Towards Responsible Memory Augmentation: Surveying the Intended Uses of Everyday Augmented Reality and Artificial Intelligence for Memory Processes

Graham Wilson
School of Computing Science
University of Glasgow
Glasgow, Scotland, United Kingdom
graham.wilson@glasgow.ac.uk

Thomas Goodge
University of Glasgow
Glasgow, United Kingdom
thomas.goodge@glasgow.ac.uk

Joseph O'Hagan
University of Glasgow
Glasgow, United Kingdom
Joseph.OHagan@glasgow.ac.uk

Mark McGill
University of Glasgow
Glasgow, United Kingdom
Mark.McGill@glasgow.ac.uk

Abstract

With the advent of everyday Augmented Reality (AR) glasses the public will be able to receive personalised and context-relevant spatial information displays driven by complex Artificial Intelligence (AI) processes. Research on other everyday technologies shows that use can lead to beneficial or detrimental effects on human memory, depending on the use case or individual. Therefore, it is imperative to understand how everyday *AR+AI* might be used for memory purposes ahead of time, to ensure the creation of *responsible memory augmentations*: maximising benefits whilst minimising harms. Through a survey (N=120) we captured how likely respondents would be to use *AR+AI* devices for a list of 25 memory purposes derived from the literature and commercial materials. Our results predict frequent, pervasive and varied use of *AR+AI* across memory types, and that individual differences predict specific constellations or patterns of use. We provide recommendations for research areas that academia, industry and policymakers should prioritise.

CCS Concepts

• **Human-centered computing → Mixed / augmented reality**;
• **Computing methodologies → Artificial intelligence**.

Keywords

Memory Augmentation, Augmented Reality, Artificial Intelligence

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1 Introduction

The world's leading technology companies are working towards making everyday Augmented Reality (AR) glasses - standalone and lightweight headsets for general personal computing - a *de facto* consumer platform [2, 29, 58, 72]. These headsets are equipped with cameras, microphones, and sophisticated visual and aural displays, able to alter or mediate the user's perception of reality (posing privacy risks [61]). The same companies are also explicitly putting Artificial Intelligence (AI) at the centre of their AR platforms [12, 29, 57, 87]. And so we face a likely near future where these devices - referred to here as "*AR+AI*" - become a common personal device through which users interact with and perceive the world. Individuals will experience tailored and context-specific audiovisual content embedded within the world around them. They will also be able to request - or receive autonomously - a vast array of information, guidance, and media through Generative AI (GenAI), including Large Language Models (LLMs) and Multimodal/Vision-Language Models (VLMs). This ecosystem can combine ongoing inference and understanding about the user with autonomously generated visual (and audio) feedback, opening up numerous possibilities for offloading perceptual and cognitive processes to technology. This paper begins to explore the potential of *AR+AI* for human augmentation through the specific lens of *memory*.

Research has shown how different individual technologies can be used to offload memory-related processes, including semantic (factual pieces of information) [16, 17, 82, 86], episodic (memories with a temporal and spatial component) [6, 15], procedural (learning and performing skills) [49, 99] and prospective memory (planning and enacting future actions) [41, 43]. These and other studies have evidenced how such cognitive offloading can have beneficial effects on memory, such as freeing up resources to learn other information, support those with memory impairments, or "lifelogging" to improve our understanding of our lives [15, 16, 18, 42, 43, 51, 85]. However, research also demonstrates detrimental influences of technology, such as poorer retention and understanding of information, poorer knowledge transfer and reduced brain connectivity [17, 22, 53, 69, 82, 96]. While some effects can impact the general population, others may be more effective or problematic for those with particular cognitive characteristics [4, 42, 98]. With *AR+AI* we are on the verge of new, extensive and pervasive digital memory augmentations that could amplify these benefits or exacerbate the risks across multiple forms of memory. Therefore, it is critical to understand how *AR+AI* might be used by the general public ahead of time, and so provide practitioners and policymakers with the knowledge to bring about *responsible memory augmentation*: maximising the benefits while protecting users from harm.

To start understanding how everyday *AR+AI* could be used for memory - both for potential benefits and risks - we conducted a survey to capture for what types of memory-related processes ("*memory augmentations*"), and to what extent, respondents see themselves using the technology. We compiled a list of 25 memory processes/augmentations - covering semantic, episodic, autobiographical, spatial, procedural and prospective memory - based on related literature, commercial materials, and a formative survey (N=25) that asked respondents to propose three examples. We then conducted a survey (N=120) that asked respondents to indicate to what extent/frequency they believe they would use *AR+AI* for each of the 25 memory functions, alongside other questions such as their sentiment towards *AR+AI*, their potential usage of the technology vs. smartphones and their individual characteristics including cognitive style/ability.

Our results show that respondents would regularly use *AR+AI* for all of our proposed memory augmentations, with almost half indicating they would use all functions "Frequently", "Every Day" or "Multiple Times a Day", while almost three-quarters would use them all at least "Sometimes". Respondents had a positive sentiment towards *AR+AI*, saw themselves using it in the future and using it for memory purposes more or much more than they use their smartphone for them. Therefore, there will likely be pervasive and regular use of *AR+AI* for memory in the years to come. Our analysis also showed particular individual differences and archetypes of use around specific types of augment, such as those supporting social memory/interaction. Cognitive ability use was also negatively correlated with frequency of use. Based on the results we discuss a range of potential benefits and harms that may arise from the use of *AR+AI* for memory and so what the priority research avenues should be for the community, as well as platform holders and application designers. We hope that this paves the way towards conceptualizing *responsible memory augmentation*: where novel technologies benefit and even expand human memory without harming fundamental cognitive functions.

2 Related Work

2.1 The Effects of Technology Use on Memory

As the Augmented Humans website notes, the concept of technology-enhanced augmented cognition started with Engelbart in 1962 [20], and the concept of wearable memory technologies has been around since the 1990s (*e.g.*, [47, 68]). A number of memory augmentation systems have been proposed or prototyped [9, 31, 32, 37, 44, 68, 93, 97], but many are not fully evaluated, especially in terms of measuring beneficial or harmful effects of the technology on memory. Steeds & Clinch [83] proposed a design space for memory augmentations, which comprised the axes *Processing Level* (Biological, Cognitive and Meta-Cognitive) and *Display Modality* (Non-display, Head-Mounted Display, Personal Displays and Semi-/public Displays), mapping previous contributions into the space. The vast majority of current memory augmentations fall into the Cognitive *Processing Level* (across all *Display Modalities*), leaving particular gaps in Biological and Meta-cognitive levels. Overall, reviews on the impact of technology on memory have concluded that relying on devices for memory/cognition can maintain (or even increase) task performance (*e.g.*, finding information) but then negatively affect later recall ability and transferral of knowledge/skills, and reduce brain connectivity [13, 22].

2.1.1 Negative Effects. In terms of how pervasive technologies might affect memory, the internet and smartphones have received the most attention in academia. In particular, the focus has been around the enactment of "*cognitive offloading*", a natural process where humans move a cognitive burden - *e.g.*, remembering a piece of information, performing a task - to an external source such as writing down a phone number or using a calculator. Research has shown that using the internet to find information or answer difficult questions (compared to *e.g.*, more manual methods) can allow participants to achieve good task performance (correctly answer questions in-the-moment), but it leads to poorer long-term retention and lower confidence in one's own knowledge [17, 30, 82]. Liu *et al.* [53] even linked internet searching to reduced brain connectivity and activity in areas associated with long-term memory and retrieval. It has been suggested that people offload their memory to the internet/computer and do not invest effort into their own memorisation, undermining future recall [82]. Using the internet to find information/answer questions also increases the likelihood of doing so again in the future, even if the information needed is less challenging [17, 82, 86, 95]. It has even been proposed that the internet has replaced our semantic (*i.e.* factual) memory [22].

