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General review

SenseCam: A new tool for memory rehabilitation?

Q1 L. Dubourg [a], A.R. Silva [b], C. Fitamen [a], C.J.A. Moulin [c], C. Souchay [c,*]

Q2 [a] Laboratoire d'étude de l'apprentissage et du développement, LEAD CNRS UMR 5022, université de Bourgogne, Dijon, France
[b] Université de Coimbra, Coimbra, Portugal
Q3 [c] Laboratoire de psychologie et neurocognition, LPNC, UMR CNRS 5105, université Grenoble-Alpes, bâtiment Sciences de l'Homme et Mathématiques, 38400 Saint-Martin-d'Hères, France

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ABSTRACT

The emergence of life-logging technologies has led neuropsychologist to focus on understanding how this new technology could help patients with memory disorders. Despite the growing number of studies using life-logging technologies, a theoretical framework supporting its effectiveness is lacking. This review focuses on the use of life-logging in the context of memory rehabilitation, particularly the use of SenseCam, a wearable camera allowing passive image capture. In our opinion, reviewing SenseCam images can be effective for memory rehabilitation only if it provides more than an assessment of prior occurrence in ways that reinstates previous thoughts, feelings and sensory information, thus stimulating recollection. Considering the fact that, in memory impairment, self-initiated processes are impaired, we propose that the environmental support hypothesis can explain the value of SenseCam for memory retrieval. Twenty-five research studies were selected for this review and despite the general acceptance of the value of SenseCam as a memory technique, only a small number of studies focused on recollection. We discuss the usability of this tool to improve episodic memory and in particular, recollection.

1. Introduction

Cognitive neuropsychology has focused in recent years on the use of wearable cameras [1], mainly to help patients with memory disorders [2]. Video-recording activities of daily life has been described as a log of "life data", sometimes called "life-logging" (for a full review see [2]). Producing a regular log of life images raises the question as to whether such technology could be beneficial for patients with memory disorders. For example, reviewing the day's images might be helpful for recollecting autobiographical memories. Thus having patients review their day's video might be a way to help them remember particular events, for example the discussion they had in the morning in the baker's. In this review, we will focus on the use of these tools – in particular SenseCam, a small wearable camera – with the main objective of providing a theoretical framework for research. The main suggestion is that the use of this type of tool to improve recollection should facilitate access to cues and information

* Corresponding author.
E-mail address: celine.souchay@me.com (C. Souchay).
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that are pertinent for the patient. This review of the literature will thus explore how SenseCam provides effective recall cues which can facilitate recollection.

Improving recollection in patients with memory disorders is an important field of research in neuropsychology. Up to the present time, most studies have focused on using ''internal'' strategies, for example categorical cueing or errorless learning [3,4]. However, despite widespread use of this type of aid, it has not always been possible to generalize the results to other mnemonic functions [5]. The main reason for this limitation is the fact that these strategies are generally designed to stimulate a specific type of memory (for instance procedural memory). Moreover, even when people are successful in using these strategies to improve their performances, they are generally unable to apply them in their daily life. Such failures would be due, at least in part, to the fact that the patients are unaware of their memory deficit or its importance [6]. Indeed, certain studies show that patients with the greatest difficulty in evaluating their memory disorders are also the patients who benefit least from rehabilitation because of the non-implementation of adequate strategies [7,8]. In clinical practice, internal strategies, such as the use of memory strategies, and external strategies, such as the use of technological tools, are often applied complementarily. However, the use of internal strategies could potentially be hindered by underlying anosognosia since internal strategies require personal commitment, and in particular adequate awareness of the memory problems encountered. On the contrary, external aids could be easier to use and less dependent on the patient's cognitive resources or mnemonic impairment.

External memory aids are described as physical devices, tools or equipment that allow the user to access memory more easily [9], for example personal diaries, agendas, or cell phones [10–12]. However, despite the efficacy of external aids, certain limitations are observed [13,14]. As for internal strategies, using an external memory aid implies that the user is aware of their memory deficit, or at least they recognizes that memory retrieval is difficult. This level of awareness should not only incite the patients to use the tool, but also guide them in their interaction with it, for example knowing what type of information should be recorded or how to access recorded data [15]. This awareness of the existing deficit, or lack thereof (anosognosia), is often associated with memory deficits (see [14] for a synthesis concerning Alzheimer's disease (AD) and the use of external (or internal) aids. Thus patients must consciously remember to use the tool and consult it when trying to recall memories. In this context, more passive life-logging techniques might be a more effective rehabilitation tool because they require minimal patient input.

2. Which type of memory to rehabilitate?

Beyond the question of which type of tool to use, the question of which type of memory requires rehabilitation is crucial in order to reach specific goals, for example maintain home residence, or preserve self-identity. In this context, rehabilitation of episodic memory, tightly linked with self-identity, is a new challenge for neuropsychology. Episodic memory is defined as the capacity to recall information including its source, awareness of its origin, and the feeling it belongs to oneself or is self-related [16,17]. Episodic recall, in addition to including specific event-related information (spatio-temporal framework, sensorio-perceptive aspects) [18], also provides the feeling that the recalled event belongs to one's personal past, a feeling defined as autonoetic awareness [19,20].

