Biosignal-Sensitive Memory Improvement and Support Systems

Figure 1: User wearing physiological sensing device (E4 wristband) and bone conduction headset while interacting with conversational agent for memory training, Prospero

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Abstract
Memory is necessary for our daily lives and activities, yet it is often fallible. Memory augmentation technology could improve and support our memory by facilitating memory training and providing memory assistance respectively. However, there remains a lack of research on utilising users' internal states to enable just-in-time delivery of these interventions to improve receptivity and effectiveness. With the focus on helping older adults, my research involves the design, development and evaluation of memory training and memory assistance artifacts which infer users' internal and cognitive context through physiological signals (biosignals). This work will contribute new concepts that build on previous research in the field of mobile computing and design guidelines for future work on augmenting human memory.

Author Keywords
Physiological Sensing; Human Memory

CCS Concepts
•**Human-centered computing** → **Human computer interaction (HCI);** User studies;

Context and Motivation
Memory is needed in our everyday lives. Our demands range from learning to the hustle of work and to the reminisce of our past. However, it is often fallible [25]. Prior

studies on everyday forgetting reveal the five common types of memory lapses faced: prospective memory (intended actions), semantic memory (learnt facts and knowledge), episodic memory (autobiographical and personal experiences), procedural memory (skills and processes) and attention lapses [7, 22]. Of these, prospective memory (PM) lapses have been the most frequently reported [7, 22]. By 2050, the majority of the world can expect to live beyond 60 years old. As we age, we are prone to age-related cognitive decline and are at higher risk of cognitive disorders such as dementia [30]. Emerging technologies for memory need to focus on playing a beneficial role in our daily activities, health, quality of life and independence.

My work is inspired by the visions by Engelbart [12] and Schmidt [26] to "Augment Human Intellect" by using technology to extend physical and cognitive capabilities to approach situations, to better comprehend the situations and to form solutions for them. By extending and supporting memory, which is an essential function within our intellect, my research takes a step into further realising these visions.

Background

Memory training is one of the approaches to address memory failures by maintaining or enhancing internal memory function [16]. Especially for PM, effective memory techniques which users can apply when remembering their intended tasks tend to be lab-based [29], or require regular practice and accurate application of the techniques for the training to be effective [13]. This yields potential for such technique-based memory training to be translated to more accessible platforms and facilitated through more natural modalities. Moreover, existing digital memory training systems mainly issue time-based prompts for starting training sessions [8, 11, 20]. Since prior work has shown that users were more receptive to prompts during idle or relaxed states [10, 21, 24], my dissertation explores issuing prompts during these states by estimating cognitive load and attention via users' biosignals of electrodermal activity (EDA) [27] and heart-rate variability (HRV) [15].

Memory assistance tools could also tackle challenges in everyday remembering. They compensate for our internal memory and help us to externalise memory into physical or digital objects. Post-it notes, to-do lists and calendars are the most common examples [2]. Research in the area had evolved into providing just-in-time memory assistance through proactive, context-based reminders and information [9, 23]. Prior work have used users' physiological context such as eye-gaze to identify what information to provide [17, 19] and EDA to predict parts of conversations which users might forget [1]. Biosignals could tell us other rich information related to our cognitive processes and memory [4, 32] that have yet to be explored. Eye-tracking is a promising direction that my research will probe into as it could assist in detecting if a user recognises an image [3] and potentially help to detect the common phenomenon of gaze diversion to facilitate remembering [14, 18, 28].

Problem Statement

To gain a deeper understanding of the user's physiological context when applied to the scenarios of memory training and memory assistance, further research is required. Utilising users' biosignals for just-in-time memory augmentation interventions could improve user receptivity and the effectiveness of these interventions. My dissertation will inform future research on using users' physiological context in mobile computing.

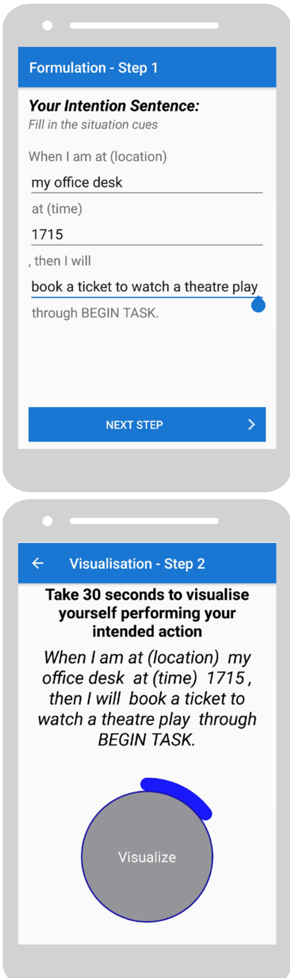

Figure 3: Screenshots of memory training tool, ProspecFit, that facilitates steps of the “when-then” memory technique

