Investigating the longevity of real-world memory following a smartphone intervention in older adults: A multi-year follow-up study

Bryan Hong (bryan.hong@mail.utoronto.ca)
Department of Psychology, University of Toronto

Eliza McCann (eliza.mccann@mail.utoronto.ca)
Department of Psychology, University of Toronto

Miranda Chang (miranda.chang@mail.utoronto.ca)
Department of Psychology, University of Toronto
Department of Psychology, Simon Fraser University

Morgan D. Barense (morgan.barense@utoronto.ca)
Department of Psychology, University of Toronto
Rotman Research Institute

Abstract

Our ability to re-experience the events from our personal past tends to decline with age, which can have profound effects on well-being. HippoCamera is a smartphone-based application developed to mitigate age-related decline by guiding users to record and review cues for real-world events using established mnemonic strategies, with previous work demonstrating improved episodic recollection and enhanced hippocampal activity following use. Here, we followed-up with older adult participants who had used HippoCamera several years prior to investigate whether any benefits persisted following use. Using a mixed-methods approach, we found stronger subjective re-experiencing of events that were recorded with HippoCamera compared to those that were not. Further, participants reported extended benefits to their overall sense of meaning and well-being. These results provide preliminary evidence characterizing the long-lasting effects of a smartphone-based tool that improves memory for everyday events in aging.

Keywords: autobiographical memory; episodic memory; aging; smartphone

Introduction

Autobiographical memory grants us the remarkable ability to mentally travel back to unique moments from our past (Tulving, 2002). This serves a critical function in directing our future actions, forming our sense of self-identity, and maintaining our social relationships (Bluck et al., 2005). Re-experiencing personal events is a reconstructive process that involves the retrieval and integration of different types of details, roughly categorized as either being episodic, information that is specific to a given time and place (e.g., remembering a conversation with a colleague at CogSci 2022 in Toronto), or semantic, information that is general across multiple events—semantic details can be further differentiated based on their relevance to the self, encompassing both personal (e.g., knowing that you have attended CogSci in the past) and general knowledge (e.g., knowing that a conference typically has keynotes, symposia, and poster presentations) (Tanguay et al., 2023).

Aging is associated with changes in memory characterized by poorer recall of event-specific information, with intact (or even strengthened) recall of general information (Grilli & Sheldon, 2022; Simpson et al., 2023). This decline in episodic recall has been linked to age-related changes in brain regions that are critical for supporting recall of past experiences (Grady, 2012; Spreng & Turner, 2019). In particular, the hippocampus is vital for the encoding and retrieval of episodic content for an event (Gilboa & Moscovitch, 2021; Scoville & Milner, 1957; Squire et al., 2004), with age-related episodic decline being linked with reductions in both hippocampal structure and functional connectivity (Gorbach et al., 2017). Given the important function of autobiographical memory, loss of episodic detail can have profound impacts on both physical and mental health (King et al., 2019).

A promising approach to mitigate episodic memory loss is the use of wearable camera technology (Allé et al., 2017; Chow & Rissman, 2017; Silva et al., 2018). Over the last two decades, memory researchers have been studying whether wearable cameras, such as SenseCam or the Vicon Revue, could be used as a tool to automatically capture photographic cues that facilitate recall for events that may otherwise be forgotten. Studies have demonstrated the mnemonic benefits of wearable cameras in clinical populations, such as individuals with hippocampal lesions from limbic encephalitis (Berry et al., 2007), mild cognitive impairment (Browne et al., 2011) and Alzheimer's disease (Woodberry et al., 2015), as well as both healthy young (Sellen et al., 2007) and older adults (Mair et al., 2018; Silva et al., 2013). Despite these promising results, there are many barriers to the widespread use and impact of wearable cameras (Crete-Nishihata et al., 2012; Dingler et al., 2021). The indiscriminate and passive capture of photographs leads to the accumulation of over thousands of images each day, requiring significant time, effort, and technical expertise to select relevant cues for later review. Further, wearing a camera at all times can influence both how one acts and is perceived, whilst also raising privacy and security concerns.

Building upon this body of work, Martin et al., (2022) developed an easy-to-use smartphone-based application called *HippoCamera*. Using memory strategies from cognitive psychology and neuroscience research, HippoCamera guides users to create and review cues for everyday events. When a user wants to create a cue for an event, HippoCamera initiates a multistep process that encourages deep levels of encoding to intentionally create a self-generated and multimodal cue (Craik & Lockhart, 1972; Mäntylä & Nilsson, 1988; Thompson & Paivio, 1994) (Figure 1A). Users record an 8-second audio description followed by a 24-second video for the event—HippoCamera then creates a cue by overlaying the audio description on a 3×

In L. K. Samuelson, S. L. Frank, M. Toneva, A. Mackey, & E. Hazeltine (Eds.), *Proceedings of the 46th Annual Conference of the Cognitive Science Society.*

speeded version of the video. This speeded video allows for an efficient review process and was inspired by hippocampal replay, a phenomenon thought to be critical for memory consolidation where patterns of hippocampal activity are reactivated in a temporally compressed manner (Carr et al., 2011). Users can then review these cues at any point in replay sessions, where up to five cues are presented sequentially with their corresponding date and time information, in a distributed manner over time (Ebbinghaus, 1913) (Figure 1B). These replay sessions are automatically curated by the application to prioritize reviewing events that are recent and significant. Following each replay session, users are encouraged to form and reflect upon the associations across the different events they have seen (Kahana et al., 2008).

