

A Mechanism-Based Design Framework for Prospective Memory Failures in Human–Computer Interaction

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Abstract. In the context of highly fragmented digital attention, existing time- or location-based reminder mechanisms struggle to effectively support prospective memory in complex situations. To address this shortcoming, this paper focuses on the state changes and human-computer behavioral differences during the formation, maintenance, triggering, and execution of intentions, identifying the disconnect between the two, and laying the foundation for future research. This study adopted the research methods of diary studies and semi-structured interviews, selecting a total of 20 participants. After conducting prospective memory journey mapping and analysis, a mismatch mechanism model between humans and systems in prospective memory failure was obtained. Based on this, a human-computer interaction design framework for prospective memory failure was proposed, providing a design perspective for state sensitivity and entry points for reminder systems and intelligent assistants.

Keywords: Prospective memory; Diary Research; Semi-structured Interview; Human-computer interaction framework

1 Introduction

Prospective memory (PM) refers to an individual's ability to remember and complete planned behaviors at a future time or context. Prospective memory not only involves the memory of events, but also requires the restoration of action plans and the execution of tasks at appropriate times, which poses challenges to attention and executive control. Traditional cognitive psychology research has shown that reminder cues such as time and location cues can assist people in more successfully recalling future intentions, but their effectiveness is significantly influenced by individual attention and task nature [1].

In the field of human-computer interaction, digital technology and reminder systems are widely used to support PM, such as AI driven reminder tools attempting to automatically identify reminder timing and content [2]. Such reminders can alleviate the decline of prospective memory under high cognitive load to a certain extent [3]. Electronic aids such as

smartphones have also been proven to improve the prospective memory performance of the elderly or people with limited cognitive resources [4].

However, the availability of the reminder tool itself may also change the individual's memory strategy. Studies have found that when users expect the existence of external reminders, their coding investment in future intentions may be reduced, which shows worse prospective memory execution when reminders are missing or failed [5]. This phenomenon aligns with the trend revealed by research on "intention outsourcing", which suggests that individuals weigh internal memory against external assistance, and this choice varies with age, task nature, and context [6].

At the same time, in the highly fragmented digital attention environment, fast context switching and multitasking interference will significantly damage PM performance. For example, fast switching of short video platforms will reduce the effect of intention maintenance and execution [7].

However, the existing research still focuses on the optimization of a single trigger mechanism, and less on the systematic analysis of the state change and failure risk of intention in the whole process of formation, maintenance, trigger and execution. Forward looking intentions in complex real situations are often difficult to trigger only by simple time or place, and digital prompt systems need intelligent support with more situational adaptability [8].

Therefore, through diary research and interviews based on story backtracking, this paper analyzes the mechanism of prospective memory failure in real situations from a dynamic perspective, and proposes a human-computer interaction design framework for prospective memory failure.

2 Research Methods

2.1 Research Object

This study is mainly a qualitative study, focusing on the time evolution of prospective memory intention in real digital life. For this reason, 20 participants were selected for this study. In order to minimize the sample bias, the participants' ages ranged from 23 to 45 years old, and the gender distribution was 10 males and 10 females. Participants came from different occupations to cover different daily rhythms and strategies, and maximize the performance differences of prospective memory under different attention environments, task switching density, and reminder dependence.

2.2 Specific Research Methods

Diary Research. Diary research is an excellent way to stimulate longitudinal and in-depth exploration of time or phenomena. It can effectively capture the dynamic process and allow participants to reflect on their behavior and experience [9]. In the real use environment, diary research can capture changes in user behavior and perception, making up for the limitations of short-term laboratory research [10].

Detailed and long-term records can cover the whole process of the formation, maintenance, start-up and implementation of prospective memory. However, due to the uncertainty of

prospective memory events and the difficulty of recording, this study mainly uses retrospective diary research, which means that for some participants who cannot record diaries at the moment, they are asked to record the process of events in a retrospective manner.