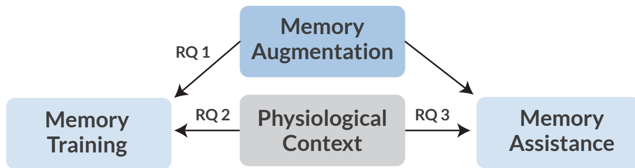

Figure 2: Overview diagram of research focus and research questions

Research Objectives

This work aims to investigate memory augmentation technology that account for physiological context to support and improve memory. It will focus on older adults as the primary users and it involves the following objectives:

- Design and develop artifacts for memory training and memory assistance
- Conduct user studies to evaluate artifacts and form design implications for future research

Research Questions

The following research questions are examined in this work (Figure 2):

RQ 1 How can existing lab-based memory training techniques be facilitated through digital forms that are usable and effective at improving memory?

RQ 2 How can memory training systems using biosignals lead to increased user receptivity to prompts for training sessions?

RQ 3 How can biosignals be used for providing effective just-in-time memory assistance?

Research Approach and Methods

Phase 1

In the first phase, a literature review of existing memory augmentation technology for memory assistance and training, as well as biosignals has been completed. Findings have been added to my dissertation.

Phase 2

In the second phase, a memory strategy training tool, ProspecFit has been developed to investigate RQ 1. ProspecFit facilities an effective memory technique called “implementation intentions” or the “when-then” technique, by allowing users to practice its two steps of formulation/verbalisation and visualisation through a smartphone application (Figure 3). The tool was designed based on findings with a focus group and usability testing. A 12-day field study and pre- and post-testing has been conducted to test the effectiveness of such digital memory training in improving PM. Findings and design insights have been published [5]. More users are being recruited to extend this study and the overall work will form a chapter of my dissertation.

Phase 3

In phase three, I expanded on the concept of ProspecFit to incorporate a more natural modality by developing a conversational agent, Prospero, which guides the same memory technique through dialogue with the user (Figure 1). Prospero’s design was informed by literature, interviews and user testing. It monitors users’ biosignals of EDA and HRV for idle/relaxed states (lowered cognitive load and attention) and gives prompts for users to begin memory training sessions (Figure 4). Users can optionally use a bone conduction headset to converse with Prospero. The concept and initial reactions to Prospero has been published [6]. A study has been conducted to answer RQ 2 and is currently under review.

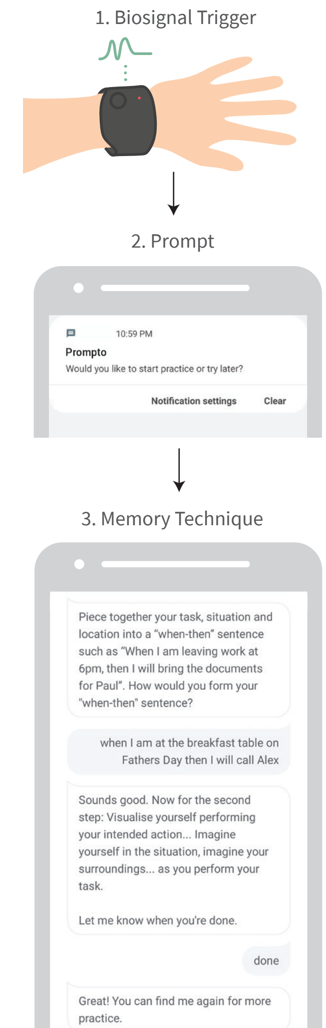

Figure 4: Interaction flow of Prospero: 1. biosignals are monitored for user states which trigger prompts, 2. prompt is issued as a notification, 3. user goes through memory training session for memory technique.

Phase 4

The final phase will help to answer RQ 3. As a starting point, user tests will be held to determine the relationship between eye-movement and visual memory retrieval processes. With the findings, a memory assistance system will be built to either detect when the user does not recognise an image or when the user is trying to retrieve information. The proposed system is planned to be a wearable image (face or object) recognition system that outputs audio information to the user. Lastly, a study will be conducted to evaluate the accuracy of the detection system, and user acceptance and sense of agency when using the system.

Results

Results from phase two using ProspecFit [5] showed that existing effective lab-based techniques like the "when-then" technique could be facilitated via a smartphone application that encouraged regular practice of technique. There has been preliminary evidence that digital memory training could still be effective at improving memory, given that the lab-based application has been showed in prior research to be effective. Users who underwent digital memory training were more on-time at completing memory tasks given during the field study and subjectively report having better PM than before the training.