More recently, Kline et al. [21] proposed that episodic memory implies not only retrieval of contextual information, but most importantly requires that the contents of the episodic memory be either (i) perceived as belonging to self; (ii) associated with a temporal sensation related to self; (iii) perceived as being the result of an action initiated by self, or finally (iv) implicating self-reflection capacities. Episodic memory is thus strongly associated with self. In contrast to episodic memory, it is easier to train semantic memory, defined as the retrieval of non-contextualized factual information [22]. Thus, it is easier to re-learn a fact, for instance *Paris is the capital of France*, than to re-learn one's autobiographical memory, for instance a wedding ceremony. To be more precise, the events that took place during the wedding ceremony could be re-learned as facts, but perhaps without ever becoming a real part of the learner's past experienced from the perspective of the self.

A few studies have nevertheless attempted to improve patients' capacity to retrieve episodic memory, for example by reading a personal diary or by looking at photos of family or friends. In this context, several studies have worked with this type of material to try to improve memory in patients with AD: three women with moderate AD [23]; six subjects with a diagnosis of mild to moderate AD [24]; one patient with severe AD [25]. The work by Bourgeois et al. [23] showed an increase in the number of autobiographical events recalled after presenting photos of the patient's everyday life or borrowed from the family album, an improvement that persisted six weeks after presentation of the photos. These results were later confirmed by others [26,27]. Sohlberg and Mateer [28] studied the effect of using a personal diary and found a decline in repeated narratives (also see [29]). Actually, these findings describe the usefulness of these tools as a memory-aid, but no study has focused on the specific effect these aids have on episodic memory. Thus it is not clear whether this type of aid can induce the patient to re-live a forgotten event similar to that induced by episodic recall. This review of the literature will focus on the idea that life-logging could enable recall of episodic information by facilitating retrieval of event-associated information, in other terms the ''something more'' that characterizes recollection [30]. Furthermore, this capacity to re-live an event with the majority of its initial richness (for example, to re-live the emotional feelings of the event) is what allows a person to maintain a coherent self-identity.

3. What type of cue?

Rehabilitation of episodic memory raises the question of the cues that will enable improvement. The critical point is to determine which tools (personal diary, videos) would facilitate retrieval of information stored in memory. As discussed above, we suggest that life-logging could be an ideal support to

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improve episodic memorization and allow patients to re-live their memories. The reason that life-logging could be an effective cue is based on the hypothesis of environmental support developed by Craik [31]. According to this theory, successful retrieval of a past memory requires both support from the outside environment and internal support, for example self-initiated memorization strategies. But, in memory impairment, for instance in AD, self-initiated internal strategic processes are affected [32,33], making external environmental support all the more important. Turlving and Arbuckle [34] distinguished between 'available' and 'accessible' information in memory. For these authors, an intact mnemonic trace is *available* and thus susceptible to retrieval, though it is not necessarily *accessible* to retrieval. Most of the time, people with memory disorders are unable to find a mnemonic trace spontaneously, not because the information is not there, but because an aid is required to make it accessible. Environmental support such as life-logging could thus facilitate retrieval of episodic information in a context where self-initiated mnemonic strategies are altered. In the remainder of this review, results will be presented from studies that have used a specific tool for the rehabilitation of episodic memory: SenseCam.

4. A new rehabilitation tool: SenseCam

SenseCam is a wearable camera that takes pictures spontaneously (without audio recording) in response to different sensors (light, temperature, sound, movement). It is a tool used to capture passive images with little or no user intervention. Users have described wearing the camera as non-intrusive [2]. Furthermore, according to Muhlert et al. [35], automatic image capture gives SenseCam a very high ecological value, since the images that will be viewed later and for which retrieval will be tested do not require any intentional encoding.

SenseCam has a wide-angle lens to obtain a maximal field of view. Photos can be taken every 30 s or in response to the sensors. This tool is not equipped with a means of viewing the images directly. To be viewed, images must be transferred to a computer and processed with dedicated software [36]. SenseCam was created by *Microsoft Research Cambridge*, and was first commercialized under the name Vicon Revue®, before taking on its most recent name Autographer® (OMG plc.). All of these versions, derived from the original, are based on the same principle: a camera that captures images automatically in order to obtain a rich set of photos of the user's daily life [36]. In this review, we will use the term SenseCam as a general term including all types of wearable cameras (Fig. 1).

4.1. *SenseCam: the something more*

The main goal of this review is to present research work that has used SenseCam as a tool to improve memory, targeting studies that measured episodic recall. We hypothesize that SenseCam (reviewing captured images) will act as a cue for the retrieval of autobiographical memories. It has been noted in certain memory disorders, such as AD, that information may

Fig. 1 – The mnemonic trace is designated by *m*.

be active in memory yet inaccessible. In other words, AD patients can recognize but not recall information [37]. We suggest that SenseCam constitutes an aid capable of elevating the activation of the mnemonic trace and thus of increasing information accessibility. This hypothesis is presented schematically in Fig. 2 (the mnemonic trace is designated by *m*). On the left, information retrieval is possible when *m* is intact. When *m* is weak (*m*/2), on the right, SenseCam can help raise the mnemonic trace above a threshold allowing information retrieval. Reviewing SenseCam images, or a full day compressed into a video, could have a beneficial effect on episodic memory. The important point is that reviewing the SenseCam images does not only allow access to earlier events, but also

