ON TEMPORAL RELEVANCE AND TEMPORAL UNCERTAINTY

IN TIME-BASED PROSPECTIVE MEMORY

by

ARLEN G. CLARK-FOOS

(Under the Direction of Richard L. Marsh)

ABSTRACT

In the present research, key variables (i.e., temporal relevance and temporal uncertainty) from models of psychological short-term timing processes are applied to time-based prospective memory in order to investigate if they have an effect on clock checks or ultimate performance in these longer term intentions. Increasing temporal uncertainty resulted in more clock checks in Experiment 1 but this effect was mediated by the effect of temporal relevance in Experiment 2. The latter interaction supports the suggestion that temporal relevance exerts an overpowering effect on attention to time, resulting in a difference in susceptibility to the influence of temporal uncertainty. We discuss these results as they relate to both psychological models of time as well as the tenets of basic models of memory and attention.

INDEX WORDS: TIME-BASED PROSPECTIVE MEMORY, TEMPORAL UNCERTAINTY, TEMPORAL RELEVANCE, ATTENTION

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ARLEN G. CLARK-FOOS

B.A. Psychology, North Carolina State University, 2003

M.S. Psychology, University of Georgia, 2006

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ARLEN G. CLARK-FOOS

Major Professor: Richard L. Marsh

Committee: Brett Clementz
Nash Unsworth

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
May 2009

DEDICATION

I would like to dedicate this manuscript to my daughter, Gaia Lennon Bentley Clark-Foos. Her early arrival in our lives gave me the inspiration to finish my doctoral requirements.

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INTRODUCTION

On temporal relevance and temporal uncertainty in time-based prospective memory

The study of time and our perception of its passage is as old, perhaps, as psychology itself. Philosophers and researchers alike from Aristotle through William James (1890) have speculated on the theoretical underpinnings that might explain how humans perceive and track time. Although time estimation has been and continues to be widely studied on the order of seconds and milliseconds, currently we know relatively little about the timing of longer intervals such as several minutes and longer. These longer intervals, however, have received some modest consideration in the time-based prospective memory literature. The present goal is to connect these heretofore unconnected literatures, with the aim of improving the theoretical predictions and general understanding of time-based prospective memory. Some efforts to combine these two literatures have appeared in a recent edited volume (Glickson & Myslobodsky, 2006), and the goal is to extend this initial work.

Prospective memory is the study of future intentions and goals (Einstein et al., 2005). Everyone has had the experience of completing an intention when a future time or context occurs. For example, most of us have attended colloquiums that start at specific times (i.e., punctuality was essential). In this example, the intention to arrive at the colloquium was the prospective memory, which was made time-based by the temporal constraint imposed by its beginning. Whereas researchers studying event-based prospective memory have developed several influential theories to explain performance, time-based prospective memory has not enjoyed the same attention. One such theory, Test-Wait-Test-Exit (Harris & Wilkins, 1982; see also Test-Operate-Test-Exit, c.f. Miller, Galanter, & Pribram, 1960) was introduced, in part, to explain the pattern of clock checking behavior found in most studies of time-based prospective memory. In this theory, participants check the clock during a test cycle. If the target time has not yet elapsed, then they return to operations of the ongoing task (i.e., they wait for more time to elapse). If enough perceived time has elapsed since the previous test, then they will test again. The cycle continues until the target time is reached, at which point the cycle ends, resulting in a successful prospective memory response. This theory can adequately explain observable behavior but there are no cognitive principles identified that might affect the duration of the waiting period or the frequency of test cycles. Our goal is to integrate influential cognitive principles from a more sophisticated model that have been successfully applied at shorter intervals and in order to determine if these same principles are involved in the timing of longer-term intentions.

Time estimation has traditionally been explained with what have been labeled accumulator models (Gibbon, Church, & Meck, 1984; Block & Zakay, 1997). Such models assume a neural network (Ivry, R. & Spencer, R., 2004; see also Buhusi & Meck, 2005) that is responsible for emitting and accumulating pulses to keep track of time. The pacemaker emits pulses at a (assumed) constant rate; although this rate is debated (e.g., Block, Zakay, & Hancock, 1998). When the signal to begin timing is given, the accumulator begins to count these neural pulses. When the count reaches an amount equal to that in working memory for the period being timed, the participant will make some sort of response; that is, a clock check or the overt action that was to be performed. In the Attentional Gate Model of time estimation, the ability of the accumulator to efficiently capture pulses is determined by how much attention is directed towards timing (for a recent application of this model to time-based prospective memory, see