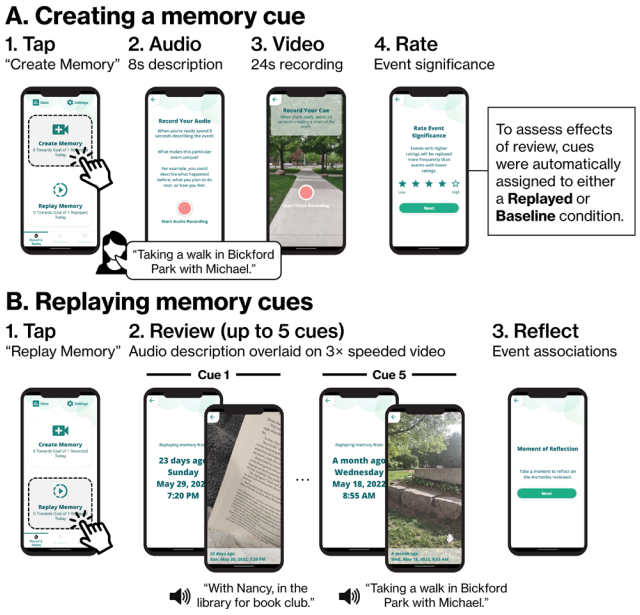

Figure 1. Overview of the HippoCamera application, describing the process of (A) creating a memory cue, and (B) reviewing memory cues in Replay sessions. To assess the effects of reviewing, cues are assigned to either a Replayed or Baseline condition after creation.

Across two experiments, Martin et al. (2022) found improved episodic recollection in older adults following replay with HippoCamera. In these experiments, older adults were instructed to use HippoCamera to record and review cues in their daily lives for either 2 or 10 weeks. Recorded cues were randomly assigned to either a Replayed condition, where they were reviewed over the course of the experiment, or a Baseline condition, where they were never reviewed. Using a modified Autobiographical Interview protocol to quantify the types of details provided at recall (Levine et al., 2002), they found that Replayed events were recalled with more episodic details than Baseline events, and that this benefit persisted three-months after HippoCamera usage ended. Functional magnetic resonance imaging showed that Replayed events had increased hippocampal pattern differentiation relative to Baseline events, and further, that the degree of hippocampal differentiation was positively associated with episodic recollection. Moreover, a sentiment analysis of recall responses found that participants recalled Replayed events with more positive language than Baseline events, suggesting that the observed memory gains may be contributing to overall emotional well-being. The boost in episodic memory for Replayed events was also shown in a case study with a 28 year-old woman with hippocampal amnesia following temporal lobe encephalitis (Martin et al., 2022), and in a study investigating the effects of experiential diversity on memory and well-being (Meade et al., 2024).

In the current study, we adopted a mixed-methods approach to investigate whether the memory gains from HippoCamera use could be observed in older adults several years following study participation. Although sustained memory benefits have been previously demonstrated several years following other memory interventions, no studies to our knowledge have extended these findings to memory for personal real-world events (Bråthen et al., 2022; Gross & Rebok, 2011; Neely & Bäckman, 1993). Here, we assessed whether the previously observed memory benefits for events following HippoCamera use would result in differences in the subjective quality of recollection. Further, we used a semi-structured interview to gain qualitative insight into any broader effects and perspectives following HippoCamera use that extend beyond memory for individual events.

Methods

Participants

13 older adults (M_{Age} = 73.8 years, SD_{Age} = 3.26 years, 9 women/4 men) who had previously taken part in an experiment reported in Martin et al. (2022) (Exp 1: n = 3; Exp 2: n = 5) and Meade et al. (2024) (n = 5) participated in the follow-up study—data collection is currently ongoing. All participants provided informed consent prior to the study and received monetary compensation for their participation. The study was approved by the Research Ethics Board at the University of Toronto.

Participants had not used HippoCamera in the intervening period between their initial study completion and the current follow-up study. The methods used in each initial study are briefly described below, with full details of HippoCamera functionality reported in Martin et al. (2022).

Martin et al. (2022) – Experiment 1 22 older adult participants (M_{Age} = 69.6 years, SD_{Age} = 4.17 years, 16 women/6 men) used HippoCamera over two weeks, where they were asked to record five events per day and view six replay sessions per day. Cues were randomly assigned to either a Replayed or Baseline condition—this random assignment meant that conditions were interleaved over the study. On average, participants recorded 4.8 events per day and viewed 5.4 replay sessions per day, with Replayed cues being seen 8.7 times. HippoCamera use took place between

July to December 2017, with the current follow-up occurring approximately 6 years after study completion.

Martin et al. (2022) – Experiment 2 12 older adult participants (M_{Age} = 66.7 years, SD_{Age} = 2.81 years, 6 women/6 men) used HippoCamera over ten weeks, where they were asked to record one event per day and view one replay session per day to better approximate real-world usage. Rather than interleaving conditions, Replayed and Baseline conditions were assigned in a blocked manner, counterbalanced and alternating across weeks on a schedule made known to participants—this was done to avoid potential bleed over effects and unintentional memory reactivation from the expectation of seeing a cue during replay sessions. On average, participants recorded 0.95 cues per day and viewed 1.05 replay sessions per day, with Replayed cues being seen 7.8 times. HippoCamera use took place between May to December 2019, with the current follow-up occurring approximately 4 years after study completion.

