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Time Perception and Time-Based Prospective Memory

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Introduction

In this chapter, we review experimental psychology research in two domains: time perception and time-based prospective memory (ProM). Intuition suggests that these domains are connected, that they involve at least some of the same high-level cognitive processes or mechanisms. In view of this intuition, it is surprising that only a small number of empirical investigations have focused directly on the processes or mechanisms that link time perception and time-based ProM. Why? In order to answer this question, in the first part of this chapter, we summarize recent empirical and theoretical work on time perception, and on how this ability changes across the adult lifespan. In the second part, we review empirical and theoretical work on time-based ProM and on how this cognitive function changes across the adult lifespan. In addition, we examine the manner in which time- and event-based ProM tasks have been defined, in order to identify where — under what kinds of study/testing conditions — time-related processes might be recruited in support of performance on time-based tasks.

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This chapter is a true team effort that was motivated by the desire to discover and delineate cognitive processes that are involved in both time perception and time-based ProM, and by the hope that it will lay the foundation for new collaborative research between these domains.

Time Perception

What are the major empirical and theoretical questions that motivate research on psychological time and time perception? To answer this question, we begin this chapter section with some observations on conceptual and method issues related to research on time perception. Next, we describe the dominant theoretical model of time perception, the internal-clock model, focusing especially on a recent information-processing version of it. Then, we use this model to guide the presentation of significant findings that have emerged from recent research, including from research on age related changes on temporal judgments.

Conceptual and Method Issues

The study of memory involves a retrospective component and a prospective component, and similarly, the study of time involves two components or research areas, one concerned with retrospective timing and the other with prospective timing. The distinction between prospective and retrospective timing concerns, respectively, situations where subjects/observers are informed in advance that they will have to make a time-related judgment versus situations where subjects/observers receive no prior warning about the need to make a time/duration judgment.[1]

In memory research, a vastly greater number of empirical and theoretical investigations have focused on retrospective memory than on ProM. By contrast, it is prospective timing that has received the most attention from time perception researchers in the past 30 years. Generally speaking, timing models developed to account for prospective judgments attempt to capture two fundamental features of temporal performance. One is related to the accuracy, or validity, of the time estimates provided by subjects, that is, it asks how closely related to physical time is subjective or perceived time. The other feature of performance concerns the variability of the perceived time estimates that have been obtained from a large number of trials.

Research is often centered on one or both or these two aspects of performance (i.e. accuracy and variability). The dependent variables used when addressing specific questions about accuracy or variability tend to be given different names, depending on the experimental method that is employed (e.g. verbal estimates, categorization, production and reproductions of intervals) as well as on the index adopted for expressing variability. The classical emphasis of time perception research has concerned the analysis of the ratio of the variability of estimated time to physical time (Weber fraction) or to the mean of the time-estimates (coefficient of variation).

Throughout the history of research on the psychology of time, a number of different independent variables have been targeted.[2] The most prominent among these are: the duration (length of time interval) under investigation,[3] the sensory modality used for marking time,[4] the nature of the cognitive demands made on subjects during an interval to be estimated, and the influence of participants' age.[5] Below, we will briefly review the research that bears either directly or indirectly on the last of these variables.

Theoretical Models

Some theoretical models of psychological time are based on the concept of a clock process, but others do not presuppose this type of construct.[3] Investigations of retrospective timing have been led by researchers with a traditional cognitive background. They held the view that subjective time is mediated by cognitive mechanisms. One classical example is Ornstein's model,[6] which deals with intervals longer than 10 s. This model postulates that the amount of storage space that needs to be allocated in memory for the purpose of estimating time varies directly with subjective duration. The availability of memory storage space is assumed to be determined by the number and complexity of stimuli to be processed during a given time period. By contrast Block and Reed[7] and Zakay and Block[8] argued that it is the number of contextual changes encoded into memory that determines the retrospective impression of duration.

A large number of different theoretical models have been proposed to account for subjects' performance on prospective timing tasks. Some models rely strictly on cognitive concepts without assuming the existence of a clock. For instance, Thomas and Weaver[9] describe time estimation in terms of an attention-based model. They assume that the number of stimuli to be processed during a given time period is inversely correlated with subjective duration because increasing attention to these stimuli leaves temporal processing with fewer, and possibly insufficient, attentional resources.

A very different way of thinking about time perception was introduced by M. Jones and collaborators (see Chap. 3 for a more complete description of their theoretical approach and how it may apply to prospective timing).[10,11] Jones and Boltz proposed a dynamic attending model.[12] In the context of ProM, this model is most interesting because it emphasizes the fact that sensitivity to the occurrence of future events might depend on the properties of past events. The occurrence of physical regularities within the flow of events in the environment is assumed to mark non-arbitrary (or coherent) beginnings and endings of several succeeding time spans which offer temporal predictability for forthcoming events. This predictability sets within an observer an attending attitude called a future-oriented attending mode. The accuracy of temporal judgments was assumed to depend on temporal coherence and on the capacity to synchronize the internal rhythmicity of attending, called attunement, with the appropriate external rhythm afforded by the environment. When sequences of events in the environment do not provide temporal coherence, an observer is forced to adopt an internal strategy, called an analytic attending mode, for dealing with such unpredictable event occurrences.

Before turning to the description of probably the most popular version of an internal clock, the pacemaker-accumulator device, the reader should note that animal timing and neuroscience offer many other timing models. For instance, Staddon and Higa proposed a pacemaker-free model where a cascade of interval timers is assumed to exist and where memory-strength decay determines specific time periods.[13,14] And most popular are pacemaker-free models that emphasize a neural network description or some oscillatory process.[15–17]

A Pacemaker-Accumulator Device. A long tradition in research on time perception has proceeded on the assumption that prospective timing is mediated by a unique or dedicated internal clock. This clock, often described as a pacemaker-counter or pacemaker-accumulator device,[18] is at the foundation of many theoretical models.[3] In general, these models assume that the pacemaker emits pulses that are accumulated in a counter, and the number of pulses that have been counted determines the perceived length of an interval.

According to this type of model, how does one explain the occurrence of errors in judging time? One central cause of error is often assumed to be the reliability of the pacemaker, i.e. errors are thought to be a property of the pulse emitter device. The mode of pulse distribution can be deterministic or stochastic, and the pacemaker rate of responding/signaling over a long time period may be fixed or variable. Differences in models are related to properties of the pacemaker.[3] Errors in timing may also occur because of variability in the latency of the onset or offset stages of responding, and in matching the internal signals with the physical dimensions of the intervals to be judged.[4] This source of error is more likely to have a small impact when intervals to be timed are relatively brief.