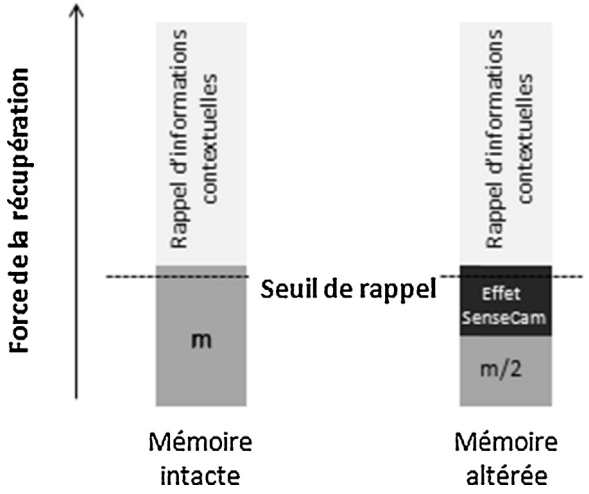

Fig. 2 – A hypothesised effect of SenseCam. When memory is altered, the mnemonic trace is activated below the recall threshold. Reviewing SenseCam images increases the force of retrieval via the cues contained in the contextual details of the original event, thus leading to activation above the recognition threshold. Contextual details can then be recalled.

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increases access to the 'something more' characteristic of recollection.

From our point of view, SenseCam is more than a simple instrument that captures images to be viewed later. It must also play a role concerning the detail contained in the images themselves, which is otherwise not easily available. Moreover, SenseCam should not only allow access to images, but also affect memory by re-initiating thoughts, feelings and (non-visual) sensorial input linked to the images. The question of transfer is raised: could SenseCam enable a broader improvement in autobiographical memory – does the use of the device transfer to improvements on tests of memory more generally? We refer here to the idea suggested by Loveday and Conway [38] by which SenseCam would allow users to access 'Proustian moments'.

According to Loveday and Conway, a 'Proustian moment' is defined as an intense moment of reminiscence when images of the past overflow into consciousness, producing a strong recollective experience. Such moments almost always have an 'aha!' quality, often offering a recollection accompanied by highly specific details that were not available and, in certain cases, not known before [38].

In line with the environmental support hypothesis, Loveday and Conway [42] propose that SenseCam helps retrieve currently inaccessible memories. They suggest that events in long-term memory are never lost as long as the neural networks within which they are represented remain stable. Thus an event could remain unavailable to recall until it is correctly cued. This is illustrated in the left part of Fig. 1. The force of the mnemonic trace designated by *m* is based on the level of activation of the neuronal network when an event is recalled. When the activation remains below the threshold, memory of the event may be preserved but difficult to recall. As explained in the environmental support hypothesis, cueing can stimulate the neuronal network to the level of possible information retrieval, leading thus to the recall of contextual information.

The right part of Fig. 1 represents the way SenseCam acts on a weakened mnemonic force (*m*/2). Our hypothesis assumes thus that SenseCam acts as a powerful cue, stimulating the event-related mnemonic trace, and thus allowing access to the event and the associated details, even including those not represented in the images. This corresponds to a ''Proustian moment'' described by Loveday and Conway: the image, as a cue, allows access to forgotten or inaccessible information. But would SenseCam really be able to generate such Proustian moments itself, or would it simply allow people to re-familiarize themselves with their past events? This would only have a weak effect on declarative memory and thus would not enable rehabilitation of episodic memory.

4.2. *SenseCam as a memory rehabilitation tool*

This section presents the studies that have used SenseCam as a memory rehabilitation tool. The databases used for this review of the literature were Pubmed, ISI Web of Knowledge, and ScienceDirect. Certain studies were also identified by analyzing reference lists or other reviews. Search items were: SenseCam; memory; life-logging. Studies were included in this review if their abstract corresponded to the topic under consideration and if they met the following criteria: SenseCam or a similar system used in the study; theoretical articles were excluded; use of SenseCam had to be the purpose of the study (i.e. we excluded studies using SenseCam devoted to analysis of daily activities, learning/education experiences, reflection/culture, life data) (for an overview of the uses of SenseCam see [39]); the studies had to describe experiences producing results and not simply analyses of a methodology, an opinion or a theory. To date, two special issues have been devoted to SenseCam (*Memory*, volume 19, issue 7, 2011; *American Journal of Preventive Medicine*, volume 11, issue 3, 2013).

The 24 scientific articles selected for this review can be divided into two categories (Table 1). The first category concerns studies using SenseCam as a tool to record personal data, life images, with a strong cueing potential for episodic recall. The teams working in this field reported case studies of patients presenting memory impairments, group studies, and neuroimaging methods. The second category of studies examined whether SenseCam has a general effect on memory performance, and thus an effect that is not limited to reactivation of the events displayed in the images (transfer).

4.2.1. *Case studies*

Eleven selected articles described case studies. Most were first attempts at memory rehabilitation using SenseCam [40,41]. Patients with limbic encephalitis [40], damage to the medial temporal lobe [42], brain injury (damage to central nervous tissue caused by head trauma) [43], mild cognitive impairment (mild memory deficit due to a degenerative process) [42], brain tumor [44], hypoxic ischemic encephalitis [45], AD [46], and Korsakoff syndrome [47] were tested for retrieval of personal memories after wearing SenseCam and reviewing the captured images.

