2

Prospective Remembering Involves Time Estimation and Memory Processes

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Introduction

Successful models of prospective remembering[a] must be parsimonious, elegant, and plausible. In addition, they should not focus solely on prospective remembering *per se*. They should follow from well-established findings and principles concerning other kinds of memory and cognitive processes, such as those involved in retrospective remembering. Thus, we think that prospective remembering does not involve any special cognitive or memory systems. Instead, prospective remembering relies on the functioning of well-known attention and memory systems. We do not deny that some additional unique abilities may also be involved in prospective remembering.[2,3] However, it is useful to begin with models that relate prospective remembering to findings and models that are well established in other, non-prospective (e.g. retrospective) memory situations.

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[a] We prefer the term *prospective remembering* because it suggests the dynamic nature of the processes involved (as in the term *prospective timing*). In addition, prospective remembering involves more than just memory.[1]

Researchers have mainly studied two types of prospective remembering situations, called *time-based* and *event-based*. One way to view this distinction is that time-based prospective remembering is more self-initiated, whereas event-based prospective remembering is more environmentally cued. Graf and Grondin (this volume) argued that this distinction is not very useful. In some naturalistic, time-based prospective remembering situations, a person has access to external chronometers, which may yield event-based cues (e.g. seeing a clock reading). Keeping this in mind, we find the distinction between time-based and event-based prospective remembering to be useful, and we explain why it is useful. We also discuss situations that may involve a mixture of time-based and event-based processes.

Other researchers have discussed a third type of prospective remembering situation, called *activity-based*. Controversy remains about whether or not activity-based intentions are distinct from event-based intentions (see Kvavilashvili & Ellis[4] for discussion). If one agrees that the distinction is needed, perhaps a slight elaboration of our model of event-based prospective remembering may also apply to activity-based prospective remembering.

In this chapter, we review relevant research and theories on time-based and event-based prospective remembering. We propose and describe two models, one that explains time-based prospective remembering (the attentional-gate model) and one that explains event-based prospective remembering (the recursive-reminding model). We show how these models are able to account for some of the major findings in the literature, as well as to guide future research. A consideration of how the two kinds of processes may interact in some mixed time-based and event-based situations is also included. We conclude by mentioning a few unusual applications in altered states of consciousness.

Time-Based Prospective Remembering

In a situation requiring time-based prospective remembering, a person forms a self-generated intention or is given (as by an experimenter) an other-generated intention to perform a specific action at a specific future time. The future time may be targeted either as a specific clock time (e.g. "at 8:30 today") or as a specific interval (e.g. "5 minutes from now"). State-of-the art explanations of time-based prospective remembering have typically relied on older theories instead of more recent theories from the extensive literature on time estimation. For example, Cook, Marsh, and Hicks[5] said that "there is no existing theory about how time-based intentions are successfully completed, except one slightly dated theory based mainly on intuition" (p. 346): Harris and Wilkins's[6] test-wait-test-exit model, which is a variant of Miller, Galanter, and Pribram's[7] test-operate-test-exit model. Einstein and McDaniel[8] also discussed this kind of model. It proposes a process in which the person loops through test-wait cycles until another test seems needed. When a test finally indicates a time at which it is appropriate to respond, the loop is exited, and the person makes the response. The test-wait-test-exit model is inadequate in that it does not explicitly address several questions: What is being tested? What happens while a person is waiting, and how does the person decide that another test is needed? How does any test indicate whether or not it is an appropriate time to respond? The fact that the test-wait-test-exit model is viewed as a state-of-the-art model reveals that most prospective remembering researchers are not aware of more recent time-estimation models, as well as that time-estimation researchers have not yet discussed the connections between their research and the topic of prospective remembering. In this chapter, we remedy these problems by proposing a more explicit model of time-based prospective remembering, the attentional-gate model. The attentional-gate model retains some of the features of the test-wait-test-exit model that have enabled that model successfully to explain extant research findings. In addition, the attentional-gate model adds some more explicitly described components that enable it to explain the same kinds of findings that the test-wait-test-exit model explains, but also to explain other extant findings and to predict future findings.

Before considering our model, consider three of the most commonly obtained findings concerning time-based prospective remembering, those concerning (a) secondary-task attentional demands, (b) age-related changes, and (c) interval length.

Secondary-task attentional demands. Time-based prospective remembering is adversely affected by the attentional, or workload, demands of any non-temporal (secondary) task.[8] If a person is performing an attention-demanding secondary task during the retention interval (between forming an intention and the target time for the action), prospective remembering is inversely related to the difficulty of that task. Task difficulty may be assessed in terms of demands on attention, working memory, or both. Prospective remembering may be measured in terms of probability of responding, latency of responding, and similar measures.