Other properties of the counter might also be a major source of timing error. Killeen and Taylor proposed the existence of a cascade of counters. If counting is hierarchical, as it is when decimal or binary systems are used, dropped counts can become increasingly costly when larger numbers are counted.[19] Killeen and Taylor noted that there should be a disproportionate error in timing each time the next stage in the counter must be set. These authors have demonstrated that the mean count registered should grow approximately as a power function of the duration of the to-be-timed interval.

An Information-Processing Theory. Probably the most frequently cited contemporary theoretical account that builds on the idea of a pacemaker-accumulator device is called the Scalar Expectancy Theory (SET).[20,21] Although it was developed primarily in order to explain animal timing data, this theory has been successfully applied to human time perception.[22] One very important feature of SET is that it acknowledges that sources of variance other than at the clock level exert a major influence on temporal performances.[23] The pacemaker-counter device is embedded in a larger information processing system, and thus is subject to errors that may be caused not only by the clock processes described above, but also by memory and decisional processes (see Chap. 2 for a discussion of the latter processes). In this version of the clock, the accumulation of the pacemaker's pulses into the counter is reported to be under the control of a switch mechanism, whose functioning is influenced by the amount of attention devoted to time processing.

SET has two fundamental properties. The first is that the mean representation of time for a series of temporal judgments equals real time. In other words, in the long run, subject produced estimates of target durations converge on the actual duration of targets. The second critical feature of SET is that the variability — often expressed as a one standard deviation unit — of time estimates or judgments increases linearly with the mean representation of time. The constant proportion between variability and the mean is said to be scalar, which is essentially known in psychophysics as Weber's law (i.e. the ratio of variability to mean time is a Weber fraction).

The availability of attentional resources is assumed to have a critical influence on the functioning of the switch mechanism.[24–26] Its role is central in accounting for the variability of time estimates and is most commonly invoked in order to explain the findings of investigations on perceived duration.[27,28] The dual-task strategy, classical in cognitive psychology, has been employed in multiple timing experiments. This strategy builds on the assumption that attention is a limited-capacity system. Therefore, if two tasks need to be carried out simultaneously, less attention will be available for each one. Brown and West showed that, in conditions where subjects were required to process multiple sources of temporal information, increasing the number of sources that had to be attended decreased the accuracy of timing.[29,30]

Somewhat along the same lines, the critical influence of attention on temporal information processing during the interval to be timed was demonstrated by Macar, Grondin and Casini. Their procedure was based on that used for analyzing attention-operating characteristics. Before each trial, a participant is asked to allocate a percentage of attention to each of two tasks to be performed simultaneously: a temporal task, which is to discriminate the length of the sensory signal, and a non-temporal task, which is to discriminate the intensity of the signal. When more attention was allocated to the temporal task, perceived duration was longer and better performance was observed in duration discrimination.[31,32]

These attentional effects can be readily accommodated by a pacemaker-accumulator model, if we assume the existence of a switch component that determines the access of pulses to the accumulator. The switch would be under the control of attention, with less attention to time resulting in a smaller transmission of pulses and in more variability.

Time Perception and Aging

Although there has been a great deal of research on time perception, only a relatively small number of investigations have focused on how this high-level ability (i.e. time perception) is affected by aging, and consequently, many important questions remain unanswered, especially questions on age-related changes in the variability of time estimates.[5,33] Because timing is so central to many simple tasks that need to be performed everyday (e.g. driving a car, carrying out a series of planned tasks), and because timing, as noted above, is so closely linked to memory and attention mechanisms (both of which are known to decline with aging), this section is dedicated to research on aging and time perception.

Overall, aging is accompanied by a decrease in the accuracy of estimating time, but this decrease appears to depend on the method adopted for conducting the investigation as well as on the range of the to-be-timed durations that are under scrutiny.

For very brief intervals (circa 50 ms), Rammsayer, Lima and Vogel reported no difference between age groups (mean ages = 25.1, 45.5 and 64.6 years old) in the ability to discriminate the relative duration of intervals marked by two brief auditory signals.[34] The mean difference threshold was about 17 ms in this experiment. However, Rammsayer reported that the discrimination of intervals of 1 s duration was poorer by older adults (70.4 years old) than by younger adults.[35] As well, in the same study, the reproduction of 1 s intervals, but not that of 15 s intervals, by older adults was longer than the reproductions by young adults.

In a task that required subjects to categorize a series of six tones on the basis of their duration (from 250 to 622 ms or from 622 to 1548 ms), McCormack, Brown, Maylor, Richardson and Darby reported that older adults (74.1 years old) performed significantly worse than young adults (19.5 years old).[36] The same authors reported that for a similar task involving 9 tones varying from 250 to 2039 ms, older adults (70.5 years old) made fewer correct responses than young adults, and the pattern of errors was different between the groups. When the pitch of nine tones had to be categorized, older adults (68.7 years old) made fewer correct responses than young adults, but both groups showed a similar pattern of errors. Based on these data, McCormack *et al.* concluded that older adults have a distorted memory representation for duration information.

The effects of age have also been examined in the categorization of intervals lasting between 3 to 6 s, and marked by auditory or visual signals.[37] In this experiment, the level of attention was manipulated: there were trials with only one stimulus presented in either modality (i.e. in the full attention condition), and trials where two stimuli, of different lengths and different modalities, were presented (i.e. in the divided attention condition). This manipulation was conducted in the morning (9 am) for half of the participants, and in the afternoon (4 pm) for the other half. The older adults (69.3 years old) showed larger effects due to the modality and attention manipulation than the young adults (20.1 years old): visually marked intervals were perceived as much shorter than auditory marked intervals, and sensitivity to time decreased in the divided attention condition. Moreover, sensitivity to time was higher and the modality effect was smaller when testing occurred in the afternoon rather than in the morning in both age groups, except that in the full attention condition, older adults tested in the morning showed better sensitivity to time for intervals marked by visual signals.

