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The use of a wearable camera, SenseCam, as a pictorial diary to improve autobiographical memory in a patient with limbic encephalitis: A preliminary report

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This case study describes the use of a wearable camera, SenseCam, which automatically captures several hundred images per day, to aid autobiographical memory in a patient, Mrs B, with severe memory impairment following limbic encephalitis. By using SenseCam to record personally experienced events we intended that SenseCam pictures would form a pictorial diary to cue and consolidate autobiographical memories. After wearing SenseCam, Mrs B plugged the camera into a PC which uploaded the recorded images and allowed them to be viewed at speed, like watching a movie. In the control condition, a written diary was used to record and remind her of autobiographical events. After viewing SenseCam images, Mrs B was able to recall approximately 80% of recent, personally experienced events. Retention of events was maintained in the long-term, 11 months afterwards, and without viewing SenseCam images for three months. After using the written diary, Mrs B was able to remember around 49% of an event; after one month with no diary

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readings she had no recall of the same events. We suggest that factors relating to rehearsal/re-consolidation may have enabled SenseCam images to improve Mrs B's autobiographical recollection.

INTRODUCTION

Psychological intervention and rehabilitation can alleviate some of the debilitating everyday memory and cognitive problems encountered by people with brain injury. The use of external memory aids to help people to compensate for their memory deficits is thought to be one of the most valuable and effective ways to aid rehabilitation (see Kapur, Glisky, & Wilson, 2002, for a review). By directly reducing the impact of memory impairment on everyday functioning, external memory aids can increase confidence and self-esteem – this in turn allows the individual to use those cognitive resources available to them, rather than being subject to further memory impairment through anxiety or depression. The psychological well-being of the carer may also improve and carer burden may lessen (Clare & Woods, 2001).

Encephalitis that primarily involves limbic system structures such as the hippocampus and parahippocampal gyrus has been described in early papers (Rose & Symonds, 1960), but it is only in recent years that the condition has been recognised as being more common than hitherto realised and the range of possible pathogens has been well documented. In comparison to herpes simplex encephalitis (Kapur et al., 1994), which involves limbic structures but also adjacent neocortical areas, limbic encephalitis is usually not associated with a specific virus, apart from rare viruses such as herpes virus 6 (Gorniak et al., 2006), and it has instead been associated with autoimmune disorders. Limbic pathophysiology may be secondary to a tumour such as an oat cell lung carcinoma, as in paraneoplastic limbic encephalitis (Corsellis, Goldberg, & Norton, 1968), or it may reflect a primary disorder, as in voltage gated potassium channel antibody limbic encephalitis (Vincent & Bien, 2005). In view of the involvement of limbic system structures in many forms of encephalitis, disorders of memory inevitably feature prominently as significant accompaniments to such conditions and serve as a focus for attempts at rehabilitation.

Most external memory aids serve to improve prospective memory functioning; that is, remembering to keep appointments, take medication, etc. There are many and varied compensatory devices available including calendars, diaries, alarm watches, whiteboards, timers, post-it notes and so on. The use of a combination of these aids has been effective in increasing independence in brain injured patients (Kime, Lamb, & Wilson, 1996; Oddy & Cogan, 2004). More sophisticated tools, such as hand-held electronic

schedulers have also been evaluated. Wilson and her colleagues have documented the effectiveness of NeuroPage, an easy-to-use pager, which the patient wears on a belt, that stores and transmits reminders (Wilson, Evans, Emslie, & Malinek, 1997; Wilson, Emslie, Quirk, & Evans, 2001).

In contrast to the domain of prospective memory functioning, there are few external memory aids that aim to improve the ability to remember past experiences. Yet people with memory problems following brain damage often experience difficulties recollecting remote and recent autobiographical events. The term "autobiographical memory" generally denotes a form of episodic or personally experienced memory that comes with a sense of reliving or recollection. Autobiographical memory appears to support the formation of one's personal life history and to contribute towards self-identity and self-concept. Conway (2005) emphasises the interconnectedness of self and memory in his Self-Memory System (SMS) framework. This model proposes that autobiographical knowledge is the database of the self, and "constrains what the self is, has been and can be" (p.594) and it advocates that a coherent and stable self induces high self-esteem, positive well-being and concomitant physical health benefits. Nelson (1993) and Hyman (2000) suggest that the significance of autobiographical memory is in sharing recollections with other people, creating solidarity and guiding present and future actions.