Block & Zakay, 2006). If timing is the primary task, then participants will devote more attention towards timing and the attentional gate will be wide open to allow these neural pulses into the accumulator. By contrast, if timing is given less emphasis, the attentional gate will be very narrow and it will be more difficult for the accumulator to capture pulses. Regardless, as the count in the accumulator gets larger, the participant should check the clock to determine if it is appropriate to perform the intended action. If the target time has not elapsed, then performance returns to the ongoing task and the accumulator continues to capture pulses. Block and Zakay (2006) have suggested recently that their attentional gate model is also applicable to the longer intentions studied with longer intervals associated with time-based prospective memory. Therefore, the current premise is that predictions of the model may help to advance the theoretical precision of all researchers studying time-based intentions. In this earlier work several factors that are known to affect time estimates of short intervals have been clearly identified. One such factor, labeled *temporal uncertainty* (Zakay, 1992) refers to the subjective belief that the length of a task can be known or estimated in advance. When people are certain of how long a task is going to take (i.e., low temporal uncertainty), the model predicts that they will recruit less attention towards timing processes in general, and thus, the attentional gate will have only a narrow opening. Consequently, the accumulator should capture fewer pulses and the subjective estimate of the duration of intervals should be accordingly shorter. By contrast, people who are unable to estimate the length of a task (i.e., high temporal uncertainty) will ostensibly recruit more resources towards timing and the attentional gate should be wide open to capture pulses. Thus, a straightforward prediction from this model would be that people experiencing temporal uncertainty should experience that time is passing more quickly as compared with people otherwise not experiencing such uncertainty.

An alternative explanation of these proposed effects could be that a temporally certain task provides a temporal segmentation that can be used to accurately allocate attention towards time-related processes only when it becomes necessary. For example, if one has an intention to respond in 8 minutes and 30 seconds, and one also knows that the final task will start when 8 minutes has elapsed, then one could allocate fewer resources towards time until the final task begins (c.f., Cook, Marsh, Clark-Foos, & Meeks, 2007). These explanations are not necessarily mutually exclusive and will be discussed in more detail later.

The prevailing theories of time estimation on which we base our predictions (Block & Zakay, 2006) posit that increasing temporal uncertainty increases the amount of attention devoted to time-related cognitive monitoring (see also Grondin & Rammsayer, 2003). Kliegel, Martin, McDaniel, and Einstein (2001) have, in fact, directly manipulated attention to time in a time-based prospective memory paradigm. When the time-based intention was given more emphasis, participants checked the clock more often and they were more accurate in the timeliness of their ultimate prospective memory response. Therefore, the increased importance of the time-based task increased those cognitive processes that were related to monitoring time. Based on the foregoing, temporal uncertainty should recruit more attention towards tracking time, and then, participants experiencing higher levels of temporal uncertainty should check the clock more often.

Consequently, in the first study we sought to understand whether time monitoring, evidenced by clock checking, in time-based prospective memory would be affected by a variable that has been shown to affect shorter time estimation judgments, namely temporal uncertainty. By contrast to making time estimation a highly salient component of the overall experiment (i.e., an importance manipulation regarding time), we chose to vary more subtlely whether time was an inherent component of the ongoing task. We reasoned that if time varied regularly on subcomponents of the ongoing task, participants should allocate less attention towards tracking time. Under this scenario attention allocation should result in fewer clock checks when the duration of the subcomponents on the ongoing task was highly regular (temporal certainty) as compared with when they were completely variable (temporal uncertainty). The following summarizes our approach.

EXPERIMENT 1

Two conditions were tested in the first experiment. One condition was instructed that every paper-and-pencil task would be timed at exactly two minutes each. The second condition was instructed that the computer would be randomly determining the length of time that they would work on each task. The primary dependent variable was the frequency at which participants checked the computer's clock in order to respond at a specific time. Additionally, the latency of the time-based response was calculated as the signed deviation from the target time in order to supplement the primary dependent variable. Theories of temporal uncertainty predict that participants with randomly timed tasks should allocate more attention to time (e.g., Zakay, 1992). As such, in this paradigm greater attention to time should be evidenced by a higher frequency of clock checks in the randomly-timed (i.e., high temporal uncertainty) as compared with the regularly-timed (i.e., low temporal uncertainty) condition. Although greater attention to time could result in more accurate (i.e., more timely) prospective memory responses, the condition with less attention allocated to tracking time (i.e., the regularly timed tasks) should be able to use the regular segmentation of the environmental event structure as support and respond just as accurately as a condition with more attention devoted to tracking time. That is, we predicted that the relationship between clock checking and ultimate prospective memory performance that is sometimes found in other studies (e.g., Kliegel et al., 2005) is not necessarily preordained. Thus, these experiments test competing theoretical predictions for applying time-monitoring theories to standard time-based prospective memory.

