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Attention allocation policy influences prospective timing

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The role of attention allocation policy control in prospective duration judgments was tested in two experiments. In the first experiment, it was demonstrated that prospective duration judgments of same clock durations are longer when timing is treated as a primary task than when it is treated as a secondary task, regardless of the difficulty of the nontemporal task filling the to-be-judged interval. In the second experiment, this finding was replicated. Additionally, it was demonstrated that when prospective timing is not preassigned a specific priority, duration judgments are longer than those obtained under secondary-task conditions, but shorter than those obtained under primary-task conditions. It was also revealed that when attention is distracted from timing, prospective duration judgments become shorter than when attention is not distracted. These findings support the notion that prospective timing creates a dual-task condition in which magnitude of duration judgments reflects the amount of attentional resources allocated for temporal information processing.

Duration judgments—especially those of seconds and minutes—involve cognitive processes that are sensitive to the contextual conditions under which the judgments are made (Block, 1989; Zakay, 1990). The degree of a priori awareness of the need to make duration judgments is an important contextual factor. Duration judgments are made prospectively when one knows before a to-be-judged interval starts that its duration is to be estimated, whereas duration judgments are made retrospectively when one does not know that a duration is to be estimated. Whereas some researchers (e.g., Brown, 1985; Brown & Stubbs, 1988) have argued that similar cognitive processes underlie prospective and retrospective timing, many others (e.g., Block, 1992; Block & Zakay, 1997; Hicks, Miller, & Kinsbourne, 1976; Underwood & Swain, 1973; Zakay, 1993; Zakay, Tsal, Moses, & Shahar, 1994) have contended that different cognitive processes govern each type of temporal judgment.

In any case, it is generally accepted that attentional processes play a major role in prospective timing, which is the focus of the present study. Prospective timing of durations filled with some nontemporal task can be analyzed as a dual task (Brown, 1997) in which attention should be shared between temporal and nontemporal information processing.

Thomas and Weaver (1975) developed a mathematical model in which attentional allocation is proposed to influence duration judgments. The model claims that the perceived duration of an interval containing certain information is a monotonic function of the weighted average of the amount of information encoded by two processors—a temporal information processor and a nontemporal information processor. The organism divides attention between these two parallel processes. Perceived duration is weighted to optimize the reliability of the information that each processor encodes because as more attention is allocated to one processor, the other becomes more unreliable. When little or no stimulus information occurs during the to-be-judged duration, people tend to allocate more attention to temporal information. In contrast, when a task demands considerable information processing, people tend to allocate more attention to this nontemporal information. Although this model was tested only by human duration judgments of stimuli presented for under 100 msec, Michon (1985) argued that the model can potentially encompass longer time periods and thus provide a general model of temporal information processing. However, Thomas and Weaver's model suffers from several drawbacks, such as not specifying the nature of temporal information processing that takes place in the temporal information processor. Another drawback is that the assumption that perceived duration of an interval is a monotonic function of the amount of information encoded by the two processors was not validated empirically for prospective duration judgments. Zakay's (1989) resource allocation model of prospective timing is an elaboration of Thomas and Weaver's model, but it claims that prospective durations are a function of the amount of attentional resources allocated to the temporal information processor.

The typical paradigm revealing characteristics of prospective duration judgments requires participants to judge the duration of either a complex or a simple task. When clock time is constant, people make longer prospective judgments of the duration of simple tasks than of complex

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tasks (e.g., Block, 1992; Brown, 1997). These findings are thought to support an attentional model because simple tasks presumably require less processing effort and thus fewer attentional resources, thereby leaving more attentional resources available for the temporal processor.

Another route for validating an attentional model of prospective timing has been to instruct participants to allocate more or less attention for timing than to a concurrent nontemporal task. If prospective timing of filled durations creates a dual task in which attention has to be shared between temporal and nontemporal information processing, it would be expected that the more attentional resources are allocated for timing, the longer prospective duration judgments should be. This was indeed demonstrated by Macar and her colleagues (Grondin & Macar, 1992; Macar, Grondin, & Casini, 1994).

