Accepted for publication in “Neuropsychological Rehabilitation”
Note: This is an uncorrected version of an author’s manuscript accepted for publication. Copyediting, typesetting, and review of the resulting proofs will be undertaken on this manuscript before final publication. During production and prepress, errors may be discovered that could affect the content.

A critical review of the effects of wearable cameras on memory

Silva, A.R.
Faculdade de Psicologia e de Ciências da Educação
Universidade de Coimbra

Pinho, M.S.
Faculdade de Psicologia e de Ciências da Educação
Universidade de Coimbra

Macedo, L.
Departamento de Engenharia Informática
Faculdade de Ciências e Tecnologia
Universidade de Coimbra

Moulin, C.J.A.
Laboratoire de Psychologie & NeuroCognition (CNRS UMR 5105)
Université Grenoble Alpes

Corresponding author: Chris Moulin
chris.moulin@me.com
@chrsmln

Chris Moulin PhD
Laboratoire de Psychologie & NeuroCognition (CNRS UMR 5105)
Université Pierre Mendès France
Bâtiment Sciences de l’Homme et Mathématiques
1251 avenue Centrale
Domaine Universitaire de St Martin d’Hères
38040 Grenoble
FRANCE

Abstract

The rise of "lifelogging" in this era of rapid technological innovation has led to great interest in whether such technologies could be used to rehabilitate memory. Despite the growing number of studies using lifelogging, such as with wearable cameras, there is a lack of a theoretical framework to support its effective use. The present review focuses on the use of wearable cameras. We propose that wearable cameras can be particularly effective for memory rehabilitation if they can evoke more than a mere familiarity with previous stimuli, and reinstate previous thoughts, feelings and sensory information: recollection. Considering that, in memory impairment, self-initiated processes to reinstate previous encoding conditions are compromised, we invoke the environmental support hypothesis as a theoretical motivation. Twenty-five research studies were included in this review. We conclude that, despite the general acceptance of the value of wearable cameras as a memory rehabilitation technique, only a small number of studies have focused on recollection. We highlight a set of methodological issues that should be considered for future research, including sample size, control condition used, and critical measures of memory and other domains. We conclude by suggesting that research should focus on the theory-driven measure of efficacy described in this review, so that lifelogging technologies can contribute to memory rehabilitation in a meaningful and effective manner.

KEYWORDS: SenseCam, Lifelogging, Memory Aid, Environmental Support, Camera, Recollection

1. Overview

An issue of major importance for memory rehabilitation and cognitive neuroscientific theory is whether some new memory aid could retrieve memories that were otherwise inaccessible, or 'lost'. This issue has always been contentious in human memory research (e.g. Loftus & Loftus, 1980). To what extent it is possible to retrieve forgotten events is now of critical importance to the field, since a new technological challenge has arisen for memory researchers: can lifelogging technology act to aid the retrieval of autobiographical memories? (e.g. Doherty, Moulin, & Smeaton, 2011).

Lifelogging is defined as the almost constant capture of data and images from our own life for future reference. In particular the neuropsychological community has become interested in wearable cameras, such as SenseCam. In this review, we focus on human memory, and recollection more specifically, to illustrate our view that memory may be rehabilitated by providing the right cues from life-logging style technologies. There are, of course, other research and clinical applications of life-logging devices. For instance, Gemming et al. (2013) showed that the use of a wearable camera facilitated the recall of dietary behaviours, thereby reducing the under-report of calorie intake. Here we focus on the examination of what is lost from memory, and whether digital materials could ever come close to providing the perfect memory aid. There is a fundamental point here: if we watch a stream of images from our past life, are we capable of remembering it all; will it *all* cue the retrieval of the past?

To illustrate the challenges facing technological interventions for memory loss we review the use of wearable cameras in the context of a specific memory function, namely the cognitive neuroscience of recollection. In particular, the notion of environmental support is a critical issue when considering the loss of information and its possible inaccessibility. Our main argument is that though technological devices show promise in experimental settings, the nature of human memory means that we cannot assess their value in daily life without a change in the paradigm which we use to measure their benefit.

The aim of this review is to ultimately consider lifelogging's value in rehabilitation. Rehabilitation is not just about improving memory or recall. For instance, Alzheimer's patients may benefit from a deeper level of processing, or extra study time, in memory tasks, but that alone is not normally classified as rehabilitation. In rehabilitation, the concepts of transfer and generalization of gains of training to daily activities is critical. The concept of *quality of life* described by the World Heath Organisation (2015) as an “individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns" as an ultimate goal of neuropsychological rehabilitation is also critical to understand the extent of this type of rehabilitation.

The most critical conceptual issue in the neuropsychological rehabilitation of memory is the comparison of internal and external aids. Studies conducted with the purpose of providing effective techniques to improve performance for memory impaired patients have focused primarily on internal aids, which tend to focus on strategic control of memory (e.g., category cues, self generation activities, errorless learning, vanishing cues, mnemonic strategies). For instance, Lalanne et al. (2015) have used a cognitive training programme to significantly improve autobiographical memory retrieval and mood in Alzheimer’s disease. Such interventions are strong in terms of its theoretical background, but have showed relatively limited efficacy to stimulate people's memory in general and on a long term basis (Backman, 1992; Lustig, Shah, Seidler, & Reuter-Lorenz, 2009; Rebok, Carlson, & Langbaum, 2007). External memory aids are described as devices or mechanisms that are external to the person and that facilitate memory accessibility (Intons-Peterson & Newsome, 1992). They include personal diaries, alarms, agendas, pagers and calendars. External aids have proved efficacious for patients with traumatic brain injury (Ehlhardt et al., 2008; Wilson, 1997), but they also face several limitations: they require that the subjects are aware of their memory problems in order to be able to interact with the aids, knowing what information to record, how and when to access that information (Grandmaison & Simard, 2003). For its use to be effective, each aid requires training so the user can benefit from the device, which can be an obstacle (Lee & Dey, 2008).

Altogether, both internal and external strategies have several problems, mainly concerning the fact that they require the subject’s awareness and input, which is often compromised in memory impairment. That is, to benefit from keeping a daily journal, for instance, one must remember to both write the journal in the first place, and to consult it at the appropriate time. If we return to the definition at the beginning of this section, there is also the issue of transfer and quality of life. Lifelogging technologies perhaps offer a more passive form of rehabilitation tool – since intelligent systems can compensate for problems in awareness, and constant ongoing monitoring can overcome the need for carers to select and filter information on-line during the use of an external aid. We return to this issue later.

2. Memory loss and recollection

Our understanding of memory impairment has been greatly enhanced by our knowledge of the human memory system; and in particular the fractionation of long-term memory into different types based on both biological and psychological considerations. Possibly the most important distinction is between episodic and semantic memory (e.g. Tulving, 2002). The most commonly experienced form of memory loss is from episodic memory (Baddeley, 2001). This form of memory is particularly difficult to rehabilitate since it is by definition, personal and based on the *recollection* of our own past episodes and experiences, retrieved with a sense of 'mental time travel' (Tulving, 2004).

There are two issues here, both of which are critical to our argument. First, unlike language information and general knowledge (semantic memory), there is no shared basis for the vast part of episodic memory – it can be easy to re-learn facts which exist in the public domain, such as *David Cameron is the prime minister of the UK* – but it is far less easy to train someone on their personal past since it will be idiosyncratic to that one person, and perhaps not even recorded. Second, episodic memories are retrieved with a particular experiential characteristic: that of 'remembering'. Whereas we might learn again significant dates and recognize acquaintances with some rehabilitation technique or other, with episodic memory, we might never re-experience them in the same rich evocative way which is central to episodic memory and specifically, recollection. Finally, the role of recollection is captured in the difference between actively *recalling* and passively *recognizing* something. Recall is disproportionately impaired in many memory disorders, and is also more reliant on recollection processes (Mandler, 1980, 2008; Souchay & Moulin, 2009; Yonelinas & Levy, 2002).

Episodic memory, despite being difficult to rehabilitate, is also the form of retrieval which resonates with lay conceptions of 'memory', easily evoked by looking at our old diaries, reading journals, or looking at old photographs of family and friends. Unsurprisingly, researchers such as Bourgeois (1990, 1992) and Sohlberg and Mateer (1989, 2001) have used such materials to try and ameliorate memory loss in Alzheimer's disease (AD). For example, Bourgeois focused on evaluating the efficacy of "memory wallets" (which included photographs of people and relevant occasions) to improve the ability of making factual statements and the conversational skills of patients with moderate AD, and benefits were found at a 6-weeks follow up in the number of events described, a finding that was then replicated by others (Hoerster, Hickey, & Bourgeois, 2001; McPherson et al., 2001; Yasuda, Kuwabara, Kuwahara, Abe, & Tetsutani, 2009). Solhberg and Mateer (1989) trained patients to keep a personal diary/memory notebook and found that this reduced repetitive discourse (findings also described by Donaghy & Williams, 1996). Despite these findings that photographs and personal diaries are useful for patients with memory impairment, it is noted that there was no focus specifically in episodic memory, and it is not clear whether these kinds of aids enable the patients to re-experience forgotten events.