In a task involving the reproduction of intervals lasting 6, 8 or 10 s, Vanneste and Pouthas showed that older adults (65.3 years old) were more sensitive than younger adults (20.2 years old) to a manipulation of attention to time.[38] The participants had to pay attention to one, two or three stimuli that marked time. The results showed that in the 2- and 3-target conditions, the older participants were more variable and less accurate than the younger ones. This age-related effect on timing performance might be due to an age-related reduction of attentional resources. However, in a study by Craik and Hay that employed intervals of 30, 60 or 120 s during which subjects were occupied with a perceptual judgment task, older participants (72.2 years old) gave shorter verbal estimates and produced longer intervals than younger adults (22.2 years old), but the level of complexity of the task had a negligible effect on performance.[39]

As underscored by this brief review of the relevant research, it is difficult to reach compelling conclusions about the effect of aging on temporal performance. Nevertheless, for very brief intervals (<100 ms), it appears that the clock function is intact but when judging longer intervals (up to 10 s), experimental manipulations that focus on attentional resources and on memory processes are likely to show larger effects in groups composed of older than younger participants.

Time-Based Prospective Memory

Prospective memory (ProM[a]) is the ability to formulate plans and intentions, to retain them, and to execute them upon the occurrence of the appropriate cues.[40,41] Like retrospective memory, ProM covers a vast domain. To navigate this domain and to facilitate communication, researchers have distinguished among different types of tests or situations that require the use of the ProM function. The most prominent of these distinctions has focused on how the retrieval of a previously formed plan or intention is cued or triggered.[42,43] Tests or situations where retrieval of a plan is signaled by a specific event (e.g. the occurrence of a specific sensory stimulus, the completion of a specified activity)

[a]We use the label ProM rather than PM for a number of different reasons, most importantly, because in mainstream memory research (i.e. a research area dominated by questions about retrospective memory), PM has long been used as an abbreviation for Primary Memory. In addition, we eschew using PM because future work may show that primary memory is a critical cognitive function that is required for both retrospective and prospective memory tasks.

are said to be event-based or event-cued tests. By contrast, time-based or time-cued tests are those where plan retrieval is signaled by a specified clock time (e.g. meet me today at 5 pm) or by a specified amount of elapsed time (e.g. call me back in 20 min). The focus of this section is on the latter tests.

Although the label *time-based* evokes a direct link between time and memory processes, a review of the literature indicates that this link has not been a major focus of research on time-based ProM or on how this aspect of memory changes across the adult lifespan. Instead, the bulk of time-based ProM research has targeted other factors, most notably, the role of attention-resources and how changes in their availability across the adult lifespan affects overall task success rate under different conditions of testing. Our objective in this chapter section is, first, to review the research on age-related changes on time-based ProM tasks, second, to highlight factors that might have prevented or at least discouraged investigations of time-related processes in this domain, and third, possibly to identify a sub-domain of time-based ProM where future research may be more successful in revealing an important link between time and memory processes.

Basic Properties of Time-Based Prospective Memory

By far the best-known experiment on time-based ProM is the classical 1985 study by Ceci and Bronfenbrenner.[44] Although this study did not focus on age-related performance changes, it is a convenient vehicle for portraying the general method that is typically used for investigating time-based ProM, for previewing the pattern of age-related changes that tend to occur in these investigations, and for introducing the basic questions that continue to motivate this kind of research.

Ceci and Bronfenbrenner's experiment explored the development of time-based ProM in 10- and 14-year old children. For one part of their first experiment, the children's main task was to remove cupcakes from the oven, after a delay of 30 minutes, when they would be properly baked. The children had to carry out this task either in the familiar context of their own home or in the unfamiliar context of a typical psychology research laboratory. While waiting for the cupcakes to be baked, the children played a popular video game in an adjoining room that was furnished with a clock they could use for monitoring time. Of interest to the experimenters was to find out, first, whether or not the children would remove the cupcakes from the oven at the appropriate time (i.e. will he/she succeed in carrying out the task according to the instructions), and second, how often — according to what schedule — they would check the clock during the retention interval (i.e. the 30 min required for baking the cupcakes).

The main findings reported by Ceci and Bronfenbrenner were that in the unfamiliar laboratory context, only one child failed to remove the cupcakes from the oven at the appropriate time whereas 42% of the children either failed or were late on this task when they had to do it at home. There was also a clear and surprising developmental effect on the baking-task success rate. In the familiar home context, failures were three times more common among the 10-year olds than among the 14-year olds. In addition, as highlighted by the results in Fig. 1, the children used different schedules for clock checking in the home and laboratory contexts. When tested in the context of their own homes children showed a U-shaped pattern of clock checking, whereas in the laboratory the frequency of clock checking started low, but then increased steadily with the approach of the end of the baking period. Overall, the children checked the clock more often in the laboratory context, where task success rate was higher (at the ceiling), than in the home context. However, the number of clock checks did not predict task success rate, as evidenced by the finding that in the home context, the younger children made more clock checks than the older children and yet task success rate was higher in the older children. As emphasized by Ceci and Bronfenbrenner, task success is predicted not by the number of clock checks but by their effective and strategic allocation toward the end of the baking period. To the extent that clock-checking is efficient and skillful (i.e. allocated in the most informative manner), it leaves more time and attention resources that can be harnessed for other ongoing activities, such as the video game the children were playing while waiting for the cupcakes to be baked.

Ceci and Bronfenbrenner's[44] main focus was on the childhood development of clock checking strategies, and on the contextual determinants of these strategies. Similar questions about clock checking strategies have been targeted by a small number of more recent investigations (reviewed by Mäntylä and Carelli in Chap. 8 of this volume), but the vast majority of them have focused on other questions about age-related changes in time-based ProM. The most important of these other questions concerns the overall rate of task successes and failures rather than clock checking strategies; it asks whether aging has a larger or smaller effect on time- versus event-based ProM tasks. The second most often asked question, following on the heels of Ceci and Bronfenbrenner's[44] work, asks about contextual influences on ProM task performance.

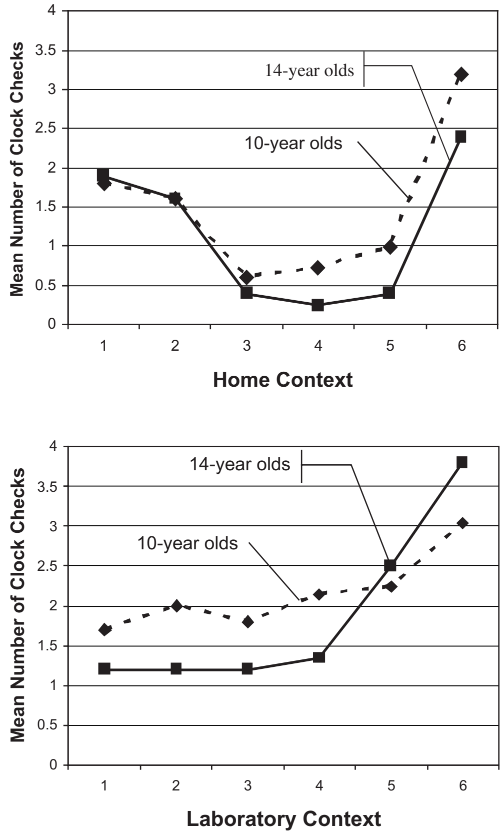

Fig. 1. The figure, adapted from Ceci and Bronfenbrenner,[44] shows the mean number of clock checks during each 5-minute period of the retention interval. The figure highlights the different schedules of clock checking used by children who were tested in the context of their own homes versus in the laboratory, as well as the fact that the younger children checked the clock more often than the older children.