The goals of the present study were to further support the attentional model of prospective timing by (1) replicating Macar et al.'s (1994) findings within a paradigm that also manipulates nontemporal task complexity; (2) demonstrating the role of attention by utilizing an attentional distraction manipulation; (3) demonstrating that attention is shared between the temporal and nontemporal tasks even when no specific instructions are given; and (4) broadening the generalization of the findings by using two judgment methods and different nontemporal tasks.

The study is composed of two experiments, which are reported in the following sections.

EXPERIMENT 1

The purpose of this experiment was to test the assumption that prospective duration judgments are a function of the amount of attentional resources allocated for timing. This assumption was tested by employing the secondary-task method and by manipulating nontemporal information processing requirements via task complexity. Prospective duration judgments are expected to be longest when timing is the primary task and the concurrent nontemporal task is simple in terms of resource demands. Similarly, prospective duration judgments are expected to be shortest when timing is the secondary task and the accompanying nontemporal task is complex.

Method

Participants. Sixty 1st-year social science students at Tel-Aviv University participated in the experiment as part of their course requirements. Participants' ages ranged from 18 to 30 years. All participants had normal hearing.

Experimental tasks. An auditory Stroop task (AST) was designed. A 25-sec recording was constructed during which two tones each appeared five times in random order. During each exposure, a tone was presented for 750 msec with an intensity of about 70 dB. One tone was high (i.e., the "do" on the second octave on the piano), and the other tone was low (i.e., the "do" on the first octave on the piano). A 1,750-msec silent interval separated any two consecutive tones. The recording started with a "start" signal followed by a silent interval and ended with a tone followed by a "stop" signal. Participants were asked to listen to the recording and to mark on a response form whether the tone was high or low.

In the simple task, the response form was composed of two rows of squares, one above the other. Participants were asked to mark the appearance of a high tone by crossing a square in the upper row and to mark a low tone by crossing a square in the lower row. In the complex task, the response form was identical to that of the simple task, but participants were asked to mark high tones by crossing a square in the lower row and to mark low tones by crossing a square in the upper row. Due to stimulus–response incompatibility (Wickens, 1992), an interference between the dimensions of "high" and "low" tones and "upper" and "low" rows existed.

Priority manipulation. The secondary-task method commonly used to measure mental workload (see, e.g., Gopher & Donchin, 1986) was employed. Differences in primary-task resource demands are assumed to be reflected in secondary-task performance. Therefore, if participants are instructed to treat duration judgments as the primary task, their prospective duration judgments should increase as compared with those for which duration judgment is the secondary task. This discrepancy should presumably arise because of the allocation of more resources for temporal information processing.

In all cases, AST performance and prospective duration judgments were required. Whereas in the primary-task condition participants were told that the achievement of an accurate duration judgment was the most important task, in the secondary-task condition, the achievement of an accurate performance on the AST was presented as the most important task.

Experimental design. A 2 × 2 between-subjects complete factorial design (task complexity × duration judgment priority) was employed, thus forming four experimental groups.

Procedure. Participants were randomly assigned to the four experimental groups and were tested individually. The two tones were presented and the nature of the AST was explained. Appropriate instructions were then given according to the experimental condition to which a participant had been assigned, and the recording was played. Upon the termination of the recording, each participant was asked to report in writing the duration judgment in seconds. They were asked to give the most accurate judgment possible. All together, each participant stayed about 10 min in the laboratory.

The subjective duration judgments and the number of performance errors conducted in the AST were registered for each participant. A *performance error* was defined as any incongruent response (i.e., marking an upper or a lower square when a low or a high tone was heard, respectively).

Results

Means and standard deviations of prospective duration judgments, as well as number of performance errors, are presented in Table 1.