With the proliferation of camera-equipped smartphones, several studies have explored whether taking photos of events affects the individual's memory compared to focusing on it at the time, and the results are mixed. Some studies found that taking photos led to poorer memory of what was seen [35, 81, 88], while others show no such inhibitory effects [3, 35]. Risko *et al.* [69] found that offloading memories to digital storage makes users more susceptible to later manipulation of those memories, believing changes/falsities to be their own experience. Finally, relying on Global-Positioning Systems (GPS) for guidance can allow participants to get to where they need to go quickly and accurately, but they suffer poorer spatial understanding and knowledge of the route/environments they went through, leaving them less able to navigate or orient themselves unaided [13, 21, 25, 26, 40, 50, 62]. This also leads to a reduction in brain matter in areas relating to spatial memory [21, 55].

2.1.2 Positive Effects. In contrast to the above, some research has suggested that relying on technology for knowledge provides cognitive benefits such as freeing up resources for additional or more ambitious undertakings [5, 33, 34, 54]. Heersmink [33] sought to counter the narrative of negative effects of the internet on memory/cognition, pointing out that many studies are not ecologically valid, such as using artificial/unrepresentative tasks (*e.g.*, remembering trivia) or lacking long-term data. In contrast to the "Google Effect" [82] Storm & Stone [85] found that when participants knew that one set of information would be saved they were able to remember more of a second set of information. Contrasting with their earlier study [17] Dong and colleagues found that sourcing information through the internet over 6 days led to good recall and faster reaction times [18] and increases in brain matter connectivity/integrity [16].

"*Lifelogging*" - the act of capturing one's daily activities through photos or videos - can lead to better memory and understanding of what the individual has done [19, 31, 36, 48, 77, 80]. Technology can have a particularly strong benefit for those with memory impairments, either from age or injury. Jamieson has reviewed and demonstrated how reminder systems on smartphones - referred to as cognitive prosthetics [42] - can help those with acquired brain injury carry out everyday tasks that require prospective memory (tasks that require retaining and performing future actions) [43] while Chang *et al.* demonstrated enhanced autobiographical memory [10]. Lifelogging can improve recall in both healthy users as well as those with memory impairment [1, 36], while camera-based systems that detect and record an older user's interactions with objects might improve their memory of how to use them or what state the objects are in [51].

2.1.3 Cognitive Style and Ability. Barr *et al.* [4] explored how individual cognitive differences may mediate the impact of technology on memory, or the likelihood of a user relying on cognitive offloading. Based on dual-process theories, they argue that those who innately have a more autonomously cued, intuitive cognitive style (Type 1 processes) are more likely to rely on technology than those of more deliberative analytical style (Type 2 processes). Those who exhibit high smartphone and internet search usage had significantly lower cognitive style measures (*i.e.* more intuitive/Type 1 processes) as well as cognitive *ability* measures [4]. And so the potential effects of technology use on memory will vary depending on how the individual is typically willing or able to approach memory/cognitive problems. Memory formation - called consolidation - is largely dependent on deeper thought, repetition and the value of what is learned [78]. Barr *et al.* argue that smartphones "*characterize a modern form of cognitive miserliness*", where users often adopt fast and easy intuition in their approach to cognition, allowing their phones "*to do their thinking for them*", particularly for intuitive thinkers or those of lower cognitive ability. Evidence shows that there are growing levels of cognitive, memory and learning difficulties among the public, especially young people [65, 76, 92, 98]. As *AR+AI* devices are likely to offer always-available memory assistance, there is a risk that all users - but particularly those with greater cognitive challenges - may experience compounding effects of poorer memory consolidation.

2.2 Augmented Reality and Memory

There has been an increased interest in how novel immersive devices could affect or probe how users remember events. In an early example, Fajnerova [21] found that those who used a head-worn AR device (Google Glass) for navigation instructions over 3 months ended up with significantly lower brain connectivity in areas related to spatial navigation than those that used no device. Viewing objects in-situ in smartphone AR (vs. on traditional flat screens) while exploring a room might lead to more involuntary memories of those objects, suggesting AR content may be more memorable [66]. However, the effect arose mostly when participants were directed to remember, and there may be novelty effects.

Researchers have also looked at how the immersive nature of virtual and augmented reality experiences may in fact alter a users memory of what they see or experience, particularly in terms of dark patterns or malicious manipulations [90]. Bonnail *et al.* [7] found that users can confuse whether information came from reality or a VR experience, as well as between different sources within reality (veridical truth, imagination, pictures), which could have ramifications for information presented through everyday AR devices. In an earlier study, Bonnail *et al.* [8] explored how extended reality (XR) devices could be used to manipulate memory: how XR users or platform holders could deliberately alter what the user sees, primarily to reflect a reality that does (or did) not exist. Interface designers and memory experts collaborated to suggest a range of both beneficial and harmful XR memory manipulations enacted by both the user on themselves as well as platform holders or malicious actors on end users. While many were VR-oriented, a number were related to AR, such as blocking out aspects of reality to guide attention or avoid unwanted reminders. The information displays in AR have the potential to subconsciously manipulate the perceptions, thoughts and behaviours of users [46, 60, 70].

2.3 Risks and Challenges of AI In-the-Loop

As platform holders are placing AI at the core of everyday AR devices, users will be able to receive or produce information with relatively little effort. Generative AI (GenAI) models greatly shortcut the process of collating, analysing and producing complex texts, imagery and music, which users can access by interacting with Large-Language Models (LLMs). Less time will be spent understanding, consolidating and re-purposing information, either to the benefit of re-allocating resources elsewhere, or to the detriment of less knowledge or understanding [78]. It has also been shown that users can adopt false memories of what has been seen/experienced when incorrect or misleading content is produced using GenAI [63, 64], and AI has been shown to produce manipulative content unprompted [45]. Concerns have been expressed over the potential negative effects of AI on cognitive and design skills [79] as well as the higher-level coordination of cognitive processes [89]. High confidence in AI or lower domain knowledge lead to lower critical thinking and more reliance on the tools [49], which has led researchers to call for users to be actively prompted by the system to reflect on and consider their usage [49, 99]. When having AI guide them through manual tasks such as using a new coffee machine or building circuitry, prompts led to significantly better memory of the process than just passively following instructions [99].