Age-Related Changes in Time-Based Prospective Memory

One of the foundational assumptions implicit in Ceci and Bronfenbrenner's[44] work is the notion that strategic (e.g. skillful, calculated) clock checking is adaptive, that it increases ProM task success rate, requires less frequent clock checking and thereby releases time and resources for other simultaneously occurring activities. This basic assumption is consistent with the broad theoretical claims that have motivated the vast majority of recent investigations of age-related changes in time-based ProM. One of these claims stems from

Craik's[45] influential proposal that all remembering tests or situations can be arranged along a continuum that marks the extent to which retrieval performance depends on self-initiated, subjects controlled or attention-resource demanding processes as opposed to being dependent on environmentally-driven, automatic processes. Craik further proposed that of all memory tests, performance on ProM tests is most dependent on self-initiated, attention-resource demanding processes. Therefore, consistent with the widespread view that aging is accompanied by a decline in the attention-resources that are available for processing informatiom,[46–49] he predicted that age-related changes in performance would be larger on ProM tests than on any other kind of memory tests.

For a number of reasons to be discussed later in this chapter, Einstein and McDaniel[43,50] went one step beyond Craik and argued that performance on time-based ProM tests is more dependent on self-initiated resource demanding processes than performance on event-based tasks, and consequently, they predicted that age-related performance declines would be larger and more common on the former than latter tests.

The pattern of results predicted by Einstein and McDaniel has been found, for example, by Einstein, McDaniel, Richardson, Guynn and Cunfer[51] and by Park, Hertzog, Kidder, Morrell and Mayhorn.[52] However, a number of other studies have shown that older adults consistently tend to outperform their younger counterparts on time-based ProM tasks, but only when testing occurs in the context of their everyday life.[53–58]

The results of a meta-analysis by Birt[40] highlight these different patterns of age-related changes in performance on ProM tests. She sampled a total of 25 different articles published in peer reviewed journals that reported on 34 different experiments. Altogether, these experiments included a total of 2,695 different participants, and Birt was able to compute 96 different age effect sizes (Cohen's d), each defined according to Cohen[59,60] as the difference between the mean performance for the young group and for the old group divided by the pooled population standard deviation. Of the 96 effect sizes, 71 (74%) came from experiments that focused on event-based ProM and 25 (26%) came from experiments on time-based ProM. By contrast to the prediction of Einstein and McDaniel,[43] the overall results of the analysis showed larger age effects on event-based tasks than on time-based tasks, with mean weighted effect sizes of $d = 0.59$ and $d = -0.05$, respectively.

This general summary of the results is misleading, however, because it ignores the context in which memory performance was assessed. In part motivated by the classic study of Ceci and Bronfenbrenner,[44] time- and event-based ProM have been investigated under naturalistic field conditions, that is, in the context of subjects' familiar home and everyday life, as well as under the relatively unfamiliar and artificial conditions that prevail in a typical psychology research laboratory. Birt's[40] meta-analysis included, for time-based ProM, 12 age-effect sizes from data that were collected under artificial laboratory conditions and 13 effect sizes based on data obtained under naturalistic field conditions, and for event-based ProM, 39 and 6 age-effect sizes came from laboratory and naturalistic field studies, respectively. The results of the meta-analysis, summarized in Table 1, showed a larger mean age-effect for time- than event-based tasks for the laboratory studies (note, however, there is overlap in the 95% confidence intervals). This outcome is consistent with the prediction by Einstein and McDaniel.[43] However, in stark contrast to this prediction, the results from the field studies show a reversed age-effect, that is, compelling evidence that older adults are more successful than young adults on time-based tasks if those tasks had to be performed in the context of their everyday life.

The finding that age-effects on time-based ProM tasks are dependent on contexts raises intriguing questions about the factors that determine performance. To explain their findings, Ceci and Bronfenbrenner[44] assumed that their context manipulation affected performance because young children are more familiar with the home than laboratory environment, and consequently, they were more anxious in the laboratory. They further speculated that the heightened anxiety level may have led the children to check the clock more frequently, thereby increasing task success rate. Another possibility is that Ceci and Bronfenbrenner's children participants viewed the ProM task as more important, relative

Table 1. The table shows age-effect sizes (Cohen's *d* means and 95% confidence intervals) obtained on event- and time-based ProM tasks that had to be carried out either under the relatively artificial conditions of a typical psychology research laboratory or under the naturalistic field conditions of subjects' own home and every day life. The data are adapted from the PhD dissertation of Angela Birt.[40]

	Event-Based Tasks		Time-Based Tasks	
STUDY TYPE	Mean *d*	95% CI	Mean *d*	95% CI
Laboratory	0.7	0.62/0.79	0.99	0.76/1.21
Field	0.34	0.16/0.53	−0.6	−0.77/−0.43

to playing the video game, in the laboratory context than in the home context. Previous work has shown that performance is higher on ProM tasks that are designated (i.e. by the experimenter) or self-evaluated (i.e. by participants) as more important.[61]

The results in Table 1 do not show the overall level of performance in the different contexts (instead, they focus on age-related performance effects that occur in different contexts) and thus are not directly comparable to the context effects reported by Ceci and Bronfenbrenner.[44] Nevertheless, consistent with Ceci and Bronfenbrenner, it might be argued that the findings in Table 1 are, at least in part, a reflection of subjects' degree of familiarity with the contexts of laboratory and field studies. The young adults who typically participate in memory experiments tend to be undergraduate students, whereas the older participants tend to be community living individuals, and thus, it seems likely that the former would be more familiar with psychology laboratories and more at ease with the personnel and equipment that are involved in laboratory studies.