Meade et al. (2024) 18 older adult participants (M_{Age} = 70.7 years, SD_{Age} = 4.54 years, 10 women/8 men) used HippoCamera over eight weeks, where they were asked to record one event per day and view one replay session per day. Replayed and Baseline conditions were assigned in a blocked manner, as in Experiment 2 in Martin et al. (2022). To investigate the effect of experiential diversity in daily life, participants were encouraged to engage in more unique events on Replayed weeks and more typical events on Baseline weeks. On average, participants recorded 1.04 cues per day and viewed 1.49 replay sessions per day, with Replayed cues being seen 11.2 times. HippoCamera use took place between May to August 2020, with the current follow-up occurring approximately 3.5 years after study completion.

Task design

At the start of the follow-up session, participants were asked to describe any events they could recall from the time period of their initial HippoCamera use on a pen-and-paper worksheet. Participants were then presented with a randomized series of 40 previously tested HippoCamera cues (20 Replayed/20 Baseline) with their corresponding date and asked about various characteristics of their memory for the corresponding event. Participants were given a practice trial to ensure they understood the instructions for each measure.

Recollection rating Participants assessed their degree of recollection for an event using a 7-point scale, with 1 corresponding to Knowing, where the event is recognized with a feeling of familiarity, and 7 corresponding to Remembering, where the event has a personal recollective experience (Gardiner, 2008; Hyman et al., 1998; Tulving, 1985). Participants were also given the option to indicate that they had no recollection of the event, which was used to calculate overall recall rates.

Phenomenological characteristic ratings Participants made a series of ratings to assess various phenomenological characteristics of their memory to capture their subjective re-experiencing of an event using a 7-point scale to indicate their agreement with a series of statements, with 1 corresponding to "Strongly disagree" and 7 corresponding to "Strongly agree". These statements were drawn from the Memory Experiences Questionnaire (Sutin & Robins, 2007)—specifically, we probed the dimensions of Vividness, Coherence, Accessibility, Sharing, and Distancing.

Episodic probe task To investigate memory for details outside of the cue itself, participants made a forced choice response between two probe words, drawn from the neuroimaging task described in Martin et al. (2022). Probe words referred to a person, place, thing, or action corresponding to a given event, as previously recalled during their initial study—importantly, these were not immediately evident from the cue itself. Probe words could either be a target, if they corresponded to the tested event, or a lure, if they did not (to our knowledge). Probe words were created from their existing initial recall responses if they had not been previously generated (i.e., did not participate in the neuroimaging component of Martin et al. (2022)).

Free and cued recall Participants indicated whether the event corresponded to any of the events they had freely recalled at the beginning of the current session, as indicated on their pen-and-paper worksheet. Participants then provided a brief verbal description of their memory for their cued event. Results from free and cued recall are not reported in the current paper.

Semi-structured interview After seeing all 40 HippoCamera cues, a semi-structured interview was conducted to glean insight from the participant perspective on any outcomes that may not be adequately captured by the quantitative measures gathered. The interview guide included questions that probed topics such as reminiscence, recollection, subjective memory change, and their overall experience using HippoCamera.

Calendar control task

In the initial study sessions, Replayed and Baseline conditions were assigned following cue creation with HippoCamera. To investigate whether memory for events recorded with HippoCamera differed from those that were not, participants were contacted after the follow-up session and asked if they had access to a calendar (physical or digital) where they had logged events around the time period that they had participated in the initial study. If so, participants were invited to return for a second session where their memory was assessed for these calendar events. 4 older adults (M_{Age} = 72.0, SD_{Age} = 2.71, 3 women/1 man) participated in this second session.

During the second session, participants were asked about their memory corresponding to 20 calendar events.

Participants were cued with a randomized series of dates in the neighboring months from their initial HippoCamera usage (e.g., if they had participated in September 2019, participants were cued with dates from August and October 2019). They were then asked if they had an entry for that date and whether they were comfortable sharing their memory of the event. If so, they were asked to provide a recollection rating, phenomenological characteristic ratings, and a cued recall response for the corresponding event, as described in *Task design*. Participants were also asked to indicate the importance (5-point scale, from "Low" to "High") and typicality (4-point scale, from "Very unique" to "Very typical") of each event, as done in Martin et al. (2022) and Meade et al. (2024).

Data analyses

We adopted a mixed modelling approach using the *lme4* package in *R* (Bates et al., 2015) to compare each quantitative memory outcome across Replayed, Baseline, and Calendar events, nesting individual events within participants. Separate models were fit for each outcome measure. For recollection ratings, responses were first categorized as either recalled or not, depending on whether they indicated having any recollection for the cued event. A binomial generalized linear mixed model was first used to compare recall rates across event conditions. A linear mixed model was then used to compare the degree of recollection for recalled events across event conditions. For episodic probe responses, a binomial generalized linear mixed model was used to compare target accuracy across event conditions.

For each model, we estimated a fixed effect for event condition (Replayed vs. Baseline vs. Calendar; effect-coded) and a random intercept for each participant. All models were estimated using an unstructured covariance matrix. Wald chi-squared tests were conducted to determine significance of the fixed effect of event condition using the *car* package (Fox et al., 2021). Post-hoc comparisons were conducted using the *emmeans* package (Lenth et al., 2021), with the Kenward-Roger approximation for degrees of freedom and Tukey adjustment for p-values.