Method

Participants. All 70 participants in this experiment were University of Georgia undergraduates who volunteered in exchange for partial fulfillment of a course research appreciation requirement. Each participant was tested individually in sessions lasting approximately 20 minutes. The participants were quasi-randomly assigned to the two experimental conditions that we have labeled regularly and randomly timed tasks. The labels denote the timing of the tasks that constituted the ongoing activities (i.e., regularly occurring or randomly occurring). One participant was removed from the analysis because he chose to answer a phone call during the experiment.

Materials. The ongoing tasks consisted of a series of five paper-and-pencil activities that were randomly ordered anew for each participant. The activities consisted of identifying the proper synonym for a target word, solving anagrams, working on Sudoku puzzles, locating an embedded figure in a larger image, and searching for hidden words in a word puzzle. These tasks were chosen because each would take longer than the allotted time before the software requested they move to the next task. Thus, regardless of condition, all participants were continuously engaged.

Procedure. When participants arrived at the lab, they were assigned to one of the two between-subjects conditions. They were asked to read instructions on a computer monitor that provided detailed instructions for the five paper-and-pencil tasks that they would be completing in the ongoing task. For the synonym task, they were asked to identify the correct synonym for each of (potentially) 100 target words by selecting the correct alternative from a four-option multiple-choice list. In the anagram task, a word would appear with two letters transposed. Participants were asked to rearrange the transposed letters (identified by a carat under each of them) to form a proper English word. Sudoku is a puzzle where the goal is to include every digit from 1-9 in each column, row, and grid of the puzzle. The Sudoku puzzles chosen for this experiment were classified as difficult by experts in Sudoku (Sheldon, 2005). We chose difficult puzzles to ensure that participants could not finish the puzzles before the specified time ran out for that task. The embedded figure task consisted of complex geometric images with specific to-be-identified figures embedded within each (for a similar task, see Miller, A., 2007). The final task was held constant for both conditions (i.e., not subject to randomization) and was a simple word search task. By using the same task as the final task for both conditions we could compare clock checking frequency and response latency in the final block of the experiment without any confounding influences of task complexity (see Martin & Schuman-Hengsteler, 2001).

After participants read instructions for the paper-and pencil tasks that constituted the ongoing task, they were informed of their time-based prospective memory intention. Specifically, they were asked to make a special response (i.e., press the '/' key) on the computer keyboard whenever 8 minutes and 30 seconds had elapsed from the beginning of the first task. They were correctly informed that the clock would begin at the moment the first task began, and they were informed that they could check the computer's clock at *any time* by pressing the 'Z' key. Doing so brought up a small clock of the form 4:20 in the upper right-hand corner of the monitor which, in this example, would indicate that 4 min and 20 s had elapsed. The clock appeared for 1 s and then disappeared automatically. The software recorded all key presses. To avoid any external reminders, the '/' and Z keys were not specially labeled, and all participants in both conditions were asked to remove from their person all external time keeping devices such as wrist watches and cellular phones.

One key procedural aspect of this experiment was that participants in the condition with regularly timed tasks were correctly informed that each paper-and-pencil task would be timed by the computer at exactly two minutes each. They were told that the computer would prompt them to switch tasks at these predetermined two minute intervals. Those participants in the randomly timed tasks condition were given different instructions (correctly) that the computer would be randomly determining the length of time that they would work on each of the five indidivudal tasks. In both conditions, participants were accurately told whether the timing of the tasks could or could not be used to help them to keep track of time in order to respond at 8 minutes and 30 seconds. Such instructions are at the crux of the manipulation of temporal uncertainty. We gave people a short break between tasks, and thus, participants in both conditions were told that the first ten seconds of each task was to be used to rest and prepare for the next task. When the formal instructions had been read from the computer monitor, it was cleared and the experimenter then reiterated all of the instructions again in his or her own words and answered any questions before the experiment was commenced.

Results and Discussion

Unless stated otherwise, all inferential tests in this experiment and those that follow meet the acceptable risk of Type I error (i.e., $p < .05$). Recall that participants in the randomly-timed tasks condition should check the clock more often over the course of the experiment due to temporal uncertainty. This prediction was confirmed. Participants in the random condition checked the clock more often as compared with participants in the regular condition, $t(68) = 2.67$, $d = .64$, see Table 1. In many TBPM studies, a difference in clock checking is also found in the final portion of the experiment preceding the target response. Although no differences in clock checking frequency were found in the last 30 seconds of this experiment, there was a difference in clock checking in the last minute, $t(68) = 2.14$, $d = .52$.