However, rather than emphasizing how context familiarity might affect subjects' level of anxiety, as did Ceci and Bronfenbrenner,[44] the researchers who collected the evidence summarized in Table 1 tended to focus on the context-dependent availability and use of strategic knowledge. They have noted that older adults, to a greater extent than younger adults, have spent a lifetime developing specific skills and reminder systems for time-based ProM tasks, and the use of this strategic knowledge facilitates their task performance.[55,62] We can understand older adults' poor performance under laboratory conditions on the additional assumption that their reminder systems are context specific (e.g. connected with the context of home), and not easily tuned to or adapted for the relatively stark, barren environment of the typical research laboratory. Moreover, it may be that the very attempt to employ their well-practiced reminder system prevents the older participants from discovering or relying on the more abstract, context-independent clock-checking strategies that may be more appropriate in the laboratory context. In order to decide among such possibilities, future research will need to explore age-related changes in the strategies used under different testing conditions, as well as the factors that trigger the deployment of different strategies (e.g. testing contexts, the availability of resources).

The finding of a typical age-related decline in time-based ProM task performance under laboratory conditions versus a reversed age-effect under field conditions is well known, but the debate about what causes this age-effect pattern continues. What is more important for this chapter is that even though the findings in Table 1 have focused attention on the strategies that are engaged for time-based ProM tasks under different testing conditions by subjects from different age groups, only a very small number of investigations have attempted to explore these strategies (for a review, see Chap. 8 of this volume by Mäntylä and Carelli). And despite the celebrated work by Ceci and Bronfenbrenner,[44] even fewer studies have examined age-related changes in clock-checking strategies and in time-related processes.

What accounts for the dearth of research on these issues? We believe the answer to this question is intimately connected with the very nature of time-based ProM, with what is unique about this memory function, and with how it tends to be employed. In the remaining parts of this chapter, we shall attempt to identify what is special about time-based ProM. Specifically, we shall argue that time-based ProM is composed of several distinguishable components or functions, and argue that clock-checking strategies and time-related processes are likely to be critically involved in only some of them.

What, if Anything, is Special about Time-Based Prospective Memory?

The quick and most common answer to this question is that time-based ProM tasks are different from event-based tasks by virtue of the fact that while specific external cues are available to signal when a previously formed plan is to be retrieved for the latter tasks, no external cues are provided for the former tasks. However, this basis for distinguishing between tasks is readily dismissed by the argument that a particular clock reading (e.g. when both hands of the clock point straight up, when the number 12 appears on the face of a digital clock) is as much an external cue as, for example, the appearance of a colleague in the hallway. Moreover, there is considerable empirical evidence showing that not all retrieval cues are equally effective.[43,63–65] Cues that are larger or louder are more effective than cues that are smaller or softer. Cues that are presented in the visual-fovea are more effective than peripherally presented cues. Cues that are perceptually distinctive are more effective than those that are non-distinctive. Consistent with this type of evidence, therefore, it may be that the specific cues used in connection with time- and event-based prospective tasks differ in terms of potentially important perceptual properties (e.g. intrusiveness, loudness). If so, future research ought to explore the nature of these properties and their specific role in determining performance on time- and event-based ProM tasks.

More important, however, this line of reasoning suggests that the difference between time- and event-based prospective tasks is not defined or definable by the presence versus absence of specific retrieval cues.

A more compelling case in support of a distinction between time- and event-based ProM tasks focuses on the predictability or calculable-proximity of cues or situations that signal when it is appropriate or necessary to retrieve a previously formed plan. To highlight this potentially important feature of time- and event-based ProM tasks, consider the following two examples: making a phone call tomorrow at 9 am and giving a message to a colleague on the next encounter with him/her. For the first task, it is possible at any time during the retention interval to compute and therefore know how close we are to the situation where a plan needs to be retrieved and executed. However, we may have no idea when and where the next encounter with a colleague might occur. Therefore, consistent with these examples, it is possible that performance differences between time- and event-based ProM tasks occur because only the former provide warning signals, an opportunity for monitoring the approach or proximity of retrieval cues, and consequently, for suspending competing attentional demands and for preparing to execute a planned activity.

However, by contrast to the core assumption implicit in the foregoing paragraph, many events such as the next encounter with a colleague or the location of the supermarket on our way home are reasonably predictable and thus permit a sort of proximity calculation. The power to make predictions in these cases comes from knowledge of our colleague's habits, familiarity with the location of the supermarket in our neighborhood, perhaps even shared cultural knowledge about the typical location of mailboxes on our city streets. Consequently, to the extent that at least some event-based tasks permit some type of cue proximity calculations, the core difference between time- and event-based ProM tasks is not the presence versus absence of retrieval cue predictability. Rather, the critical difference may be the nature of the dimension (e.g. time versus memory for habits or for spatial location) that is available for making cue proximity calculations. It is possible that the between-task difference is the relative prominence of the dimension(s) available for making proximity calculations (note: the time dimension is highlighted by the description of time-based tasks whereas the description of event-based tasks does not identify possible dimensions for making predictions and thus relevant dimensions need to be inferred or discovered), the reliability of the information provided by each dimension, or the users' familiarity with each dimension. To our knowledge, to date there has been no systematic investigation either of the possibility that time- and event-based tasks implicate different dimensions for estimating the proximity of plan retrieval cues, or of any other such variable that might be used to define the difference between the two task types (i.e. time- and event-based tasks).

An additional factor that complicates efforts to define the difference between time- and event-based tasks stems from the fact that subjects may translate or transform one type of task into the other. Qualitative evidence for this type of translation comes from interviews on the strategies subjects employ for different types of ProM tasks.[66] When required to describe the strategies they would use for a typical time-based task, such as a doctor's appointment at 2 pm on Thursday, subjects tend to link the planned task with other activities or events scheduled for that day (e.g. I plan to leave immediately after my yoga class). To the extent that subjects engage in this type of translation activity, the nominal difference between time- and event-based tasks ceases to exist.

Recent work by Cook, Marsh and Hicks[67] showed that when this type of time-event linking occurs, it may serve either to facilitate or inhibit performance on the target task. Cook *et al.* conducted an experiment in which subjects were required to make pleasantness ratings about words in Phase 1, complete a demographics questionnaire in Phase 2 and carry out a syllable counting task in Phase 3. In addition to completing these tasks, subjects were also required to carry out a nominal time-based ProM task, specifically to press a target key on the keyboard after a delay of 6 minutes. Between subjects, Cook *et al.* manipulated the length of Phase 1 such that it took about 3.5 min in one condition compared to 7 minutes in the other condition. More importantly, they also manipulated subjects' expectations about when the time-based prospective task would have to be carried out. They told half of their subjects that the prospective task would most likely have to be executed in Phase 3 of the experiment, during the syllable counting tasks; the remaining half of the subjects were not provided this additional information. Because of the manipulation of the length of Phase 1, the additional information given to half of the subjects was valid for those who received the short Phase 1 task, but it was misleading for those who received the long Phase 1 task.