Age-related changes. Any variable that is correlated with attentional resource allocation also affects time-based prospective remembering. For example, there are medium-to-large effects of normal aging on time-based prospective remembering, with older adults showing decreased probability of responding and increased latency, especially under conditions in which there are relatively high secondary-task attentional demands.[8,9] As we discuss later, time-based tasks depend heavily on self-initiated monitoring (executive) processes, and processes that involve attentional resource allocation tend to show age-related declines.[10,11] However, with increasing age, people show an increased tendency to rely on external aids and other time-management strategies (Francis-Smythe, this volume; see also Maylor[12]). Perhaps as a result of the use of strategies in naturalistic conditions (which may not be available in laboratory conditions), older adults' prospective-remembering performance may actually be better than younger adults' performance in those situations.[9]

Interval length. Although researchers have not systematically investigated large ranges of the interval between the formation of a time-based intention and the target time, some evidence suggests that time-based prospective remembering is better at shorter intervals than at longer intervals.[13] In addition, people attend more to time toward the end of the interval than at the start of it.[6,8,14] This is expected on the basis of a models like our attentional-gate model (see later; see also Church[15]).

Prospective Duration Judgment

The time dimension is always embedded in any human experience or activity and is an inseparable part of it.[16] However, the relevance and importance of time is not constant but varies depending on the meaning assigned to a certain situation. Consider, for example, a person who is relaxing on a beautiful beach on the first day of vacation, reading a novel. Not having any obligations, deadlines, or scheduled meetings for the next two weeks, time is probably not an important issue for that person. A typical result of such a situation is that when the person becomes aware of clock time, he or she is amazed to learn that the subjective duration that was felt is much shorter than the objective time that elapsed since coming to the beach. In other words, subjective time was advancing slower than objective time. Now, consider a situation in which the person is waiting for a date with an attractive person encountered earlier but is not sure whether or not the attractive person will arrive. When the objective time of the date is exceeded by a few minutes, a typical behavior of the person waiting will be to look again and again at a watch and with each glance at the watch to discover that objective time did not advance much since the last glance. In this situation, subjective time was advancing much faster than objective time. The discrepancy between the two situations indicates that duration judgments in each case were based on different processes. Although in the first case retrospective duration judgment processes were mainly involved, prospective duration judgment processes were involved in the second case.

This distinction is related to the different nature of the cognitive processes underlying retrospective duration judgment and prospective duration judgment. Retrospective duration judgment is inferred on the basis of information retrieved from memory that reflects the amount of change in cognitive context which occurred during a target interval.[17,18] Prospective duration judgment, on the other hand, is based on an attentional process and reflects the amount of attentional resources allocated for temporal information processing.[19] This difference led Block[20] to refer to retrospective duration judgment processes as *remembered duration* and to refer to prospective duration judgment processes as *experienced duration*. The differences between the cognitive processes underlying retrospective duration judgment and prospective duration judgment have received strong empirical support.[21,22]

In order to understand better the conditions under which retrospective or prospective duration judgment processes are initiated, Zakay[23] introduced the concepts of temporal relevance and temporal uncertainty. Temporal relevance refers to the significance of time in a certain situation in terms of reaching optimal behavior. For example, if performing a task requires accurate timing, temporal relevance is high; however, if timing has no impact on task performance, temporal relevance is low. Temporal uncertainty refers to the degree to which the duration of a to-be-performed task is known or can be accurately estimated. For example, while performing a routine, well-known task, temporal uncertainty is low; but if an unexpected obstacle prevents the completion of the task and it is not known when the obstacle will be removed, temporal uncertainty is high. When both temporal relevance and temporal uncertainty are high, most available attentional resources will be allocated for temporal information processing (e.g. the example of waiting for an attractive person to arrive), and prospective duration judgment processes will be initiated. However, when both temporal relevance and temporal uncertainty are low (e.g. reading a novel while on vacation), few attentional resources will be allocated for temporal information processing. If the situation leads the person to estimate the duration of the past time period, retrospective duration judgment processes will be initiated.

The process of attentional resource allocation is continuous and under the control of executive functions that monitor the person's current resource allocation strategy,[24] as we explain later. This allocation is flexible[25] and reflects the relative strength of temporal relevance and temporal uncertainty at a given moment. Because the allocation process is continuous, so is the shift between prospective duration judgment and retrospective duration judgment. For example, the person reading on the beach is not interested in time, and both temporal relevance and temporal uncertainty are low. However, if suddenly the person receives a message that something has happened and that the person must come to a certain place as quickly as possible, then both temporal relevance and temporal uncertainty become high, many attentional resources are allocated for temporal information processing, and a process of prospective duration judgment is initiated.