Agentic AI can automate or support everyday tasks. Meta's "Persistent Assistant" AI [12] autonomously infers about the user's goals and analyses the environment to provide AR-rendered guidance on objects of interest. It reduces the users active engagement with tasks, cognition and the world around them. In "Memoro" [100], participants preferred an autonomous "query-less" AI assistant - that provides auditory information about the user's current context - over one that required active queries. Given the increasing capability and automation of AI agents more than 50 authors from various Universities and major industry partners (including Google) came

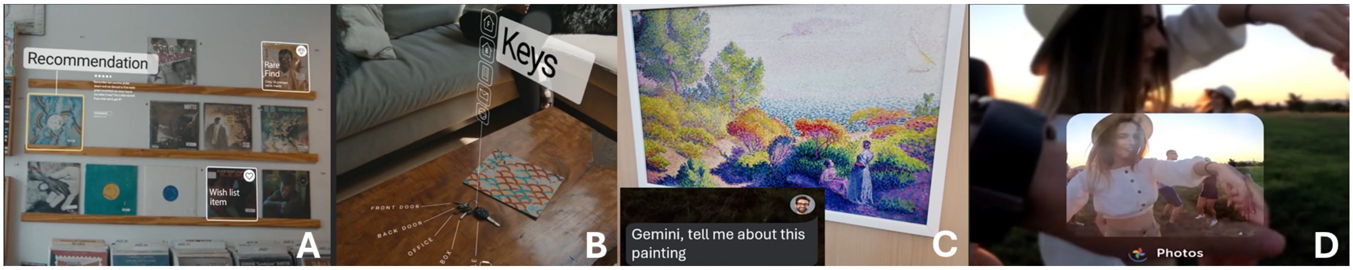

Figure 1: A selection of screenshots of example AR applications shown to survey respondents to convey how AR glasses might be used. Highlighting objects of interest in the environment (A) or showing where lost objects are (B; both from Meta [58]). Asking AI for information about something seen in the environment (C) and taking photos (D; both from Google [29]).

together to publish a position paper on "The Ethics of Advanced AI Assistants" [24]. The >200-page paper covers a range of topics however, there is no mention of potential positive or negative effects (or ethical concerns) regarding human memory, cognition or everyday living. There is only a short paragraph acknowledging the potential for reliance on AI agents. We take this is a sign that both HCI and industry are not properly considering how AI (especially in combination with AR) might affect everyday users.

2.4 Summary and Research Questions

It is clear from the literature that *AR+AI* devices could have considerable beneficial or harmful effects on human memory. Academic and regulatory fields can often be left behind in understanding the ramifications of new, rapidly adopted technologies, and so it is crucial to understand how *AR+AI* might be used for memory ahead of time, to guide communities towards *responsible memory augmentation*. We had four Research Questions (RQs): **RQ1** - How likely are members of the public to use *AR+AI* for memory augmentation? **RQ2** - What anticipated benefits and harms might arise from this usage? **RQ3** - Are there relationships between cognitive style/ability and likely use of *AR+AI* for memory? **RQ4** - How might the extent of *AR+AI* usage for memory differ from smartphone usage?

3 Methods and Survey Design

We conducted a survey using Prolific [67] to capture how frequently respondents believe they would use *AR+AI* for a set list of memory-related processes, across semantic, episodic, autobiographical, spatial, procedural and prospective memory. These uses were derived from the related literature that has shown beneficial or detrimental effects of technology use on memory or memory-related brain connectivity, or from the promotional or aspirational materials released by commercial companies (as these indicate likely functions that companies will provide). To help us put responses into context of individual characteristics, we also captured a range of demographic data, attitudes towards technology, and cognitive style and ability. The research was approved by our college ethics committee.

3.1 List of Memory Augmentations

Our review of the literature on how technology may benefit or harm memory, as well as publicly available commercial materials from device manufacturers, led us to compile a non-exhaustive list of 24 potential *AR+AI* memory augmentations. These are listed in Table 1 alongside the academic and/or industrial sources that motivated their inclusion. However, to ensure the list was as complete and representative of likely usage as possible, we conducted a formative survey asking respondents to provide their own suggestions for how *AR+AI* could be used for memory-related processes.

3.1.1 Formative Survey. The survey asked respondents to provide three suggestions for how they think *AR+AI* devices could be used for memory, and we added any suggestions that did not fall under the existing topics to the list. We recruited participants in batches until we reached a subjective point of saturation, where all (or the vast majority) of suggestions fell under one of the list items. We summarise the survey contents here, while the full survey can be found in the Supplemental Materials. The survey began with an information and consent sheet that explained the study's purpose, and what data would be gathered. We then provided text and images to explain and illustrate the functionality and potential use cases for everyday AR glasses powered by AI (examples in Fig. 1). We captured respondents' ***Age*** and asked two questions on their overall ***Familiarity*** with AR devices and AI technologies, using a five-point Likert scale (Never, Once or Twice, A Few Times, Many Times, Regularly). To capture the **Suggested Uses** of *AR+AI* for augmentations, we duplicated the same text/question three times, in each case providing an open text box with a requirement to write at least two lines of text (to improve data quality). The questions asked respondents to "*Please give 3 unique examples of how you would be likely to use AR+AI for memory-related purposes in your everyday life*".

Participants (N=25) were recruited on Prolific [67] and ranged in age from 22 to 58 years old (mean = 35.08, SD = 10.11); nine identified as Female, 16 as Male. Three used AR devices "Regularly", six used them "Many Times", seven "A Few Times" and "Once or Twice" and two reported having "Never" used them. 13 respondents used AI technologies "Regularly" while the remaining 12 had used them "Many Times". Based on the suggestions only one additional memory-related usage emerged to be added to the list of augmentations (see item *5-Language* in Table 1): one participant suggested using *AR+AI* to help with learning and understanding *foreign languages*, including real-time translation. As only 1/75 responses constituted a new suggestion we made a judgement that we had effectively reached saturation and so we did not recruit further participant batches.

ID	Memory-Related Purpose	Source	Type
1-AIinfo	Query the internet/AI for specific bits of information (e.g. the distance between two locations)	[19, 56, 84] [18, 20]	Sem
2-AIsuminfo	Use AI to summarise multiple sources of information together (e.g. multiple news stories, documents or perspectives)	[26, 48] [49, 52]	Sem
3-AIwrite	Use AI to write documents, emails, messages etc	[49, 52]	Sem
4-AIexplain	Query AI to identify or explain objects, events or locations that I can see	[31, 59, 61]	Sem
5-Language	For foreign languages (e.g. translate speech or signs)	[31], Survey	Prc/Sem
6-AIprod	Use AI and AR for productivity tasks (e.g. writing, programming, art)	[26, 49, 52]	Prc/Sem
7-Manual	Use AI and AR support during manual or physical tasks (e.g. operating a device, repairs, cooking etc)	[101]	Prc
8-Media	Use AI to summarise media that I have consumed (e.g. TV show, movie, book, game)	[48, 49] [84, 88]	Epi/Sem
9-LocateObj	Use AI and AR to tell me where things are in my environment (e.g. misplaced belongings)	[59, 61]	Epi
10-Unwant	Use AR to cover up/block out visible objects, places or people to help forget unwanted memories	[10]	Epi
11-RecImage	Use headset cameras to capture specific images and videos of things I want to remember	[15, 31]	Epi/Aut
12-EventRev	Watch headset recordings in AR to review events that occurred during the day	[3, 17]	Epi/Aut
13-EventQue	Query AI about what I have seen or experienced recently/in the past	[41, 79] [72, 82]	Epi/Aut
14-EventDisc	Converse with an AI assistant to discuss events that have occurred recently/in the past	[41, 79] [72, 82]	Epi/Aut
15-MetWho	To tell or remind me who people I meet are	[4, 8]	Epi/Aut
16-MetInfo	To tell or remind me things about a person I meet	[4, 8, 102]	Epi/Aut
17-MetConv	To tell or remind me what conversations I’ve had with someone I meet	[8, 102]	Epi/Aut
18-MetSugg	To give me recommended conversation topics or things to say	[8, 63]	Epi/Aut
19-AlterImg	Use AI and AR to alter or enhance images or videos recorded through the headset	[10]	Epi/Aut
20-AlterVis	Use AI and AR to alter or enhance what is visible in-the-moment during an activity or event	[10]	Epi/Aut
21-Moments	Watch headset recordings to review emotional life moments	[3, 8, 21] [10, 72]	Aut
22-Navigate	Use AR for navigation, including visual feedback placed in the environment	[31, 61] [15, 23]	Spa/Epi
23-Remind	Use an AI assistant to proactively give me reminders during the day	[45, 46]	Psp
24-HighlObj	Use AR to highlight interesting, useful or desirable objects in the world (e.g. based on profile or needs)	[45, 61]	Psp
25-CoverDis	Use AR to cover up/block out visible distractions and highlight important things to remember (e.g. for signs, or meetings/presentations)	[10]	All