For qualitative responses in the semi-structured interview, we used an inductive thematic analysis to examine patterns of responses shared across participants (Braun & Clarke, 2006). Interviews were transcribed verbatim, reviewed amongst authors, and prepared within Taguette (Rampin & Rampin, 2021). A data-driven approach was adopted, with participant responses being classified using an open codebook to identify responses relating to their experiences using HippoCamera. Codes were then organized to generate overarching themes and subthemes.

Results

Recollection rating

There was no significant effect of event condition on overall recall rates (i.e., recalled vs. not recalled) when making their recollection ratings ($\chi^2(2) = 3.50$, $p = .174$) (Figure 2A). However, there was a significant effect of event condition on the degree of recollection ($\chi^2(2) = 14.55$, $p < .001$) (Figure 2B). Specifically, relative to Calendar events, participants reported a higher degree of recollection for Replayed ($b = -1.05$, $SE = 0.286$, $t(591) = -3.69$, $p < .001$) and Baseline ($b = -0.71$, $SE = 0.292$, $t(592) = -2.42$, $p = .042$) events. There was no significant difference in recollection between Replayed and Baseline events ($b = -0.35$, $SE = 0.180$, $t(581) = -1.93$, $p = .130$).

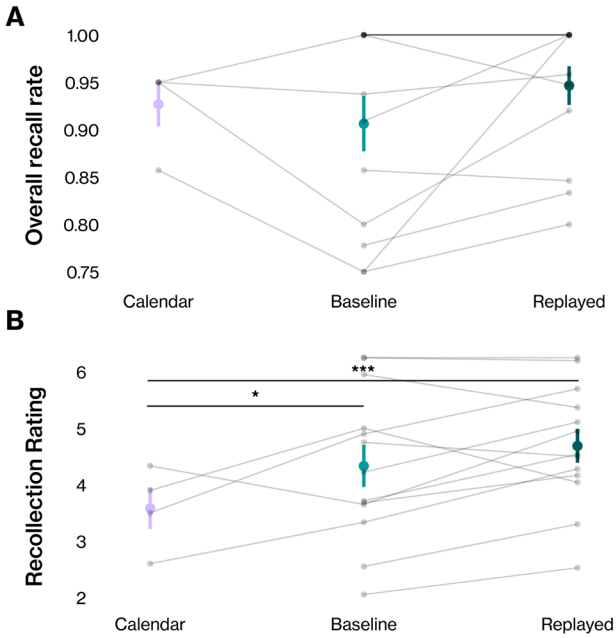

Figure 2. (A) Overall recall rates (i.e., recalled vs. not recalled) and (B) recollection ratings across event conditions (higher ratings indicate stronger recollection). Error bars indicate standard error. Dots represent individual participants. * $p < .05$, *** $p < .001$

Phenomenological characteristic ratings

There was a significant effect of event condition on phenomenological characteristic ratings for accessibility ($\chi^2(2) = 21.74$, $p < .001$), coherence ($\chi^2(2) = 17.77$, $p < .001$), vividness ($\chi^2(2) = 15.96$, $p < .001$), and psychological distance ($\chi^2(2) = 18.29$, $p < .001$) (Figure 3). There was no difference in levels of sharing across event conditions ($\chi^2(2) = 3.10$, $p = .213$).

Participants reported that Replayed events were more accessible ($b = -1.06$, $SE = 0.236$, $t(589) = -4.49$, $p < .001$), coherent ($b = -0.87$, $SE = 0.215$, $t(591) = -4.02$, $p < .001$), vivid ($b = -0.91$, $SE = 0.242$, $t(582) = -3.79$, $p < .001$), and psychologically close ($b = -0.66$, $SE = 0.160$, $t(589) = -4.11$, $p < .001$) than Calendar events. Baseline events were also reported as being more accessible ($b = -0.702$, $SE = 0.241$, $t(588) = -2.92$, $p = .010$), coherent ($b = -0.549$, $SE = 0.220$, $t(592) = -2.49$, $p = .0344$) and psychologically close ($b = -0.65$, $SE = 0.163$, $t(589) = -4.00$, $p < .001$) than Calendar events. Further, Replayed events were reported as being more

accessible than Baseline events (b = -0.357, SE = 0.149, $t(582)$ = -2.40, p = .0442).

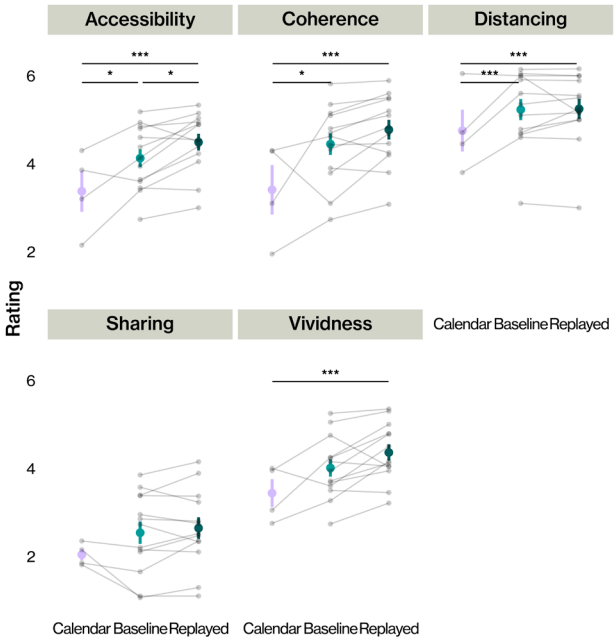

Figure 3. Phenomenological characteristic ratings across event conditions. Error bars indicate standard error. Dots represent individual participants. * $p < .05$, *** $p < .001$

Episodic probe task

There was no difference in target accuracy between Replayed and Baseline events on the episodic probe task (b = 0.210, SE = 0.131, z = 1.60, p = .11) (Figure 4).