A 2 × 2 analysis of variance (ANOVA) was performed and a significant main effect of priority [$F(1,56) = 4.75$, $p < .05$] was revealed, indicating that duration judgments were longer when timing was a primary task than

Table 1
Means and Standard Deviations of Prospective Duration Judgments (PDJ) and Number of Errors (n = 15 in Each Condition)

	Duration Judgment Priority							
	Primary Task				Secondary Task			
	PDJ		Errors		PDJ		Errors	
Task	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Simple	20.93	6.20	1.00	0.22	17.87	7.20	0.07	0.05
Complex	17.27	4.62	0.73	0.18	13.87	4.45	0.41	0.14

when it was a secondary task. A second significant main effect was obtained for AST complexity level [$F(1,56) = 6.67, p < .05$]. Duration judgments were longer when AST was simple than when it was complex. The interaction was not significant ($p > .10$). Regarding the number of performance errors, a significant main effect of priority [$F(1,56) = 4.15, p < .05$] was revealed. AST complexity level did not yield a significant effect.

As expected, the longest duration judgments were obtained when duration judgment was a primary task and AST was simple, and the shortest duration judgments were obtained under secondary-task and complex AST conditions. This difference was significant (Duncan multiple range test, $p < .01$).

Discussion

The results obtained in the first experiment support the notion that prospective timing processes are highly influenced by the focusing of attention on temporal information processing and that magnitude of duration judgments reflects the amount of attentional resources allocated for timing. The validity of the priority manipulations was supported by the analysis of performance errors. The number of errors was significantly higher when timing was a primary task than when it was a secondary task. This was true for both the simple and the complex conditions. Most probably, fewer resources are available for performing the AST when timing is a primary task than when it is a secondary task. Prospective duration judgments were higher when the nontemporal task performed during the to-be-judged interval was simple than when it was complex. These findings replicate previous studies (e.g., Predebon, 1996; Zakay, 1993) and indirectly support the attentional model of prospective timing. The fact that prospective duration judgments were higher when timing was a primary task than when it was a secondary task provides more direct support. This result replicates findings reported by Macar et al. (1994). The unique contribution of the present experiment is in the simultaneous manipulation of the difficulty of the nontemporal task and the division of attention. The absence of a significant interaction between time judgment priority and nontemporal task complexity suggests that each one of these two factors has a somewhat independent influence on prospective timing processes. Duration judgment priority might be more related to a deliberate allocation policy, whereas nontemporal task complexity might enhance interference between timing and nontemporal processes. This independence is reflected in the finding that prospective duration judgments were longest for a simple task when timing was a primary task and shortest for a complex task when timing was a secondary task.

EXPERIMENT 2

The objective of this experiment was to replicate the findings from the first experiment with another nontemporal task, a different objective duration, and a different method of duration judgment. Such a replication is important for ensuring the generality of the findings. A second objective was to add a new attentional manipulation with the introduction of a nontemporal stimulus that attracts attention away from timing. It was expected that when the distraction manipulation was activated, the amount of attentional resources directly allocated for timing would be reduced, thereby causing prospective duration judgments to be shorter than when such a distracting stimulus was not activated. This effect has been found with 6- to 8-year-old children (Zakay, 1992), but has not yet been tested in adults. A third objective was to explore the natural priority assigned to timing processes when the priority is not predetermined by the experimenter. Revealing this aspect of timing is important for understanding timing processes in natural settings.

Method

Participants. A total of 144 undergraduate students at Tel-Aviv University participated in the experiment as a partial fulfillment of their course requirements. Participants ranged in age from 19 to 33 years.

Nontemporal tasks. The word (W) and color–word (CW) Stroop (1935) tasks were selected as the simple and complex nontemporal tasks, respectively. In the W task, color names, written with incongruent inks in terms of color, are presented and participants are asked to speak out the names. In the CW task, participants are asked to ignore the color name and to speak out the name of the color of the incongruent ink. In numerous studies, it has been found that the CW task is more demanding and difficult to perform than the W task (e.g., Dyer, 1973; McCleod, 1991). It has also been found that prospective timing is sensitive to the levels of mental effort associated with these two tasks (see, e.g., Zakay, Block, & Tsal, in press).

Timing priority. Timing priority was manipulated as in the first experiment. However, a neutral condition was added in which priority was not mentioned and the instructions given to participants referred only to timing and to the performance of the Stroop task.