The data in Fig. 2, adapted from a table in Cook, Marsh and Hicks,[67] show that under control conditions when the subjects did not have any specific expectations about the context in which they had to carry out the planned task, their performance was about the same ($\sim$52%) with the short and long Phase 1 task, that is, performance was not significantly affected by the nature of the context

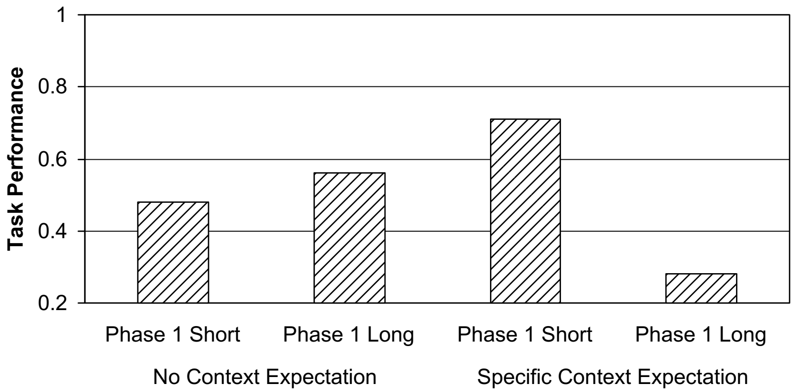

Fig. 2. The bars show the mean proportions of successful performance on a time-based ProM task under conditions where subjects either did or did not have a specific expectations about the context in which a planned task had to be executed (figure constructed on the basis of data reported in Cook, Marsh and Hicks[67]).

in which the planned task had to be carried out (i.e. whether the ongoing task required making pleasantness ratings or counting syllables). By contrast, in the conditions where subjects did have a specific expectation about the context where the planned task would need to be executed, performance was facilitated when subjects' expectations were valid (i.e. if the task had to be executed in the context where they expected it), but it was impaired when their expectations were invalid. Until these findings have been replicated, it is premature to draw strong inferences from them. However, they do suggest that when both time and event cues are available for a ProM task, performance is more strongly influenced by event cues.

What lessons follow from these reflections on the similarities and difference(s) between time- and event-based ProM tasks? In the foregoing paragraphs, we have acknowledged potential differences between the two task types. However, we have emphasized the similarities between them, and suggested that especially in the rich context of everyday life, the nominal differences between time- and event-based tasks might be minimized or absent because of the specific strategies subjects employ to manage commitments to future plans and intentions within the regular and predictable circumstances of their daily life. Consistent with this suggestion, we encourage more investigations of the different strategies subjects employ for time- and event-based ProM tasks, especially investigations of the factors that cause the age-effect pattern of performance shown by the results in Table 1.

One obvious implication of the suggestion that the differences between time- and event-based ProM tasks are minimized by subjects' reliance on knowledge about the regular and predictable circumstances of their daily life is that differences between these task types would be more evident, magnified, when testing occurs in the barren, unfamiliar and unpredictable context of the psychology research laboratory. It is tempting to regard the evidence in Table 1 as supporting this possibility, but this use and interpretation of the data would be inappropriate. To our knowledge, only one study, conducted by Logie, Maylor, Della Sala and Smith[68] has directly compared time- and event-based ProM task performance under the exact same controlled laboratory conditions (i.e. in the absence of obvious confounding variables), but the results of this study are marred by performance ceiling effects in several conditions.

The final lesson we draw from our reflections on the similarities and difference(s) between time- and event-based ProM tasks is that even in the barren context of the research laboratory, clock-checking strategies and time-related processes are more likely to be critically involved when the retention interval is relatively short. Consistent with the research finding that time-related processes are attention demanding, it seems that extensive reliance on these kinds of processes would be adaptive only for activities to be carried out in the immediate future. When the retention interval is longer than a few minutes, it would most likely be filled by other activities (e.g. I might check my email if I have 5 min before the next meeting), and our experience-driven ability to estimate the duration of these activities would provide an alternative basis for calculating/monitoring when to execute a planned task. It seems likely that the impact on task performance due to clock-checking and time-related processes would be reduced by the extent to which subjects rely on such alternative monitoring strategies.

The suggestion that different processes might mediate performance on time-based tasks with short versus long retention intervals is consistent with the proposal that ProM encompasses a number of functionally distinct components,[42] the most prominent of which are: monitoring, episodic ProM and habitual ProM. The monitoring function, analogous to retrospective's short-term or working memory, is engaged for short-term tasks such as pressing the record button when a movie resumes or turning off the kettle after the water has come to a boil. Distinct about tasks that require monitoring is the fact that a plan, once formed, remains active and perhaps dominant in consciousness throughout the retention interval. Episodic ProM[41,69] is analogous to episodic retrospective memory, and it differs from monitoring primarily because plans and intentions do not remain active in consciousness through the retention interval. Remembering to stop for groceries on the way home from work or to convey a message to a colleague the next time we meet are everyday examples of episodic ProM tasks. Finally, episodic ProM seems different from habitual ProM primarily because the former function is engaged for one-off situations, whereas the latter is used for repeated tasks, for example, for taking medication according to a prescribed schedule.[42] Future research may reveal that clock-checking and time-related processes are critical for performance in situations that require monitoring, but not in situations that involve episodic ProM or habitual ProM.

Conclusions

Do time-based ProM tasks involve a timing mechanism that exerts a significant influence on performance? Is this mechanism the kind of pacemaker-counter device that has been targeted by research on time perception? Are age-related changes in performance of time-based ProM tasks caused by changes in memory processes, in timing processes or in both? Current research on time-based ProM and on age-related changes in time-based ProM does not provide clear answers to such questions, mostly because by and large, they have not yet been the focus of systematic investigation.

In this chapter, we underscored the fact that the words *time-based* are nothing but a label, a common way of describing the manner in which the retrieval of previously formed plans and promises is signaled for some ProM tasks. We have argued that although this label suggests that time-based ProM involves time-related processes, these processes are likely to be implicated only for some special purposes, specifically, for situations that require monitoring. Monitoring is the short-term function of ProM that is analogous to the short-term component of retrospective memory. It may be that in monitoring situations, the most effective strategy is one that involves clock-checking and depends on a pacemaker-counter device, either because alternative strategies are not available or their implementation is more resource demanding.