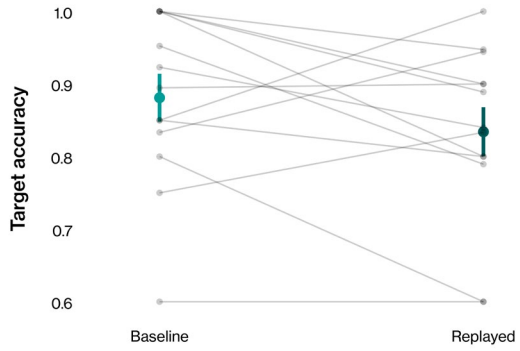

Figure 4. Target accuracy on the episodic probe task across Replayed and Baseline conditions. Error bars indicate standard error. Dots represent individual participants.

Semi-structured interview

Two themes, each with two corresponding subthemes, relating to HippoCamera use were generated from our thematic analysis of the semi-structured interview responses (Table 1). These are elaborated upon in further detail below, with illustrative quotes from participants in parentheses.

Table 1: Themes generated from semi-structured interview responses relating to HippoCamera use

Theme	Subtheme
Perceived benefits	Episodic memory
	Meaning and well-being
Attitudes and beliefs	Towards HippoCamera
	Towards their memory

Perceived benefits Overall, most participants found that previously using HippoCamera and reflecting on the cues during the follow-up task was an enjoyable experience that produced benefits both for episodic memory and for their broader sense of meaning and well-being. Participants noted the importance of documenting cues to facilitate memory for events and indicated that they were positively surprised by their memory for the events with many participants noting that seeing the HippoCamera cues helped trigger memory for the corresponding event ("*I was actually surprised that I could remember as much of it as I did. It was almost like a sense memory where you could remember being in that time and place for whatever reason, and this was due to the visual clues, obviously, and somewhat the audio of what was being said as well.*"; s120). In addition to cueing memory for individual events, participants reported reminiscing back more widely upon the time of HippoCamera usage from seeing their cues throughout the study ("*It was nice to go back and sort of feel cumulatively sort of the emotions and warmth of that time.*"; s504). Moreover, participants commented that the daily usage of HippoCamera had made them reflect more upon their day-to-day life as they were seeking interesting events to record and review ("*It does cause you to pause and reflect on what you're doing with your life when you have two months of your life that you're routinely living.*"; s502). Participants expressed a feeling of gratitude for their lives, particularly in relation to the social relationships in their lives ("*Many of these serve as a reminder of what in the fullness of time has come to be all that matters to me, and it is the people that I share my life with.*"; s501).

Attitudes and beliefs In light of the perceived benefits, some participants also mentioned that they would likely not use HippoCamera in their daily lives, commenting on the effortful nature of the study. This may reflect their overarching attitudes and beliefs, both towards HippoCamera and towards their own memory, more generally. Participants mentioned seeing value in HippoCamera for those with memory impairments, but not for themselves ("*I mean, certainly I can see where it would have an application if you were struggling to remember things.*"; s502). Participants expressed a preference for using the existing tools to assist their memory, such as cameras or journals, in addition to a general reticence towards relying on technology ("*...I have a journal. I don't have the video. I have a journal of pertinent things.*"; s505). Furthermore, when reflecting upon their cues, many participants commented upon the routine nature of the events in their lives ("*I found myself making judgments*

about how pedestrian, how boring, I thought the videos were."; s501). However, they did note that this may be due to the compressed nature of the study, particularly for those who had used HippoCamera over the course of two weeks in Martin et al. (2022) – Experiment 1 ("*I'm thinking maybe over three months or something like that, you could choose better and they would be more interesting.*"; s208). Other participants also mentioned feelings of sadness toward some cues, particularly for those with individuals who have since passed. Although some participants mentioned noticing changes in their memory with age, they expressed acceptance with not having to remember everything ("*I think my memory for details of things has probably declined a bit too, but in a way, it's almost like you reach a certain age and you almost want to let it go and feel like you don't have the stress of trying to remember everything all the time.*"; s120).

Discussion

This study investigated the persistence of memory benefits for real-world events in older adults following use of a smartphone-based memory aid, HippoCamera, to record and review autobiographical memory cues. Here, we invited participants from Martin et al. (2022) and Meade et al. (2024) for a follow-up session to assess memory for personal, real-world events that have taken place 3.5 to 6 years prior. We found preliminary evidence of enhanced subjective re-experiencing of events that were recorded with HippoCamera previously relative to those from a calendar control task. In addition to improved memory for specific events, we found that participants described broader changes to their sense of meaning and well-being following use of HippoCamera and reflection on their cues.

The present findings suggest that the enhanced episodic memory following HippoCamera use persisted several years later in the subjective quality of re-experiencing for a given event, rather than the complete rescue of a memory that would otherwise be inaccessible. Specifically, we observed a stronger sense of recollection, and increased accessibility, coherence, vividness, and psychological closeness, as measured using ratings of the phenomenological characteristics of recall. However, there was no difference in either overall recall rates when making a recollection rating across event conditions or target accuracy on the episodic probe task across Replayed and Baseline events.