Most of these case studies compared the use of SenseCam (photos repeatedly reviewed several times a week) with reading a personal diary. In these studies, patients were asked to recall detailed autobiographical events a few weeks or a few months after using SenseCam. In this context, the study by Berry et al. [41] compared the use of SenseCam with a personal diary versus a control condition where no aid was proposed. The three conditions were performed consecutively. Photos of the patient's daily life were taken. In the diary condition, patients were asked to write down the events that occurred in their daily life. In the control condition, no specific action was requested. At the end of each condition, a life-event recall test was performed every two days for two weeks. After a first recall, the SenseCam images or diary were reviewed. The study showed that viewing the SenseCam images increased recall of autobiographical events. Moreover, for this study, long-term recall was also increased, with 80% recall of events at one month in the SenseCam condition versus 49% in the personal diary and 2% in the control condition. Very long-term recall was also observed (67% at 2 months, 76% at 3 months). In comparison with a personal diary, SenseCam thus enabled sustained long-term recall (results corroborated by [40] in a 63-year-old woman with limbic encephalitis, by [48] in a 28-year-old man with brain trauma, by [49] in a 55-year-old woman with mild cognitive impairment, and by [44] in a 13-year old with anterograde amnesia). SenseCam was also

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Table 1 – Summary of experiences using SenseCam as a memory rehabilitation tool. The articles are listed by type of study, year of publication, and type of sample.

Authors (year)	Type of study	Sample	Methods	Results
Berry et al., 2007	Case study	63-year-old woman with limbic encephalitis (Mrs B)	Intra-subject design 3 conditions SenseCam: review of photos taken with SenseCam Written diary: reading diary Control: no memory aid. Recall tested every 2 days for 2 weeks Follow-up: recall tested at 1, 2, 3 months for the SenseCam condition and at 1 month for the written diary condition	At 1 month, better event recall with the SenseCam condition (80%) compared with the written diary condition (49%) and control (2%). Sustained long-term event recall with SenseCam (67% recall after 2 months, 76% after 3 months)
Berry et al., 2009	Case study	68-year-old woman with limbic encephalitis (Mrs B)	Intra-subject design Condition 1: SenseCam images taken during a memorable trip (first visit to a luxury hotel) Condition 2: SenseCam images taken during a trip Condition 3: SenseCam images taken by another person Condition 4: Personal diary written during a trip. Review of images or reading diary event every 2 days for 3 weeks (except condition 1). Image recognition test (Know/ Familiar/Guess) for each condition under fMRI	No difference between conditions 1 and 3. Better image recognition for the SenseCam review conditions and written diary ($P < 0.001$). fMRI showed increased cortical activation in the frontal and posterior regions for the SenseCAm image review condition versus written diary
Bowen et al., 2008	Case study	36-year-old woman with damage to the medial temporal lobe and severe anterograde amnesia (Mrs CB)	Intra-subject design Administration of an event (board game) 3 times a week for 4 weeks 3 conditions: visual recording of the event with SenseCam, audio recording, no recording Immediate and differed recall tests (5, 15, 30, 50 min) at each event administration. Recall test: questions on the events with different levels of difficulty	Delay was main effect on recall for the 3 conditions ($P < 0.01$) No SenseCam effect on recall (P = NS) Recall cue better for SenseCam condition vs control ($P = 0.01$, SenseCam = 3, control = 2.1)
Doherty et al., 2012	Case study	Healthy 34-year-old man (Mr CG)	SenseCam images taken for 2.5 years. 50 important events selected by subject and by dedicated software. Then random selection of 50 events. Subject rated personal importance of each event. Investigation of the software capacity to identify important personal events	The subject attributed higher scores to self-selected events compared with software-selected events. Subject attributed higher scores to software-selected events than to random-selected events
Browne et al., 2011	Case study	56-year-old woman with mild cognitive impairment (Mrs W)	Intra-subject design 2 conditions: SenseCam, written diary 6 remarkable events performed, recall test every 2 days for 2 weeks and review of images or reading diary after each recall test Differed recall at 1, 2 and 3 months without cueing (image review or diary reading) Quality-of-life questionnaire	Better recall for the SenseCam condition compared with diary for short-term recall (64% vs 51%) and long term recall. Sensecam short-term recall (68% vs 30%) Decreased stress and increased confidence with SenseCam

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Table 1 (*Continued*)