In this diary study, all participants were asked to select an event that had just happened or was happening to record. This study provided participants with a template of relevant content to be recorded, including the time and context when the intention of the event first appeared, whether to add relevant external reminders, the task or context switching from the formation to the execution period, the way of triggering and awareness, whether it is executable at the moment, and the final result. These fixed templates and forms are helpful for subsequent cross case analysis and comparison.

Semi-Structured Interview. The semi-structured interview lasted about one and a half hours for each participant. When conducting the previous diary research, participants will be told that they will conduct interviews based on the diary research in the future, which will enable participants to think deeply about the understanding and significance of each step in the diary in advance. Diary research mainly focuses on the process of events, while semi-structured interview is to deeply explore the thoughts and thinking logic of participants behind events. During the follow-up cross case analysis and comparison, a second round of interviews was conducted with six participants on relevant details.

In the whole process of the interview, this study first conducted an overall discussion with the participants on memory and decision-making, and discussed how the participants viewed and needed external reminders, as well as their expectations for external reminders and their impact on mentality. Then, based on the daily records recorded by the subjects, the key nodes were queried, and the participants' judgment, confidence, and external decisions were inquired about in stages to supplement the subjective mechanism that was difficult to capture in the diary, so as to improve the research and promote subsequent analysis and conclusions.

2.3 Analytical Tools

Prospective Memory Journey Map. Journey maps are often used in user experience and service design to show the phased interaction process of workflow or service experience, as well as user related pain points and needs. The journey map in this study is also an analytical representation tool, which visualizes the text data in diary research and semi-structured interviews into readable objects that are easier to analyze on the basis of retaining the time sequence and stage logic of events.

Data Analysis. The prospective memory events are time structured through the sequence of formation, retention, triggering and execution. This time structure shows the location and mode of prospective memory failure of different participants, and can be compared with different participants at the same time. Secondly, in order to identify the reasons for the failure of prospective memory, not just its location, this study also conducted a qualitative analysis of each stage, namely how situational interruption, metacognitive judgment, and externalized decision-making interact at each stage of the journey. Finally, by integrating the research data of different participants and comparing the patterns in their journey maps, highlighting common failure locations and potential explanatory mechanisms, a model of the human system mismatch mechanism in prospective memory failure is constructed.

3 Result

3.1 Initial intention formation and system intervention

In the participants' records, the intention was initially formed under high attention or task switching conditions, at which point the participants recognized the need to take action in the future, but did not form specific action details such as time, steps, etc. This vague intention is not an executable command, and at this stage, the existing reminder system is missing. It only activates when a specific time and location are determined, resulting in a gap where users lack support when the intention is most fragile.

3.2 Routine structuring and intention suspension

Eleven participants highly structured their routines and incorporated their intentions into existing work or life processes, such as executing actions on their way home or upon arrival at a certain location. In the intent maintenance and initiation phase, they believe that structured routines will serve as triggers to provide them with clues or achieve their goals by setting external reminders. However, when structured routines are interrupted or when reminders are delayed at inappropriate times, the system fails to detect their situation and fails to recognize the risk state they represent, resulting in intentions entering a suspended state lacking reactivation mechanisms.

3.3 Reminder of Dependency and Silent Failure

In the interview, there were 7 participants who heavily relied on reminders. External reminders changed their internal behavior, and setting reminders gave them a sense of relief, reducing their internal practice of the event. When reminders occur during moments of high cognition or load, participants often choose to postpone action by ignoring or delaying notifications. In the execution phase, due to the unresolved intention suspension state mentioned above, the inconsistency between users' dependence on reminders and the lack of reactivation of the system often leads to failures occurring silently, and participants usually only realize the failure and process rupture when reviewing the process afterwards.

3.4 Model of Human System Mismatch Mechanism in Prospective Memory Failure

Overall, as shown in Table 1, the model suggests that prospective memory failure is not a sporadic error in a single stage, but rather a result of accumulated human system mismatch across multiple stages. This mechanistic analysis provides a foundation for rethinking the role and intervention boundaries of reminder systems from a human-computer interaction perspective in the future.