This pattern of results may be attributable to the nature of the HippoCamera memory cues themselves. Memory for both Replayed and Baseline events were tested using a personalized cue that incorporates both an audio description and a video, whereas Calendar events were tested with much more limited information, oftentimes comprising only a few words. Although previous experiments with HippoCamera were designed to assess the effects of repeated review on episodic memory, we hypothesize that the act of intentionally creating a self-generated, multimodal cue also improves memory. In addition, participants had the experience of verbally recalling these events previously when being initially tested, which may itself produce a mnemonic enhancement via retrieval practice (Roediger & Karpicke, 2006). These combined effects from cueing, encoding, and testing may explain the similar reported memory for Replayed and Baseline events. Interestingly, Replayed events were reported as more accessible than Baseline events, suggesting some persistence of the previously demonstrated effects of repeated review.

Participant responses on the semi-structured interview also pointed to benefits beyond memory for individual events, with participants describing perspectives on meaning and well-being after using HippoCamera. Participants noted feeling more attentive to the present moment when they were seeking events to record and review daily. Further, after seeing the cues that they had recorded from the initial period of HippoCamera use during the follow-up session, participants expressed feelings of reminiscence and gratitude, with specific mention of the importance of their social relationships. These responses underscore the importance of autobiographical memories, particularly the identity and social functions of autobiographical memory (Bluck et al., 2005), and suggest that both reviewing memory for specific events and reflecting upon how these events integrate together to can affect overall well-being and sense of self (Conway, 2005; McAdams, 2001).

Some participants also mentioned that they would likely not use HippoCamera in their daily lives outside of the context of a study, which may be a result of attitudes and beliefs both towards HippoCamera itself and towards their memory. Although participants reported seeing the potential utility of a tool like HippoCamera for those living with memory impairments, participants commented upon the effortful nature of daily use and a wariness towards technology more generally. Further, they noted how the events highlighted the routine nature of their lives and the desire to not have to remember all the events in their lives. These observations highlight the need to involve and integrate the perspectives and lived experiences of individuals when considering how a tool, such as a wearable camera or HippoCamera, is used outside of the context of a laboratory (Yardley et al., 2015).

A major limitation of the current study is the small sample size, which may restrict our ability to detect any differences between Replayed and Baseline events. Participant recruitment is currently ongoing, with results from a larger sample allowing us to better characterize the extent of long-term effects of HippoCamera use. Given the difference in accessibility across Replayed and Baseline events, future work could also investigate effects in involuntary memory by using experience sampling or a structured diary to capture spontaneous recall in daily life (Berntsen, 2010).

Here, we report preliminary evidence that the improved episodic memory following HippoCamera use can be observed several years later in the form of improved subjective re-experiencing and well-being. This demonstrates the potential for applying findings from memory science to create evidence-informed, non-invasive, and accessible tools to mitigate age-related memory decline for real-world events.

Acknowledgments

The authors thank the anonymous reviewers for their helpful feedback. This research was supported by Project Grants from the Canadian Institutes for Health Research to MDB (PJT-173336 and PJT-126003), a Scholar Award from the James S. McDonnell Foundation to MDB, a Connaught Innovation Award to MB, and a Centre for Aging & Brain Health Innovation (CABHI) Researcher Clinician Partnership Program Grant to MDB to MB. MB was supported by a Canada Research Chair and a Max and Gianna Glassman Chair in Neuropsychology. BH was supported by a Postdoctoral Award in Technology and Aging from AGE-WELL and the Accelerate Program (IT38172) from Mitacs.

The authors declare a conflict of interest. BH and MB own shares in Dynamic Memory Solutions Inc., a company focused on developing digital tools to improve memory. The University of Toronto holds the ownership rights to the HippoCamera technology used to conduct the research described herein, but has given Dynamic Memory Solutions the rights to commercialize. The authors also have a patent to disclose, Patent No.: 11,397,774. No person, nor organization received any financial remuneration for the use of the HippoCamera application in the studies described here. At the time of publication, this is a research-dedicated application that we will make available to other memory scientists at no charge.

References

Allé, M. C., Manning, L., Potheegadoo, J., Coutelle, R., Danion, J.-M., & Berna, F. (2017). Wearable cameras are useful tools to investigate and remediate autobiographical memory impairment: A systematic PRISMA review. *Neuropsychology Review*, *27*(1), 1. https://doi.org/10.1007/s11065-016-9337-x

Bates, D., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1.

Berntsen, D. (2010). The unbidden past: Involuntary autobiographical memories as a basic mode of remembering. *Current Directions in Psychological Science*, *19*(3), 138–142. https://doi.org/10.1177/0963721410370301

Berry, E., Kapur, N., Williams, L., Hodges, S., Watson, P., Smyth, G., Srinivasan, J., Smith, R., Wilson, B., & Wood, K. (2007). The use of a wearable camera, SenseCam, as a pictorial diary to improve autobiographical memory in a patient with limbic encephalitis: A preliminary report. *Neuropsychological Rehabilitation*, *17*(4–5), 582–601. https://doi.org/10.1080/09602010601029780

Bluck, S., Alea, N., Habermas, T., & Rubin, D. C. (2005). A TALE of three functions: The self–reported uses of autobiographical memory. *Social Cognition*, *23*(1), 91–117. https://doi.org/10.1521/soco.23.1.91.59198

Bråthen, A. C. S., Sørensen, Ø., de Lange, A.-M. G., Mowinckel, A. M., Fjell, A. M., & Walhovd, K. B. (2022). Cognitive and hippocampal changes weeks and years after memory training. *Scientific Reports*, *12*(1), 1. https://doi.org/10.1038/s41598-022-11636-4