Authors (year)	Type of study	Sample	Methods	Results
Loveday and Conway, 2011	Case study	47-year-old woman with damaged medial temporal lobe (Mrs CR)	Intra-subject design 2 conditions: SenseCam, diary One discrete event recorded each week for 4 weeks Free and cued recall each week. Comparison of number of episodic details recalled	Better recall in the SenseCam condition vs diary ($P < 0.05$). More episodic details recalled with SenseCam (329) than with diary (250)
Pauly-Tackacs et al., 2011	Case study	13-year old with anterograde amnesia due to intracranial metastases (Patient CJ)	Photos taken during a walk with key localizations (art gallery, café, church.). Comments were made about each visited site in order to generate contextual information to be tested later. SenseCam was operating for two sites and not operating for two others Image recognition at 2, 10 and 15 weeks	Increased image recognition for SenseCam image review condition of but only for information contained in the images. SenseCam would thus aid in formulating personal semantic memories
Garrood, 2012	Case study	10-year-old girl with encephalopathic ischemic hypoxia (Patient AB)	SenseCam worn during a treasure hunt containing cues at certain sites and actions to perform. Recall test 24 h later then review of SenseCam images at +24 h and +1 month	Preliminary data Improved recall only for events contained in the images. SenseCam helps formulate personal semantic memories
Piazek et al., 2012	Case study	85-year-old man with mild Alzheimer's disease (Mr J)	SenseCam used for 7 weeks. Images viewed twice a week with recording of comments and thoughts about the images	Better detail recall concerning events and details recalled not seen in SenseCam images
Svander and Evans, 2013	Case study	51-year-old woman with moderate Korsakoff syndrome (Mrs A)	Evaluation of subjective memory, self-esteem, anxiety and depression after using SenseCam	Improvement in subjective memory and self-esteem (4.36-point increase). No change in mood
Sellen et al., 2007	Experimental group	19 healthy young adults (10 male, 9 female, age 18–22 years)	Intra-subject design 3 conditions Passive SenseCam image capture; active SenseCam image capture; control Short-term (3 days later) and long-term (10 days later) memory tests: remember/know/guess paradigm and recognition test	Greater number of events recalled with SenseCam compared with control condition (before $P < 0.02$, after $P < 0.03$) Greater number of K (known) events with SenseCam. Better event recall for passive versus active capture
Doherty and Gurrin, 2009	Experimental group	3 healthy males	Review of SenseCam images recorded over a 1-month period and marking boundaries between each event Repeated 1 and 2 years later	Boundaries determined better by persons who lived the event. Loss of boundaries after 1 and 2 years
Kalnikaite et al., 2010 [71]	Experimental group	18 healthy adults (4 female, 14 male, age 25–56 years)	Intra-subject design 2 conditions: SenseCam images and GPS for 2 weeks vs no aid Review of SenseCam Images 5 weeks after event (images alone, images + GPS, GPS alone) Remember/know/guess paradigm	Better detail recall with SenseCam + GPS ($P < 0.01$) SenseCam alone and control condition identical ($P > 0.05$) Superior recall for SenseCam alone compared with GPS alone or GPS + SenseCam ($P < 0.01$)
Milton et al., 2011a, 2011b	Experimental group	15 healthy young adults (8 male, 7 female, age 18–25 years)	SenseCam used for 2 days. Remember/Know test under fMRI Study repeated 5 months later with 10 participants	Retrieval did not cause any activation in the medial temporal lobe after a 5-month delay. But superior activation of the parahippocampal posterior gyrus for familiarity versus remember was observed Recruitment of extra-medial temporal lobe regions when memories were far

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Table 1 (*Continued*)

Authors (year)	Type of study	Sample	Methods	Results
Sas et al., 2013	Experimental group	14 healthy young adults (7 male, 7 female, age 18–23 years)	SenseCam and Sensewear used for 6 hr. At the end of the day, review of 4 photos with strong emotional intensity and 4 photos with weak emotional intensity	Emotional intensity increased detail recall for the events ($P < 0.01$) The event, the localization, and associated emotions were recalled better than temporality or thoughts, irrespective of emotional intensity
Seamon et al., 2013	Experimental group	144 healthy young adults aged 17–23 years	Inter-subject design 3 conditions: Sensecam, diary, no aid for a walk where atypical actions were performed After the walk the group was divided in 2 for photo review, individually or in group Review performed 1 week before free event recall	Social reminiscence better than self-reminiscence (0.78 vs 0.64) Recall of atypical actions not different between SenseCam (0.74), diary (0.69) and control (0.68)
St Jacques et al., 2013	Experimental group	Study 1: 42 healthy young adults (15 male, 27 female, mean age 21.1 years) Study 2: 43 healthy young adults (18 male, 25 female, mean age 21.41 years)	Study 1: guided visit to a museum with SenseCam 18 h delay before viewing any new images Chronological manipulation of the images. Study 2: same procedure, manipulation concerned origin of images (self versus other person)	Better recognition of images belonging to own experience versus someone else's images ($P < 0.01$) Higher rate of false recognition with new images ($P < 0.01$) Improved memory, but also false recognitions ($P < 0.01$)
St Jacques et al., 2011	Two experimental groups	23 healthy subjects (12 female, 11 male, age 18–35 years)	Intra-subject design SenseCam and diary for 6 days fIRM 1 day after reviewing SenseCam images and verbal cuing + subjective evaluation	Superior subjective evaluation of vivacity, reviviscence, importance, emotion and uniqueness for SenseCam condition ($P < 0.01$) fMRI pattern more marked for men than women, better activation of the left hippocampus, the retrosplenial cortex, the left inferior frontal gyrus as well as the right occipital cortex for the SenseCam condition compared with diary
Silva et al., 2012	Two experimental groups	15 adults and 14 elderly adults	Intra-subject design SenseCam used for 3 days then diary for 3 days Neuropsychological tests after each condition (conditions counterbalanced, parallel test forms)	Better performance on all neuropsychological tests after SenseCam vs diary (example: autobiographical memory, $P < 0.01$; size effect 0.82) Strong impact on memory tasks and executive functions
Muhlert et al., 2010	Two experimental groups: control vs clinical	11 patients with transient epileptic amnesia and 11 matched healthy controls	SenseCam used during a cultural visit. Images reviewed the same day then 1 and 3 weeks later Comparison of forgotten events, forgotten events on a list of words, and a procedural memory task	Accelerated forgetfulness in the amnesia group for event memory, maximum number of forgotten events on first day compared with controls ($P < 0.05$). Declarative memory was specifically forgotten; the procedural memory appeared to be intact
Woodberry et al., 2014	Clinical group	6 adults with mild to moderate Alzheimer's disease (age 64-84 yrs)	2 conditions: SenseCam, written diary Patients' memory of an event, followed by review of SenseCam images, was tested every 2 days for 2 weeks Recall 3 months later	Better recall of details for the SenseCam condition versus diary ($P < 0.01$) Long-term results (3 months) 4/5 patients recalled more details of the events

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Table 1 (*Continued*)