In the current study we evaluated the use of a wearable camera, SenseCam, as an aid to improve recent autobiographical memory in a patient with severe memory impairment following limbic encephalitis. By regularly reviewing the images, we intended that SenseCam would be used as a pictorial diary to both cue and consolidate autobiographical memories. In a separate control condition, a written diary was used to cue and consolidate our patient's recall of recent autobiographical events. In a further "baseline" condition we evaluated our patient's baseline memory by replicating the SenseCam and written diary conditions without the use of memory aids or rehearsal.

METHOD

Participant details

Clinical history. Mrs B is a 63-year-old, right-handed woman. She was born and educated in South Africa, where she gained a BA in English and a Higher Diploma in Bibliography and Librarianship. Prior to her illness and memory problems she was working as a freelance proofreader and copy editor. Mrs B met her husband, to whom she has been married for 35 years, in Southern Africa. For the past 18 years they have been living in England.

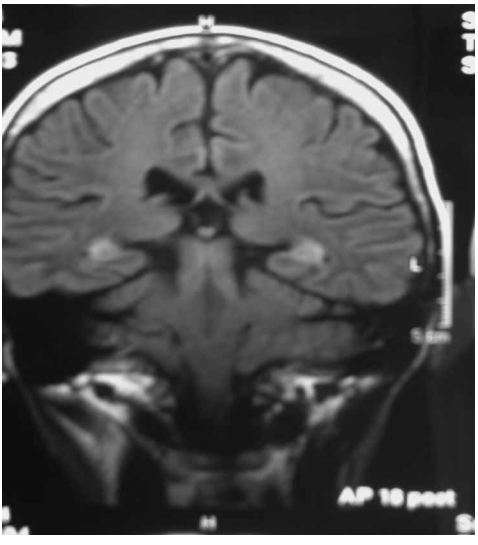

Figure 1. Magnetic resonance brain scan (coronal view) showing bilateral hippocampal lesions.

In March 2002 Mrs B was admitted to hospital in a febrile confusional state. She was diagnosed with limbic encephalitis. An MRI scan in April 2005, shown in Figure 1, showed a mild degree of volume loss in the medial temporal lobes, specifically the hippocampi. Mrs B made a good clinical recovery of her acute illness. However, formal neuropsychological assessment (Table 1) highlighted residual cognitive dysfunction.

Between April 2003 and April 2005, a wide range of neuropsychological tests were administered to Mrs B. Estimates of premorbid cognitive functioning suggested someone who was in the above-average range, in keeping with her educational history. On memory tests, Mrs B demonstrated marked anterograde memory impairment and mild to moderate retrograde memory impairment. Performance on the Autobiographical Memory Interview revealed difficulties in her recall of autobiographical events across both recent and remote time periods. Emotionally, Mrs B had a moderate degree of anxiety about her memory difficulties, in particular about social situations. Before her illness Mr and Mrs B led an active social life, travelled extensively and entertained regularly. After her recovery, Mr and Mrs B aimed to continue these activities, but because of her memory deficits, Mrs B said that she lacked confidence in company, fearing that she would forget who people were.

Mr B is a well-educated 70-year-old former senior businessman. He hoped that SenseCam would improve his wife's autobiographical memory. He also hoped that if her memory improved, he might be able to share experiences with his wife again.