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Browne, G., Berry, E., Kapur, N., Hodges, S. E., Smyth, G., Watson, P., & Wood, K. (2011). SenseCam improves memory for recent events and quality of life in a patient with memory retrieval difficulties. *Memory*, *19*(7), 7. https://doi.org/10.1080/09658211.2011.614622

Carr, M. F., Jadhav, S. P., & Frank, L. M. (2011). Hippocampal replay in the awake state: A potential substrate for memory consolidation and retrieval. *Nature Neuroscience*, *14*(2), 2. https://doi.org/10.1038/nn.2732

Chow, T. E., & Rissman, J. (2017). Neurocognitive mechanisms of real-world autobiographical memory retrieval: Insights from studies using wearable camera technology. *Annals of the New York Academy of Sciences*, *1396*, 202–221. https://doi.org/10.1111/nyas.13353

Conway, M. A. (2005). Memory and the self. *Journal of Memory and Language*, *53*(4), 4. https://doi.org/10.1016/j.jml.2005.08.005

Craik, F. I. M., & Lockhart, R. S. (1972). Levels of processing: A framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, *11*(6), 671–684. https://doi.org/10.1016/S0022-5371(72)80001-X

Crete-Nishihata, M., Baecker, R. M., Massimi, M., Campigotto, R., Kaufman, L. D., Brickman, A. M., Steinerman, J. R., & Black, S. E. (2012). Reconstructing the past: Personal memory technologies are not just personal and not just for memory. *Human-Computer Interaction*, *27*, 92–123.

Dingler, T., Agroudy, P. E., Rzayev, R., Lischke, L., Machulla, T., & Schmidt, A. (2021). Memory augmentation through lifelogging: Opportunities and challenges. In T. Dingler & E. Niforatos (Eds.), *Technology-Augmented Perception and Cognition* (pp. 47–69). Springer International Publishing. https://doi.org/10.1007/978-3-030-30457-7_3

Ebbinghaus, H. (1913). *Memory: A contribution to experimental psychology*. Teachers College, Columbia University.

Fox, J., Weisberg, S., Price, B., Adler, D., Bates, D., Baud-Bovy, G., Bolker, B., Ellison, S., Firth, D., Friendly, M., Gorjanc, G., Graves, S., Heiberger, R., Krivitsky, P., Laboissiere, R., Maechler, M., Monette, G., Murdoch, D., Nilsson, H., … R-Core Team. (2021). *car: Companion to Applied Regression* (3.0-11). https://cran.uni-muenster.de/web/packages/car/car.pdf

Gardiner, J. M. (2008). Remembering and knowing. In J. H. Byrne (Ed.), *Learning and Memory: A Comprehensive Reference* (pp. 285–305). Academic Press. https://doi.org/10.1016/B978-012370509-9.00167-4

Gilboa, A., & Moscovitch, M. (2021). No consolidation without representation: Correspondence between neural and psychological representations in recent and remote

memory. *Neuron*, *109*(14), 2239–2255. https://doi.org/10.1016/j.neuron.2021.04.025

Gorbach, T., Pudas, S., Lundquist, A., Orädd, G., Josefsson, M., Salami, A., de Luna, X., & Nyberg, L. (2017). Longitudinal association between hippocampus atrophy and episodic-memory decline. *Neurobiology of Aging*, *51*, 167–176. https://doi.org/10.1016/j.neurobiolaging.2016.12.002

Grady, C. (2012). The cognitive neuroscience of ageing. *Nature Reviews Neuroscience*, *13*(7), 7. https://doi.org/10.1038/nrn3256

Grilli, M. D., & Sheldon, S. (2022). Autobiographical event memory and aging: Older adults get the gist. *Trends in Cognitive Sciences*, S1364661322002248. https://doi.org/10.1016/j.tics.2022.09.007

Gross, A. L., & Rebok, G. W. (2011). Memory training and strategy use in older adults: Results from the ACTIVE study. *Psychology and Aging*, *26*(3), 503–517. https://doi.org/10.1037/a0022687

Hyman, I. E., Gilstrap, L. L., Decker, K., & Wilkinson, C. (1998). *Manipulating remember and know judgements of autobiographical memories: An investigation of false memory creation*.

Kahana, M. J., Howard, M. W., & Polyn, S. M. (2008). Associative retrieval processes in episodic memory. In J. H. Byrne (Ed.), *Learning and Memory: A Comprehensive Reference* (pp. 467–490). Academic Press. https://doi.org/10.1016/B978-012370509-9.00185-6

King, D. B., Cappeliez, P., Canham, S. L., & O'Rourke, N. (2019). Functions of reminiscence in later life: Predicting change in the physical and mental health of older adults over time. *Aging & Mental Health*, *23*(2), 2. https://doi.org/10.1080/13607863.2017.1396581

Lenth, R. V., Buerkner, P., Herve, M., Love, J., Riebl, H., & Singmann, H. (2021). *emmeans: Estimated Marginal Means, aka Least-Squares Means* (Version 1.6.1) [R Package]. https://cran.r-project.org/web/packages/emmeans/emmeans.pdf

Levine, B., Svoboda, E., Hay, J. F., Winocur, G., & Moscovitch, M. (2002). Aging and autobiographical memory: Dissociation episodic from semantic retrieval. *Psychology and Aging*, *17*(4), 4.