Attentional-Gate Model

Considering that prospective duration judgment processes depend on the amount of attentional resources allocated for temporal information processing, the nature of such temporal information processing needs to be explained. A basic assumption regarding prospective duration judgment processes is that they almost always occur under dual-task conditions because there is almost always some nontemporal task that should be performed simultaneously with the timing task. Imagine an extreme case in which timing is certainly the most important task, such as waiting impatiently for some event to occur. In such a case, one is usually thinking about possible reasons for the delay and about consequences of the delay. Thus, resources are divided between timing and the nontemporal task.[26] This competition over shared resources is resolved by the person's resource allocation strategy. But what is the nature of the temporal information processing itself?

We proposed an attentional-gate model in order to provide an explanation for this issue.[27,28] The attentional-gate model is an elaboration of a so-called *scalar-timing* model, an information-processing version of scalar expectancy theory, which was originally proposed to explain processes underlying animals' temporal behavior.[29] The typical scalar-timing model is composed of a pacemaker that emits signals at a constant rate, a switch, an accumulator (which is also called a *counter*), and a decision-making process. The literature on animal and human timing also contains descriptions of variants of this basic pacemaker-counter kind of model.[30] The additional component that we added to the scalar-timing model in order to create the attentional-gate model is an attentional gate. The idea underlying the addition of this component is that whereas all other components developed in the early stages of the evolution of timing mechanisms in animals, attentional control is probably unique to primates in that it is associated with brain areas that are not highly developed in earlier mammals. One of these, for example, is the anterior cingulate gyrus, which is intimately involved in the executive control of attention.[31] The attentional gate is therefore assumed in order to explain the influence of a person's attentional resource allocation on prospective timing.

As modified to account for time-based prospective remembering, the attentional-gate model operates in the following way (see Fig. 1):

(i) A pacemaker emits signals (pulses) at a fairly constant rate that is only slightly changed as a result of changes in arousal level. Although the origin of these relatively constant signals is not fully understood, they may become manifest as synchronized neural firings in specialized neural networks.

(ii) The flow of signals passes through an attentional gate, which is controlled by the executive functions that determine a person's resource allocation policy. The more resources are allocated for timing, the wider (metaphorically speaking) the gate is opened, thus allowing for more signals in a time unit to pass through and enter the accumulator. Thus, the number of signals that enter the accumulator is determined by the amount of attentional resources allocated for timing. To the extent that a person needs to perform a concurrent nontemporal (external stimulus) information-processing task, fewer attentional resources are available to attend to time.

(iii) The meaning assigned to a situation influences a switch. When the meaning implies a beginning of a target interval that should be timed, the switch opens, enabling the flow of signals from the pacemaker to the accumulator. (In the literature, this condition is often described as causing the switch to be closed, using a metaphor of electrical conductivity. We prefer to use a metaphor of a flow and to speak about switch opening.) When the meaning of a situation implies the end of a target interval, the switch closes again, thus preventing further flow of signals.

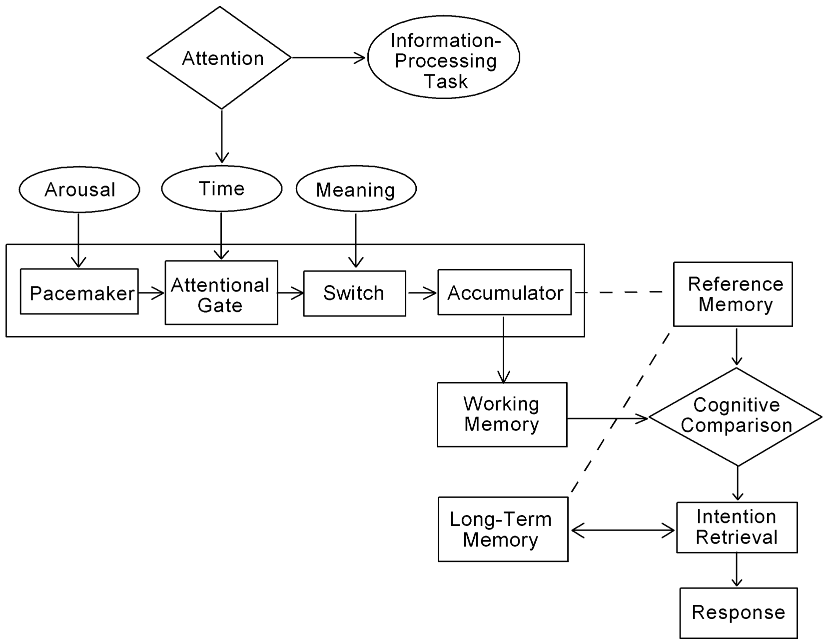

Fig. 1. An adaptation of the attentional-gate model of prospective timing to processes involved in time-based prospective remembering.