Authors (year)	Type of study	Sample	Methods	Results
Lee and Dey, 2008	Clinical group	3 adults with mild Alzheimer's disease	Intra-subject design Significant personal events recorded using SenseCam for 2 weeks, audio and GPS recordings 4 conditions: control (no aid), patients wearing SenseCam, caregiver wearing SenseCam, caregiver wearing SenseCam and selecting images	Recall and number of details was greater (ca. 40% recall) when patients wore SenseCam compared with caregiver wearing SenseCam ($P < 0.05$). In this latter condition, performances declined (ca. 10% recall, $P < 0.05$)
Crete-Nishihata et al., 2012	Clinical group	5 adults with Alzheimer's disease or mild cognitive impairment	SenseCam used for 3 short journeys with an assistant After each journey, evaluation for 2 weeks with 5 autobiographical interviews 3 months after each event, autobiographical interviews were again conducted	Better episodic event recall for the SenseCam condition (for 4/5 participants) ($P < 0.05$)

fMRI: functional magnetic resonance imaging.

described in these studies as affecting recall specificity (more details were provided for events seen in images) [2,43]. The authors did not state whether the details provided were present in the images themselves, but we can tentatively suggest that the extra details recalled were an effect of SenseCam. The study by Loveday and Conway [38] conducted in a 47-year-old woman with a damaged medial temporal lobe also showed increased specificity for events not present in the images, results that support our hypotheses.

Elsewhere among the case studies, two studies indicated an improvement in semantic autobiographical memory [44,45]. Pauly-Takacs et al. [44] studied a 13-year old with anterograde amnesia due to intracranial metastases and Garood [45] studied a 10-year old with encephalopathic hypoxic ischemia. These authors suggest that the beneficial effect of SenseCam observed in their patients is due to a change in personal semantic information. For instance, one patient recalled whilst reviewing his images, that the image showed the longest corridor in Europe, adding ''I went there''. This appears to suggest a re-learning process, or what Kalnikaite and Whittaker [40] call an 'inference' from the images, re-stated as a fact. These people could 'recognize' or extrapolate from events depicted in the images and relearn this information as personal knowledge that would be recorded in the semantic memory system and not in episodic memory.

4.2.2. *Group studies*

Other studies have explored the usefulness of SenseCam in the process of normal aging and in specific clinical populations. These studies reinforce the idea that SenseCam improves both episodic memory and personal semantic knowledge. Many of these studies have measured the number of items retrieved after viewing SenseCam images (quantitative analysis), but also self-assessed memory performance (qualitative analysis). This latter approach is essential for our hypothesis. Indeed, our hypothesis suggests that SenseCam enables an improvement in the episodic aspect of memory. SenseCam should not only have a beneficial effect on the amount of information retrieved, but should also improve the quality of the information recalled, with more detail, and a richer experience for past events. An improvement in episodic memory with SenseCam has been demonstrated both in healthy populations – a group of 3 men [50], a group of 18 adults [28], a group of 14 young adults [51] – and in populations presenting with memory disorders – 3 adults with AD [52], 5 adults with AD or mild cognitive impairment [53], 6 adults with AD [1].

Studies in cohorts of healthy participants show that the use of SenseCam leads to improved recollection. Sellen et al. [54] (19 healthy young adults) probably provided the clearest example showing an improvement in recollection. These authors tested 19 students who had worn a SenseCam for 13 consecutive days using image recognition tests (SenseCam captures) while wearing the SenseCam on days 3 and 10. Three conditions were used: in the first, SenseCam captured images passively; in the second images were captured actively (capture triggered by the participant); in the third photos taken by other people were used as a control condition. Memory was tested three ways: a self/other condition (is this photo one of yours?); a classification test where images were to be placed in chronological order; and a recall test where the participants generated the events of the day in detail. This test examined free recall before and after viewing 10 images (SenseCam or control). For this recall test, the participants had to class their memories as being either recollected or merely recognized 'known' [30]. The results showed that simply wearing the SenseCam considerably improved retrieval of the day's events. The events classed as known were recalled less and SenseCam had no effect on these memories. The classification task demonstrated that the participants classified more easily their own events of the day than the events of another person. For the recognition task, a number of false positives were observed, but the majority of the participants successfully (80%) discriminated their own photos. Summarizing, the results of Sellen et al. underscore the idea that SenseCam improves event recall, but also permits acces to details which are recollected.

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These group studies have also contributed to a clarification of the usefulness of SenseCam in comparison with other types of recording instruments, a critical point for its status as a rehabilitation device. Sellen et al. [54] for example concluded that in the control population, passive capture of SenseCam images (according to the on-board sensors) is better than active capture obtained with ordinary cameras.

Certain studies have however questioned the idea that SenseCam is associated with an improvement in memory [55]. St Jacques and Schacter [55] studied 53 healthy young adults and suggested that SenseCam helps improve the quality of judgment concerning the images, but also contributes to increased false recognition with confusion between images taken by the participant and images taken by others. In their study [55], the authors compared recognition between images of actions actually performed and new images (similar environment, but not where the participant had been). According to Schacter et al. [56], this task would lead to a confusion of the source memory because of the similarity of the photos. In a similar study, Seamon et al. [57] asked 144 healthy young adults to recall atypical actions they had made a week earlier (for example press the elevator button with one's elbow). The results showed that SenseCam review did not contribute to better recall of atypical actions actually performed and thus did not enhance memory.