For wearable cameras, we are interested in recollection, since it is the focus on the retrieval of 'something more' rather than the mere assessment of prior occurrence (Moulin, Souchay, and Morris (2013)). This is a particularly important point when considering the effects of re-presenting a previously encountered stimulus to a person with memory difficulties. We are interested in how such a recognition prompt may promote *recall* of associated information. It is this process of recollection which we are targeting, since otherwise we are only considering the passive and relatively limited retrieval of something which is already identified in a stimulus. In turn, when we consider recollection we also emphasize the personal experience of the information to be recollected (Piolino, Desgranges, & Eustache, 2009), and this is proposed to be the ‘mental time travel’ system responsible for our self-identity (James, 1890). Thus, the rehabilitation of memory, in our view, encompass a strong episodic character, and the goal must be to focus not only in the ability to recognise a specific and meaningful personal event, located in time and space, but also the ability to travel back into the past and relieve specific details of that event distinguishing it from any similar one. According to this argument we should see the rehabilitation of memory as reinstating recollection of a prior event. Of course, there is a long tradition of memory improvement through repeated recall and retrieval practice (e.g. Sumowski et al., 2014; and see Wilson & Glisky, 2009 for a full discussion), and we are not claiming wearable cameras would replace these techniques, but possibly offer new materials to be used with such techniques, rather than verbal materials, for instance.

2.1 The environmental support hypothesis

Our focus on recollection and rehabilitation means that we need to consider how the overlap between cues at encoding and retrieval may lead to autonoetic remembering (Nairne, 2002). A critical issue is the extent to which cues (such as a diary or images provided by a wearable camera) can support the retrieval of information from memory. We are already discounting the idea that lifelogging could replace episodic remembering, since our recollection hypothesis above, suggests that episodic memory is never just about 'facts' but about experiences (this is an idea which resonates with the philosophical and phenomenological debate about episodic memory; see (Dokic, 2014)). Of course, we think it may be useful to have procedures and external stores of information which can be re-accessed, but for the purposes of rehabilitation of episodic memory, if we do not reproduce the core phenomenology of episodic memory we have not improved episodic function, but compensated for it.

We suggest that to understand how the input of external information can enervate the memory system, and support rather than replace retrieval we can draw upon the environmental support hypothesis. Craik (1986) made the assumption that the key for retrieval success is an interaction between external support (environmental) and internal, self-initiated processes. As such, in episodic memory impairment, the execution of self-initiated processing is compromised (Craik & Byrd, 1982), and more extended environmental support is required to retrieve the information. For example, someone with Alzheimer's disease may not be able to recall a given item from a list of words, but can nonetheless recognize it, when shown it, or recall it with the right prompt. For this reason, when an adequate and strong environmental support is provided at retrieval, people with memory problems are more able to retrieve information, but when there is less support from external stimulation, they fail to provide answers based on re-experience of events and instead provide judgments based on familiarity (Backman & Small, 1998; Bialystok, Craik, & Luk, 2008). Tulving and Arbuckle (1966) make a distinction between the information stored in memory that is available and the information that is accessible, because they consider that intact memory traces of information without the appropriate recall conditions are available in memory storage, but are not accessible for retrieval. This again suggests that people with memory impairment fail to find otherwise intact traces in storage, not necessarily because the information is not there, but because it is not accessible. Nelson (1978) showed that there were enduring consequences of information in memory. Even if a piece of information had been forgotten, it was possible to measure the effects of previously having had that information in memory using tests of interference.

Neuroscientifically, we suggest that environmental support acts to stimulate the critical medial temporal lobe memory system, when self-initiated frontal contributions are weak – and there is the failure to set up adequate cues for retrieval (e.g. Moscovitch and Behrmann (1994)). That is, external information acts to excite the memory networks which through a process of spreading activation lead to the retrieval of associated information. At such point the network of neurons (presumably through Hebbian associations) becomes large and self-sustaining, and we may experience a rich and evocative form of episodic memory, i.e. recollection. Our hypothesis is that the retrieval of personal information through wearable cameras should necessarily invoke the rich evocative recollection of the self in the past. The environmental support provided by lifelogging images will operate to stimulate remaining neural networks, and should, if activation is sufficient, access other associated information in memory. Therefore, the result of 'self-in-the-past' cues will reinstate remembering, not just the passive decision, *yes, that was me, I was there*. We are not arguing, however, that wearable cameras are the only means to access such information, and other internal and external memory aids would have the same goal.

3. The state of art: SenseCam and other wearable cameras

Hodges et al. (2006) first developed SenseCam, a wearable camera that takes still images (and which does not record sound) according to triggers from sensors, as a 'retrospective memory aid'. SenseCam is a lifelogging device where the images are taken passively, which means that the user has no intervention in the action of taking photographs of the events. Additionally, as it is worn around the neck it creates images from the point of view of its user. According to Muhlert, Milton, Butler, Kapur, and Zeman (2010) the automatic capture of images is of great ecological value because no intentional encoding is required for information that will later be showed and tested at retrieval.

SenseCam has a fish-eye lens in order to maximize the field of view, and it either takes one picture every 30 seconds by default, or it takes pictures according to its set of sensors (light, temperature, sound, movement) – in practice this means it takes several pictures per minute. A display to see photos is not included in the device, meaning a computer is required to upload the images and display them later. SenseCam was built by Microsoft Research Cambridge and its first commercial appearance was as the Vicon Revue®, manufactured by OMG PLC and then developed into the Autographer® which also had GPS and Bluetooth capability. Both of these devices are no longer commercially available, but Narrative Clip (http://getnarrative.com/), a similar, smaller, wearable camera is available. All of these devices are based on the same principle of a wearable camera that takes still images passively and automatically, in order to provide a rich set of photos of a person's daily activities (Doherty et al., 2011). Here we use the generic term "wearable camera" to apply to all such devices, using the term 'SenseCam more specifically for issues related only to that one device. In this field we can also find mobile applications that include functions similar to these wearable cameras, such as the One Day app (https://www.oneday.com/), an application that instantly creates short videos allowing the user to include music and a theme to organize their videos of important events. However in this case, the possibility to create videos without the users' input is not available.

3.1 How wearable cameras work: The 'something more' hypothesis

The aim of this article is to review wearable cameras in the context of our view of recollection and the environmental support hypothesis. Our hypothesis is represented in Figure 1. We have established that brain disease or damage presumably can leave information in memory networks active but inaccessible. We suggest that wearable cameras provide cues which can raise activation above threshold and increase accessibility. The review of lifelogging images, where a whole day can be compressed into a 'movie' sequence of still images, should have a beneficial effect on episodic memory. The critical point is that reviewing such images should not act merely on an assessment of prior occurrence ('*yes, I was there'*, or even '*I must have been there*') but it increases access to the 'something more' of recollection.

According to our view, if wearable cameras are to be anything more than merely a device which takes photos for later review (i.e. like any other camera), it has to work on information not readily available in the images itself. This is in part related to issues around the transfer effect in rehabilitation: it would be good if review of images from wearable cameras improved performance in ways that went beyond just the images themselves. We would also hope that wearable cameras can act to reinstate previous thoughts, feelings and sensory information not in the images themselves. We are not the first to suggest this idea. Loveday and Conway (2011) suggest that the SenseCam works by giving viewers 'Proustian Moments':

> A ''Proustian moment'' (PM) is a moment of intense recollection when images of the past flood into consciousness, and the rememberer has a powerful experience of recollection. Such moments have an almost ''aha!'' quality to them and may often

> feature the recall of highly specific details that were not available previously and, in some cases, were not previously known.
>
> Loveday and Conway (2011), p. 697-698

Other authors had also previously described such recall of details after being cued by the images (Berry et al., 2007; Browne et al., 2011). In keeping with the environmental support hypothesis, Loveday and Conway (2011) propose that the SenseCam helps reinstate memories that are not currently accessible. They suggest that events in long term memory are 'never lost' until the neural networks in which they are represented 'decay' or become unstable. That is, information can be unavailable for recall until cued effectively, and events can lie below threshold in memory. This is illustrated in the left-most column of Figure 1. We show a memory strength of *m*, based on the level of activation of neural networks that represent a given event. Where activation is below threshold, we may retain a memory of the event, but not be able to recall it. Cueing may energize the neural networks to reach a point where additional information can be retrieved, labeled 'recall of contextual information'. This information is bound to the event knowledge and rests in the same neural networks, but is not directly represented in the images themselves.

The right hand bar represents how review of images from a wearable camera may act on a weakened memory trace (*m*/2). Our hypothesis is that wearable cameras act as a powerful cue to raise the activation of the event above threshold, and like any other cue, it will make information and detail available to the experient, even if it is not represented in the images. This is Loveday and Conway's Proustian Moment: the image cues access to information we may have thought forgotten or unavailable. The critical point for us is that, unless lifelogging technologies can generate such a Proustian effect, it is rather unimpressive: the alternative is that it merely re-familiarizes participants with scenes. Thus, in the rest of this review, we focus on what evidence there may be that wearable cameras act to give back recollection of prior events, and that it therefore transfers to other meaningful domains, thoughts and general wellbeing.

