

Prospero: A Personal Wearable Memory Coach

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ABSTRACT

Prospective memory, which involves remembering to perform intended actions, is essential for independent daily living especially as we grow older. Yet, majority of everyday memory failures are due to prospective memory lapses. Memory strategy training can help to tackle such lapses. We present Prospero, a wearable virtual memory coach that guides users to learn and apply a memory technique through conversation in natural language. Using physiological signals, Prospero proactively initiates practice of the technique during opportune times where user attention and cognitive load have more bandwidth. This could be a step towards creating more natural and effective digital memory training that could eventually reduce memory decline. In this paper, we contribute with details of its implementation and conversation design.

CCS CONCEPTS

• **Human-centered computing** → **Ubiquitous and mobile computing systems and tools**;

KEYWORDS

Memory Training, Memory Coach, Conversational Agent

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1 INTRODUCTION

Prospective memory (PM) involves remembering to perform intended actions [7]. It is needed in daily activities, such as attending an appointment or taking medication, yet PM

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Figure 1: Overview of the Prospero system. User wears bone conduction headset and E4 wristband. Prospero initiates practice when system detects a less-stressful moment based on skin conductance (SC) and heart-rate variability

lapses remain the most frequently reported in everyday forgetting [15].

Conversational agents, like Google Assistant¹ and Siri² are powerful platforms for natural-language interactions. Their combination with wearables such as Google Pixel or Apple Watch, provide even more seamless interaction. These conversational agents can also be presented as virtual memory coaches that train the use of memory strategies to improve PM (as opposed to simply reminding PM tasks). Social interaction and physiological understanding of the user could create effective digital memory tutors which relate to and understand us better. Such training could reduce age-related PM decline and lower the risk of cognitive diseases like Alzheimer’s [19].

We present Prospero (Figure 1), a virtual memory coach which 1) is wearable and always-available, 2) uses natural-language to guide users in learning and applying the “when-then” technique, a technique found to be effective at strengthening PM in adults [5], and 3) proactively initiates dialogue to suggest practice of the technique at suitable moments of low attention and mental load which are estimated from physiological measures. This paper contributes with details on its hardware and software implementation, as well as conversation design.

¹<https://assistant.google.com/>

²<https://www.apple.com/siri/>

2 RELATED WORK

When-Then Technique

The "when-then" technique, also known as implementation intentions, was developed by Gollwitzer [9]. It has been shown to improve PM performance and mainly taught by researchers in lab settings [5]. There are two steps in implementation intentions: 1) verbalising/formulating a "when-then" sentence [3] such as "When I leave home at 2pm tomorrow, then I will bring Henry's gift.", and 2) visualising yourself performing the action. This method helps users to form stronger associations between situation cues (event, time or location) and intended actions [8], so that they are more likely to perform their PM tasks. Our system teaches users about the technique and works with them to practice it on their own tasks. Since using the "when-then" technique requires high attention and planning demands [13], our system aims to start the practice with users when attention and mental load have more capacity.

Physiological Measures

Our autonomic nervous system regulates physiological activities in the body such as heart rate, respiration and sweating. Electrodermal activity (EDA) refer to electrical changes on the skin, usually measured via variations in skin conductivity. Increased cognitive load, arousal and attention causes increase in sweating and skin conductivity. EDA can be used as an attention index, where Skin Conductance Responses (SCRs) occur when a person is attentive [20]. Bahrainian et al. found that a memorable segment of a conversation is preceded by a rapid decrease in EDA signal, shortly after the local minimum of the signal [2]. Another measure, heart rate variability (HRV), reflects changes in the time intervals between consecutive heartbeats called inter-beat-intervals (IBI) [16]. IBI is derived from photoplethysmography (PPG) signals which measure blood volume change. The root mean square of successive differences between normal heartbeats (RMSSD) is a common time-domain estimate of HRV [4, 16]. Lowered HRV is typically observed during sustained attention and cognitive load [18], while RMSSD is a good indicator to assess cognitive load [10]. Our system aims to initiate practice of the technique when EDA values are low while HRV is high to avoid divided attention and interruption, and possibly increase memorability.

Conversational Tutors

Prior work on memory training using digital platforms involve either completing memory exercises [1, 17] or facilitating a memory strategy³, on computers and smartphones.

³<https://apps.ankiweb.net/>

Our work investigates memory training through a conversational interface that guides the application and practice of the "when-then" technique.

Hirsch et al. investigated how social robots could be designed as memory coaches to help the elderly as memory training tools [11]. They discussed that memory exercises should be trained with personal memories, and be done in a comfortable and concentrated learning environment. Social interaction can be beneficial for memory as it is seen as more challenging and it involves emotions [12]. With a conversational interface, learning of the "when-then" technique would be more similar to how participants conventionally learn about method in lab-based contexts [5] and could support the experience of verbalising (first step of technique).