Certain group studies have also focused on improved mnemonic performance with SenseCam during the normal aging process [58]. Silva et al. [58] studied 15 young adults and 14 older adults focusing on the evaluation of a global effect (recall of information contained in the images was not measured) using standardized neuropsychological tests. In this study, the participants wore a SenseCam for three consecutive days then wrote a personal diary for three more days. Neuropsychological tests were performed after each phase. The results of this study show an improvement in memory for all of the mnemonic measures studied (test of autobiographical memory [59], free recall/cued recall FR/CR16 [60], symbol search and coding [61], month ordering [62]), that was only present after using SenseCam for three days (in comparison with reading a personal diary). These results thus support the idea that SenseCam stimulates memory in general and does not simply cue the recall of information present in the images.

Finally, certain studies have explored the use of SenseCam in group studies with clinical populations. Muhlert et al. [35] studied two groups of subjects (11 epileptic patients versus 11 healthy subjects) to compare how verbal and non-verbal memory is forgotten over time in patients with transient epileptic amnesia. In this study, visual memory was assessed using SenseCam photos. The patients wore a SenseCam while taking walks. Memory of the events captured by SenseCam was tested at 3 h, 1 day, 1 week and 3 weeks after image capture. Five photos were presented to the participants who were to recall the event depicted in the photo and give as many details as possible. The results showed that a similar number of events and details were recalled 1 day after the photo capture by both the patients and the control group, but that during the following three months epileptic patients lost memory of the events more rapidly than the controls. This study is a little different because it uses SenseCam to measure memory in a naturalistic manner, rather than seeking to improve memory function. In a more recent study, Woodberry et al. [1] studied the SenseCam effect on autobiographical memory performance in a sample of six patients with mild to moderate AD. The patients' memory of events captured on SenseCam was tested twice a week for two weeks. Comparison with a written diary showed a significant improvement in the number of details provided when using SenseCam. These results confirm that the use of SenseCam in these patients is associated with an improvement in autobiographical memory (results corroborated by Lee and Dey [52] and by Crete-Nishihata et al. [53]).

In sum, the majority of the studies presented have found a beneficial effect of SenseCam on retrieval of information stored in memory. Indeed, all of the studies emphasize the increase in both the quantity – number of events recalled – but also the quality of the memories, with a greater number of details provided about the recalled events. Nevertheless, the studies reported here remain quite heterogeneous in terms of the methodologies used and the clinical populations studied. In other words, the question of the beneficial effect of SenseCam remains to be fully elucidated.

4.2.3. *Neuroimaging studies*

Part of the studies cited above report neuroimaging data that also provides information concerning the hypothesis that SenseCam leads to an improvement in episodic recall. These studies focus on the activation of brain regions implicated in memory, particularly the mediotemporal regions often associated with recollection [30]. In a study by Milton et al. [63], participants wore a SenseCam for two consecutive days then performed image recognition tests with functional magnetic resonance imaging (fMRI) 36 hr and 5 months after using SenseCam. The results in 15 young healthy adults revealed an activation of the right anterior and posterior hippocampal regions when the participants reviewed SenseCam Images 36 hr after their capture [63]. After a longer delay (5 months), the images triggered an activation of the neocortical regions (medial prefrontal cortex), regions associated with strategies involved in memory retrieval. In a study by St Jacques et al. [64], the participants wore a SenseCam for six consecutive days and one week later had an autobiographical event retrieval test under fMRI. SenseCam images were used as cues. This study compared between men and women the impact of viewing SenseCam images on brain activation during autobiographical retrieval. Activation of the medial temporal lobe was also revealed. The results of these two studies suggest that the prefrontal cortex and the medial temporal lobe are activated by SenseCam giving force and longevity to memories [63]. The purpose of SenseCam being to capture self-referential information, the study by St Jacques et al. [63] supports the notion that the self-projection given by SenseCam would activate the medial prefrontal cortex. The medial prefrontal cortex stimulates the medial temporal lobe associated with the memory process. Thus, the increased activation of the medial temporal lobe would allow retrieval of information indispensable for successful recollection (information depicted in the images, contextual information, autonoetic awareness) as proposed by Loveday and Conway [38].

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5. Discussion

We will begin this discussion by presenting the characteristic features that make SenseCam a beneficial tool for memory rehabilitation. The first characteristic was described by Conway [65] as the 'mimetism' of autobiographical memory. SenseCam captures images from an egocentric point of view and does not require explicit intervention by the user. According to Conway [65], capturing images from an egocentric point of view is essential for the efficacy of SenseCam. Moreover, earlier studies have demonstrated that photos taken from one's own viewpoint enable a more vivid, more specific and more emotional memory retrieval [66]. This thus leads to 'mental time travelling'. These results have also been corroborated by neuroimaging data [65]. Neuroimaging demonstrates an activation of the neuron networks implicated in re-experience of the past and in autonoetic awareness, via reviewing SenseCam photos. The SenseCam photos induce an important feeling of identity, sustaining strong mnemonic traces [38]. This represents the 'something more' hypothesis where recalled information goes beyond the information presented in the photos themselves [38,44].

Another characteristic feature making SenseCam a suitable rehabilitation device comes from the fact that the tool requires very little user input, being a relatively passive device. Certain patients with memory disorders are also anosognosic and thus have only minimal perception of their own difficulties. The advantage of SenseCam is to provide this type of patient with a rehabilitation tool that requires little or no awareness of the disorder. Aside of wearing the device and reviewing the images, there is no need for active involvement with the device during its operation.

The final characteristic is the capacity of SenseCam to compensate for deficient self-initiation processes, again a problem often present in patients with memory disorders. Most of the time these patients, because of altered self-initiation processes, fail to find sought-for information spontaneously (due to an absence of context). Here, SenseCam can play a critical role by providing the necessary context to trigger successful information retrieval.