Figure 2: Table showing the 25 memory-related purposes used in the main survey, which respondents were to indicate how frequently they believe they would use them. “Source” indicates which academic reference or commercial materials motivated the potential effects on memory. “Memory Type” refers to the classification of memory under which the item generally falls: Sem = Semantic, Prc = Procedural,Epi = Episodic, Aut = Autobiographical, Spa = Spatial, Psp = Prospective.

3.1.2 Final List. The full list of 25 augmentations included in the survey is shown in Table 1. It shows the academic/commercial source that motivated each item, as well as the general type of memory that it falls under (*e.g.*, semantic, episodic, prospective etc). We did not seek to have an equal number of items under each type of memory but rather let the available academic/industrial materials inform what should be included. Based on the uses that arose from our literature/commercial review, we can informally group the augments as follows, to aid understanding: Five items (*1-AIinfo*, *2-AIsuminfo*, *3-AIwrite*, *4-AIexplain*, *6-AIprod*) relate to using AI to provide or produce information or productivity-related materials. Four relate to guiding attention in the environment (*9-LocateObj*, *10-Unwant*, *24-HighlObj*, *25-CoverDis*). Four use AR and AI to view, relive or reconsider past experiences (*12-EventRev*, *13-EventQue*, *14-EventDisc*, *21-Moments*) while five cover social interactions (*5-Language*, *15-MetWho*, *16-MetInfo*, *17-MetConv*, *18-MetSugg*). Four relate to creating or consuming personal media e.g., photos/videos

(*8-Media*, *11-RecImage*, *19-AlterImg*, *20-AlterVis*) and three provide task-related support (*7-Manual*, *22-Navigate*, *23-Remind*).

3.2 Questions Asked and Survey Flow

The full survey can be seen in the Supplemental Materials[1]. It started with an information and consent sheet where we explained the purpose of the research and what kinds of questions would be asked. We then asked the following:

Familiarity 6 questions, all on 5-point Likert scales that captured how familiar respondents were, and how often they had used, smartphone AR, headset AR, and Artificial Intelligence technologies.

Textual examples of each technology were provided for reference.

Attitudes to AI The General Attitudes to Artificial Intelligence Scale (GAAIS) [74] captures the extent to which they trust or agree that AI has positive or negative characteristics.

Cognitive Style and Ability Based on Barr *et al.* [4] we captured *cognitive style* (type 1 vs type 2) using the four Base-Rate Problems from De Neys & Glumicic [14] and the Cognitive Reflection Test from Frederick [23]. For *cognitive ability* we used the Wordsum task (synonyms of words) [38] and Numeracy Scale [75]. Each item was either correct or incorrect and we took the overall percentage as that individual's indicator of style (from 0/entirely intuitive to 1/entirely deliberative) or ability (from 0 to 1).

Validation A reCAPTCHA check against AI submissions.

Explaining Everyday *AR+AI* We then provided text and images to explain and illustrate the functionality and potential use cases for everyday AR glasses powered by AI (see Supplementary Materials). AR devices were shown that represent the current vision of device manufacturers such as Meta's Orion [58] and Aria [56] glasses and Google's XR glasses [29]. Alongside the glasses were images representing example applications running on such devices (some shown in Figure 1), including those from Meta and Google, pointing to how they see the devices functioning in future. The specific sensing capabilities of likely everyday AR devices were then explained, and how AI may leverage or make use of this data. We based this sensing on both past research into the types and uses of headset sensors [61] as well as technical specifications from headset manufacturers themselves [29, 56, 58].

Sentiment Towards *AR+AI* On 5-point Likert scales we captured: 1) how positively/negatively respondents feel about the adoption of *AR+AI* devices, and 2) how likely they are to use *AR+AI* as their main device.

List of Memory Uses We then presented the list of 25 memory uses. Because *AR+AI* devices are not yet a mainstream commercial reality, we provided instructions to contextualise participant responses. They were asked to follow three assumptions: 1) It is a near-future where the majority of the population (*i.e.* those who have smartphones in the present day) use AR headsets as their main personal device. 2) You also have an AR headset as your main device, or as a main way to interact with your smartphone. 3) Consider what these devices could be used for, ignoring any concerns about the companies or platforms that provide them. We then asked: "*Based on the descriptions of AR+AI devices on the previous pages,* ***how likely do you think you would be to use everyday AR+AI devices for the following memory-related purposes****?*". Respondents indicated how frequently they would use *AR+AI* for each memory augmentation on a 7-Point scale: *Would Never Use, Would Hardly Ever Use, Would Use Infrequently, Would Use Sometimes, Would Use Frequently, Would Use Every Day, Would Use Multiple Times a Day.* We also included an attention check asking "Please choose 'Would Use Multiple Times a Day' ". The order of items was randomised.

***AR+AI* vs. Smartphones; Agency over Memory** We asked: 1) whether they think they would use *AR+AI* for memory functions more or less than smartphones, 2) to what extent they think *AR+AI* would affect their agency over their memory, and 3) to what extent they or others would become reliant on *AR+AI* for memory.

3.3 Participants

We recruited 120 English-fluent respondents on Prolific: 58 identified as male, 57 as female and 5 as non-binary, and there were 20 respondents in each of 6 age brackets: 18-24, 25-34, 35-44, 45-54, 55-64, 65-80. ~31% were from the United Kingdom, ~21% from South Africa and ~18% from the United States. The remaining were from across Europe (17.5%), Africa (~4%), Canada (~4%), Asia (~3%) and Mexico (0.8%). While our sample is largely Western and European, this is common among recent HCI papers using Prolific [11, 84, 91], partly due to language requirements (fluent English) and the infeasibility of reaching an equal worldwide sample. In terms of GAAIS attitudes to AI, the average score for positive items was 3.68/5 (SD = 0.7), and 3.14/5 (SD = 0.88) for negative items, indicating an overall slightly positive sentiment. Familiarity and usage of AR and AI technologies are shown in Figure 3. Median completion time was ~25min with compensation equivalent to ~$11/€9.50/£8.35 per hour.

4 Results

4.1 Intended Usage of Memory Augmentations

We summarise the frequency ratings for each memory augmentation in Figure 4. Our respondents foresaw extensive and wide-ranging use of *AR+AI* for performing memory-related processes. All the proposed augmentations would be used by some people and to the extent of multiple times per day. An average of 46.7% of respondents would use all functions "Frequently", "Every Day" or "Multiple Times a Day" (18% to 73% depending on the augmentation), while more than a quarter (27.8%) would use them at least "Every Day" and almost three quarters (72%) at least "Sometimes". The augmentations with the highest likely level of usage were: *Query AI for information* (*1-AIinfo*), *AR for Navigation* (*22-Navigate*), *Query AI to explain objects, events, places* (*4-AIexplain*), *Foreign Languages* (*5-Language*) and *Proactive Reminders* (*23-Remind*).

