, 59-83.
- Wearden, J. H., & McShane, B. (1988). Interval production as an analogue of the peak procedure: Evidence for similarity of human and animal timing processes. *The Quarterly Journal of Experimental Psychology*, 40, 363-375.
- Wilkening, F., Levin, I., & Druyan, S. (1987). Counting strategies for time quantification and integration: A developmental study. *Developmental Psychology*, 23, 823-831.
- Wilsoncroft, W. E., & Stone, J. D. (1975). Information processing and estimation of short time intervals. *Perceptual & Motor Skills*, 41, 192-194.

- Zakay, D. (1989). Subjective time and attentional resource allocation: An integrated model of time estimation. In I. Levin & D. Zakay (Eds.), *Time and human cognition: A life span perspective* (pp. 365-397). Amsterdam, North Holland: Elsevier Science Publishers.
- Zakay, D. (1992). The role of attention in children's time perception. *Journal of Experimental Child Psychology*, 54, 355-371.
- Zakay, D. (1993). Relative and absolute duration judgments under prospective and retrospective paradigms. *Perception & Psychophysics*, 54, 656-664.
- Zakay, D., & Block, R. A. (1996). The role of attention in time estimation processes. In M. A. Pastor & J. Artieda (Eds.), *Time, internal clocks, and movement* (pp. 143-164). Amsterdam: Elsevier.
- Zakay, D., Nitzan, D., & Glicksohn, T. (1983). The influence of task difficulty and external tempo on subjective time estimation. *Perception and Psychophysics*, 34, 451-456.