4. A review of wearable cameras in the memory literature

Here we present a review of the extant wearable camera literature, outlining research that illustrates the broad use of this device to understand memory and how it can be enhanced. The databases used for this search were *Pubmed*, *ISI Web of Knowledge* and *ScienceDirect,* and we also identified studies by reference tracing and through citations. The search terms were “*wearable camera*”, "*SenseCam*", "*memory*", and "*lifelogging*". From the databases described we initially found 92 papers that included two or more of these search terms in the title, whose abstracts were screened. We included the 25 papers for this review after screening the abstract according to the following criteria: SenseCam or its similar devices must have been used in the experiment and not only referred to (the wearable camera should have been used as the main material of the experiment); the purpose of using wearable cameras in the studies should be memory-related and/or with rehabilitation purposes (i.e. we excluded studies that used SenseCam to analyze physical activity/lifestyle, teaching/education profiles, reflection/culture). (For a practical overview of the uses of SenseCam see Doherty et al. (2013).) Also, selected articles described experiments with results and not methodologies, opinions or editorials and theory statements. (To date, there have been two special issues on SenseCam (Memory Volume 19 issue 7, 2011 and American Journal of Preventative Medicine, Volume 44, Issue 3, 2013).) All studies described in this paper used the experimental or commercial versions of SenseCam (Vicon Revue), none of them used the more recent wearable cameras (Autographer or Narrative Clip).

From the twenty-five papers selected (see Table), eleven papers describe case studies, most of them representing the first attempts to rehabilitate memory with SenseCam (Berry et al., 2009a; Berry et al., 2007). Patients are reported with limbic encephalitis (Berry et al., 2009a), medial temporal lobe damage (Bowen, 2008), acquired brain injury (Brindley et al., 2011), mild cognitive impairment (Browne et al., 2011), brain tumour (Pauly-Takacs et al., 2011), hypoxic ischemic encephalopathy (Garrood, 2012), Alzheimer's disease (Piazek et al., 2012) and Korsakoff's syndrome (Svanberg & Evans, 2014). Compared to a personal diary or to a baseline condition, SenseCam improved retrieval of events depicted in the images (Berry et al., 2007, 2009; Brindley et al., 2011; Browne et al., 2011; Pauly-Takacs et al., 2011). SenseCam was also described in these studies as improving the specificity of recall, i.e., the events were described in more detail after viewing SenseCam images (Doherty et al., 2009; Brindley et al., 2011). The authors are not clear whether the extra detail was immediately apparent from the images reviewed, but in general we can cautiously suggest that the extra detail retrieved is in line with an effect of recollection attributed to SenseCam review. One of these studies placed emphasis on an increase in specificity for events *not depicted* in the images (Loveday & Conway, 2011) – which is critical for our hypothesis.

This issue of retrieval of events not depicted in the images is a critical one, and has been a theme in many of the case studies since the earliest examinations of SenseCam in memory impaired groups (e.g. Browne et al., 2011; see also Woodberry et al., 2015). It is neatly summed up by a quote from Berry et al. (2007, p. 597), describing one of their patients: "Mrs B reported that seeing the beginning of a clip brought the images 'flooding back' without necessarily having to view further images, suggesting that she was remembering the event itself rather than the movie clip, something that was confirmed by Mr B, who said that his wife was able to recall details of events not depicted in the images." A priority for research is to examine these types of experiences in more detail with designs which explicitly test the quality and quantity of non-depicted images which can be retrieved.

From this set of case studies, two experiments point to an enhancement of memory which is not episodic in nature. Both Pauly-Takacs et al. (2011) and Garrood (2010) suggest that the beneficial effect of wearable cameras in their patients is due to a change in personal semantic information. For instance, Pauly-Takacs et al. presented facts during a tour of campus with their patient. He was able to retrieve the given facts when presented the relevant image: *'Longest corridor in Europe. I have been there'*. This suggests that people can re-learn information as knowledge, which is registered in the semantic system. Perhaps more worryingly, there was also a tendency for this semantic memory to over-extend to inappropriate cues, in the form of false memories. Pauly-Takacs et al. note that their patient would regularize any picture with distinctive architectural columns in it to having been a place he had visited on the basis of having learned from his own SenseCam images that he had visited a place on campus with salient columns.

A further set of studies was also based on single group experimental designs in healthy and clinical populations. Naturally, the use of inferential statistics is a strong point of group studies, although the sample sizes range from 3 to 144 participants. Again, these studies reinforce the idea that wearable cameras improve both episodic memory and personal knowledge. Many of these studies measured the amount of information retrieved following review (quantity), but some also asked participants to give subjective evaluations of their memory (quality) – a measure critical for our hypothesis. Studies found both improvements in the quantity and quality of information after wearable camera image review, with more details retrieved about the events and more specific judgments about event boundaries, for instance. This was true of both for healthy (Doherty et al., 2010; Kalnikaite et al., 2010; Sas, 2013) and memory impaired populations (Lee & Dey, 2008, Crete-Nishihata et al., 2012, Woodberry et al., 2014).

Within this category, Sellen et al. (2007) perhaps provide the clearest test of our reollection hypothesis, in that they measure the phenomenological experience of remembering (i.e. recollection) and knowing of events. Sellen et al. tested 19 undergraduates who wore wearable cameras and carried out recognition memory tests across 13 consecutive days. They ran a yoked design whereby the photos from another person’s camera served as a control condition. They tested memory in three different ways: a self/other condition ("was this image one of your own?"), an ordering test where they had to put their images from a day in order, and a recall test where they generated details and events from the day. Most importantly, this recall test examined the effect of free recall of events before and after reviewing just 10 of their own (or yoked control) images. For this free recall of events, they were asked to classify their memory for the events according to Tulving’s remember/know (R/K) distinction.

Sellen et al. report a number of interesting findings, not least, that merely wearing a SenseCam significantly improves memory for that day’s events (i.e. without reviewing the images). Importantly, image review lead to a significantly higher number of remembered events from the SenseCam days, and also it appeared to improve retention for the events when tested after a delay of 10 days. Fewer events were known than remembered in general. When participants reviewed their images, there was no main effect of review on ‘knowing‘, although there was the suggestion that SenseCam review acted to maintain the knowledge of events over time. The ordering task provides a somewhat more objective measure, where we can compare the real order with the participants’ response. This showed a large effect of image review, but it is an unusual measure: participants are better at ordering the events in their own day than someone else’s. Such unorthodox measures point to some of the methodological challenges of working with wearable cameras which we discuss below. With their recognition test, the task is similarly difficult to interpret, since it is a judgment about whether the image represents one’s own day, or someone else’s. Interestingly, there were false positives: people did misinterpret others days as their own, but in general, participants could significantly discriminate their images from other people’s (80% of the time). Several other studies report that participant’s own images are significantly more powerful cues than others' images, or than pictures from their own life taken by others (Doherty & Smeaton, 2010; M. Lee & Dey, 2008; St Jacques & Schacter, 2013).

In summary, the Sellen et al. article – notably the recall results – offer some support for the idea that wearable camera images (just ten of them, in fact) help people retrieve events from their day: an extra two events on average are retrieved as a consequence of SenseCam review. There appears to be no effect on personal semantics, however, or the ‘knowledge’ of events. However, within this set of articles, there are other studies which suggest an improvement in personal semantics, and the improvement in this semantic memory appears to prevail for longer periods of time, compared to the decay in memory for specific events (Doherty & Smeaton, 2010; Finley et al., 2011).

These studies also examine whether wearable cameras are different from other kinds of recording devices, which is critical for both the marketability of SenseCam and its status as a rehabilitation device (compared to for instance, a standard digital camera, or an audio recorder). For example, Sellen and collaborators (2007) concluded that the passive capture provided by the SenseCam automaticity is better than the active capture that regular cameras offer (because this active capture will influence the way moments/events are experienced). Moreover, Hodges et al., 2011 suggested that SenseCam might deliver such a powerful effect because it takes so many images: the chances of any one image cueing a memory are higher. Researchers have also combined visual information given by SenseCam with locational data (GPS), now available in the Autographer device (OMG®) (Kalnikaité et al., 2010). Kalnikaité et al.

concluded that locational and visual data together are better that visual data alone at cueing memories, but that visual data alone is more useful for recollection (true recall obtained by the number of remember judgments divided by the number of events recalled) than locational data alone. This suggests that the more information wearable cameras can give people about the past, the more powerful they will be as memory aids.

However, two studies within this set showed more negative results. Seamon and collaborators (2014) showed that use of SenseCam did not help to improve recognition for atypical actions performed during a walk. Using a tour of a museum, St Jacques and Schacter (2013) showed that despite SenseCam helping to improve the quality of the judgments about reviewed images, it also improved false recognition (distortions) between own images and related novel images. These two studies were conducted with decent sample sizes (see Table) of healthy participants, and both included a planned walk with events to perform or to see.

An important set of the studies identified in the Table studies are those that present neuroimaging data. This again could speak to our hypothesis about activation of the memory network as a result of image review, since the neuroanatomical location of recollection has been shown to be the medial temporal lobe (see Moulin, Souchay & Morris, 2013 for a review). Imaging studies (fMRI during recognition judgments), show that viewing images from wearable cameras increases cortical activation in the short term, and indeed, in the medial temporal lobes. For instance, review of images activated the right anterior and posterior parahippocampal regions (Milton, Muhlert, Butler, Smith, et al., 2011). In long term retention, SenseCam evoked a set of areas in the neocortex (medial prefrontal cortex) and not the medial temporal lobes. One can add to this data a set of conclusion brought by other experimental design (two groups), where St Jacques and colleagues (2011) compared the impact of SenseCam in both males and females cortical activation in short term, and here medial temporal lobes activation was also present but more for males, whereas females activated regions of prefrontal cortex, that was previously associated to long term retention. As females are known to present generally better autobiographical memory than males (e.g. Bloise & Johnson, 2007), and the data gathered here highlight that long term improved recollection is more due to prefrontal cortex than medial temporal lobes, one may, therefore, suggest that these regions are activated by SenseCam to stimulate stronger and longer memories (St Jacques et al., 2011).