One augmentation was by far the *least* likely to be used: *Using AR to block unwanted memories* (*10-Unwant*). 25% of respondents would "Never" use it, 22.5% "Would Hardly Ever Use" and 15.8% "Use Infrequently". Other augmentations more often rated "Would Use Infrequently" or less include: *Suggesting conversation topics* (*18-MetSugg*), *Use AR to cover distractions and highlight information* (*25-CoverDis*), *Converse with AI about past events* (*14-EventDisc*), *Watch recordings to review emotional moments* (*21-Moments*) and *Alter recorded images or videos* (*19-AlterImg*). However, on average,

[1]Note that there are more questions in the survey than we were able to report in the paper due to space restrictions. We focus on the most relevant.

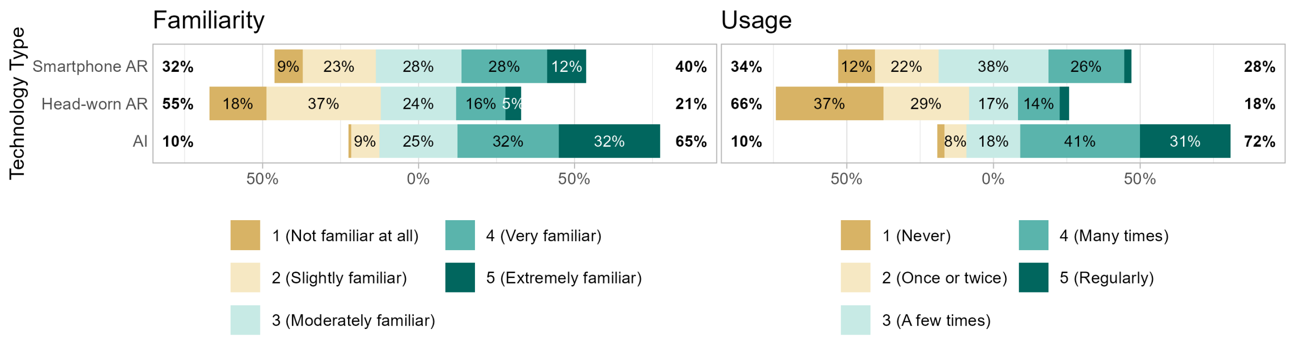

Figure 3: Self-reported levels of familiarity and usage of AR (smartphone and headset) and AI technologies.

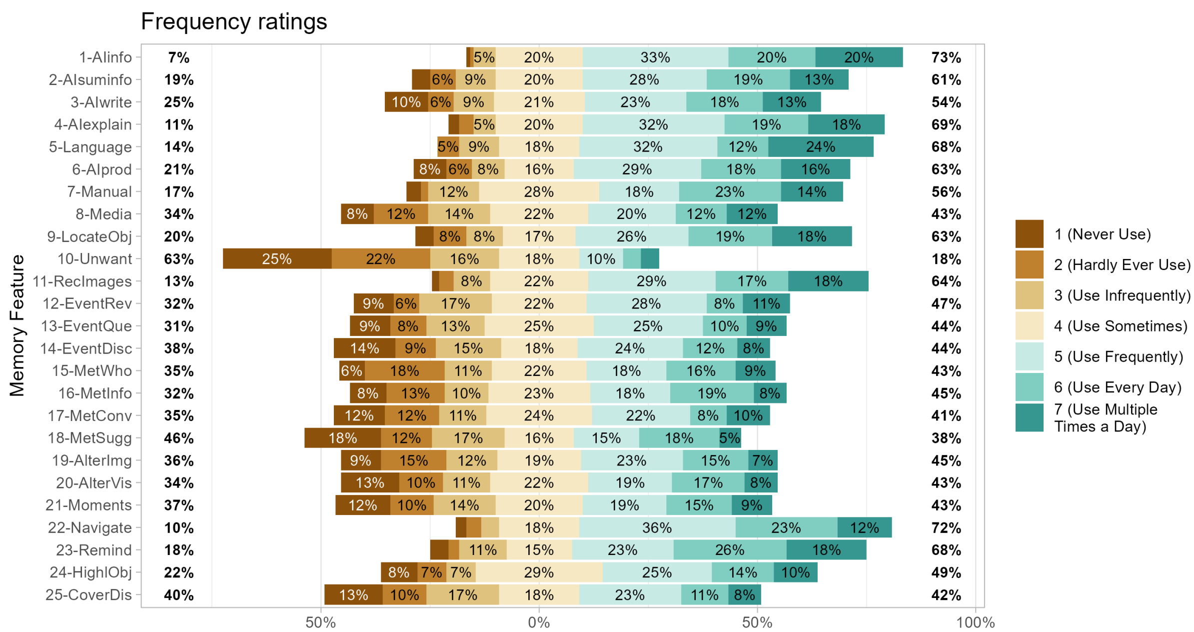

Figure 4: Overall frequency ratings for how often respondents think they would use *AR+AI* for each memory purpose. Ratings are centered around "Would Use Sometimes" and percentages in bold on far left/right indicate the proportion of infrequent (left, less than "Sometimes") or frequent (right, more than "Sometimes") use.

these augmentations would still be used at least "Frequently" by ~42% of respondents.

4.2 Clustering Augmentations by Frequency

We conducted hierarchical clustering using Ward's method on the frequency data for all 25 memory augmentations, to explore whether there are groups or clusters of processes particularly likely or unlikely to be used. The resulting dendrogram (provided in the Supplementary Materials) indicated the data best fit into two clusters - one representing highly-used augments and one representing less used augments. However, based on both the dendrogram (3 clusters being the next best fit) and the clear outlier of *10-Unwant* (Using AR to block out unwanted memories), a 3-cluster solution was adopted. Cluster 1 contains 11 augmentations (Items 1-7, 9, 11, 22, 23 in Figure 4), Cluster 2 contains 13 (8, 12-21, 24, 25) and Cluster 3 contains only *10-Unwant*. Based on the frequency data (in Supplementary Materials) we labelled Cluster 1 "*Mass Adoption*", Cluster 2 "*Targeted Adoption*" and Cluster 3 "*Niche Adoption*".

4.2.1 Cluster 1: Mass Adoption. "*Mass Adoption*" augmentations had the highest likelihood of usage, with 84.2% of respondents using them at least "Sometimes", 64.6% using them "Frequently" or above and the highest proportion of 16.7% using them "Multiple Times a Day". The 11 augmentations in this cluster are predominantly practical or productive functions and use cases that exist today in smartphones or computers - *e.g.*, using AI to gather/summarise/generate content, navigation, reminders - as well as two that are not yet possible/mainstream: *Using AR to highlight useful objects in the world*, and *Using AI and AR support during manual or physical tasks*.

These augmentations largely relate to semantic (factual) memory (Augments 1-6 in Figure 4), with two related to episodic (or autobiographical) memory (9, 11), two to procedural memory (5, 6), one to spatial memory (22) and one to prospective memory (23).