One unresolved question in time-based research is whether differences in clock checking will always result in differences in the final time-based response latency or performance, as indexed by the proportion of participants making a prospective response within a pre-determined window. Response latency was calculated as the amount of time before or after (signed) the target time to respond (i.e., 8 minutes and 30 seconds). We imposed a window for time-based response performance at 6 seconds (i.e., ± 3 seconds within the specified target time; c.f., Kliegel et al., 2001). Only participants that made their prospective response within this window were scored as accurate in this analysis. Although we did find a significant difference in clock checking between the regular and random conditions, there was no difference in either time-based response latency or overall performance with this analysis, both *p*s > .25. The absence of a difference in performance or response latency demonstrates that although participants in the random condition did indeed check the clock more often over the experiment, they responded just as accurately as the regular condition when making their ultimate prospective memory response. This outcome suggests the lack of a functional relationship between clock checking frequency and ultimate performance. Checking the clock more often should, intuitively, result in more accurate (i.e., shorter latency) prospective memory responses. In order to investigate this issue further, a Pearson’s correlation coefficient was calculated between signed deviation latencies and overall clock checking frequency (for a similar analysis, see Kliegel et al., 2005). This analysis revealed a negative correlation between response latency and clock checking, $r = -.305$, $p < .01$. Temporal uncertainty did not affect prospective memory responding differentially between conditions. There was, however, still an effect of clock checking on response latency.

Therefore the suggestion that there is no relationship between response latency and clock checking requires further scrutiny based on these results. The result of this correlational analysis suggests that checking the clock more often throughout the experiment was accompanied by shorter latencies in prospective memory responding.

The outcomes here provide support for the goal of introducing time estimation principles, such as temporal uncertainty, into theories of time-based prospective memory. Clearly, participants experiencing high temporal uncertainty (i.e., random tasks) checked the clock more often over the course of the experiment as compared with participants experiencing low temporal uncertainty (i.e., regular tasks). Although no differences in ultimate prospective memory responding were found in either signed latency or proportion of accurate responses, a significant relationship between clock checking and response latency was found when both conditions were pooled.

When the ongoing tasks were regularly timed by the computer, people checked the clock more often. When the tasks were randomly timed, they were unable to rely on the task changes in the ongoing task to help them keep track of the passage of time. One proposal is that the environment (i.e., temporal segmentation from regular task timing) provided a useful environmental structure for people in the regular condition. Participants did not need to generate their own internal cues as often to remind them to check the computer's clock. Stated alternatively, when the environment was regularly timed, they were able to use the beginning of the final task to remind them to start checking the clock; little attention was needed for tracking time over the preceding four tasks. Because both conditions received the last cue to time (i.e., task switch) at the exact same point in the experiment, clock checking was equated otherwise psychologically in the last 30 seconds (following the final switch) but was significantly different when this window was expanded to include the thirty seconds prior to this event. This result may be similar to the effect found on task interference in event-based prospective memory tasks when intentions are linked to a future context. More specifically, by informing participants that an event-based cue will not occur until a later phase, no interference (i.e., slowing) to an ongoing task is found in the early phases (Marsh, Hicks, & Cook, 2006). This effect has been replicated recently in time-based prospective memory as well (Cook, Marsh, & Hicks, 2005; Cook, Marsh, Clark-Foos, & Meeks, 2007). Such an outcome might also explain why participants in both conditions checked the clock equally in the last 30 seconds. When the tasks were randomly timed and uncertain in length, people were already checking the clock at a higher frequency, and this checking was maintained in the final block. When the tasks were regularly timed and certain in length, the final task could be used as a salient cue to begin checking the clock more diligently. An alternative explanation does not rely on such context linking explanations and instead appeals to a general allocation of attention. When people experienced temporal uncertainty they could have recruited additional resources towards tracking the passage of time. If such processes resulted in longer estimates of the perceived passage of time, then greater clock checking frequency would be a natural result. Disambiguating between these two competing predictions by examining differences in additional dependent variables (such as speed and accuracy on the ongoing tasks) will be informative regarding any differences in attention allocation. To this end, our next experiment made use of an ongoing task that would allow us to observe any differences in these task interference measures that might occur when people allocate attention towards time and, thus, away from the ongoing task.