In another study using wearable cameras to analyze cortical activity for own versus other images (St Jacques, Conway, Lowder, & Cabeza, 2011), we can also consider another unique characteristic of SenseCam over other methods of memory improvement. The purpose of wearable cameras is to capture self-referent information, and this study shows that the self-projection provided by SenseCam activated the ventral medial pre-frontal cortex (*mPFC*), an area that contributes to the medial temporal lobe (MTL) network linked to memory processes, thus energising this network to a level where is possible to re-experience the personal past, allowing the retrieval of both information depicted in the images, the related contextual information, and the autonoetic consciousness, critical for recollection success, as proposed by Loveday & Conway (2011).

The last two studies presented in the Table used between group comparisons, aiming to study, the effects of age (Silva et al., 2013) and the effects of transient epileptic amnesia (Muhlert et al., 2010) on memory performance after being presented SenseCam, Diary and Verbal materials. Silva and colleagues (2013) attempted to study the effect of wearable cameras in stimulating memory in general, not testing the memory for information depicted in images, but instead testing general memory performance, assessed through standardised cognitive tests. This study is the first, and so far only, to use outcome measures that are not related to the content of the training with SenseCam. The results were again in agreement with our hypothesis, as all the memory measures used (e.g., Autobiographical Memory Test, California Verbal Learning Test-II, Digit Span, Month Ordering) showed improved performance after three days wearing SenseCam and reviewing its pictures, compared to a condition of keeping a diary for the same amount of time. There was no examination of the memory for information captured by the camera versus the information written in the diary, and so this supports our view that wearable cameras might provide a general boost in memory networks, 'something more' than only cueing recall for information in the images.

For the clinical study that compared patients with Transient Epileptic Amnesia with matched controls (Muhlert et al., 2010), the information gathered makes less of a contribution to understanding the role of SenseCam to improve recollection. The patients, as expected, showed accelerated forgetting both for information captured with wearable cameras and for verbal stimuli, but no comparison of the differences between the amount of forgetting for SenseCam pictures versus word lists was made. Thus, no information was provided to examine potential differences between SenseCam and verbal cues for recall and forgetting, which is critical to understand the value of wearable cameras in these patients. However, Mulhert et al. do point to the utility of wearable cameras in measuring issues such as forgetting in real world contexts.

In summary, across these articles, there appears to be a clear benefit of review of images from wearable cameras on both recall and recognition. The studies however are heterogeneous as regards methods and populations, and there are some studies reporting null findings, and others which provoke some interesting questions. Even though there appears to be a clear benefit of reviewing images, for instance, there was one study that also gave a clear benefit of just wearing SenseCam (without even reviewing the images). We might therefore imagine that using a technology such as wearable cameras – at least in the short term – changes how people act and encode events in real life.

4.1 Methodological reflections

Here we address a few methodological issues of importance. One issue which we do not cover here are the ethical challenges associated with capturing and storing a large number of images, many of which are personal but are captured in the public domain. For an article on this topic see Kelly et al. (2013).

There are a meaningful number of studies in the literature after 2006 that used wearable cameras for memory related purposes, with both healthy and memory impaired populations. However, with the exception of a small number of studies (Seamon et al., 2014; St Jacques et al., 2011, 2013; Silva et al., 2013; Muhlert et al., 2010) these were mostly single case studies (mostly with no control group) or group studies with small groups of subjects ($n < 20$). Thus, the support for our hypothesis, at this stage, is statistically limited. A further weakness is that several of the articles reviewed were conference proceedings on SenseCam where the involvement of peer-review is not clear. This reflects the differences in publication habits amongst computer scientists and software engineers, and cognitive scientists and clinicians.

The reference to studies which themselves had not been presented in any great experimental detail is also critical. For example, one interesting study (Doherty et al., 2010, reported in Doherty et al., 2012) concerned autobiographical memory using a recollection (remember/familiar) methodology for CG, a healthy male who at the time of testing had worn a SenseCam everyday for two and a half years and was tested on his memory for 29,301 personal events taken from his store of 2,579,455 SenseCam images. This study is reported second-hand in multiple places, but no original article presenting the case in detail appears. CG was tested on “who, where, what” questions (cf. Perfect, Mayes, Downes, & Van Eijk, 1996), when reviewing 50 events randomly chosen from his large collection, as well as making remember and familiar judgements. For these 50 events, he reported recollecting only 14% of events (which was supported by his ability to answer who, where, and what questions). The aims of this study are very close to our aim of knowing – in real life – what can be retrieved from memory, and suggests that, at least in healthy groups, the extra recollection enabled by lifelogging technologies is actually rather modest. Clearly, however, such a fundamental issue warrants more than a single case design reported briefly in conference proceedings.

Seamon and colleagues used a between subjects design to analyze if wearable cameras were more helpful than a diary or no memory aid to improve recall of atypical actions that participants had performed one week earlier (long term delay) (Seamon et al., 2014). However, one major limitation of this study for our hypothesis is that both the outcome measure (written recall one week after having reviewed the images) and the material used (atypical actions) are very much different from the way clinicians and cognitive researchers would use wearable cameras in rehabilitation. Their procedure is that participants review images directly after encoding, but not during or immediately before the final test (so the retrieval conditions are sub-optimal – there is no environmental support at time of retrieval). Thus, we think that their high-powered study might be thought of merely as a test of whether wearable cameras aid the consolidation of memories shortly after their formation – and their null findings suggest they do not. This is a valuable finding for our understanding of how wearable cameras might work: they do not appear to consolidate memories if used shortly after the initial encoding. However, this methodology cannot address the impact of wearable cameras in recollection, nor does it speak to rehabilitation. We do not suppose that having worn a wearable camera at an earlier date, someone would choose *not* to use it when trying at a later point to retrieve the details of the previous experience. That is, in this study, review of images was not carried out at the final retrieval test in either the SenseCam or control condition.

In memory rehabilitation research there is a need for ecological validity. Most of the studies in this review used dependent variables which were not useful for measuring generalization, nor recollection. One commonly used measure was the recall percentages of particular events (some chosen by the caregiver) (Berry et al., 2007, 2009; Lee & Dey, 2008; Doherty et al., 2012; Brindley et al., 2011; Browne et al., 2011). Others used self report scales (Crete-Nishihata et al., 2012; St Jacques et al., 2011; Svanberg & Evans, 2014). Nearly all of the dependent variables concerned retrieval of information directly related to, and possibily depicted in the images themselves. In these studies, there is another issue: it is difficult to differentiate between genuine recall and information that is depicted in the images themselves or inferred from them (or indeed inferred from general knowledge). For example, when reviewing an image people can make sense of their life with statements such as: "I am walking to Spanish or German class. I know this because the tree angle is very dramatic and it wouldn't be at noon. Which is when I'd normally leave this area." Finley et al., 2011, p.10). In this example, there is little evidence that the participant has produced a Proustian Moment, or has re-accessed their personal past in a way which indicates recollection.

In other case studies, where more detailed information was retrieved by the participant, (Doherty et al., 2010; Pauly-Takacs et al., 2011), it was not limited to episodic information, with several authors pointing to the fact that wearable cameras improve personal semantics. This points to a general effect of wearable cameras that goes beyond cueing of information in the episodic system, and along with 'inferencing' suggests that wearable cameras are responsible for supporting more than just the recognition of pictures. Perhaps the clearest illustration of a general effect of wearable camera use is shown by Silva et al., 2013, who were not interested in what came to mind as people reviewed images, but their cognitive performance after review. They used general neuropsychological tests to test the efficacy of SenseCam over a diary in general cognitive performance. On the one hand, this is positive: because the effect of wearable cameras may transfer to other domains and tasks; but the negative interpretation of such results is that wearing or using a wearable camera somehow stimulates cognitive function more generally, and this could even just be due to the positive emotional consequences of using a device which was fun or novel.

Although the goal of many of the studies has been rehabilitation, they lack a measure of quality of life and of functional capacity that could contribute to understanding the impact in daily life of lifelogging methods, as highlighted by Wilson and Glisky (2009) in the definition of neuropsychological rehabilitation as a paradigm aimed to provide *"the best chance of reducing everyday problems and enhancing independent living and quality of life for the majority of those with organic memory deficits"* (p.20). Some studies used a set of subjective ratings such as vividness and mood, but they were not found to be useful to analyze the efficacy of wearable cameras over other kinds of training, mostly due to the short-term assessment in which they were used (Loveday & Conway, 2011; Svanberg & Evans, 2014; Silva et al., 2013). It could be that like errorless learning, the best way forward is to match the approach to the goals of the person receiving rehabilitation. Errorless learning is an internal rehabilitation procedure which works well in memory impairment (for reviews see Clare & Jones, 2008; Middleton & Schwartz, 2012), but to have benefits for social function which may improve the wellbeing of our patients, the procedure needs to be tailored to suitable materials (re-learning the names of friends and club members, for instance (Clare, Wilson, Carter, Roth, & Hodges, 2002; Thivierge, Simard, Jean, & Grandmaison, 2008). For such a system to work, we thus need to have not only a mnemonic technique, but also a certain degree of user and carer input to tailor the materials to the patient.