The concept of Prospero from phase three [6] showed that the memory technique could also be facilitated through visual or audio dialogue with a conversational agent and alternatively, in a wearable form. Initial findings from the completed study users were more receptive to prompts for memory training during low cognitive load than during high cognitive load.

Dissertation Status and Next Steps

I am in the second year of my three-year PhD program and considered a doctoral candidate with my dissertation proposal approved by my university's provisional year review committee. Phase 1, 2 and 3 have been mostly completed, apart from the ongoing extension of the study for phase 2 that is planned to be completed by October 2020. My next and final step is Phase 4. The study design for user tests to investigate the relation between eye-movement and visual memory retrieval have been designed and is currently being held. I plan to complete the tests by December 2020 and begin development of the memory assistance system in January 2020. The studies planned to evaluate this system will start in May 2020 after attaining ethics approval.

Contributions

The research contributions of the proposed dissertation to the field of human–computer interaction could be classified into two categories according to Wobbrock and Kientz [31]:

Artifact Contribution

Three high-fidelity prototypes: 1) a memory training tool to facilitate a memory technique, 2) a conversational agent for memory training to guide the use of a memory technique and issues prompts based on users' biosignals, 3) a wearable memory assistance system that uses biosignals to aid in visual memory retrieval.

Empirical Contribution

Findings from user studies conducted using the prototypes to contribute further empirical knowledge to answer research questions and develop design guidelines for memory augmentation technology.

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REFERENCES
[1] S. A. Bahrainian and F. Crestani. 2017. Towards the next generation of personal assistants: systems that know when you forget. In *Proc. ICTIR'17*. 169–176. DOI:http://dx.doi.org/10.1145/3121050.3121071

[2] R. N. Brewer, M. R. Morris, and S. E. Lindley. 2017. How to Remember What to Remember: Exploring Possibilities for Digital Reminder Systems. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 1, 3 (Sept. 2017), 38:1–38:20. DOI: http://dx.doi.org/10.1145/3130903

[3] A. Bulling and D. Roggen. 2011. Recognition of Visual Memory Recall Processes Using Eye Movement Analysis. In *Proceedings of the 13th International Conference on Ubiquitous Computing (UbiComp '11)*. ACM, New York, NY, USA, 455–464. DOI: http://dx.doi.org/10.1145/2030112.2030172

[4] A. Bulling and T. O. Zander. 2014. Cognition-Aware Computing. *IEEE Pervasive Computing* 13, 3 (July 2014), 80–83. DOI: http://dx.doi.org/10.1109/MPRV.2014.42

[5] S. W. T. Chan, T. Buddhika, H. Zhang, and S. Nanayakkara. 2019a. ProspecFit: In Situ Evaluation of Digital Prospective Memory Training for Older Adults. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 3, 3, Article 77 (Sept. 2019), 20 pages. DOI: http://dx.doi.org/10.1145/3351235

[6] S. W. T. Chan, H. Zhang, and S. Nanayakkara. 2019b. Prospero: A Personal Wearable Memory Coach. In *Proceedings of the 10th Augmented Human International Conference 2019*. ACM, 26. https://doi.org/10.1145/3311823.3311870

[7] S. Clinch and C. Mascolo. 2018. Learning from our mistakes: Identifying opportunities for technology intervention against everyday cognitive failure. *IEEE Pervasive Computing* 17, 2 (2018), 22–33. https://dx.doi.org/10.1109/MPRV.2018.022511240

[8] Posit Science Corporation. 2002. BrainHQ. (2002). Retrieved 2019-07-03 from https://www.brainhq.com/

[9] R. W. DeVaul, B. Clarkson, and others. 2000. The memory glasses: towards a wearable, context aware, situation-appropriate reminder system. (2000).

[10] T. Dingler, D. Weber, M. Pielot, J. Cooper, C. Chang, and N. Henze. 2017. Language learning on-the-go: opportune moments and design of mobile microlearning sessions. In *Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services*. ACM, 28. DOI: http://dx.doi.org/10.1145/3098279.3098565

[11] D. Elmes. 2015. Anki. (2015). Retrieved 2019-07-24 from http://ankisrs.net

[12] D. C. Engelbart. 1962. Augmenting human intellect: A conceptual framework. *Menlo Park, CA* (1962).