EXPERIMENT 2

Based on the foregoing results, we were interested in whether overall attentional allocation policies would affect one's susceptibility to the influence of temporal uncertainty. According to the basic tenets of the Attentional Gate Model (Block & Zakay, 2006), there are two separate factors that influence how one allocates attention towards timing processes over short intervals (see Figure 2). The first, temporal uncertainty, has been shown herein to affect longer intervals that are used in time-based prospective memory. The second, *temporal relevance*, refers to the importance of timing to one's current goals (Zakay, 1992; Block & Zakay, 2006). This variable is a more general manipulation of attention to time; and consequently it should interact with temporal uncertainty in these longer term intentions. More specifically, low temporal relevance should eliminate differences arising from varying the level of temporal uncertainty. As outlined, the theoretical principles suggest that temporal relevance is an overarching factor that controls whether temporal uncertainty can affect attention allocation policies. That is, when timing is not relevant to current goals, whether someone experiences conditions of temporal uncertainty should not affect performance. To test this prediction, we orthogonally crossed temporal relevance and temporal uncertainty to create four between-subjects conditions in the experiment that follows.

Method

Participants. A total of 140 participants from the University of Georgia were recruited from the same population to participate in this experiment. Each participant was tested individually in sessions lasting approximately 20 minutes. The participants were quasirandomly assigned to the four experimental conditions based on their arrival at the laboratory. That is, half of our participants experienced temporal uncertainty or not via our manipulation of regularly- versus randomly-timed tasks as in Experiment 1. These groups were further divided into conditions that either did or did not emphasize the importance of timing or ongoing task accuracy. We believed that an importance manipulation (see Kliegel et al., 2001) would create the two levels of temporal relevance depending on whether timing versus the ongoing task was given emphasis. As outlined, the key question of interest was whether people would still check the clock more often under conditions of temporal uncertainty when the timing task was made less relevant to their overarching goals. Three participants with at-chance performance on the ongoing task were replaced, under the assumption that they were not cognitively engaged in the tasks that we asked them to perform.

Materials and Procedure. In this experiment we were interested in whether changes in attention allocation could be observed in ongoing task accuracy. Therefore, we switched paradigms from a series of paper and pencil tasks to a finer-grained computer-based lexical decision task that would allow the collection of reaction times as well as ultimate accuracy in judgment. Such measures were not possible from the collection of paper and pencil tasks used in the first experiment. All participants were told that a letter string would appear on the computer screen and they would be asked to decide if it was a valid English word or was a nonword. To create the conditions of temporal uncertainty, half of the participants were told that the font of the letter string would be randomly changing from trial to trial, and thus they could not use color as an accurate cue to current time. By contrast, the other half of the participants were told that the font color would be changing every two minutes exactly, thus replicating in spirit the regularly- and randomly- timed tasks from the previous experiment. Additionally, these two groups of participants were subdivided into two additional groups that manipulated the temporal relevance variable. Following Kliegel et al.'s (2001; 2004) use of importance instructions we chose to emphasize both the speed and accuracy of the temporal task (i.e., performing the time-based response at precisely 8 minutes and 30 seconds) or, alternatively, the speed and accuracy of the ongoing task (i.e., performing the lexical judgments as quickly and accurately as possible). This orthogonal crossing resulted in the four conditions mentioned earlier.

As in the previous experiment, all participants were told to make their prospective response by pressing the "/" key when 8 minutes and 30 seconds had elapsed during the lexical decision task. They were also told that they could check the clock at any time by pressing the 'Z' key. Doing so brought up a clock of the form 4:20 for one second, indicating 4 minutes and 20 seconds had elapsed since the beginning of the task.

Results and Discussion

To recapitulate, we believed that temporal uncertainty would only influence attention to time – thus replicating the first experiment – when timing was perceived to be an important aspect of task goals. Thus, no difference in clock checking was expected between regularly- and randomly-timed tasks when participants were asked to emphasize ongoing task goals as compared with emphasizing timing. To investigate this prediction we conducted a 2 (temporal uncertainty) X 2 (temporal relevance) ANOVA on the total number of clock checks during the entire experiment. Replicating the Experiment 1, a main effect of temporal uncertainty was found in which more clock checks occurred when the color change was randomly-timed as compared with when it was timed at exactly two minutes, $F(3, 136) = 7.77$, $\eta_p^2 = .06$. This effect was qualified, however, by a significant interaction with temporal relevance, $F(3, 136) = 5.79$, $\eta_p^2 = .02$, see Figure 1. This significant interaction supports our prediction that temporal uncertainty only affected participants' attention to time when timing was made relevant to current overarching goals. When participants were told to emphasize their performance on the ongoing task, the effect of temporal uncertainty vanished.