Adaptive learning systems and affect-sensitive conversational tutors, like AutoTutor [6], use physiological measures during teaching to adapt delivery and content of learning accordingly. However, this is different from the scope of this paper, as we are using physiological signals to deduce attention and cognitive load before learning and practice begins.

3 PROSPERO

Hardware

We implemented a proof-of-concept of Prospero using an E4 wristband⁴, bone conduction headset and Android phone. Figure 2 shows the system diagram for Prospero. The E4 wristband is usually worn on non-dominant hand of the user and it streams EDA and PPG readings to an Android phone application (app) via Bluetooth. The bone conduction headset with an in-built microphone is connected to the Android phone via Bluetooth as well. It outputs Prospero's voice to the user and streams voice input from the user. Android phone running the app can be placed in the user's pocket or nearby.

⁴<https://www.empatica.com/en-gb/research/e4/>

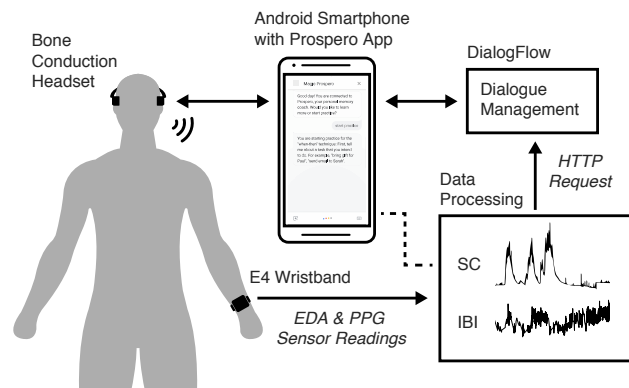


Figure 2: System Diagram for Prospero

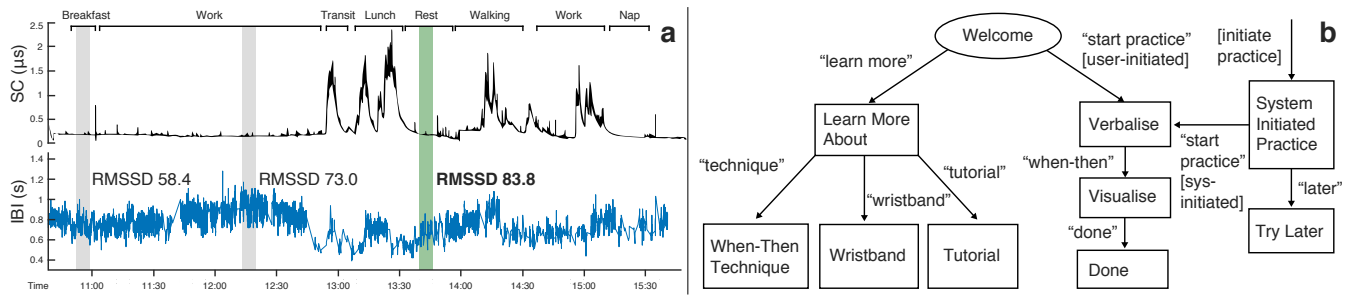


Figure 3: a) Skin conductance (μS) and inter-beat-interval (s) analysis with tagged activities showing five hours of data. Highlighted areas represent 5-min intervals showing calculated RMSSD values (in ms). Green/Darker highlighted area represent opportune moment for practice initiation. b) Conversation flow of Prospero

Software

The Android app runs the conversation interface and communicates with a DialogFlow⁵ agent that manages the dialogue between Prospero and the user. The app has a visual text-based chat interface for users who are not comfortable with speech interaction or require silent interaction, such as when in public spaces. Having both voice and visual interfaces is useful in overcoming privacy and preference limitations of purely voice interfaces [14]. A separate data processing manager is also run by the app. It processes incoming EDA and PPG readings, to attain skin conductance (SC) and IBI data (used to derive RMSSD), over 5-minute intervals. Baseline measures for calibration are taken upon the first 5 minutes of the E4 wristband connection to the app. Preliminary physiological recordings (in Figure 3a) show that opportune moments for practice coincide with RMSSD readings greater than 80ms and EDA value close to baseline (resting levels) at less than $0.5\mu S$. Once these conditions are met, a HTTP request is sent to the DialogFlow agent as a custom event which triggers the agent to suggest starting practice.

Conversation Structure and Flow

Intents represent user intentions that are matched based on what the user said. Figure 3b shows the conversation flow for Prospero. When the user runs Prospero, it starts with the "Welcome" intent that leads to two choices: 1) to learn more about system and technique or 2) to start practice.