(iv) An accumulator stores the number of signals that passed through the gate from the start of a target interval. When the target interval ends, the switch closes, and the number in the accumulator is a representation of the duration of the target interval. This number is then transferred to a working memory component. A representation of a target interval can be encoded in reference memory directly from long-term memory, such as when one has to produce an interval defined in seconds and minutes. In this kind of situation, one can retrieve from long-term memory a respective representation and store it in reference memory.

(v) When a target interval has to be produced or reproduced, the same processes occur, but in this case the number of signals that have entered the accumulator is compared on a constant basis with a representation stored in reference memory. This process, a cognitive comparison, continues until a decision is made that a close match is obtained, upon which the process stops. The person then retrieves the representation of the intended response, which was previously encoded in long-term memory, and makes the target response.

Based on the assumptions of the attentional-gate model, the nature of temporal information processing can be understood as the process of counting the signals in the accumulator as well as the process of making the decision, a process that also demands attentional resources. The strength of the attentional-gate model lies in its ability to provide coherent explanations of most phenomena that characterize prospective duration judgment and to define temporal information processing in a parsimonious and plausible way in terms of the functioning of the central nervous system. Predictions stemming from the attentional-gate model have been empirically supported in several experiments.[32,33] From a structural and functional point of view, however, the attentional-gate model should be treated as a hypothetical construct waiting to be validated further, mainly by brain research.[33] We also note that other models have been suggested in the literature, including timing-without-a-timer models (i.e. models that do not propose a pacemaker-counter, or internal clock, kind of process).[34] Whether the attentional-gate model or competing models better explain time-based prospective remembering is an empirical issue, as well as a theoretical one.

Prospective Timing and Executive Functions

Time-based prospective remembering can be considered to be a high-level executive function that requires monitoring and controlling the execution of activities at future times. From this perspective, it is of interest to show that the attentional-gate model can explain prospective timing in relation to the activity of high-level executive functions. This is also in line with Brown's[32] argument that prospective timing consumes resources associated with the executive control of working memory. Zakay and Block[35] conducted two studies in which prospective timing was requested simultaneously with tasks that must be monitored and controlled by high-level executive functions. In the first study, participants were required to time the duration of reading sentences that contained syntactic ambiguity, a task that requires high-level executive functions. Duration judgments (reproduced durations) were compared to duration judgments during which reading unambiguous sentences was required. Because resolving syntactic ambiguity demands more resources than regular reading, fewer attentional resources can be allocated for timing in the first condition than in the second condition. The result should be shorter reproductions in the semantic-ambiguity condition than in the no-ambiguity condition, a prediction that was supported by the findings. In a second study, Zakay and Block tested the impact of switching between tasks on prospective timing. The task-switching paradigm is a robust manipulation of executive control. As predicted by the attentional-gate model, objective intervals were prospectively judged to be shorter for the task-switching condition than for the no-switching condition. Findings from both studies support the attentional-gate model.

Attentional Distractions, the Asymmetric Interference Effect, and the Attentional-Gate Model

The dependency of prospective duration judgment processes on the allocation of attention for temporal information processing makes it vulnerable to attentional distractions by competing stimuli and by nontemporal tasks. When a distractor appears, the attentional gate narrows, reflecting the reduction of resources allocated for timing. The result will be a reduced accuracy of timing (in the direction of underestimating the objective time that has elapsed), as well as an increased variability. The increase in variability can be explained by the relative shortage of attentional resources. Brown[32] also discussed a related phenomenon, the asymmetric interference effect. The asymmetric interference effect is found when timing competes with the performance of a concurrent nontemporal task. In most cases, unless the nontemporal task inherently includes counting, the timing task suffers more than the nontemporal task. Zakay and Bibi[36] argued that the asymmetric interference effect reflects a natural tendency to treat timing as the secondary task and to treat the nontemporal task as the primary one. They found that the asymmetric interference effect is eliminated when timing is treated as the primary task. Another condition under which the asymmetric interference effect disappears is when the nontemporal task is relatively automatic.[37,38] The attentional-gate model can explain these findings. For example, in the later case, the nontemporal task is not competing directly with timing and the attentional gate can reflect a resource allocation policy according to which timing gets all of the available resources.

Attentional-Gate Model: Successful and Future Predictions for Time-Based Prospective Remembering

In a time-based prospective remembering task, temporal uncertainty is low but temporal relevance is very high. As a result of both, a significant amount of attentional resources are allocated for timing, and a prospective duration judgment process is initiated. If the target time for the action is in the range of seconds and minutes in the future, the processes described by the attentional-gate model provide a necessary and sufficient description for the prospective remembering process. In such a case, the representation of the target duration is probably taken from long-term memory and stored in reference memory. When a match between this representation and the ongoing count of signals is obtained, the person performs the action (e.g. turns on the television in order not to miss the news headlines). If this is the case, then it is expected that a person will find it difficult to be accurate and will probably be checking a watch or clock before the target time, because the typical finding is that in prospective situations target durations are underestimated. (A similar phenomenon occurs in the negative-asynchrony task, as described by Zakay and Block.[39]) Another potential mistake is a failure of prospective remembering attributable to distraction, a failure that is also explained by the attentional-gate model. If the target time associated with the prospective task is far in the future (e.g. hours, days, or weeks), a person will probably divide it into several shorter intervals until the target time is near. The reason for this is the difficulty of continuing to allocate attention while timing a long period. The error of missing the target time because of attentional distraction is expected to be greater in a long-duration condition than in a short-duration condition.