In order to test the hypothesis that temporal uncertainty and temporal relevance affect overall attention allocation, we examined reaction times to the lexical decisions in the ongoing task. The prediction was that when more attention was allocated towards timing (i.e., when temporal relevance was high and/or the ongoing task was regularly-timed), less attention would remain for making ongoing task judgments (Kahneman, 1973; Naveh-Benjamin, Guez, & Marom, 2003; Naveh-Benjamin, Kilb, & Fisher, 2006). This reduction in attention should result in longer latencies during the lexical decision task (for a discussion of attention allocation in prospective memory, see Marsh, Hicks, Cook, Hansen, & Pallos, 2003; Hicks, Marsh, & Cook, 2005). This was not, however, the case in the present experiment, $F < 1$.

GENERAL DISCUSSION

In time-based prospective memory, one must monitor the passage of time in order to complete an intended action in the future. Aside from the relatively older test-wait-test-exit model (Harris & Wilkins, 1982), only one other theory attempts to explain how people track time in service of such future goals. Block and Zakay's Attentional Gate Model (Zakay & Block, 1996, 1998; Zakay, 2000) has traditionally been applied to short time intervals to explain the roles of memory and attention in timing the future. In a recent book chapter (Block & Zakay, 2006), these scholars suggest that the model can be applied to the longer time intervals studied in time-based prospective memory but no empirical data is reported. They suggest that time-based prospective memory is a combination of both retrospective and prospective timing processes. Traditionally, retrospective timing has been attributed largely to memory mechanisms (e.g., Block & Zakay, 1997; Zakay & Block , 1997, 2003) whereas prospective timing is thought to involve processes of attention (Zakay, 1992, 1998; Zakay & Block, 1996). Although the Attentional Gate Model, with its specific role of attention, would appear to be relevant only to prospective timing paradigms, we believe that it is a viable model (with mutatis mutundis) for explaining behavior in time-based prospective memory.

Based on predictions from the model, temporal uncertainty and temporal relevance should have exerted an effect on clock monitoring behavior in time-based prospective memory through their proposed influence on prospective timing (Zakay, 1992, 1998). Specifically, an increase in temporal uncertainty should have resulted in an increase in attention to time, an effect that would be evidenced by an increase in clock monitoring (see also Kliegel et al., 2001). Both experiments confirmed these initial predictions as derived from the model based on shorter time frames. Furthermore, we predicted that the effect that temporal uncertainty has on attention to time would be fragile and potentially sensitive to task demands. In particular, we predicted that if timing processes were made secondary by placing emphasis on the demands of a nontemporal ongoing task then attention to time would be minimized such that temporal uncertainty would be unable to affect clock monitoring (see Figure 2). Specifically, we believed that when people were told that time was not important – or was less important – for the fulfillment of current task demands that only minimal attention would be allocated away from the ongoing task and towards timing processes (see Kliegel et al., 2001, 2004). As a result, the task would become more retrospective-like in nature (Zakay & Block, 2004). By this analysis, further manipulations of attention to time (i.e., temporal uncertainty) would be unable to influence this baseline level of attention any further. The results of the Experiment 2 appear to provide support for these hypotheses. The statistically significant interaction between temporal uncertainty and temporal relevance suggests that when attention to time is observably important, then another variable relevant to timing processes can exert its effect on attention and create a difference in clock monitoring. By contrast, when attention to time is not relevant, then this same timing variable did not create a difference in clock monitoring performance. Future research, however, should seek to discover additional variables that may be able to overcome the apparently overpowering effect of temporal relevance.

There are several explanations for how temporal uncertainty and temporal relevance exert their effects on time-based prospective memory. Although we choose to remain agnostic until further evidence has been collected, we nevertheless present briefly two alternative explanations of the effects found in our study. The first explanation relies on purely memorial and attentional mechanisms (Ornstein, 1969; Thomas & Weaver, 1975; Poynter, 1983; Block, 1992, 2001; Taatgen, van Rijn, & Anderson, 2007); and this approach does not invoke the use of an internal clock. The other explanation makes use of the Attentional Gate Model (Block & Zakay, 2006) in order to explain how manipulations of attention might affect perceived internal "clock speed" via a neuroanatomical clock.

By the first account, people check a clock less often and they are less timely in their ultimate time-based response when the ongoing task is given more emphasis as compared with the time-based intention (Kliegel et al., 2001). Such differences in timing behavior resulted from task importance whereby a specific increase in attention allocated towards prospective timing occurs during the period immediately preceding a time-based response. By contrast, when the ongoing task was given greater emphasis, attention was allocated away from timing which results in fewer clock checks. In this work the total number of prospective responses did not differ, however task importance did affect the absolute timeliness of those responses. In the present study, we found no such differences in the either timeliness of prospective responses or the total number of responses, however, we did replicate the difference in the number of overall clock checks. Increasing either temporal uncertainty or temporal relevance could result in greater attention towards the prospective memory task by this strategic attentional allocation hypothesis (c.f., Kliegel et al., 2001). Such increased attention to time may have resulted in a greater number of self-initiated reminders (Craik, 1986) or an increase in the fluency (Marsh, Hicks, & Bink, 1998) associated with retrieving the intended action. Either result would theoretically result in greater clock checking as well as a more timely prospective response. The lack of any differences in reaction times to the ongoing tasks suggests that if attention to time was, indeed, manipulated that it had its ultimate effect on clock monitoring and not, on the entire experiment per se (see Kliegel et al., 2001).