Learn More About System and Technique: If the user says "learn more", Prospero asks whether the user wants to learn more about the "when-then" technique, the wristband, or go through the tutorial. Learning more about the technique will give information that it helps with PM and the mechanism behind it. Learning about the wristband tells about what it does and what it is used for. By selecting the tutorial, Prospero explains the two steps of the technique and gives

a scenario for the user to apply the technique. After that, prompting the user to "start practice" to try with their own intended actions.

Proactive System-Initiated and User-Initiated Practice: The user can initiate a practice session at any time. Proactive initiation will only occur when the DialogFlow agent receives the HTTP request to initiate practice, invoking the "System Initiated Practice" intent. During which, Prospero informs the user that it notices her/she is more "calm" and asks if the user would like to start a practice session. The users also have the option to try later instead. Once user intentions matches to "start practice", Prospero guides the user through the verbalisation step where user is prompted to think about a task they intend to do, and related situation cues of event, time or location. Prospero provides a summary of user responses, then prompts to verbalise the "when-then" sentence and corrects the sentence when needed. The user is then led to the second step, visualisation, to visualise oneself performing the task with the situation cues in mind. After that, the session is complete and the user can have more practice, learn more or leave the conversation. Below is a *sample of system-initiated dialogue:*

Prospero: Noticed that you are more relaxed now. Would you like to start practice or try later?

User: Start practice.

Prospero: You are starting practice for the "when-then" technique: First, tell me about a task that you intend to do. For example, "bring gift for Paul" or "send email to Sarah".

User: Buy movie ticket.

Prospero: Good. And in what situation do you intend to do this? It can be when an event occurs like "after breakfast tomorrow" or at an estimated time like "on Friday around 2pm".

User: When I get back home.

Prospero: OK. Next, in what location would you usually need to remember this? Make it specific like "in my living

⁵<https://dialogflow.com/docs>

room" or "at my desk". If you really can't think of a place, just say "no location".

User: My desk.

Prospero: Well done. To summarise: Your task is "buy movie ticket". For situation cues, your event is "when I get back home", and location is "my desk". Let's move on to the first step - verbalisation step of the "when-then" technique. Piece together your task, situation and location into a "when-then" sentence such as "When I am leaving home at 2pm, then I will bring chocolates for mom". How would you form your "when-then" sentence?

User: When I am at my desk at home, then I will buy the movie tickets.

Prospero: Sounds good. Now for the second step - visualisation. Visualise yourself performing your intended action... Imagine yourself in the situation, imagine your surroundings... as you perform your task. Let me know when you're done.

User: ...Done.

Initial User Reactions

To test the system and gain initial user reactions, two participants (55 and 57 yrs, 1 male & 1 female) were invited to interact with the Prospero system. Participants were first instructed to sit and relax for 5 minutes to get their baseline readings. They were allowed to go through all of the intents (which took about 5 minutes). After that, they completed a stressor activity: 5-minute Stroop colour-word test [21]. Last, participants were allowed to rest and calm down for the next 10 minutes. During this time, the proactive initiation occurred and they responded accordingly.

Participants felt that the proactive initiation part of Prospero would be useful, especially if they want to learn the memory strategy or train their memory, but are not in the habit of self-initiating regular practice. They appreciated that Prospero was able to feedback that they were relaxed, thus suggesting that they practice. They pointed out that it made sense that when you're calm and composed, you're more open and ready to do the practice. One participant noted that sometimes being calm may not mean that she wants to start practice, and liked that there was an option to try later.

4 LIMITATIONS AND FUTURE DIRECTIONS

Determining the Times to Intervene: In this version, user attention and mental load are approximated using baseline comparison and threshold methods. Future research would explore the use of machine learning classification to predict when to suggest practice. The future version would also benefit from having a "Do Not Disturb" feature or schedule to avoid prompting at these times.

Custom Single-Piece Headwear: The current implementation uses multiple devices and it takes a while to wear the different pieces. It would be more convenient and seamless to have a custom single-piece headset which integrates all the hardware components needed and runs on the Android operating system.

User Studies: To expand upon our findings from preliminary user tests, we plan to conduct user studies to collect additional physiological data and to evaluate usability, conversation design and its utility when applying to daily PM tasks in long-term usage.

5 CONCLUSION

In this paper, we present Prospero, an always-available wearable memory coach which guides users through the "when-then" technique in natural-language conversations, while providing proactive suggestions to start practice when user is under low attention and cognitive load. We explained the hardware, software and conversational structure of the proof-of-concept, including initial user feedback. This brings us closer to developing more effective and personalised conversational tutors, aimed at augmenting our memory.

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