The time-perception models reviewed earlier in this chapter seem compatible with the proposal that time-related processes are invoked for time-based monitoring tasks. Monitoring tasks have been described as dual task situations[42] where attention needs to be allocated to at least two sources, for example, an ongoing activity (e.g. cleaning up the office desk) and the flow of time (e.g. is it time to leave yet?). The claim that in time-based monitoring task subjects are aware of time is consistent with the pacemaker-counter models described earlier in this chapter as well as in the next chapter. More important, if time-based monitoring tasks require some type of pacemaker-counter, we expect future research to demonstrate a strong predictive link between performance on time-estimation tasks and performance on time-based monitoring tasks.

References

1. Hicks R, Miller G, Kinsbourne M. Prospective and retrospective judgments of time as a function of amount of information processed. *American Journal of Psychology* 1976; **89**: 719–730.
2. Roeckelein J E. *The Concept of Time in Psychology (A Resource Book and Annotated Bibliography)*. Westport, Ct: Greenwood, 2000.
3. Grondin S. From physical time to the first and second moments of psychological time. *Psychological Bulletin* 2001; **127**: 22–44.
4. Grondin S. Sensory modalities and temporal processing. In Helfrich H, ed. *Time and Mind II: Information Processing Perspectives*. Göttingen, Germany: Hogrefe & Huber, 2003: 75–92.
5. Block R A, Zakay D, Hancock P A. Human aging and duration judgments: A meta-analytic review. *Psychology and Aging* 1998; **13**: 584–596.
6. Ornstein R. *On the Experience of Time*. New York: Penguin, 1969.
7. Block R A, Reed M A. Remembered duration: Evidence for a contextual-change hypothesis. *Journal of Experimental Psychology: Human Learning and Memory* 1978; **4**: 656–665.
8. Zakay D, Block R A. Prospective and retrospective duration judgments: An executive-control perspective. *Acta Neurobiologiae Experimentalis* 2004; **64**: 319–328.
9. Thomas E A C, Weaver W B. Cognitive processing in time perception. *Perception & Psychophysics* 1975; **17**: 363–367.
10. Barnes R, Jones M R. Expectancy, attention, and time. *Cognitive Psychology* 2000; **41**: 254–311.
11. Large E W, Jones M R. The dynamics of attending: How we track time varying events. *Psychological Review* 1999; **106**: 119–159.
12. Jones M R, Boltz M G. Dynamic attending and responses to time. *Psychological Review* 1989; **96**: 459–491.
13. Staddon J E R, Higa J J. Time and memory: Towards a pacemaker-free theory of interval timing. *Journal of the Experimental Analysis of Behavior* 1999; **71**: 215–251.
14. Block R A. Psychological timing without a timer: The roles of attention and memory. In Helfrich H, ed. *Time and Mind II: Information Processing Perspectives*. Göttingen, Germany: Hogrefe & Huber, 2003: 41–59.
15. Church R M, Broadbent H A. Alternative representations of time, number, and rate. *Cognition* 1990; **37**: 55–81.
16. Grossberg S, Schmajuk N A. Neural dynamics of adaptive timing and temporal discrimination during associative learning. *Neural Networks* 1989; **2**: 79–102.

17. Treisman M, Faulkner A, Naish P L N, Brogan D. The internal clock: Evidence for a temporal oscillation underlying time perception with some estimates of its characteristic frequency. *Perception* 1990; **19**: 705–743.
18. Killeen P R, Weiss N A. Optimal timing and the Weber function. *Psychological Review* 1987; **94**: 455–468.
19. Killeen P R, Taylor T. How the propagation of error through stochastic counters affects time discrimination and other psychophysical judgments. *Psychological Review* 2000; **107**: 430–459.
20. Gibbon J. Ubiquity of scalar timing with a Poisson clock. *Journal of Mathematical Psychology* 1992; **36**: 283–293.
21. Meck W H. (Ed.) *Functional and Neural Mechanisms of Internal Timing*. Boca Raton, Fl: CRC Press, 2003.
22. Wearden J. Applying the scalar timing model to human time psychology: Progress and challenges. In Helfrich H, ed. *Time and Mind II: Information Processing Perspectives*. Göttingen, Germany: Hogrefe & Huber, 2003: 21–39.
23. Gibbon J, Church R M. Sources of variance in an information processing theory of timing. In Roitblat H L, Bever T G, Terrace H S, eds. *Animal Cognition.* Hillsdale, NJ: Erlbaum, 1984: 465–488.
24. Brown S W, Boltz M. Attentional processes in time perception: Effects of mental workload and event structure. *Journal of Experimental Psychology: Human Perception and Performance* 2002; **28**: 600–615.
25. Burle B, Casini L. Dissociation between activation and attention effects in time estimation: Implications for internal clock models. *Journal of Experimental Psychology: Human Perception and Performance* 2001; **27**: 195–205.
26. Grondin S. Time psychophysics and attention. *Psychologica* 2001; **28**: 177–191.
27. Block R A, Zakay D. Retrospective and prospective timing: Memory, attention and consciousness. In Hoerl C, McCormack T, eds. *Time and Memory: Issues in Philosophy and Psychology*. Oxford: Clarendon Press, 2001: 59–76.
28. Glicksohn J. Temporal cognition and the phenomenology of time: A multiplicative function for apparent duration. *Consciousness and Cognition* 2001; **10**: 1–25.
29. Brown S W, Stubbs D A, West A N. Attention, multiple timing, and psychophysical scaling of temporal judgments. In Macar F, Pouthas V, Fiedman W, eds. *Time, Action, Cognition: Towards Bridging the Gap.* Dordrecht Netherlands: Kluwer, 1992: 129–140.
30. Brown S W, West A N. Multiple timing and the allocation of attention. *Acta Psychologica* 1990; **75**: 103–121.
31. Macar F, Grondin S, Casini L. Controlled attention sharing time estimation. *Memory & Cognition* 1994; **22**: 673–686.
32. Grondin S, Macar F. Dividing attention between temporal and nontemporal tasks: A performance operating characteristic — POC — analysis. In Macar F, Pouthas V, Friedman W, eds. *Time, Action, Cognition: Towards Bridging the Gap.* Dordrecht, Netherlands: Kluwer, 1992: 119–128.
33. Lustig C. Grandfather's clock: Attention and interval timing in older adults. In Meck W H, ed. *Functional and Neural Mechanisms of Internal Timing.* Boca Raton, Fl: CRC, 2003: 261–293.