4.2.2 Cluster 2: Targeted Adoption.

The second cluster includes augmentations that had a wider spread of usage frequency, forming more of a bell-curve with a fairly even likelihood of frequent or infrequent usage (though it is slightly skewed towards “Frequent” use, see Supplementary Material). We called this cluster “Targeted Adoption” as it shows which augments will be of particular utility to subsets of the population: some will use them >=“Frequently” (43%), others will use them <= “Infrequently” (35%). The augmentations in this cluster are mostly episodic or autobiographical in nature, and relate to social interaction, emotionality (reviewing and discussing past events and emotional moments) and altering reality (covering distractions, altering images or what is visible).

4.2.3 Cluster 3: Niche Adoption.

This cluster only has one augmentation (*10-Unwant*, using AR to block unwanted memories) as it stands out as being the only one where a majority would use it “Infrequently” or less. While this might suggest that this ’cluster’ indicates *e.g.*, “unwanted” augmentations, the results are more nuanced, as ~8% of respondents still want to use this at least every day, and 18% - almost 1/5th of people - would use it at least “Frequently”.

4.2.4 Clustering “Targeted Adoption” Participants by Augmentation.

To look for any patterns in what individual needs may be - *i.e.* whether respondents typically want to use specific constellations of augmentation within this cluster - we performed a secondary hierarchical clustering. Rather than clustering augmentations by frequency, we are clustering respondents by augmentation. To do this, we assigned a score of 1 for each augmentation in this cluster that participants rated “Would Use Frequently” or above, and 0 for anything else. We then clustered those participants who had a score of 1 for at least one augmentation (*i.e.* those who fall into the “Targeted Adoption” cluster). We did this as the formation of memories requires repetition and deliberate thought, and so frequent use could be a meaningful cut-off for both gaining benefits (support is used often enough to strengthen consolidation) or maladaptive use (effortful thought is supplanted/avoided enough). The resulting dendrogram indicated that 4 clusters (referred to here as *sub-clusters* to avoid confusion with the higher level clustering) gave the best explanatory fit.

Sub-cluster 1 (labelled “*All Targeted Uses*”) represented those users (N=28) who would use all or nearly all augmentations in the “Targeted Adoption” cluster frequently. Conversely, sub-cluster 4 (“*Few Targeted Uses*”) represented those who had similarly lower levels of usage across augmentations (N=24). Sub-cluster 2 (N=24) indicated a particular interest in two augmentations: *Tell/remind me who people I meet are* (*15-MetWho*) and *Tell/remind me things about a person I meet* (*16-MetInfo*). They also had likely usage of *Remind me what conversations I’ve had with someone I meet* (*17-MetConv*), *Query AI about what I have seen/experienced* (*13-EventQue*) and *Use AI and AR to alter or enhance recorded images or videos* (*19-AlterImg*). We label this cluster “*Social and Episodic Information*”, as the augmentations particularly correspond to supporting or augmenting social interaction and gathering information about previous events. Finally, sub-cluster 3 (N=19) we label as “*Autobiographical Appraisal*”, as respondents in this cluster were most likely to want to *Watch headset recordings to review events that occurred during the day* (*12-EventRev*), *Converse with AI to discuss events that have occurred* (*14-EventDisc*), *Watch headset recordings to review emotional life moments* (*21-Moments*) as well as *Use AR to highlight interesting, useful or desirable objects in the world* (*24-HighlObj*).

4.3 Influence of Individual Characteristics

4.3.1 Cognitive Style and Ability.

Cognitive style scores in our data set ranged from 0 (entirely intuitive/type 1) to 1 (entirely deliberative/type 2) with an SD of 0.33, and ability scores ranged from 0.2 to 0.93 (SD = 0.18). To examine whether cognitive ability/style had any bearing on our respondents likely use of memory augmentations we summed the frequency counts for “Frequent” or above (indicating a high level of usage) for each participant and performed a Pearson correlation with the cognitive ability/style measures. There was no significant correlation between cognitive style and frequent usage $r(118) = -.08$, p = .40, suggesting no relationship between the two. However, there was a significant negative correlation between cognitive ability and frequent usage $r(118) = -.22$, p = .01: as cognitive ability reduces, the likelihood of regularly using memory augmentations increases.

4.3.2 Age.

To explore the influence of participant Age on their likely usage of *AR+AI* we summed the number of ratings at or above “Would Use Frequently” within each age band for each augmentation and performed a hierarchical clustering analysis using Ward’s method. This would identify if particular age bands were more likely to want to use particular augmentations. However, the resulting dendrogram showed the same 3 clusters as those that arose during the overall usage analysis, suggesting there is no influence of age on what purposes *AR+AI* would be used for.

4.4 Sentiment Towards *AR+AI*

The largest number (40%) were “Somewhat Positive” towards the adoption of *AR+AI*, followed by 27.5% who were “Very Positive”, 14% “Somewhat Negative”, 8% “Neither Positive nor Negative” and only 2% were “Very Negative”. Therefore, many more viewed the technologies positively (76%) than negatively (16%). We also asked respondents how likely they would be to use *AR+AI* themselves as their main personal device. Again, 40% were “Somewhat Likely”, with similar numbers (13-15%) indicating each of the other options.

4.5 Smartphones vs. *AR+AI*, Agency, Reliance

In terms of whether they think they would use *AR+AI* for memory uses more or less than they currently use their smartphone, Figure 6 shows that the largest number would use *AR+AI* “Somewhat More” (37%), followed by “About the Same” (26%). 15% would use it “Somewhat Less” than their phone, 14% “Much More” and only 8% “Much Less”. So, more would use *AR+AI* to a greater extent (51%) than a lesser extent (23%), but many think they would use them about the same (26%).

A majority of respondents believe that they or others will be “Moderately Reliant” (58%) on *AR+AI* for memory purposes, with a further 24% foreseeing “Entirely Reliant” (Figure 6). 10% were on

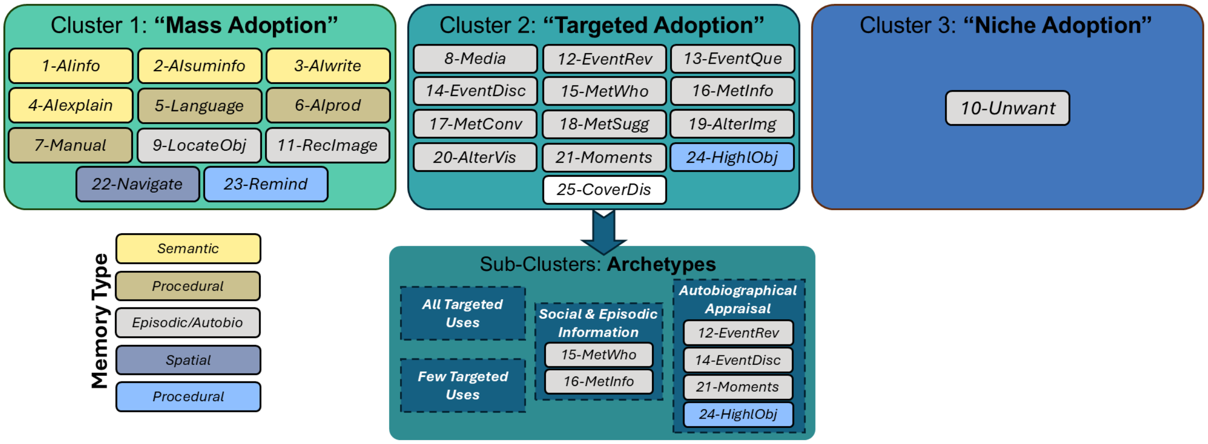

Figure 5: Visualizing the results of our hierarchical clustering analysis. The three clusters along the top group augmentations based on frequency of use. The sub-clusters of "Targeted Usage" group augmentations by those who would use them, indicating four archetypes of use. Augmentations are coloured relative to memory type as shown in Table 2.