Our belief is that the best method to assess a new technology to rehabilitate memory is to have an informed approach that takes on board the neuroscientific basis of memory. However, to meet the criteria of memory rehabilitation, and not just memory 'improvement', there must be clear links to real-world behaviors and functions. In fact, the use of errorless learning has developed in exactly this manner – from a theory-driven technique derived from experimentation, to something that can now be adapted to a person's needs and difficulties.

For wearable cameras, we stress that the choice of control condition is a critical methodological issue when considering transfer to self-relevant materials. We note that several of the reviewed studies used a recognition test based on a Self/Other paradigm (Pauly-Takacs et al., 2011; Sellen et al., 2007; St Jacques & Schacter, 2013) where the question is, *did this happen to me*? Or, *is this one of my pictures*? For our recollection hypothesis, and for generalisability, we want to know if wearable camera image review promotes re-experiencing of previous events. A test which just asks if the image is from the self or other does not assess the 'Proustian Moment'. In daily life we rarely think of an event or meet a person and ask ourselves, *was it me who met this person, or someone else*? Thus the use of completely novel images from another person's life, seems to be an unsuitable set of control images. On the other hand, suppose we take as control images a set of plausible images, like a close friend or partner's images or those of a student at the same University. They will frequent the same places and have the same friends, and may even attend the same events. As such, we would expect there to be some effect of reviewing others' images in recalling their own experiences. In sum, we suggest that vast differences in the images between the test and control conditions render the test too easy; but having an overlap between the two conditions may lead to genuine cueing and memory effects as shown in several of the reviewed articles (e.g. in the museum tour study, there was cueing effects from non-visited locations; St Jacques & Schacter, 2013).

For our recollection hypothesis, aside of asking people about their experiential state, the critical test is of recall and not recognition. However, many studies tested only recognition and not recall (Milton, Muhlert, Butler, Benattayallah, & Zeman, 2011b; Milton, Muhlert, Butler, Smith, et al., 2011; Pauly-Takacs et al., 2011; St Jacques & Schacter, 2013). Even those studies which did assess subjective experience in recollection overlooked the category critical for recollection: Know and Familiar judgments (but without Remember) judgments were taken by Berry et al. (2009). Sometimes only subjective measures were taken, in the form of ratings, so we do not know if extra information was retrieved, or whether there was only a 'sensation' of retrieval (Piasek et al., 2012; St Jacques et al., 2011; Svanberg & Evans, 2014).

The use of immediate recall or very short term recall limits the conclusions we can make about the efficacy of wearable cameras, because in daily life we would want to look at long term effects. Recall was tested immediately or in the short-term in two of our reviewed studies (Garrood, 2010; Sas et al., 2013). On the other hand, a too long delay between review of images and test is also not reflective of real-world use of wearable cameras; presumably you would watch the film at the moment you wanted to remember what had happened. Recall was tested after a long delay between review and test in one of the studies reviewed here (Seamon et al., 2014).

Arguably, if we wish to make claims about the efficacy of wearable cameras in memory rehabilitation, then we should follow a medical style, randomized placebo controlled clinical trial. However, using a 'placebo' method is difficult with such a technology, and instead it seems ethically and experimentally critical to settle on a suitable control condition. This is not a problem which is unique to wearable camera research. Many recent studies have investigated the introduction of robotic devices into the field of stroke rehabilitation, for instance (Chang & Kim, 2013). Like with lifelogging, both ethical and methodological constraints hinder the design of double-blind randomized controlled studies of robot-assisted therapy. In the absence of such methods, meta-analysis is desirable, with a consideration of effect sizes. After the steady accumulation of data in wearable camera experiments this will be a priority – although there is insufficient homogenous data at this point. Chang and Kim argue that where there are methodological issues in evaluating the efficacy of a technique (in their case robotic rehabilitation of motor capacities) then theory-driven approaches are critical.

5. Conclusions

To conclude, a number of research groups using different methods and populations have indicated the value of SenseCam as a memory rehabilitation technique. Our goal was to bring together these early studies into a coherent whole, and provide a theoretical basis for any improvement in memory from the use of wearable cameras. We argued that the ideal test of the efficacy of wearable cameras is that it should enable the recall of ‘something more’. This hypothesis has a sound basis in how we think about episodic memory – and the capacity to ‘recollect’ our personal past. A small proportion of the articles reviewed here also focused on this ‘remembering’ component of memory. At the moment, the evidence for this special action of wearable cameras is weak, though positive, and future research efforts should focus on this particular theory-driven measure of the device’s efficacy. A further issue related to this, might be to better understand whether, and how wearable cameras differ from standard cameras in memory improvement. This would be a relatively simple idea to test. The theory is that wearable cameras in some way mimic human memory, by giving a visual input of time slices which are temporally ordered, and which offer a first person perspective. Reviewing the sequence of ‘snapshots’ is proposed to emulate the retrieval from episodic memory (Hodges et al., 2011). This would mean that wearable cameras are superior to devices which do not share these features.

We also stress that the multidisciplinary nature of research thus far has left a gap between an appropriate theoretical basis to sustain the use and effectiveness of wearable cameras and the rapid innovation of these devices. For memory rehabilitation specialists, however, wearable cameras may represent another tool that can be used to help alleviate memory impairment. As well as the cognitive effects of these devices, and the theoretical basis of their function, we also need to consider more the motivations for using such devices (for more on the motivations to use lifelogging see Caprani et al., 2014). It is also critical to think not just about cognition, but transfer to other domains such as the self and identity. (For more on this issue in Alzheimer’s disease and in relation to lifelogging, see Piasek et al., 2015.) Since it is a rather non-invasive technology which can be used passively, it is unlikely to be harmful. For the longer term, research efforts need to concentrate on the rapid, efficient and meaningful retrieval of appropriate images from large databases of personal information, and a robust evidence base for the ‘something more’ hypothesis needs to be generated.

Declaration of Interest

The authors have no declarations of interests.

Acknowledgements

This work was supported by funding from the Region of Bourgogne (FABER) and Fondation Médéric to Céline Souchay and Chris Moulin: "*Conscience et Mémoire dans la maladie d'Alzheimer"* & "*Nouvelles technologies et Maladie d'Alzheimer : vers une utilisation optimale de l'autographer"*

References

Backman, L. (1992). Memory training and memory improvement in Alzheimer's disease: rules and exceptions. Acta Neurol Scand Suppl, 139, 84-89.

Backman, L., & Small, B. J. (1998). Influences of cognitive support on episodic remembering: tracing the process of loss from normal aging to Alzheimer's disease. Psychol Aging, 13(2), 267-276.

Baddeley, A. (2001). The concept of episodic memory. Philos Trans R Soc Lond B Biol Sci, 356(1413), 1345-1350. doi: 10.1098/rstb.2001.0957

Berry, E., Hampshire, A., Rowe, J., Hodges, S., Kapur, N., Watson, P., Browne, G., Smyth, G., Wood, K., & Owen, A. (2009). The neural basis of effective memory therapy in a patient with limbic encephalitis. J Neurol Neurosurg Psychiatry, 80(11), 1202-1205. doi: 10.1136/jnnp.2008.164251

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. Neuropsychol Rehabil, 17(4-5), 582-601. doi: 10.1080/09602010601029780

Bialystok, E., Craik, F., & Luk, G. (2008). Cognitive control and lexical access in younger and older bilinguals. J Exp Psychol Learn Mem Cogn, 34(4), 859-873. doi: 10.1037/0278-7393.34.4.859

Bloise, S. M., & Johnson, M. K. (2007). Memory for emotional and neutral information: Gender and individual differences in emotional sensitivity. Memory, 15, 192-204. doi: 10.1080/09658210701204456

Bourgeois, M. S. (1990). Enhancing conversation skills in patients with Alzheimer's disease using a prosthetic memory aid. J Appl Behav Anal, 23(1), 29-42. doi: 10.1901/jaba.1990.23-29

Bourgeois, M. S. (1992). Evaluating memory wallets in conversations with persons with dementia. J Speech Hear Res, 35(6), 1344-1357.

Bowen, M. (2008). An investigation of the therapeutic efficacy of SenseCam as an autobiographical memory aid in a patient with medial temporal lobe amnesia. (MsC), University of Exeter, University of Exeter Press.

Brindley, R., Bateman, A., & Gracey, F. (2011). Exploration of use of SenseCam to support autobiographical memory retrieval within a cognitive-behavioural therapeutic intervention following acquired brain injury. Memory, 19(7), 745-757. doi: 10.1080/09658211.2010.493893

Browne, G., Berry, E., Kapur, N., Hodges, S., 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), 713-722. doi: 10.1080/09658211.2011.614622

Caprani, N., Piasek, P., Gurrin, C., O'Connor, N., Irving, K., Smeaton, A. (2014) Life-long collections: motivations and the implications for lifelogging with mobile devices. International Journal of Mobile Human Computer Interaction, 6 (1). pp. 15-36. ISSN 1942-3918

Chang, W., & Kim, Y. (2013) Robot-assisted Therapy in Stroke Rehabilitation. Journal of Stroke. 15(3):174-181. doi:10.5853/jos.2013.15.3.174.