Research on prospectively made productions has mostly used intervals on the order of seconds, whereas research on prospective remembering has also used intervals on the order of minutes, hours, days, and weeks. Different processes may apply if the target time is hours, days, or weeks in the future. Perhaps the nominally time-based situation becomes more like an event-based situation as the target time is extended further into the future. At the very least, researchers should systematically explore the effects of interval length.

Finally, if a person suffers from relatively low attentional resources, or in the relative inability to divide attention between competing tasks, time-based prospective remembering may be impaired. For example, compared to younger adults, older adults show a decreased ability to divide attentional resources.[11,40] In a time-based prospective remembering situation, older adults also tend to perform the specified action at a relatively late time, to be more variable in the timing process, and more frequently to fail to perform the action at all.[14,41,42] This kind of finding is an additional one that the attentional-gate model can easily explain: Older adults tend to make more variable time productions than do younger adults.[43]

Event-Based Prospective Remembering

In a situation requiring event-based prospective remembering, a person forms a self-generated intention or is given (as by an experimenter) an other-generated intention to perform a specific action when a specific event occurs in the future, with the exact time-of-occurrence usually being somewhat vaguely defined. The future event may be understood or described in terms of a specific spatial location (e.g. "when I pass the post office"), a specific object or person (e.g. "when I next see my friend Mary"), and in other such ways.[44]

Researchers are undecided about which of several models can best explain event-based prospective remembering (for a discussion of some of them, see Einstein and McDaniel[8]). Before considering our model, consider three of the most commonly obtained findings concerning time-based prospective remembering: (a) secondary-task attentional demands, (b) age-related changes, and (c) contextual changes.

Secondary-task attentional demands. In contrast to time-based prospective remembering, event-based prospective remembering is not affected much, if at all, by secondary-task attentional demands, or workload.[45] If a person is performing a task during the retention interval (between forming the intention and the target time for an action), event-based prospective remembering is apparently adversely affected only if the relevant cue is outside of focal attention.[46,47] Assuming that the person attends fully to the retrieval cue, there is little or no evidence that event-based prospective remembering requires the availability of executive processes.[48]

Age-related changes. Just as older adults tend to perform worse than young adults on time-based tasks, they also tend to perform worse on event-based tasks. However, the literature is somewhat inconsistent. In two experiments, Einstein and McDaniel[49] found no difference between younger and older adults on a task that involved pressing a key whenever a specific target word appeared. This kind of finding contrasts with the typical finding that there are usually medium-to-large age-related deficits in the performance of time-based prospective remembering tasks.[41,45] However, meta-analytic findings reveal that there are medium-size age-related deficits in the performance of event-based prospective remembering tasks.[9,50,51]

Contextual changes. Contextual changes are important in event-based prospective remembering (see, for example, Marsh and colleagues[52]). If the target event does not occur in the environmental context expected at the time the intention was formed, event-based prospective remembering performance is impaired.[8]

Four Relevant Stages

At least four major stages must be understood in order fully to explain event-based prospective remembering: encoding, retention, retrieval, and decision. First, a person forms an intention to perform a specific action at some future time, an occasion during which some target event is expected to occur, thereby encoding a memory trace of the intention (which we will refer to as *event-plus-action*). Second, this information must be retained during the interval separating the time of encoding and the time of occurrence of the event. Third, the person encounters the target event and may (or may not) retrieve the memory trace that was encoded earlier. Finally, the person may (or may not) decide to perform the intended action. Prospective memory researchers have studied some of the variables that affect these four stages, although to our knowledge they have not yet studied all of the variables that may be expected to influence prospective remembering of event-based intentions.

Encoding. A person may form an event-based intention, and thereby encode it into memory, in one of two ways. First, a person may perceive an external stimulus, or cue, and encode an intention about a future action to be taken at some future time when the same external stimulus occurs again. This is what often happens in laboratory studies, in which an experimenter tells a person what action to perform when he or she encounters a specific stimulus in the future. Second, a person may simply imagine performing a future action in a future context, thereby encoding a memory trace of the action, along with contextual associations related to the expected future context. For example, a person may think about telling a colleague something at the next opportunity, which is likely to be at his or her office. The colleague-in-office context is encoded into memory in somewhat the same way that it would be if an instructional stimulus had been provided (within limits to be determined experimentally).