[13] N. J. Gates, P. S. Sachdev, M. A. F. Singh, and M. Valenzuela. 2011. Cognitive and memory training in adults at risk of dementia: a systematic review. *BMC geriatrics* 11, 1 (2011), 55. DOI: http://dx.doi.org/10.1186/1471-2318-11-55

[14] A. Glenberg, J. L. Schroeder, and D. A. Robertson. 1998. Averting the gaze disengages the environment and facilitates remembering. *Memory and Cognition* 26, 4 (7 1998), 651–658. DOI: http://dx.doi.org/10.3758/BF03211385

[15] E. Haapalainen, S. J. Kim, J. F. Forlizzi, and A. K. Dey. 2010. Psycho-physiological measures for assessing cognitive load. In *Proc. Ubicomp'10*. 301–310. DOI: http://dx.doi.org/10.1145/1864349.1864395

[16] M. J. Intons-Peterson and J. Fournier. 1986. External and internal memory aids: When and how often do we use them? *Journal of Experimental Psychology: General* 115, 3 (1986), 267–280. DOI: http://dx.doi.org/10.1037/0096-3445.115.3.267

[17] Y. Ishiguro, A. Mujibiya, T. Miyaki, and J. Rekimoto. 2010. Aided Eyes: Eye Activity Sensing for Daily Life. In *Proceedings of the 1st Augmented Human International Conference (AH '10)*. ACM, New York, NY, USA, Article 25, 7 pages. DOI: http://dx.doi.org/10.1145/1785455.1785480

[18] R. Johansson and M. Johansson. 2014. Look Here, Eye Movements Play a Functional Role in Memory Retrieval. *Psychological Science* 25, 1 (2014), 236–242. DOI: http://dx.doi.org/10.1177/0956797613498260 PMID: 24166856.

[19] B. Kim, J. Kim, R. Mallipeddi, and M. Lee. 2015. A Glass-type Agent for Human Memory Assistance for Face Recognition. In *Proceedings of the 3rd International Conference on Human-Agent Interaction*. ACM, 283–286. DOI: http://dx.doi.org/10.1145/2814940.2814998

[20] CogniFit Ltd. 1999. CogniFit. (1999). Retrieved 2019-07-04 from https://www.cognifit.com/

[21] A. Mehrotra, V. Pejovic, J. Vermeulen, R. Hendley, and M. Musolesi. 2016. My phone and me: understanding people's receptivity to mobile notifications. In *Proceedings of the 2016 CHI conference on human factors in computing systems*. ACM, 1021–1032. DOI: http://dx.doi.org/10.1145/2858036.2858566

[22] L. Ramos, E. van den Hoven, and L. Miller. 2016. Designing for the Other 'Hereafter': When Older Adults Remember About Forgetting. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. ACM, New York, NY, USA, 721–732. DOI: http://dx.doi.org/10.1145/2858036.2858162

[23] B. J. Rhodes and P. Maes. 2000. Just-in-time information retrieval agents. *IBM Systems journal* 39, 3.4 (2000), 685–704. DOI: http://dx.doi.org/10.1147/sj.393.0685

[24] H. Sarker, M. Sharmin, A. A. Ali, Md. M. Rahman, R. Bari, S. M. Hossain, and S. Kumar. 2014. Assessing the availability of users to engage in just-in-time intervention in the natural environment. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing*. ACM, 909–920. DOI:http://dx.doi.org/10.1145/2632048.2636082

[25] D. L. Schacter. 2002. *The seven sins of memory: How the mind forgets and remembers*. HMH.

[26] A. Schmidt. 2017. Augmenting Human Intellect and Amplifying Perception and Cognition. *IEEE Pervasive Computing* 1 (2017), 6–10. https://dx.doi.org/10.1109/MPRV.2017.8

[27] Y. Shi, N. Ruiz, R. Taib, E. Choi, and F. Chen. 2007. Galvanic skin response (GSR) as an index of cognitive load. In *CHI'07 extended abstracts on Human factors in computing systems*. ACM, 2651–2656. DOI: http://dx.doi.org/10.1145/1240866.1241057

[28] J. Theeuwes, C. N. L. Olivers, and C. L. Chizk. 2005. Remembering a Location Makes the Eyes Curve Away. 16, 3 (2005), 196–199. DOI:http://dx.doi.org/10.1111/j.0956-7976.2005.00803.x

[29] E. R. Waldum, C. L. Dufault, and M. A. McDaniel. 2016. Prospective Memory Training: Outlining a New Approach. *Journal of Applied Gerontology* 35, 11 (Nov. 2016), 1211–1234. DOI: http://dx.doi.org/10.1177/0733464814559418

[30] World Health Organization WHO. 2015. *World report on ageing and health*. World Health Organization. https://www.who.int/ageing/events/world-report-2015-launch/en/

[31] J. O. Wobbrock and J. A. Kientz. 2016. Research Contributions in Human-computer Interaction. *interactions* 23, 3 (April 2016), 38–44. DOI: http://dx.doi.org/10.1145/2907069

[32] T. O. Zander, J. Brönstrup, R. Lorenz, and L. R. Krol. 2014. Towards BCI-based implicit control in human–computer interaction. In *Advances in Physiological Computing*. Springer, 67–90. DOI: http://dx.doi.org/10.1007/978-1-4471-6392-3_4