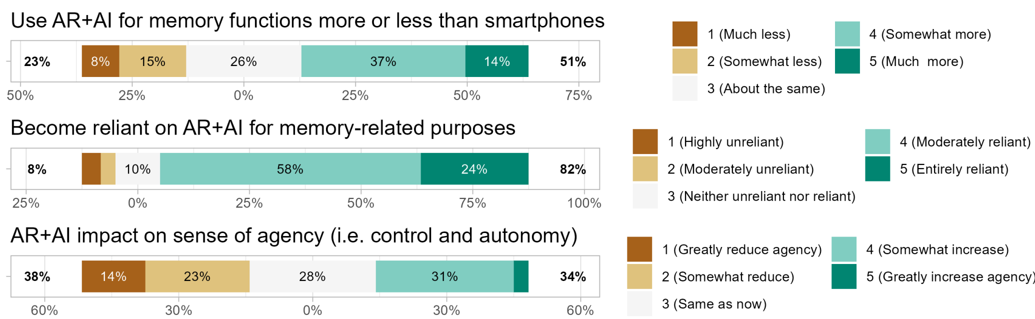

Figure 6: Average ratings regarding the use of *AR+AI* for memory functions vs. current smartphones, how reliant users may become, and the effect of the technology on agency over memory.

the fence while only 3-4% foresaw the public being "Moderately" or "Entirely Unreliant". In terms of their perceived agency over what they remember or what is done for them, the largest number (31%) believe AR+AI would "Somewhat Increase" their agency, but a similar number believed it would be the "Same as Now" (28%). 23% thought their agency would "Somewhat Reduce" while 14% thought it would "Greatly Reduce". Only 3% thought their agency would "Greatly Increase". Overall, similar numbers foresee Increasing (34%) and Decreasing (37.5%) agency, and many see no difference (28%).

5 Discussion

5.1 Use of *AR+AI* Memory Augmentations May be Pervasive (RQ1)

RQ1 asked "*How likely are members of the public to use AR+AI for memory augmentation?*". Our survey responses indicate that there is likely to be widespread, frequent and varied use of *AR+AI* for memory augmentations by the public, at least in the more western countries covered by our Prolific sample. On average, almost half of respondents would use all posited memory augmentations at least "Frequently" and more than a quarter would use them all at least "Every Day". Three quarters of respondents view the adoption of *AR+AI* positively, more than half of respondents foresee themselves using *AR+AI* for memory purposes more than they currently use their smartphone, and more than 4/5ths think they or others will become reliant on *AR+AI* for memory purposes.

Our list of augmentations cover multiple types of memory - semantic, episodic, autobiographical, procedural, spatial and prospective - meaning that the public are likely to be using their everyday, always-available AR headsets to regularly perform, enhance or replace a range of fundamental cognitive processes. Many of the augmentations that were most likely to be used frequently are those that are available now in smartphones: using AI to gather or summarise information [27], navigation [39], reminders, language translation [28] etc. This may be because respondents can more easily foresee how they would use these augmentations or the benefits they would provide, compared to those that are not yet feasible (or widespread). Future work employing ideation and participatory design may allow participants to more deeply engage with speculative functionality. However, most respondents still clearly saw value in all augmentations, based on the frequency ratings. While this usage remains hypothetical, and prospective users can overstate their level of interest, it is necessary to try and gauge usage ahead of real adoption in order to guide stakeholders towards beneficial deployments of memory augmentations.

5.2 The Continued Offloading of Semantic Memory (RQ1&2)

RQ2 asked "*What anticipated benefits and harms might arise from this likely usage?*" Some academics have proposed that the internet has largely replaced our semantic memory [22, 82, 96] and our results suggest that this will only continue - and potentially expand - through *AR+AI*: widespread use of always-available information acquisition and composition. The majority of respondents would use AI for getting or summarising information at least "Frequently"; more than two-thirds would use it frequently to identify and explain things that they can see; and more than half would use it to produce written or productivity materials. Two-thirds would use AR with AI to show them where objects are in the environment, such as misplaced objects, meaning they would not need to perceive or remember where things are.

Humans have engaged in semantic offloading throughout history. The introduction of the printing press drew concern from some in the 15th century - such as Johannes Trithemius and Hieronimo Squarciafico - for how it would negatively affect memory or learning. We have used an abacus or calculator for calculations, and stored phone numbers on paper or smartphones *etc.* Not having to remember more trivial information can allow us to focus on and remember things which are more important or valuable [5, 33, 34, 54, 78]. Offloading is not inherently problematic, but the more that is offloaded, and the more types of information, the greater scope there is for problems to arise, as it can impair our ability to learn in general and make it more likely that we will rely on technology in the future [17, 30, 82, 86, 95]. Concerns are also being raised over how the use of AI negatively impacts learning, understanding and skill transferral [49, 79, 89], and our results suggest that the public will frequently rely on AI for semantic memory.

5.3 Potential Impacts of Autobiographical and Episodic Augmentations (RQ1&2)

Compared to semantic memory, comparatively little research has been done on how technology affects episodic or autobiographical memory [13, 33]. Our results give insight into augmentations beyond Lifelogging [31, 36, 48, 77, 80] or photo-taking [3, 35, 81, 88], to show that respondents would be likely to use *AR+AI* for a range of other functions. On average just under half of respondents would frequently want to use their headset to appraise or discuss events that have taken place. This includes watching headset recordings (*i.e.* from their point-of-view) to review everyday events or emotional life moments, as well as engaging with AI to get help with understanding or processing those events. ~42% of people would at least frequently use real-time support during social interactions, including being told information about a person, being reminded of past conversations, and having conversation topics suggested.

Autobiographical memory (AM) - episodic memories with a particular importance or relevance to oneself - serves a number of crucial functions [6]: the *Directive* factor corresponds to the use of memories to direct future behaviours, the *Self* factor relates to using memories to work out who we are as a person , and the *Social-Developing* and *Social-Nurturing* factors inform how we use the past to establish or maintain/deepen social connections. Wide use of episodic/AM augmentations could extend and deepen the benefits seen in lifelogging, where an individual can later re-live or re-appraise past events to consolidate or reframe their knowledge of what happened, bolstering the *Directive* or *Self* functions. Talking to AI could potentially offer alternative ways of thinking about the events, providing different perspectives [94, 100].

If a user is discreetly told the name of a person they have forgotten, or given suggestions for what to talk about, it could alleviate social anxiety or facilitate easier interaction, supporting the two *Social-* functions. However, if the formation of these memories is undermined - externalising those experiences or understanding that would otherwise inform our AM - it could potentially affect our sense of self, our decision-making or our ability to form social relationships. Rewatching past events may lead us to lose the personal meaning derived from it in favour of focusing on finer semantic details that weren't perceived at the time [13]. Users are also at risk of manipulation when it comes to XR [7, 8, 90] and the output of generative AI [52, 63, 64, 69], leaving critical AM faculties at risk of being undermined or altered.