TABLE 1
Neuropsychological test results for Mrs B (April 2003 to March 2005)

Test	*Raw score*	*Scaled score or percentile (where appropriate)*	*Comments*
Estimate of premorbid cognitive functioning			
National Adult Reading Test	13 errors	Predicted FSIQ = 115	Above average estimated premorbid cognitive functioning
Memory			
Doors and People Memory Test: All tests			1^{st}–5^{th} percentile
Autobiographical Memory Interview: All tests			
Childhood Personal Semantic	18/21		Acceptable range
Childhood Autobiographical Incidents	2/9		Definitely abnormal
Early Adult Life Personal Semantic	15/21		Probably abnormal
Early Adult Life Autobiographical Incidents	3/9		Definitely abnormal
Recent Life Personal Semantic	15/21		Definitely abnormal
Recent Life Autobiographical Incidents	3/9		Definitely abnormal
Language			
Pyramids and Palm Trees	51/52		Within normal limits
Graded Naming Test	22/30	75^{th} percentile	Within normal limits
Attention			
Test of Everyday Attention Two Tests: Lottery and Map Search			Within normal limits
WAIS-III Digit Span	22	SS = 14	Within normal limits
Executive Function			
Hayling	15	SS = 5	Moderate average
Brixton	13 errors	SS = 7	High average
Behavioural Assessment of the Dysexecutive Syndrome: All tests			Within normal limits
Visuo-Perceptual Functioning			
Visual Object Space Perception Battery: All tests	Pass		Within normal limits
Benton Line Orientation	27/30		Within normal limits
AMIPB Complex Figure Copy	64	$>90^{th}$ percentile	Within normal limits

SenseCam

SenseCam, shown in Figure 2, is a small (6 cm × 8 cm × 3 cm) digital camera that is designed to be worn by the user, for example, on the chest hanging from a lanyard around the neck. It takes photographs automatically without user intervention. Unlike a regular digital camera or a cameraphone it

Figure 2. The SenseCam.

does not have a viewfinder or a display that can be used to frame photos. Instead, it is fitted with a wide-angle (fish-eye) lens that maximises its field-of-view and results in nearly everything in front of the camera being photographed. A number of different environmental sensors are built into SenseCam. These include a light intensity and colour sensor, a passive infrared (body heat) detector, a temperature sensor, a microphone and an accelerometer (movement detector). These sensors are monitored by the camera, and changes in sensor readings automatically trigger the camera shutter. For example, a significant change in light level or a sudden noise are used as triggers. Additionally, an internal timer triggers the shutter every 30 seconds, causing two images to be captured automatically every minute even in the absence of sensor-based triggers. If the camera is shaking excessively at the time when a photograph is due to be taken, the built-in accelerometer will detect this movement and will delay the shutter until the SenseCam is relatively stable, in order to reduce blur in the photographs.

During the course of a day, SenseCam may record several hundred images, which can then be uploaded to a standard PC for longer-term storage and subsequent review. Special image viewing software which runs on the PC has been developed. Using a technique known as rapid serial visual presentation (RSVP) (Spence, 2001), the potentially large number of images recorded by SenseCam may be viewed at different speeds (up to around 10 images per second), like watching a flip-book movie. The viewing software also allows the user to view images individually and to delete specific images. More details of the operation of the most recent version of SenseCam hardware and software are given in Hodges et al. (2006).

TABLE 2
Experimental design used in the study

Condition	*Recall testing schedule*	*Follow-up retention testing*
Sensecam	SenseCam images viewed and recall tested every 2 days for 2 weeks	1 month, 2 month and 3 month long-term recall trials
Written diary	Written diary viewed and recall tested every 2 days for 2 weeks	1 month long-term recall trial only
Baseline	No memory aids or rehearsal. Recall tested every 2 days for 2 weeks	No long-term recall trials

Conditions

There were three conditions (Table 2): a SenseCam condition, a written diary (control) condition and a baseline condition.

SenseCam condition

The SenseCam condition took place first. This was because we did not want Mr and Mrs B to undertake the written diary (control) and baseline conditions, which required effort and time on their part, if viewing the SenseCam images did not improve Mrs B's memory. The SenseCam trial lasted 11 months. Mr and Mrs B were given a SenseCam and a laptop computer, with detailed instructions of how to use both. They were taken through the instructions by one of the research team. Although they were not familiar with computers before this experiment, both Mr and Mrs B demonstrated that they were able to use SenseCam, upload the images and to view them with no apparent difficulty.