Clare, L., Wilson, B. A., Carter, G., Roth, I., & Hodges, J. R. (2002). Relearning face-name associations in early Alzheimer's disease. Neuropsychology, 16(4), 538-547.

Craik, F. (1986). A functional account of age differences in memory. In F. Klix & H. Hagendorf (Eds.), Human memory and cognitive capabilities: mechanisms and performances (pp. 409-422). Amsterdam: Elsevier Science Publishers.

Craik, F., & Byrd, M. (1982). Aging and cognitive deficits: The role of attentional resources. In F. Craik & S. Trehub (Eds.), Aging and cognitive processes (pp. 191-211). New York: Plenum.

Crete-Nishihata, M., Baecker, R., Massimi, M., Ptak, D., Campigotto, R., Kaufman, L., Brickman, A., Turner, G., Steinerman, J., & Black, S. (2012). Reconstructing the Past: Personal Memory Technologies Are Not Just Personal and Not Just for Memory. Human-Computer Interaction, 27(1-2), 92-123. doi: 10.1080/07370024.2012.656062

Doherty, A., Pauly-Takacs, K., Caprani, N., Gurrin, C., Moulin, C., O'Connor, N., & Smeaton, A. (2012). Experiences of Aiding Autobiographical Memory Using the SenseCam. Human--Computer Interaction, 27(1-2), 151-174.

Doherty, A., Hodges, S., King, A., Smeaton, A., Berry, E., Moulin, C., Lindley, S., Kelly, P., & Foster, C. (2013). Wearable Cameras in Health The State of the Art and Future Possibilities. Am J Prev Med, 44(3), 320-323. doi: 10.1016/j.amepre.2012.11.008

Doherty, A., Moulin, C., & Smeaton, A. (2011). Automatically assisting human memory: A SenseCam browser. Memory, 19(7), 785-795. doi: 10.1080/09658211.2010.509732

Doherty, A., Pauly-Takacs, K., Caprani, N., Gurrin, C., Moulin, C., O'Connor, N. E., & Smeaton, A. F. (2012). Experiences of Aiding Autobiographical Memory Using the SenseCam. Human-Computer Interaction, 27(1-2), 151-174. doi: 10.1080/07370024.2012.656050

Doherty, A., & Smeaton, A. (2010a). Automatically augmenting lifelog events using pervasively generated content from millions of people. Sensors (Basel), 10(3), 1423-1446. doi: 10.3390/100301423

Dokic, J. (2014). Feeling the Past: A Two-Tiered Account of Episodic Memory. Review of Philosophy and Psychology, 5(3), 413-426.

Donaghy, S., & Williams, W. (1996). A new protocol for training severely impaired patients in the usage of memory journals. Brain Injury, 12, 1061-1076.

Ehlhardt, L. A., Sohlberg, M. M., Kennedy, M., Coelho, C., Ylvisaker, M., Turkstra, L., & Yorkston, K. (2008). Evidence-based practice guidelines for instructing individuals with neurogenic memory impairments: what have we learned in the past 20 years? Neuropsychol Rehabil, 18(3), 300-342. doi: 10.1080/09602010701733190

Finley, J. R., Brewer, W. F., & Benjamin, A. S. (2011). The effects of end-of-day picture review and a sensor-based picture capture procedure on autobiographical memory using SenseCam. Memory, 19(7), 796-807. doi: 10.1080/09658211.2010.532807

Garrood, I. (2010). The crocodile ate my treasure - using SenseCam with a 10 year old memory impaired child. Paper presented at the SenseCam 2010, Dublin.

Gemming, L., Doherty, A., Kelly, P., Utter, J., & Mhurchu, C. N. (2013). Feasibility of a SenseCam-assisted 24-h recall to reduce under-reporting of energy intake. European journal of clinical nutrition, 67(10), 1095-1099.

Grandmaison, E., & Simard, M. (2003). A critical review of memory stimulation programs in Alzheimer's disease. J Neuropsychiatry Clin Neurosci, 15(2), 130-144.

Hodges, S., Williams, L., Berry, E., Izadi, S., Srinivasan, J., Butler, A., . . . Wood, K. (2006). SenseCam: A Retrospective Memory Aid. Paper presented at the 8th International Conference of Ubiquitous Computing (UbiComp 2006).

Hoerster, L., Hickey, E., & Bourgeois, M. (2001). Effects of memory aids on conversations between nursing home residents with dementia and nursing assistants. Neuropsychol Rehabil, 11, 399-427.

Intons-Peterson, M., & Newsome, G. (1992). External memory aids: effects and effectiveness. In D. Herrmann, H. Weingartner, A. Searleman & C. McEvoy (Eds.), Memory improvement: Implications for memory theory. New York: Springer-Verlag.

James, W. (1890). The principles of psychology. New York: Holt.

Kalnikaité, V., Sellen, A., Whittaker, S., & Kirk, D. S. (2010). Now let me see where i was: understanding how lifelogs mediate memory.

Kelly, P., Marshall, S., Badland, H., Kerr, J., Oliver, M., Doherty, A., & Foster, C. (2013). An ethical framework for automated, wearable cameras in health behavior research. Am J Prev Med, 44(314-319).

Lalanne, J., Gallarda, T., & Piolino, P. (2015). “The Castle of Remembrance”: New insights from a cognitive training programme for autobiographical memory in Alzheimer's disease. Neuropsychological rehabilitation, 25(2), 254-282.

Lee, M., & Dey, A. (2008). Lifelogging memory applicance for people with episodic memory impairment. Paper presented at the 10th International Conference on Ubiquitous Computing. Ubicomp ’08.

Loftus, E., & Loftus, G. (1980). On the permanence of stored information in the human brain. American Psychologist, 35(5), 409-420.

Loveday, C., & Conway, M. (2011). Using SenseCam with an amnesic patient: Accessing inaccessible everyday memories. Memory, 19(7), 697-704. doi: 10.1080/09658211.2011.610803

Lustig, C., Shah, P., Seidler, R., & Reuter-Lorenz, P. (2009). Aging, training, and the brain: a review and future directions. Neuropsychol Rev, 19(4), 504-522. doi: 10.1007/s11065-009-9119-9

Mandler, G. (1980). Recognizing: The judgment of previous occurence. Psychology Review, 87, 252-271.

Mandler, G. (2008). Familiarity breeds attempts: A critical review of dual process theories of recognition. Perspectives in Psychological Sciences, 3, 392-401.

McPherson, A., Furniss, F., Sdogati, C., Cesaroni, F., Tartaglini, b., & J., L. (2001). Effects of individualized memory aids on the conversation of persons with severe dementia: A pilot study. Aging & Mental Health, 5, 289-294.

Milton, F., Muhlert, N., Butler, C., Benattayallah, A., & Zeman, A. (2011a). The neural correlates of everyday recognition memory. Brain Cogn, 76(3), 369-381. doi: 10.1016/j.bandc.2011.04.003

Milton, F., Muhlert, N., Butler, C. R., Smith, A., Benattayallah, A., & Zeman, A. Z. (2011). An fMRI study of long-term everyday memory using SenseCam. Memory, 19(7), 733-744. doi: 10.1080/09658211.2011.552185

Moscovitch, M., & Behrmann, M. (1994). Coding of Spatial Information in the Somatosensory System: Evidence from Patients with Neglect following Parietal Lobe Damage. J Cogn Neurosci, 6(2), 151-155. doi: 10.1162/jocn.1994.6.2.151

Moulin, C., Souchay, C., & Morris, R. (2013). The cognitive neuropsychology of recollection. Cortex, 49(6), 1445-1451. doi: 10.1016/j.cortex.2013.04.006

Muhlert, N., Milton, F., Butler, C., Kapur, N., & Zeman, A. (2010). Accelerated forgetting of real-life events in Transient Epileptic Amnesia. Neuropsychologia, 48(11), 3235-3244. doi: http://dx.doi.org/10.1016/j.neuropsychologia.2010.07.001

Nairne, J. (2002). The myth of the encoding-retrieval match. Memory, 10(5-6), 389-395. doi: 10.1080/09658210244000216

Nelson, T. (1978). Detecting small amounts of information in memory: Savings for nonrecognized items. Journal of Experimental Psychology: Human Learning and Memory, 4: 453-468.

Pauly-Takacs, K., Moulin, C., & Estlin, E. (2011a). SenseCam as a rehabilitation tool in a child with anterograde amnesia. Memory, 19(7), 705-712. doi: 10.1080/09658211.2010.494046

Perfect, T., Mayes, A., Downes, J., & Van Eijk, R. (1996). Does context discriminate recollection from familiarity in recognition memory? Quarterly Journal of Experimnetal Psychology A, 49(3), 797-813. doi: 10.1080/713755644

Piasek, P., Irving, K., & Smeaton, A. (2012). Case study in SenseCam use as an intervention technology for early-stage dementia. International Journal Computers in Healthcare, 1(4), 304-319.