Table 1. A Model of Human System Mismatch Mechanism in Prospective Memory Failure

Intention formation cycle Perspective	Forming	Maintaining	Triggering	Executing
	People	vague intention	indirectly recalling but not taking action	delay action

System	support when specifying time/location	single point reminder	reminder will be suspended when delayed	
Mismatch	no support when the intention is formed	reminder will not change user policy	no reactivation	no recovery/remediation mechanism

4 Discussion

4.1 Reasons for the formation of research results

This study suggests that prospective memory failure does not stem from simple forgetting, but rather from the gradual loss of controllability of intentions in different states. Most failures do not occur in a state where the intention has completely disappeared, but in an intermediate state where the intention still exists but cannot be activated or executed in a timely manner. Participants often fail due to excessive internal trust judgments, frequent attention switching, and a lack of further management in delayed decision-making. And prospective memory failure is more like a cross stage process rupture rather than a single point forgetting.

4.2 A human-computer interaction design framework for prospective memory failure

Based on the above mechanism, this article proposes a human-computer interaction design framework for prospective memory failure (as shown in Table 2). Horizontally, there are intention states in use, namely unformed intention, background state (intention does not occupy current attention and has not been converted into an action plan, but exists in a low activation state in the cognitive background), suspended state (choosing to delay execution), and failure/tending towards failure. Vertically, there are variables that can be actively adjusted in the design of human-machine interaction.

Table 2. A human-computer interaction design framework for prospective memory failure

Variables that HCI can actively adjust in design	Intention state in use			
	Unformed intention	Background state	Suspended state	Failure/Tending towards failure
	Manifesting vague intentions as understandable objects	Maintain low interference visibility	Mark delayed action	
Presentation format	Support disassembly and restatement, rather than assuming that the user has already completed the intended plan	Place the intention in a background that can be perceived again	Prevent intent from completely disappearing in the interface	Presenting failure itself as a perceptible state

The timing and logic of intervention	Avoid early timing reminders	Intervene at situational transition nodes rather than fixed times (such as returning to the workplace or ending the current task)	Delay should not terminate trigger logic	
	Prioritize intervening in the intention shaping window (such as task switching, reflection moments)		The system needs to design a trigger point again, rather than a one-time reminder	
Controllability of delay			Delay should be accompanied by perceptible commitments or consequences	Provide low-cost remedies and re planning
Feedback, responsibility, and recovery		Provide risk feedback for long-term inaction	If the delay is not restored, the risk should be explicitly indicated	The system should support reflection, strategy adjustment, and future migration

4.3 Reflection on Methods and Research Limitations

This study used retrospective diary research and semi-structured interviews to obtain data information, but retrospective data may cause participants to add subjective changes during the retrospective, resulting in data bias. In addition, the sample size of this study is limited, and the purpose of the research is to reveal the mechanism and design space, rather than providing general statistical conclusions. Future research can combine system logs, longitudinal tracking, or prototype intervention to further examine the role of different design frameworks in real systems.

5 Conclusion

Through research, this paper finds that the failure of prospective memory is not a single forgetting event, but the result of the gradual loss of controllability in the process of intention formation, maintenance and delay. This failure often does not originate from a single defect, but from the continuous mismatch between human and technological systems in different stages of intention support. Based on the analysis of prospective memory experience in real situations, this paper further summarizes and proposes a human system mismatch mechanism model, and constructs a human-computer interaction design framework for prospective memory failure.

This study fills the gap of insufficient attention to the intermediate state and process mechanism of prospective memory in human-computer interaction research, and expands the focus of analysis from when to trigger reminders to intention state management. The human-

computer interaction design framework proposed in this paper provides a design perspective of an appropriate state and entry point for the alert system and intelligent assistant.

On this basis, future research can further test the applicability and effectiveness of the framework in real systems through longitudinal research or prototype system verification. At the same time, it can also be extended to a wider range of people and situations to explore the differences in intention state transition of different individuals in diverse living and working environments, so as to continuously improve the understanding of the prospective memory support mechanism.

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