Distraction manipulation. The startle effect was used in order to distract attention since it has been proven to elicit a very general effect by a strong and unexpected stimulus. The startle pattern is a single brief episode that indicates both a general activation and a preparation for action (Woodworth & Schlosberg, 1965). On the basis of a pilot study, an unpleasant explosion such as noise with an intensity of 100 dB was activated for 1 sec during 3 points selected at random along the to-be-judged interval.

Duration judgment method. A reproduction method was employed. Participants were asked to reproduce the judged duration by pressing a button for the same duration as that of the judged interval. The pressing of the button activated an electronic timer that was accurate to a 10th of a second.

Experimental design. A $2 \times 2 \times 3$ complete between-subjects factorial design was used. The independent variables were task complexity (low, high), attentional distraction (activated or not), and timing priority (primary task, secondary task, or neutral instructions).

Procedure. Participants were randomly assigned to 1 of the 12 experimental conditions and tested individually. Appropriate instructions were given to each group. In all groups, participants were told that they would be asked to judge the duration of task performance. However, in the secondary group, the performance of the Stroop task was emphasized, and in the primary group, accuracy of duration judgment was emphasized. In the neutral group, no task was defined as primary or secondary. In the distraction groups, the noise manipulation was activated.

The to-be-judged interval began with a "start" signal and ended with a "stop" signal. Five Stroop stimuli were presented on a computer screen for 1 sec each with an interstimulus interval (ISI) of 1.5 sec. Participants were asked to give the response during the ISI. The objective duration was 12.5 sec. Immediately after the termination of the interval, participants were asked to reproduce its duration. This was followed by asking the participants to rank the complexity of the task they had performed on a 5-point scale, ranging from 1 (*very simple*) to 5 (*very complex*).

Results

Means and standard deviations of duration judgments and complexity ratings are presented in Table 2. A $2 \times 2 \times 2$ ANOVA (task complexity $\times$ distraction $\times$ timing priority) without the neutral group was conducted on duration judgments in order to determine whether the findings from the first experiment had been replicated. Sig-

Table 2
Means and Standard Deviations of Prospective Duration Judgments (PDJ) and Complexity Ratings (CLX) (n = 12 in Each Condition)

	Duration Judgment Priority																							
	Primary task								Secondary task								Neutral instructions							
	D−				D+				D−				D+				D−				D+			
	PDJ		CLX		PDJ		CLX		PDJ		CLX		PDJ		CLX		PDJ		CLX		PDJ		CLX	
Task	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Simple	10.24	2.17	1.58	0.66	8.65	2.34	2.00	0.73	6.89	1.99	1.66	0.65	6.53	1.83	2.00	0.73	8.60	2.22	1.83	0.66	7.86	2.15	2.33	0.77
Complex	9.91	2.29	4.00	0.60	5.46	1.98	4.00	0.73	5.55	2.26	4.50	0.67	4.56	1.68	4.75	0.45	6.11	2.16	3.91	0.66	6.61	2.50	4.50	0.86

Note—D−, distraction not activated; D+, distraction activated.

nificant main effects were obtained for complexity level [$F(1,88) = 16.16, p < .01$], timing priority [$F(1,88) = 40.19, p < .01$], and distraction [$F(1,88) = 19.00, p < .01$]. Neither of the possible interactions was significant. Duration judgments were longer when timing was a primary task than when it was a secondary task (means were 8.56 and 5.88, respectively) and when the nontemporal task was simple than when it was complex (means were 8.07 and 6.37, respectively). When the distraction was not activated, duration judgments were longer than when it was activated (means were 8.14 and 6.30, respectively). Accordingly, a replication of the first experiment was obtained. A second 2 × 2 × 3 ANOVA, similar to the first one but including the neutral group, was also performed. Significant main effects similar to those found in the former analysis were found for complexity level [$F(1,132) = 24.60, p < .01$], timing priority [$F(2,132) = 11.61, p < .01$], and the distraction [$F(1,132) = 12.74, p < .01$]. Again, no significant interaction was obtained. Duncan multiple range tests ($p < .01$) revealed that, as expected, the longest duration judgments were obtained for the simple task, when timing was a primary task and the distraction was not activated, and the shortest duration judgments were obtained for the complex task, when timing was a secondary task and the distraction was activated. Duncan multiple range tests revealed that duration judgments obtained under neutral conditions were significantly shorter than those obtained under primary-task conditions (means of 7.29 and 8.56, respectively, $p < .05$) and significantly longer than those obtained under secondary-task conditions (means of 7.29 and 5.88, respectively, $p < .01$). These findings indicate that in the neutral condition, fewer attentional resources were allocated for timing than in the primary-task condition, but more than in the secondary-task condition.