The interaction in our second experiment lends support to Zakay's (1992; also see Figure 2) hierarchical organization of temporal relevance and temporal uncertainty. That is, in order for temporal uncertainty to have an effect on attention to time, people must already be experiencing relatively high temporal relevance. By this account, attention to time cannot be decreased further if it is already reduced to near floor levels by temporal relevance (i.e., task importance) instructions (Kliegel et al., 2001).

An alternative explanation of our findings appeals to the Attentional Gate Model (Block & Zakay, 2006). In particular, an internal clock mechanism may be used to estimate the passage of time in prospective paradigms (i.e., those in which people are consciously aware that they should be paying attention to time; Zakay & Block, 2004). According to such models, a neural network is responsible for emitting and accumulating pulses to keep track of time (e.g., Gibbon, Church, & Meck, 1984; Zakay & Block, 1998; Church, 1999; Wearden, Norton, Martin, & Montford-Bebb, 2007; and for an alternative account that appeals to neural oscillators see, Crystal & Baramidze, 2007). In order to explain the systematic effects of attention on timing, an attentional gate has been proposed (Zakay & Block, 1997; Block & Zakay, 2006; see also Lejeune, 1998). In this modified model, a gate controls the efficiency of the accumulator at capturing pulses. When attention to timing processes is high, the gate is open wide in order to allow a greater number of pulses to enter the accumulator as compared with when attention to time is low and the gate is more narrowly adjusted. Because the count in the accumulator is used to estimate the perceived passage of time, greater attention results in the subjective feeling that time is passing more quickly. Therefore, our manipulations of temporal relevance and temporal uncertainty have affected the amount of attention participants allocated towards timing. In the present study the attentional gate was open to varying degrees depending on the particular task demands and the resulting levels of attention. When the gate was fully open (i.e., when temporal uncertainty and/or temporal relevance were high), people experienced that time was passing quickly and they checked the clock more often throughout the experiment.

In conclusion, the current research on importance in time-based prospective memory may somewhat under represent the cognitive processes involved in time-based prospective memory; consequently we have tried to specify the potential mechanisms that might underlie this important cognitive task. Although our results do not necessarily support either of the explanations of the cognitive mechanisms that do underlie time-based prospective memory, theses two alternative explanations warrant further scrutiny in relation to the present findings. Nevertheless, this work serves as an initial empirical step towards applying the theoretical principles from the timing literature to what we feel is an understudied cognitive process (i.e., time-based prospective memory).

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Table 1.

Overall clock checking in Experiment 1 as a function of temporal uncertainty.

Level of Temporal Uncertainty	
High	Low
10.6	7.7
(.92)	(.73)

Note. Standard errors are in parentheses.