34. Rammsayer T H, Lima S D, Vogel W H. Aging and temporal discrimination of brief auditory intervals. *Psychological Research* 1993; **55**: 15–19.
35. Rammsayer T H. Ageing and temporal processing of durations within the psychological present. *European Journal of Cognitive Psychology* 2001; **13**: 549–565.
36. McCormack T, Brown G D A, Maylor E A, Richardson L B N, Darby E R J. Effect of aging on absolute identification of duration. *Psychology and Aging* 2002; **17**: 363–378.
37. Lustig C, Meck W H. Paying attention to time as one gets older. *Psychological Science* 2001; **12**: 478–484.
38. Vanneste S, Pouthas V. Timing and aging: The role of attention. *Experimental Aging Research* 1999; **25**: 49–67.
39. Craik F I M, Hay J F. Aging and judgments of duration: Effects of task complexity and method of estimation. *Perception & Psychophysics* 1999; **61**: 549–560.
40. Birt A R. Prospective memory: A distinct form of remembering? Evidence from task comparisons and normal aging. Unpublished doctoral dissertation, University of British Columbia, Vancouver, BC, Canada, 2001.
41. Graf P. Prospective memory retrieval revisited. In Ohta N, MacLeod C M, Uttl B, eds. *Dynamic Cognitive Processes*. Tokyo: Springer, 2005: 305–332.
42. Graf P, Uttl B. Prospective memory: A new focus for research. *Consciousness and Cognition* 2001; **10**: 437–450.
43. Einstein G O, McDaniel M A. Normal aging and prospective memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 1990; **16**: 717–726.
44. Ceci S J, Bronfenbrenner U. Don't forget to take the cupcakes out of the oven: Prospective memory, time-monitoring and context. *Child Development* 1985; **56**: 152–164.
45. Craik F I M. A functional account of age differences in memory. In Klix F, Hagendorf H, eds. *Human Memory and Cognitive Capabilities, Mechanisms, and Performances*. Amsterdam: Elsevier, 1986: 409–422.
46. Hasher L, Zacks R T. Automatic and effortful processes in memory. *Journal of Experimental Psychology: General* 1979; **108**: 356–388.
47. Jorm A F. Controlled and automatic information processing in senile dementia: A review. *Psychological Medicine* 1986; **16**: 77–78.
48. Salthouse T A. A theory of cognitive aging. Amsterdam: North Holland, 1985.
49. Salthouse T A. Resource-reduction interpretations of cognitive aging. *Developmental Review* 1988; **8**: 238–272.
50. Einstein G O, McDaniel M A. Retrieval processes in prospective memory: Theoretical approaches and some new empirical findings. In Brandimonte M, Einstein G O, McDaniel M A, eds. *Prospective Memory: Theory and Application*. Mahwah, NJ: Erlbaum, 1996: 115–141.
51. Einstein G O, McDaniel M A, Richardson S L, Guynn M J, Cunfer A R. Aging and prospective memory: Examining the influences of self-initiated retrieval processes. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 1995; **21**: 996–1007.
52. Park D, Hertzog C, Kidder D P, Morrell R W, Mayhorn C B. Effect of age on event-based and time-based prospective memory. *Psychology and Aging* 1997; **12**: 314–327.
53. Martin M. Aging and patterns of change in everyday memory and cognition. *Human Learning* 1986; **5**: 63–74.

54. Maylor E A. Age and prospective memory. *Quarterly Journal of Experimental Psychology* 1990; **42A**: 471–493.
55. Moscovitch M. A neuropsychological approach to memory and perception in normal and pathological aging. In Craik F I M, Trehub S, eds. *Aging and Cognitive Processes*. New York, NY: Plenum, 1982: 55–78.
56. Patton G W, Meit M. Effect of aging on prospective and incidental memory. *Experimental Aging Research* 1993; **19**: 165–176.
57. Rendell P G, Craik F I M. Virtual week and actual week: Age-related differences in prospective memory. *Applied Cognitive Psychology* 2000; **14**: S43–S62.
58. West R L. Prospective memory and aging. In Gruneberg M M, Morris P E, Sykes R N, eds. *Practical Aspects of Memory: Current Research and Issues* (Vol. 2) Chichester, England: Wiley, 1988: 199–125.
59. Cohen J. Statistical power analysis for the behavioral sciences (1st edn.). New York: Academic Press, 1969.
60. Cohen J. Statistical power analysis for the behavioral sciences (revised edn.). New York: Academic Press, 1977.
61. Kliegel M, Martin M, McDaniel M A, Einstein G O. Importance effects on performance in event-based prospective memory tasks. *Memory* 2004; **12**: 553–561
62. Maylor E A. Does prospective memory change with age? In Brandimonte M, Einstein G O, McDaniel M A, eds. *Prospective Memory: Theory and Application*. Mahwah, NJ: Erlbaum, 1996: 173–197.
63. Brandimonte M A, Passolunghi M C. The effect of cue-familiarity, cue-distinctiveness, and retention interval on prospective remembering. *Quarterly Journal of Experimental Psychology* 1994; **47A**: 565–587.
64. Cohen A, Dixon R A, Lindsay D S, Masson M E J. The effect of perceptual distinctiveness on the prospective and retrospective components of prospective memory in young and old adults. *Canadian Journal of Experimental Psychology* 2003; **57**: 274–289.
65. McDaniel M A, Einstein G O. The importance of cue familiarity and cue distinctiveness in prospective memory. *Memory* 1993; **1**: 23–41.
66. Siu D, Graf P. Plans for success: Improving prospective memory task performance. Presented at the *2nd International Conference on Prospective Memory*, Zurich, Switzerland, 2005.
67. Cook G I, Marsh R L, Hicks J L. Associating a time-based prospective memory task with an expected context can improve or impair intention completion. *Applied Cognitive Psychology* 2005; **19**: 345–360.
68. Logie R H, Maylor E A, Della Sala S, Smith G. Working memory in event- and time-based prospective memory tasks: Effects of secondary demand and age. *European Journal of Cognitive Psychology* 2004; **16**: 441–456.
69. Kvavilashvili L, Ellis J. Varieties of intentions: Some distinctions and classifications. In Brandimonte M, Einstein G O, McDaniel M A, eds. *Prospective Memory: Theory and Application*. Mahwah, NJ: Erlbaum, 1996: 23–51.