One of the major problems in the studies reviewed here is the lack of statistical power of the effects reported. Excepting a small number of studies [55,57,58,35,64], the majority have been reports of individual cases or small groups of users ($n < 20$). Consequently, the results observed to date need to be confirmed. Furthermore, the beneficial effect of SenseCam could be diminished by a possible cognitive overload effect caused by reviewing the images. SenseCam sometimes captures a large volume of information that might induce mnemonic overload [38], or even cognitive fatigue. In response to this problem, recent studies [e.g. 2] have begun exploring the possibility of segmenting the events, dividing them according to different benchmarks such as the environment, the time point, the theme or the persons involved. Thus the purpose of the study by Doherty et al. [2] was to develop a segmentation program mimicking the way memory functions. Thus the SenseCam images that were classed according to the different benchmarks would provide better cues for episodic recall and avoid possible overloading.

The studies presented in this review of the literature thus suggest that SenseCam has a beneficial effect on episodic memory performance as well as on certain other cognitive domains, including executive function. Silva et al. [58] assessed executive functions by testing verbal fluency and found improved test performance after using SenseCam. The focus on memory function is a limitation of the existent research. For example, there has been no assessment of the impact of SenseCam on subjective complaints or quality-of-life. And the goal of rehabilitation is not limited to a simple improvement in memory performance, but is aimed at improving the patient's quality-of-life. It would thus be necessary to assess these criteria in future studies.

One of the questions that also remain to be explored is whether the use of external aids such as SenseCam would improve patients' awareness of their memory problems (metamemory). The literature shows that people who have mnemonic disorders present, for the majority, metamemory deficits [67]. Certain studies have showed that awareness of memory problems has a positive impact on rehabilitation, and thus on memory performance [68,69]. The use of SenseCam, via improved awareness of mnemonic disorders, could thus indirectly improve memory and potentially have an impact on the mnemonic and/or cognitive complaint.

One of the hypotheses we put forward at the beginning of this review was the following: SenseCam could constitute an adequate environmental support, acting like a cue for retrieval of autobiographical memories. Overall, the results presented in this review would appear to confirm this hypothesis of environmental support. Furthermore, SenceCam constitutes a particularly appropriate tool for memory rehabilitation in comparison with other available tools. Neuropage [70] for example, is a paging system that was developed for patients with memory disorders. This tool works by reminders. A list of things to recall can be inserted into the Neuropage software that then automatically sends a recall message to the paging system at the appropriate moment. Alone, this tool cannot improve prospective memory. Coupled with other tools such as a personal diary, Neuropage might be able to influence other types of memory functions, for instance autobiographical memory. However, this would mean that the patients would have to use two tools instead of one, a further constraint. Wilson et al. [70] evaluated the effect of Neuropage in 143 patients with brain lesions (head trauma or stroke). The patients presented at least one of the following disorders: memory disorder, planning disorder, attention, or organizational problems. The impact of Neuropage was tested two to seven weeks after beginning to use the tool. The results showed improved execution of daily activities (personal hygiene, use of medications…) for more than 80% of patients. Neuropage thus appears to reduce observed memory deficits and organizational problems.

Svoboda et al. [10] tested the use of a cell phone as well as a 'personal digital assistant' in order to stimulate memory. This study, conducted in 10 amnesic patients, demonstrated that the use of these devices diminished considerably deficits in prospective memory (forgotten appointments, taking medication). Another study by Quittre et al. [12] used a cell phone to create an automatic agenda. In this case study conducted in a patient with mild cognitive impairment, the results demons-

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trated a beneficial effect of using the memory aid. Despite the demonstration of the beneficial effect of these technologies (Neuropage, personal digital assistant, cell phone) on memory, these tools, unlike SenseCam, do not enable rehabilitation of episodic memory, but rather mainly influence prospective memory.

Finally, SenseCam-like rehabilitation tools have been implemented on cell phones [11]. Patients have to wear the cell phone on a neck strap so that it can capture images automatically throughout the day. The effect of reviewing the acquired images on autobiographical memory was tested. These two tools (cell phone and SenseCam) were similar in all ways in terms of use, but the cell phone had the advantage of data transfer; it captured images throughout the day and transferred them to a safe server automatically. Videos were rapidly created from the photos and sent to patients by email or DVD. The advantage of being able to transfer images and rapidly create videos is undeniable, especially for longitudinal implementations where the videos should be reviewed regularly. For SenseCam, the investigator needs to visit the patient at home regularly in order to transfer the images and create videos–or the patients' caregiver could be trained to transfer images and create videos. This adds a supplementary constraint, in addition to using the tool. The cell phone eliminates this problem by its data transfer function.

6. Conclusion

In conclusion, the studies presented in this review of the literature have demonstrated the potential of SenseCam as a technique for memory rehabilitation. The goal of this review was to provide a complete update on published studies in order to set the basis for solid theoretical analysis concerning the memory improvement obtained via SenseCam. At the present time, the evidence supporting the efficacy of SenseCam is weak, though positive. It is also noteworthy that because of the rapid development of these novel devices the research conducted to date has been highly heterogeneous, leaving much room for further study in this field of neuropsychology. In the long run, studies should focus on much more qualitative aspects of the question, testing the effect of this tool on patients' quality-of-life and metamemory. They should also provide solid evidence concerning the 'something more' hypothesis assumed to result from the use of SenseCam.

Disclosure of interest

The authors declare that they have no competing interest.

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