Mair, A., Poirier, M., & Conway, M. A. (2018). Memory for staged events: Supporting older and younger adults' memory with SenseCam. *Quarterly Journal of Experimental Psychology*, 1–12. https://doi.org/10.1177/1747021818765038

Mäntylä, T., & Nilsson, L.-G. (1988). Cue distinctiveness and forgetting: Effectiveness of self-generated retrieval cues in delayed recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *14*(3), 502–509. https://doi.org/10.1037/0278-7393.14.3.502

Martin, C. B., Hong, B., Newsome, R. N., Savel, K., Meade, M. E., Xia, A., Honey, C. J., & Barense, M. D. (2022). A smartphone intervention that enhances real-world memory and promotes differentiation of hippocampal activity in older adults. *Proceedings of the National Academy of Sciences*, *119*(51), e2214285119. https://doi.org/10.1073/pnas.2214285119

McAdams, D. P. (2001). The psychology of life stories. *Review of General Psychology*, *5*(2), 100–122. https://doi.org/10.1037/1089-2680.5.2.100

Meade, M., Chang, M., Savel, K., Hong, B., Martin, C. B., & Barense, M. (2024). *Unique events improve episodic richness, enhance mood, and alter the perception of time during isolation* [Preprint]. PsyArXiv. https://osf.io/ep92q

Neely, A. S., & Bäckman, L. (1993). Long-term maintenance of gains from memory training in older adults: Two 3 1/2-year follow-up studies. *Journal of Gerontology*, *48*(5), P233-237. https://doi.org/10.1093/geronj/48.5.p233

Rampin, R., & Rampin, V. (2021). Taguette: Open-source qualitative data analysis. *Journal of Open Source Software*, *6*(68).

Roediger, H. L., & Karpicke, J. D. (2006). Test-Enhanced Learning: Taking Memory Tests Improves Long-Term Retention. *Psychological Science*, *17*(3), 249–255. https://doi.org/10.1111/j.1467-9280.2006.01693.x

Scoville, W. B., & Milner, B. (1957). Loss of recent memory after bilateral hippocampal lesions. *Journal of Neurology, Neurosurgery, and Psychiatry*, *20*, 11–21.

Sellen, A., Fogg, A., Aitken, M., Hodges, S., Rother, C., & Wood, K. (2007). *Do life-logging technologies support memory for the past? An experimental study using SenseCam*. 10.

Silva, A. R., Pinho, M. S., Macedo, L. M., & Moulin, C. J. (2018). A critical review of the effects of wearable cameras on memory. *Neuropsychological Rehabilitation*, *28*(1), 1. https://doi.org/10.1080/09602011.2015.1128450

Silva, A. R., Pinho, S., Macedo, L. M., & Moulin, C. J. (2013). Benefits of SenseCam review on neuropsychological test performance. *American Journal of Preventive Medicine*, *44*(3), 302–307. https://doi.org/10.1016/j.amepre.2012.11.005

Simpson, S., Eskandaripour, M., & Levine, B. (2023). Effects of healthy and neuropathological aging on autobiographical memory: A meta-analysis of studies using the Autobiographical Interview. *The Journals of Gerontology: Series B*, *78*(10), 1617–1624. https://doi.org/10.1093/geronb/gbad077

Snijders, T. A. B., & Bosker, R. J. (2011). *Multilevel Analysis: An Introduction to Basic and Advanced Multilevel Modeling*. Sage Publications. https://www.torrossa.com/en/resources/an/4912508

Spreng, R. N., & Turner, G. R. (2019). The shifting architecture of cognition and brain function in older adulthood. *Perspectives on Psychological Science*, *14*(4), 523–542.

Squire, L. R., Stark, C. E. L., & Clark, R. E. (2004). The medial temporal lobe. *Annual Review of Neuroscience*, *27*, 279–306.

Sutin, A. R., & Robins, R. W. (2007). Phenomenology of autobiographical memories: The Memory Experiences

Questionnaire. *Memory*, *15*(4), 390–411. https://doi.org/10.1080/09658210701256654

Tanguay, A. F., Palombo, D. J., Love, B., Glikstein, R., Davidson, P. S., & Renoult, L. (2023). The shared and unique neural correlates of personal semantic, general semantic, and episodic memory. *ELife*, *12*, e83645. https://doi.org/10.7554/eLife.83645

Thompson, V. A., & Paivio, A. (1994). Memory for pictures and sounds: Independence of auditory and visual codes. *Canadian Journal of Experimental Psychology*, *48*(3), 380–398.

Tulving, E. (1985). Memory and consciousness. *Canadian Psychology*, *26*(1), 1–12. https://doi.org/10.1037/h0080017

Tulving, E. (2002). Episodic memory: From mind to brain. *Annual Review of Psychology*, *53*(1), 1. https://doi.org/10.1146/annurev.psych.53.100901.135114

Woodberry, E., Browne, G., Hodges, S., Watson, P., Kapur, N., & Woodberry, K. (2015). The use of a wearable camera improves autobiographical memory in patients with Alzheimer's disease. *Memory*, *23*(3), 340–349. https://doi.org/10.1080/09658211.2014.886703

Yardley, L., Morrison, L., Bradbury, K., & Muller, I. (2015). The Person-Based Approach to intervention development: Application to digital health-related behavior change interventions. *Journal of Medical Internet Research*, *17*(1), e4055. https://doi.org/10.2196/jmir.4055