Several major encoding-related variables may influence the likelihood that an intention is retrieved later, when the target event actually occurs. To our knowledge, researchers have not adequately investigated all relevant variables. Based on well-established principles of retrospective memory, these are nevertheless the kinds of variables (among others) that are expected to influence the likelihood that the encoding will lead to successful future action:

(i) The person may encode the event-plus-action memory trace on more than one occasion, and those repeated encoding episodes may be separated by various temporal spacings, or lags. The likelihood that the encoded information will be retrieved when the event occurs is expected to increase as a function of the number of repetitions of the encoding, as well as the spacing of them.[53] Encoding an event-plus-action memory trace on several occasions that differ in context prevailing during encoding may also enhance later retrieval.[54]

(ii) The person may encode the event-plus-action memory trace in a verbal (propositional) code, an imaginal code, or both. To the extent that the event-plus-action memory trace is encoded in more than one type of code, performance is expected to improve.[55] Similarly, the person may encode the event-plus-action memory trace at various levels of processing, ranging from shallow to deep. Deeper encodings are likely to form relatively more durable memory traces.[56]

(iii) At the time of encoding, the person may not know the future context in which the target event will occur. To the extent that the event-plus-action memory trace is encoded with few or no contextual associations, it is relatively impoverished, and retrieval of the encoded memory trace may fail. Similarly, knowing when a future event is likely to occur will lead to an encoded memory trace that is more likely to match the actual temporal context when the event occurs. If an event occurs in a temporal or environmental context that is different from what was encoded, retrieval may fail. For example, someone may intend to tell a colleague something when he or she is next encountered, which usually occurs in an office setting. If the colleague is encountered in another setting prior to the office setting, the person may fail to retrieve the encoded intention.

Retention. The length of the retention interval between the time of encoding and the future event is expected to affect the likelihood of successful prospective remembering according to well-known principles of forgetting. As the retention interval lengthens, the encoded intention is more likely to be forgotten, just as there are effects of retention interval on retrospective remembering. In addition, there may be interference effects, both proactive and retroactive. A person may encode different intended actions that concern the same contextually defined event, and whether or not any particular event-plus-action association is retained and retrieved may depend on the number of similar intentions encoded in memory. For example, a person may encode an intention to tell a friend about a new movie when the friend is encountered next, then encode an intention to tell the same friend about some new software, and then encode an intention to tell the same friend about a past dinner engagement. These three event-plus-action associations share the same context (i.e. the next occasion on which the friend is encountered), and as a result they may suffer from interference effects. This influence on forgetting, which increases as a function of the similarity of memory traces, is well known in the memory literature, even though researchers may not have discussed or studied it much (but see Taylor and colleagues[47]).

Retrieval. The third stage is perhaps the most critical, as well as the least understood in the literature. Researchers have been relatively silent on a theoretical understanding of this process. A notable exception is the theorizing of Graf.[57] He discussed several basic steps involved at the time of successful retrieval: cue noticing, cue identification, and plan recollection. Here, we propose a different view of the processes involved.

Some retrospective memory literature clearly reveals a likely process that may underlie retrieval of an event-plus-action memory trace. In the original mention of this kind of process, it was called *study-phase retrieval*; more recently, it has been called *recursive reminding*.[58–60] The basic finding underlying the recursive-reminding model is that when an event occurs more than once, memory traces of previous occurrences of the event are retrieved in a relatively automatic way, along with associated contextual information (e.g. the approximate time, or temporal context, of the earlier event, as well as the place, or environmental context, in which the event occurred). Although this process does not occur if two events are completely unrelated,[61] it is likely that the events do not have to be identical. Hence, when a person experiences an event, perceiving that event may result in retrieving a memory trace of an earlier intention concerning that event, which was encoded earlier.

The notion that the retrieval of a previously encoded intention (event-plus-action memory trace) is often relatively automatic may be useful in clarifying some findings. Specifically, some researchers have found that event-based prospective remembering is not affected much, if at all, by whether or not a person is performing an attention-demanding secondary task at the time the target event occurs.[62]

Even though the retrieval of a previously encoded event-plus-action memory trace may occur in a relatively automatic way if the event receives attention, several variables may nevertheless influence the success or failure of event-based prospective remembering:

(i) The memory trace encoded earlier may not be retrieved later because the context in which the event was expected to occur does not match the actual context in which the event actually occurred. Consider the previous example, in which a person thinks about telling a colleague something at the next opportunity, which is likely to be at his or her office. However, the person may encounter the colleague at a grocery store before going to the office. The actual colleague-in-store context inadequately matches the encoded colleague-in-office context, and the person does not retrieve the previously encoded intention and therefore does not perform the desired action.