Piasek, P., Irving, K., & Smeaton, A. F. (2015). Exploring Boundaries to the Benefits of Lifelogging for Identity Maintenance for People with Dementia. *International Journal of Mobile Human Computer Interaction (IJMHCI), 7*(4), 76-90. doi:10.4018/IJMHCI.2015100105

Piolino, P., Desgranges, B., & Eustache, F. (2009). Episodic autobiographical memories over the course of time: cognitive, neuropsychological and neuroimaging findings. Neuropsychologia, 47(11), 2314-2329. doi: 10.1016/j.neuropsychologia.2009.01.020

Rebok, G., Carlson, M., & Langbaum, J. (2007). Training and maintaining memory abilities in healthy older adults: traditional and novel approaches. J Gerontol B Psychol Sci Soc Sci, 62 Spec No 1, 53-61.

Sas, C., Fratczak, T., Rees, M., Gellersen, H., Kalnikaite, V., Coman, A., Hook., K. (2013). AffectCam: arousal- augmented sensecam for richer recall of episodic memories. Paper presented at the CHI '13 Extended Abstracts on Human Factors in Computing Systems, Paris, France.

Seamon, J., Moskowitz, T., Swan, A., Zhong, B., Golembeski, A., Liong, C., Narzikul, A., & Sosan, O. (2014). SenseCam reminiscence and action recall in memory-unimpaired people. Memory, 22(7), 861-866. doi: 10.1080/09658211.2013.839711

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. Paper presented at the Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, San Jose, California, USA.

Sellen, A. J., & Whittaker, S. (2010). Beyond total capture: a constructive critique of lifelogging. Commun. ACM, 53(5), 70-77. doi: 10.1145/1735223.1735243

Silva, A., Pinho, S., Macedo, L., & Moulin, C. (2013). Benefits of SenseCam Review on Neuropsychological Test Performance. Am J Prev Med, 44(3), 302-307. doi: 10.1016/j.amepre.2012.11.005

Sohlberg, M., & Mateer, C. (1989). Training use of compensatory memory books: a three stage behavioral approach. J Clin Exp Neuropsychol, 11(6), 871-891. doi: 10.1080/01688638908400941

Sohlberg, M., & Mateer, C. (2001). Improving attention and managing attentional problems. Adapting rehabilitation techniques to adults with ADD. Ann N Y Acad Sci, 931, 359-375.

Souchay, C., & Moulin, C. (2009). Memory and consciousness in Alzheimer's disease. Curr Alzheimer Res, 6(3), 186-195.

St Jacques, P., Conway, M., & Cabeza, R. (2011). Gender differences in autobiographical memory for everyday events: retrieval elicited by SenseCam images versus verbal cues. Memory, 19(7), 723-732. doi: 10.1080/09658211.2010.516266

St Jacques, P., & Schacter, D. (2013). Modifying memory: selectively enhancing and updating personal memories for a museum tour by reactivating them. Psychol Sci, 24(4), 537-543. doi: 10.1177/0956797612457377

Sumowski, J.F., Coyne, J., Cohen, A., & Deluca, J. (2014). Retrieval practice improves memory in survivors of severe traumatic brain injury. Archives of Physical Medicine and Rehabilitation, 95(2): 397-400

Svanberg, J., & Evans, J. (2014). Impact of SenseCam on memory, identity and mood in Korsakoff's syndrome: a single case experimental design study. Neuropsychol Rehabil, 24(3-4), 400-418. doi: 10.1080/09602011.2013.814573

Thivierge, S., Simard, M., Jean, L., & Grandmaison, E. (2008). Errorless learning and spaced retrieval techniques to relearn instrumental activities of daily living in mild Alzheimer's disease: A case report study. Neuropsychiatr Dis Treat, 4(5), 987-999.

Tulving, E. (2001). Episodic memory and common sense: how far apart? Philos Trans R Soc Lond B Biol Sci, 356(1413), 1505-1515. doi: 10.1098/rstb.2001.0937

Tulving, E. (2002). Episodic memory: from mind to brain. Annu Rev Psychol, 53, 1-25. doi: 10.1146/annurev.psych.53.100901.135114

Tulving, E. (2004). [Episodic memory: from mind to brain]. Rev Neurol (Paris), 160(4 Pt 2), S9-23.

Tulving, E., & Arbuckle, T. Y. (1966). Input and output interference in short-term associative memory. J Exp Psychol, 72(1), 145-150.

Wilson, B. & Glisky, E., (2009). Memory rehabilitation: Integrating theory and practice. New York: Guilford Press.

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: 340-349. doi: 10.1080/09658211.2014.886703

World Health Organisation. (2015). http://www.who.int/healthinfo/survey/whoqol-qualityoflife/en/ accessed on 7 July 2015.

Yasuda, K., Kuwabara, K., Kuwahara, N., Abe, S., & Tetsutani, N. (2009). Effectiveness of personalised reminiscence photo videos for individuals with dementia. Neuropsychol Rehabil, 19(4), 603-619. doi: 10.1080/09602010802586216

Yonelinas, A. P., & Levy, B. J. (2002). Dissociating familiarity from recollection in human recognition memory: different rates of forgetting over short retention intervals. Psychon Bull Rev, 9(3), 575-582.

Table

Table 1. Summary of experiments using SenseCam for memory-related purposes. Papers are organized in this table according to the type of study, then by publication year and type of sample (controls, clinical)

Authors (Reference No)	***Type of study***	***Sample***	***Method***	***Results***
(Berry et al., 2007)	Case study	63-year old female with limbic encephalitis (Patient "Mrs B")	Within-subject design 3 Conditions: Baseline, Written Diary, SenseCam for recording interesting events Free recall before and after SenseCam review Follow-up 1, 2 and 3 months after	80% of events recalled after SenseCam condition, superior to Diary (49%) and Baseline (2%) Recall cued by SenseCam was maintained at follow up (67% after 2 months, 76% after 3 months)
(Berry et al., 2009b)	Case study	66-year old female with limbic encephalitis (Patient "Mrs B")	Within subject design 4 conditions: No review; SenseCam review; (holiday trip); written diary (holiday trip); Novel images (other person's SenseCam images) fMRI at retrieval –"Known/Familiar/Not known" to stimulus from all conditions	More Known and Familiar responses in SenseCam condition than the other conditions ($p<.01$) SenseCam viewing: increase in cortical activation.
(Bowen, 2008)	Case study	36-year old female with MTL (medial temporal lobe) damage and severe anterograde amnesia (Patient "Mrs CB")	Within subjects design 3 conditions for an event of playing a board game: SenseCam; Audio recording; No recording Immediate and delayed recall Specificity of event recall assessed	Long delay contributed to lower recall scores in three conditions ($p<.01$) No effect of SenseCam for free recall (p=n.s), but superior cued recall when asked general questions compared to baseline ($p=.01$; SenseCam mean= 3; baseline=2.1)
(A. R. Doherty et al., 2012)	Case study	34-year old Healthy adult male, "CG"	Remember/Familiar judgments for set of SenseCam picture from 2,5 years SenseCam usage	Only 14% of fifty events randomly chosen from collection of images were recollected
(Brindley, Bateman, & Gracey, 2011)	Case study	28-year old man with Acquired Brain Injury and anxiety disorder (Patient "Mr A")	Within subject design 3 conditions: SenseCam, Diary, No aid Only recorded anxiety triggering events	Mean of 94% events recalled after SenseCam, compared to 39%(Diary) and 22% (no aid) Higher specificity of emotional information recall in SenseCam
(Browne et al., 2011)	Case study	56 year-old female with non progressive Mild Cognitive Impairment (Patient "Mrs W")	Within subject design 2 conditions: SenseCam, Diary First recall of relevant events every 2 days for 2 weeks Long term recall after 1, 3 and 6 months. Quality of life scales included	SenseCam superior to Diary in short (64% vs 51% of retention percentages) and long term recall (68% vs 30%). Reduced stress and increased confidence using SenseCam.