5.4 Individual Differences in Need (RQ2&3)

RQ3 asked "*Are there relationships between personal characteristics - such as cognitive style/ability and age - and likely use of AR+AI for memory?*"Our clustering analysis indicated that a subset of augmentations were only of particular interest to some respondents. 1/5th of respondents were more likely to use *AR+AI* for "Social and Episodic Information", to support social memory and later interactions. Another 1/6th of respondents were more likely than others to want to review and reappraise episodic/autobiographical events ("Autobiographical Appraisal"). This suggests that there are particular archetypes of user: those that want to use a whole suite of augmentations, and those that may mostly desire specific support. Then there was *10-Unwant*: *Use AR to cover up/block out visible objects, places or people to help forget unwanted memories.* While most respondents said they would be unlikely to use this augment, it still has particular relevance for some, as 18% would use it at least "Frequently". It came from the "AR Eraser" scenario in Bonnail *et al.* [8], who had memory and XR experts ideate on how AR (and VR) could be used to manipulate memory, for good or ill. This function may serve a more specialist or uncommon need related to avoiding emotionally harmful triggers, as dwelling on harmful memories can stall healing and even lead to prolonged mental health conditions [13, 73, 78]. Such a use case may not be frequent, but it could be valuable for those who need help to overcome a particular challenge. Conversely, there could be a risk of people using *AR+AI* to avoid/ignore emotional issues instead of dealing with them. These findings indicate that, while overall trends show high levels of likely usage across all memory/augmentation types, personal characteristics may influence which specific ones are used most. Although users may see benefit from these features, they are also at potential risk of maladaptive use depending on their individual characteristics or circumstances.

5.5 User Autonomy and Maladaptive Use (RQ4)

RQ4 asked "*How might the extent of AR+AI usage for memory differ from smartphone usage?*"As we noted in the related work, there is evidence of a significantly increasing prevalence of cognitive disability, particularly in young people, where nearly 1/10th of the young US population now has "serious difficulty concentrating, remembering, or making decisions because of a physical, mental, or emotional condition" [98]. While we did not find the previously observed relationship with cognitive *style* [4] there was a significant negative correlation between cognitive *ability* and the likelihood of using memory augmentations frequently, and respondents near unanimously (82%) foresaw themselves or others being moderately or entirely reliant on *AR+AI* for memory purposes. While *AR+AI* could offer support to those who have the most difficulty remembering important information or events - particularly those with clinical memory impairments [1, 10, 36, 42, 43, 51] - those who cognitively offload are also more likely to do so again in the future, leading to less effortful processes, consolidation and repurposing of information [17, 86, 95].

As we said at the start of this discussion, industrial trends combined with consumer purchasing and our results here show that considerable uptake of *AR+AI* devices and the functions that they offer is likely. It is clear that our respondents saw benefits in using the technologies for all manner of memory processes. But as we have discussed through this section, there are a number of situations where users could be at risk of either maladaptive use or manipulation. In describing the internet as a 'supernormal' stimulus, Ward [96] compared it to foods that are high in both fat and sugar, something that does not occur in nature. Humans find these foods appealing as they hijack a system not developed to cope with them. Similarly, if a user has immediate and always-on access to context-specific AR visualisations backed with complex AI processes, the scope for supplanting and hijacking memory is vast, and potentially at a population-wide scale. And there will be many who are more vulnerable to maladaptive use or reliance on this technology because of their personal circumstances or characteristics. Therefore, research is needed to identify groups who have specific needs and vulnerabilities in their memory or cognitive profile, to ensure applications and services are designed to meet their needs.

5.6 Recommendations & Research Priorities for Responsible Memory Augmentation

Based on our results we recommend that academics, companies and policy makers make it a priority to better understand the following issues, to best ensure the development of *responsible memory augmentations*: maximising the benefits of *AR+AI* devices while protecting users from harm or maladaptive use.

Establish the Key Benefits and Risks. This paper gives insight into how members of the public may be likely to use everyday AR devices powered by complex AI for a wide range of memory-related processes. We have speculated on how users may benefit or engage in harmful/maladaptive use, based on previous literature. However, concrete evidence is needed to establish where the main benefits and harms lie, allowing us to target priority needs or vulnerabilities. What groups of people are most affected, by what uses, and leading to what outcomes? This could be achieved through lab studies, participatory design or consultation with domain experts in memory and neuroscience.

Long-Term Effects of Use. A recurring criticism of research on how technologies may impact memory is that the vast majority of studies are one-off (*i.e.* one lab study [82]) or short-term (*e.g.*, 6 days [18]) [13, 33]. The proper consolidation of memory requires time and repetition [78], and so if technology has supportive or disruptive effects on consolidation then it may occur over long time periods. Therefore, alongside controlled lab studies, longitudinal research is also needed to better understand how or whether repeated/chronic offloading meaningfully affects memory.

AR+AI and Cognitive Ability. We found a significant negative correlation between cognitive ability and likely use of *AR+AI* for memory, and research is evidencing a growth in cognitive difficulties in the general public, particularly in young people [4, 65, 76, 92, 98]. Given the potentially pervasive use of *AR+AI* for memory, can augmentations help arrest or reverse the growth of cognitive/memory difficulties, or could they instead exacerbate them?

Social Interactions. We found that a large number of users would adopt memory augmentations that provide them information about people they have previously met, as well as recall or suggest conversation topics. A subgroup of participants were particularly keen on this functionality. But given the importance of memory to the formation of social connections [6] could offloading knowledge about a person and how we have interacted with them affect the establishment of relationships, our connection with others, or trust?

Automation and Memory. Memory consolidation benefits from active engagement in thinking about, repeating, critiquing information etc [13, 78]. Current AI smartglasses require the user to actively provide the system with commands and prompts [29, 59, 71]. Research has begun to suggest that passively following automated guidance/information from AI leads to poorer understanding of procedural tasks or the content of generated text [49, 99], but giving users prompts to reflect on their use improves knowledge and understanding [94, 99]. It is likely that *AR+AI* devices will perform a number of functions autonomously on behalf of the user [12, 57, 100], and users prefer this 'query-less' interaction [100]. Therefore, it is necessary to understand the effects of automation vs. active engagement in AI functionality on memory, as well as the acceptance or need for usage prompts in the general public.

Perspectives Across Cultures. Our results are based on the responses from 120 age and gender-balanced people from 21 countries. However, most were from western and developed nations. Different cultures have different practices when it comes to remembering, such as the importance of oral history and information transmission, or different attitudes towards the adoption and role of technology. Research needs to examine attitudes towards, and potential usage of, *AR+AI* in a range of diverse cultures to get a full picture of how the technologies may be used across the world.

6 Conclusions

Based on both industrial trends and consumer purchasing behaviour (*e.g.*, Meta Ray-Ban) it is likely that there will be widespread public adoption of everyday augmented reality headsets powered by complex AI processes ("*AR+AI*"). Previous research has shown how the use of other everyday technologies can potentially benefit or harm the formation and persistence of human memory. Therefore, it is important to understand how this new wave of always-available *AR+AI* devices - that mediate our perception and understanding of reality - may help or hinder memory, before they reach widespread use. Via a survey (N=120) our research is the first to elucidate how the public is likely to use *AR+AI* devices for memory processes, pointing towards what the potential benefits to memory may be, as well as where the risks of maladaptive use may lie and so what the priorities should be for academia, industry and policymakers to ensure the adoption of *responsible memory augmentations.*

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