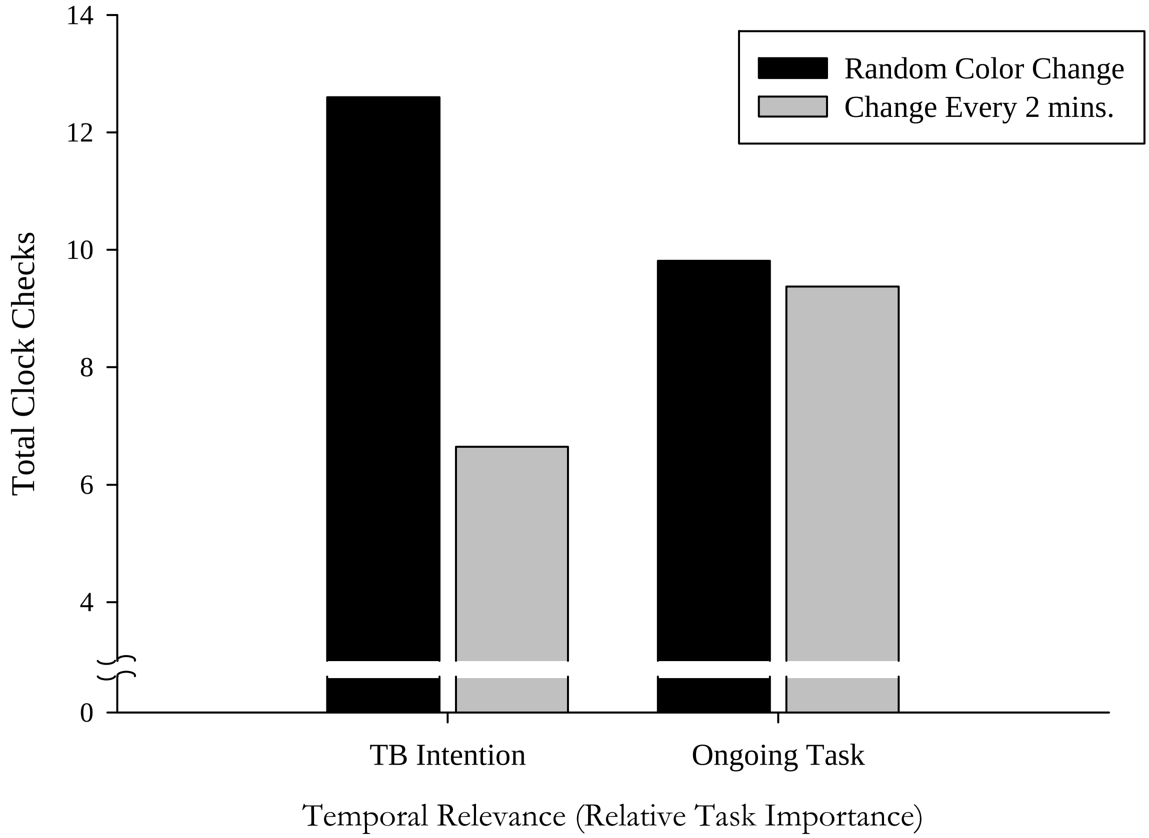

Figure 1.

Overall clock checking in Experiment 2, as a function of temporal relevance and temporal uncertainty.

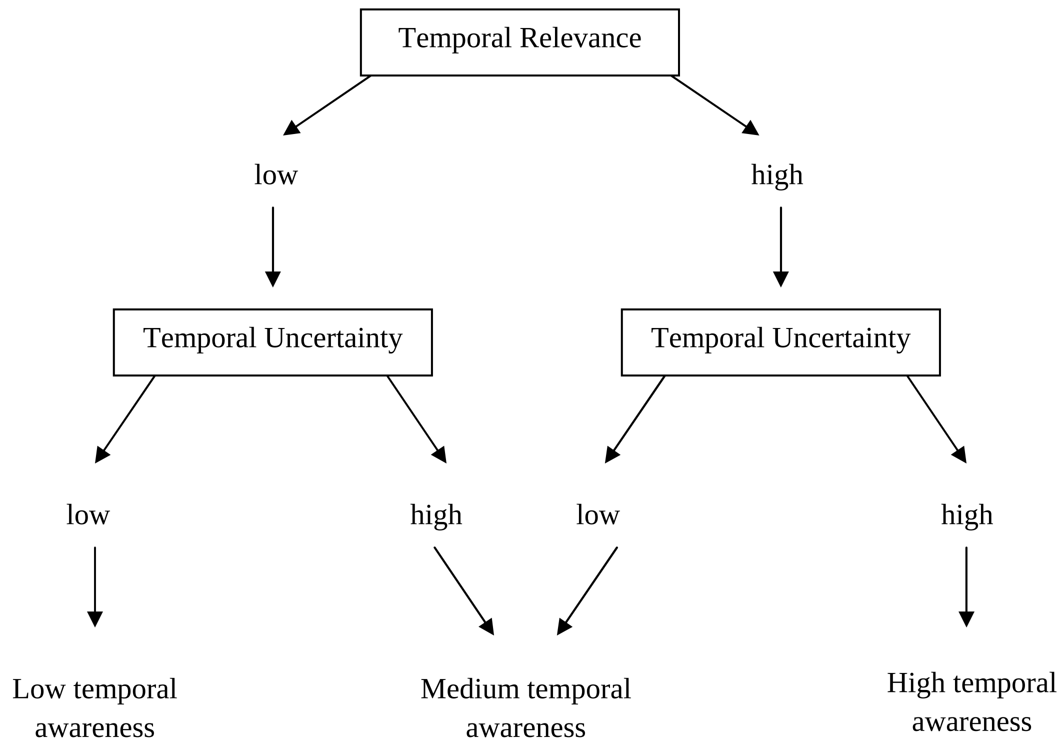

Figure 2.

Temporal Relevance, Temporal Uncertainty, and Prospective Duration Judgments (Zakay, 1992).