(ii) An event-plus-action memory trace may be encoded at a time during which the person is directly perceiving the target event or at a time during which a person is merely imagining the target event. In the latter case, failure to retrieve automatically the event-plus-action memory trace may be a result of a failure of the recursive-reminding process attributable to the fact that the two occurrences of the event were not similar enough to lead to automatic retrieval of the encoded intention.

(iii) Failure of a process called *reality monitoring* may influence whether or not an intended action is performed. This failure refers to the occasional inability of people to distinguish between internal thoughts and external events (see Mitchell and Johnson[63] for a recent review). If a person vividly imagines that he or she is performing a future action, when the person encounters the target event later, he or she may decide that the action has already been performed and, for that reason, may not perform the action.

Decision. The fourth stage, decision, is relevant in everyday prospective remembering situations, although it is probably of relatively minor importance in laboratory studies. If an event-plus-action memory trace is successfully retrieved when the target event occurs, a person may nevertheless decide not to perform the action. This may occur if circumstances have changed since the intention was encoded, and the person decides that the action either is no longer necessary or is undesirable.

Recursive-Reminding Model: Successful and Future Predictions for Event-Based Prospective Remembering

The recursive-reminding model proposes that when a repeated event occurs, memory traces of previous occurrences of the event are retrieved in a relatively automatic way, along with associated contextual information. This model successfully predicts several typical findings.

Because the underlying retrieval processes are usually relatively automatic, event-based prospective remembering is not affected much by attentional demands (workload) during the retention interval. However, if competing attentional demands or a distracting event prevent a person from attending fully to the target event, the recursive-reminding process may not occur, and prospective remembering may fail.[57] With this major exception, there is little evidence that event-based prospective remembering requires executive processes that are involved in attentional resource allocation.[48,57]

Somewhat inconsistent evidence reveals that event-based prospective remembering shows medium-size effects of variables that are correlated with attentional resource allocation, such as normal aging.[9,50,51] At first glance, this evidence seems at odds with the recursive-reminding model, which says that retrieval of an event-based intention involves relatively automatic processes that are not expected to show much age-related decline.[64,65] Older adults have relatively limited attentional resources than do younger adults. (However, there may be some event-based situations in which secondary-task attentional demands may influence performance; see Marsh and colleagues.[66]) In addition, when secondary-task or aging effects are found in event-based situations, other factors may be involved, such as a general slowing of cognitive functioning that is typical in older adults.[67]

Graf[57] recently suggested that when age-related differences are found, they may be a result of differences in encoding, not in retrieval. He concluded that there is "little support for the assumption that substantial attentional resources are required for the recollection of previously formed plans" (p. 321). In a similar way, he concluded that most age-related declines on retrospective memory tasks are attributable to the encoding phase, and fewer declines are attributable to the retrieval phase. Although the recursive-reminding model focuses heavily on the retrieval phase, it must be remembered that encoding and retention phases are also critically involved in event-based prospective remembering.

The contextual match or mismatch between the expected event and the actual event also affects event-based performance: If the event does not occur in the context expected at the time the intention was formed, event-based prospective remembering is impaired.[8] For example, Cook and colleagues[5] found that "a correct expectation of the context one will be in during the [temporally defined] response window improves time-based memory performance" (p. 352).

Situations Involving Mixed Time-Based and Event-Based Prospective Remembering

In this section, we focus on situations that involve mixed time-based and event-based prospective remembering — those in which a temporally cued future action and an environmentally cued future action may co-occur in an interacting combination. The distinction here is similar to Ellis's[44] distinction between "pure and combined retrieval contexts" (p. 5). Some combined retrieval contexts may involve what we will call an *OR rule*, whereas other combined retrieval contexts may involve what we will call an *AND rule*.

As an example of a situation involving an OR rule, suppose that it is 8:00, and a person encodes the intention to perform an action at 9:00 (i.e. after 60 minutes has elapsed). The person remembers that a clock on a local building chimes at 9:00 and also encodes the intention to perform the action when the clock chimes. In this situation, prospective remembering could be based on either time-based processes (timing 60 minutes from now) or on event-based processes (hearing the clock chime). In this example, researchers can probably tell which process was the one that was actually used by measuring the time of the action relative to the target time (9:00). If the action was performed at 8:54 (i.e. before the clock chimed), then prospective remembering must have involved the time-based attentional-gate process. On the other hand, if it was performed at 9:00:03 (i.e. 3 sec after the clock chimed), the attentional-gate process is not that precise, and prospective remembering was undoubtedly controlled by the event-based recursive-reminding process.