Complexity ratings were analyzed by a similar three-way ANOVA. A significant main effect of complexity level was obtained [$F(1,132) = 390.03, p < .01$]. Complexity ratings were higher when the nontemporal task was complex than when it was simple (means of 4.23 and 1.90, respectively). A significant main effect of the distraction manipulation was also revealed [$F(1,132) = 6.69, p < .05$]. When the distraction was activated, participants reported that the task was more complex than without the distraction (means of 3.22 and 2.91, respectively). However, the timing priority effect did not significantly affect complexity ratings. This was expected since the overall level of perceived complexity reflects performance on both the timing and the nontemporal task.

GENERAL DISCUSSION

The findings from both the first and second experiments support those from previous studies (e.g., Macar et al., 1994) indicating that the division of attention between temporal and nontemporal information processing can be controlled. Furthermore, the second experiment indicated that such a division is done naturally by participants, even when they are not instructed to do so.

The findings from the second experiment support the notion that attention plays a central role in prospective timing processes. The findings related to the priority manipulation and to the manipulation of the complexity of the nontemporal task replicated the findings from the first experiment. The fact that in the second experiment the objective duration of the to-be-judged interval, the judgment method, and the nontemporal task were different from those employed in the first experiment suggests that the generality of the findings is supported. The distraction manipulation produced a significant effect only for the complex task: Prospective duration judgments were shorter when the distraction was activated than when it was not. In the simple-task condition, the same trend was observed but the effect was not significant. This discrepancy may have arisen because the resources required for both timing and performance in the simple task were available even after the allocation of some of the resources to the processing of the distracting stimulus. However, in the complex task, not enough resources were available for both the timing and the performance of the CW task. Since the performance of the CW task itself was not impaired when the distraction was activated, one can most probably assume that fewer resources were allocated for timing, leading to the shortening of prospective duration judgments.

The present findings do not eliminate a potential role of memory and especially of prospective memory in prospective timing. However, there are some indications that the role of memory is not significant in prospective timing. In the first experiment, prospective duration judgments were found to be shorter for intervals containing complex nontemporal tasks than for intervals containing simple nontemporal tasks, but it is most plausible to assume that more information is stored in memory during the performance of a complex task than during that of a simple task. In the second experiment, prospective duration judgments were shorter when the distraction was activated than when it was not activated, although most plausibly some information related to the distraction was stored in memory. Further research should clarify these issues. In any case, the notion that attentional processes play a significant role in prospective timing is supported by the present study, which also indicates that attention is naturally divided between timing and a concurrent nontemporal task that has to be performed during a to-be-judged interval. Nonetheless, the conceptualization of attending to time and of temporal information processing is vague. Zakay and Block (1996) proposed an attentional gate model to better conceptualize these terms. The model proposes that every time an individual attends to time, a gate is opened that causes the transmission of a pulse stream produced by a pacemaker to a cognitive counter. The cognitive counter then counts or sums the pulses that have been transmitted in such a way that its momentary total pulse count is transferred to a working memory store. Additionally, certain time periods to which individuals have been previously exposed are stored in long-term memory. Duration-dependent responses are thus either based on the context of working memory or on a comparison made between the context of working memory and relevant records stored in long-term memory. Accordingly, attending to time can be conceptualized as the wider opening of the gate, allowing for more pulses to pass through in a given time unit. Temporal information processing consists of accumulating, storing, and comparing the number of pulses—cognitive functions that demand attentional resources. The load associated with performing a nontemporal task may be thought to influence the amount of resources available for temporal information processing, whereas attention allocation policy may be thought to influence the opening of the attentional gate more directly. This dissociation might explain the independent impact of the priority of timing and the nontemporal complexity manipulations. These assumptions, however, should be empirically validated.

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