(Loveday & Conway, 2011)	Case study	47 year-old female with a large MTL damage (Patient "Mrs CR")	Within subject design 2 Conditions: Record of one discrete event per weekday with SenseCam (4 weeks), writing of a brief diary style account. Recall and cued recall (each weekend) Recall experience rated for vividness	Superior recall ($p<.05$) and episodic detail in SenseCam (329 details) condition compared to diary (250 details). Proustian moments superior for SenseCam (10) than the diary (2).
(K. Pauly-Takacs, C. J. A. Moulin, & E. J. Estlin, 2011)	Case study	13 year-old male with anterograde amnesia (Patient "CJ")	Wearing of SenseCam during a walk around campus Partial review of some locations on walk Recognition memory test (2, 12 and 15 weeks after)	2 weeks recognition above chance for reviewed and non-reviewed information ($p<.01$) 12 /15 weeks recognition above chance for reviewed information ($p<.01$; $p<.01$) but not for non reviewed information ($p=.20$; $p=.12$, respectively) SenseCam helped to form personal semantic memories
(Garrood, 2010)	Case study	10 year-old female with Hypoxic Ischemic Encephalopathy (Patient "AB")	Created event with 'incidental' clues (auditory and visual), using SenseCam Cued recall (questions about event details) prior and after SenseCam viewing	Improved recall after SenseCam viewing only for information that was depicted in the images Repeated review helped to form personal semantic memories
(Piasek, Irving, & Smeaton, 2012)	Case study	85-year old male with Mild Alzheimer disease (Patient "Mr J")	SenseCam usage for seven weeks Twice a week sessions to review SenseCam pictures and registration of thoughts and comments about the viewing	Preliminary qualitative data: SenseCam contributed to encourage opinion and mental stimulation, necessary for Cognitive Stimulation Therapy
(Svanberg & Evans, 2014)	Case study	51 year-old female with Korsakoff's syndrome (Patient "Ms A")	SenseCam record of one activity a week and reviewing every day (eight weeks period) Daily monitoring with Self report scale (memory, mood and identity), no objective measures	Subjective improvement of memory for events and for self-identity (rates increased 4.36). Not significant improvement of mood (-.78 change from baseline).
(Sellen et al., 2007)	Single group experimental design	19 healthy young adults (10 male, 9 female, age range 18-22)	Within subjects design 3 variables - SenseCam vs Control - Passive vs Active capture - Short and long interval memory test Free and delayed recall, R(Remember)/K(Know)/G(Guess) judgments, Yes/No recognition	Increased number of events recalled for SenseCam days compared to control (before - $p<.02$ - and after seeing the images - $p<.03$) Know judgments are improved over time ($p<.08$) in SenseCam Passive capture is better than Active capture
(Doherty & Smeaton, 2010)	Single Group experimental design	3 healthy adult males	Review own SenseCam images from random daily life (one month) and mark boundaries between all events Repetition after 1 and 2 years respectively	Boundaries are better judged by the person who lived the event Decay of event boundary with passage of time (1/2 years)
(Kalnikaité, Sellen, Whittaker, & Kirk, 2010)	Single group experimental design	18 healthy adults (4 female, 14 male, age range 25-56)	Within subjects design 2 conditions: SenseCam images plus GPS for two weeks; No memory aid SenseCam review 5 weeks after events (Only images; Images plus GPS; GPS only)	Detailed recall superior for GPS plus SenseCam (.<.01). SenseCam images alone no better than recall with no memory aid ($p>.05$). True recall superior for SenseCam alone better than GPS or GPS plus SenseCam for true recall

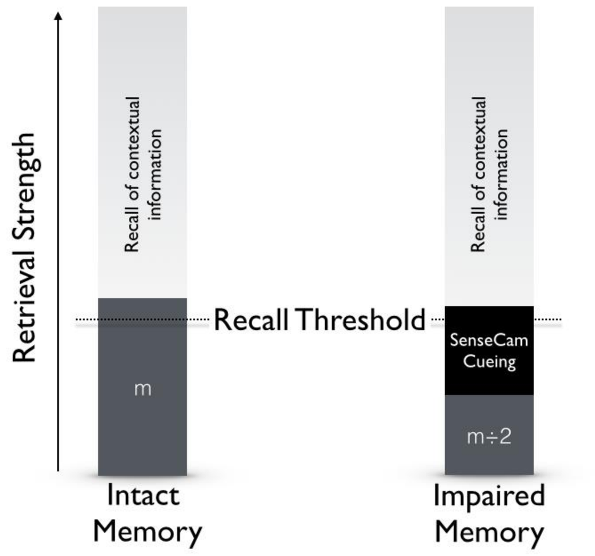
			Recall after memory questions assessed. Remember/know/guess test	(p.<.01) ("Rememberer" events divided by number of events recalled)
(Finley, Brewer, & Benjamin, 2011)	Single group experimental design	12 healthy young adults (4 males and 8 females)	Within subject design SenseCam usage during 5 days, pictures taken by fixed intervals or by sensors, pictures reviewed in two nights Recognition ratings and image cued-recall (1,3 and 8 weeks after)	Both recall and recognition higher for reviewed days (Recall M=50.55; Recognitin=3.55) than for non reviewed days (Recall M=45.51; Recognition=3.25) Decline in memory performance across time intervals
(Milton, Muhlert, Butler, Benattayallah, & Zeman, 2011a; Milton, Muhlert, Butler, Smith, et al., 2011)	Single group experimental design	15 healthy young adults (8 male, 7 female, age range 18-25)	SenseCam usage for 2 days Remember/know judgments and strong/weak recollective judgments collected fMRI during retrieval Study repeated at a 5 months interval with 10 participants	Recollection elicits no activation in the MTL at a 5-month delay; after a 5-month retrieval delay greater posterior parahippocampal gyrus (pPHG) activation for familiarity than recollection memory; Remote recollection recruits a number of extra-MTL regions
(Sas et al., 2013)	Single group experimental design	14 healthy young adults (7 males, 7 females, age range 18-23)	SenseCam and Sensewear usage for 6 hours Data inserted in AffectCam system with both SenseCam sensors and Sensewear arousal information End-of-the-day 4 high and 4 low arousal photos viewing to prompt recall	Emotional arousal increased the recall of detail for events (p<.01) Event itself, place and associated emotions are better recalled than events time and thoughts (p<.01) using SenseCam in high or low arousal pictures
(Seamon et al., 2014)	Single group experimental design	144 healthy young adults (age range 17-23)	Between subjects design 3 conditions: SenseCam, Diary, No aid (during a walk where atypical actions were performed) After walk, groups divided in social or individual reminiscence reviewing conditions; Review occurs one week before free recall	Social reminiscence better than self-reminiscence (proportion means .78 vs .64), Recall of the atypical actions with SenseCam images (.74) or diary entries (.69) was not better than no aid (.68).
(St Jacques & Schacter, 2013)	Single group experimental design	Study 1: 42 healthy young adults (15 male, 27 female (age mean=21,1) Study 2: 41 healthy young adults (18 male, 25 female, age mean=21,41)	Study 1: Self-guided museum tour wearing SenseCam 48h delay review with novel (but related) images, yes/no recognition and confidence Order of image presentation manipulated (chronological vs random) Study 2: Same procedure, different manipulation Perspective of pictures (self vs other) presentation manipulated	Higher recognition for the images corresponding to own experience (p<.01) than for others images False recognition increased for novel images (p<.01) Enhancement of memories but also distortion, false alarms more influence by prior experience than hits (p<.01).
(M. Lee & Dey, 2008)	Single clinical group experimental design	3 older adults with Alzheimer Disease	Within-subjects design Personally significant experience wearing SenseCam during two weeks, audio recorder, and GPS.	Self-guided condition increased recall of details (aprox. 40%of details recalled), compared to caregiver conditions (p<.05), where there was a decrease in performance (aprox. 10%).

			4 conditions: Control (no aid), Patient wears camera, Caregiver wears camera, and Caregiver wears and selects images	
(Crete-Nishihata et al., 2012)	Single clinical group experimental design	5 older adults with early AD or MCI	SenseCam usage during 3 personal outings accompanied by a study partner; After each outing engagement in a 2 -week evaluation, interview five times with Autobiographical Interview (AI). 3 months after each event, conduction of a follow-up with AI	Review of SenseCam images improved episodic recall for personal events over time (in 4 of 5 participants)(p<.05). Subjective experience: SenseCam reexperience was more effective at cueing memories because of the greater number of images
(Woodberry et al., 2014)	Single clinical group experimental design	6 older adults with Mild to Moderate Alzheimer disease (age range 64–84)	Every two days for two weeks each patient's memory for an event was assessed, followed by a structured review of the SenseCam images. Longer-term recall was tested one and three months later. A written diary control condition followed the same procedure.	SenseCam review method resulted in significantly more details of an event being recalled over two weeks (p<.01). 3 months post event, 4/5 patients (one drop-out) recalled significantly more details of events in the SenseCam condition while the other patient showed no difference.
(St Jacques, Conway, & Cabeza, 2011)	Two groups experimental design	12 healthy females and 11 healthy males (age range 18-35)	Within subjects design SenseCam usage and diary records for 6 days fMRI scanning one day after SenseCam and verbal cues viewing and subjective ratings recorded	Higher subjective ratings of vividness, reliving, importance, emotion and uniqueness for SenseCam cues (p<.01) fMRI patterns stronger for males than females; greater activity in left hippocampus, retrosplenial cortex, left inferior frontal gyrus, and right occipital cortex with SenseCam review (for high 'reliving' ratings)
(Silva, Pinho, Macedo, & Moulin, 2013)	Two-group experimental design	15 healthy adults and 14 healthy older adults	Within subjects design SenseCam usage for 3 days Diary writing for 3 days Neuropsychological testing after each condition (order counterbalanced, parallel forms of tests)	Higher performance in most neuropsychological tests after SenseCam usage and viewing for both age groups (ex. Autobiographical Memory Test, p<.01, Effect size .82) Larger effects for memory and executive function tasks
(Muhlert et al., 2010)	Two-group experimental design clinical versus control	Eleven patients with Transient Epileptic Amnesia and eleven matched healthy controls	SenseCam usage during a cultural visit Memory for images of events in the same day, 1 and 3 weeks later Forgetting compared to forgetting of a word list and with performance in procedural memory task	Accelerated forgetting in TEA: (i) affects memory for real-life events as well as laboratory stimuli; (ii) is maximal over the first day compared to controls (p.<05); and (iii) is specific to declarative memories, procedural memory being intact in comparison.

Figure Caption

Figure 1. The effect of SenseCam review. In memory impairment, activation strength of memories (*m*) is reduced to below the threshold of recall. SenseCam review increases retrieval strength through cueing of contextual details from original event, achieving supra threshold activation of recognition memory; recall of contextual details is now possible

Figure


Retrieval Strength
Recall of contextual information
Recall of contextual information
Recall Threshold
m
SenseCam Cueing
m÷2
Intact Memory
Impaired Memory