As an example of a situation involving an AND rule, suppose that a person intends to remember to purchase an item at a store when he or she drives by the store, but only after a week has elapsed because that is when the item will be discounted in price. In this case, the dual requirements of an environmental event and a temporal interval must be met. Although these mixed kinds of situations are not uncommon in everyday prospective remembering, only a few researchers have studied them or commented on them. Most research has mainly investigated situations in which an action is to be performed either when a specified event occurred or when a specified duration had elapsed. Additional research on AND-rule situations is needed.

A few researchers have compared event-based and time-based prospective remembering in the same experiment, although very rarely have researchers explored a temporally defined future action and an environmentally defined future action in some interacting combination. For example, in one recent experiment, younger and older adults were studied.[68] Some were asked to indicate whenever an animal appeared in a film that they were viewing, whereas others were asked to respond whenever they judged that three minutes had elapsed. In this experiment, it would have been interesting to add a condition in which participants were asked to respond either when an animal appeared or when three minutes had elapsed. Findings of these kinds of experiments should reveal effects that can be explained by a combination of the two models we described here, the attentional-gate model (for time-based processes) and the recursive-reminding model (for event-based processes).

Prospective Remembering in Altered States of Consciousness

Mainstream prospective remembering researchers have devoted little or no attention to relevant evidence from studies of people in various states of consciousness. This kind of evidence may clarify prospective remembering in general, as well as the two models proposed here (the attentional-gate and recursive-reminding models). Here we give three interesting examples.

Ordinary Sleep and Time-Based Prospective Remembering

A few researchers have investigated the claim that some people seem to be able to awaken at a preselected (experimenter-defined) time during nocturnal sleep, such as 1:23 (see, for example, Tart[69]). This is, of course, isomorphic to ordinary time-based prospective remembering; the target action in these cases is to awaken from sleep at a target time. Some researchers have reported data suggesting that such prospective remembering may occur, possibly with accuracy approaching or equaling that of ordinary (awake) time-based prospective remembering.[70] However, this evidence does not necessarily contradict the attentional-gate model (with its consciously controlled attention to time). In particular, participants under such conditions may awaken several times prior to the target time,[69] and this could entail several consciously controlled openings of the attentional gate. This evidence, as well as potential processes that may underlie successful time-based prospective remembering during sleep, needs to be clarified by additional research.[71]

Lucid Dreaming and Event-Based Prospective Remembering

Several researchers have investigated lucid dreaming, a relatively unusual state in which a dreaming person becomes aware that he or she is dreaming. In order to investigate lucid dreaming, a person may be instructed before going to sleep that if he or she becomes lucid during a dream, a certain action should be performed. This is, of course, isomorphic to ordinary event-based prospective remembering; the target action in these cases is to make a specific response when the target event (becoming aware of lucid dreaming) occurs. Evidence reveals that trained lucid dreamers can remember to perform the action (e.g. move one's eyes three times in a vertical direction, or clench one's fist three times) near the onset of the lucid dream period.[72,73]

Hypnosis and Event-Based Prospective Remembering

Hypnosis researchers have been fascinated by the possibility that people who are hypnotized and given a suggestion that at a later time (after being brought out of hypnosis) they will perform an action when a specific event occurs. For example, hypnotized people could be told that when they later hear the word *experiment*, they will automatically rub an earlobe.[74] Some research indicates that people tend to perform the action when they receive the post-hypnotic cue, which seems to be an interesting case of event-based prospective remembering. Although there is controversy surrounding the issue of the relevance of the hypnotic state,[75] this evidence may nevertheless further support the view that recursive reminding (our model of event-based prospective remembering) may occur in a relatively automatic way.

Summary and Conclusions

We proposed two models of prospective remembering, one for time-based remembering and one for event-based prospective remembering. An attentional-gate model is needed to explain time-based prospective remembering; it makes contact with relevant research on time-estimating processes. A recursive-reminding model is needed to explain event-based prospective remembering; it makes contact with relevant research retrospective-remembering processes. We described these models in detail, contrasting them to other less explicit models in the literature on prospective remembering. We also argued why they are both needed, as well as how they may interact in situations that may involve some mixture of time-based and event-based prospective remembering.

Although we disagree with Crowder's[76] de-emphasis of the term *remember* when referring to prospective remembering, we agree with him that "performing delayed intentions often depends on automatic interruptions of activities in progress" (p. 145). We have emphasized this automaticity in situations involving event-based prospective remembering. However, in situations involving time-based prospective remembering, the interruption of an activity in progress is not automatic but is instead subject to controlled processes (involving dividing attention between nontemporal and temporal information processing). We also agree with Crowder that "memory for intentions plays a role in . . . prospective situations" (p. 146). We have emphasized ways in which attention and memory are involved in the attentional-gate process and the recursive-reminding process. We have not discussed other cognitive processes involved in prospective remembering, and we agree with Crowder these processes are worthy of additional research.

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