Mrs B wore SenseCam to record interesting or non-routine events in her life – deciding on the significance of an event was usually done by Mr B. Mr B was asked to record Mrs B's recall of the interesting event and to show Mrs B the SenseCam images afterwards. The following procedure was adopted for assessing Mrs B's autobiographical memory using SenseCam.

1. After wearing SenseCam while at an interesting or non-routine event, Mr and Mrs B came home and uploaded the images onto a laptop computer. They did not look at the images that evening.
2. The next day, Mr B asked his wife if she recalled the previous day's events.
3. Mr B noted Mrs B's responses, which were later graded as a percentage (see below).

4. After noting her responses, Mr B immediately showed Mrs B the SenseCam images of the previous day's events. Generally, during this session, Mrs B looked at the images three times, but never more than four times. On the basis of pilot data, this was considered the number of times that would meaningfully give Mrs B a chance to assimilate the content of the material in the clips. As they looked through the images, they talked about the event. They then did not look at the images for two days (until the next trial).
5. Two days later, Mr B again asked his wife what she remembered of the event that had occurred a few days previously. Again, he graded her responses and showed her the SenseCam images.
6. Two days later, the procedure was repeated until seven trials had been completed.

In this way, over a two-week period, Mr B was able to keep a log of how many times Mrs B had viewed the images of a recent event, and her corresponding recall of that event.

Method of grading Mrs B's autobiographical recall. Mrs B's responses were graded on a scale of 0 to 100%. For each event, Mr B documented a number of key points – these were selected on the basis of those that he felt were important or memorable. In general, Mr and Mrs B agreed on which events were regarded as significant and memorable. The following is an example of the key points noted on a trip to Southampton General Hospital: "Drive to East Cowes, walk to ferry, ferry to Southampton, taxi to hospital, taxi back to shopping centre, shopping, light lunch, walk to ferry, walk to car, drive home."

Other examples of important points to remember might be that they met up with friends (and if so which friends), if anything memorable happened while they were out and so on. In the above example, if Mrs B remembered 7 out of the 10 key events, she would achieve a score of 70%.

Assessment of long-term autobiographical memories using SenseCam. In addition to this shorter-term testing of recall, longer-term assessment of autobiographical memories was also carried out. The time periods were selected so as to yield measures of longer-term retention within the practical limits of the study, including the need to gather data within a reasonable time-frame. At the end of the three month period during which the device was used (and shorter-term testing took place), Mr B showed Mrs B all of the SenseCam movies that had been created (nine in total). She then did not view the images for one month, and at the end of that month, Mr B tested his wife on her recall of all nine events. He graded her responses in the

manner described above. Two months after this test, Mrs B was again presented with images from all nine events but this time was asked not to view them for a period of two months. She was then tested at the end of these two months. Immediately after this test, Mrs B was presented with images from seven of the nine events (events 3 and 9 were never remembered well so Mr B decided not to test Mrs B on these, as her inability to recall them caused her distress). This time, Mrs B was asked not to view them for a period of three months. Therefore the time interval between the original occurrence of some of the earlier events and eventual testing was as much as 11 months.

SenseCam feedback. Mr and Mrs B were interviewed informally post-trial and asked about their experiences of using SenseCam. Questions included whether the camera was easy to use; whether there were any problems with the camera; whether it was uncomfortable or embarrassing; if it was easy to use the laptop and the software; if the quality of the images was good; if it was beneficial as a memory aid; if they would use it again; and any other comments or suggestions.

Written diary condition

The written diary control condition replicated the SenseCam condition as far as possible. The written diary trial took place after the SenseCam trial and lasted two months. After an interesting or non-routine event in Mrs B's life, Mr B was asked to make a written diary of the event. The written diary was a basic outline of events (recorded by Mr B alone), as outlined above when describing the trip to Southampton General Hospital. The following procedure was adopted for assessing Mrs B's autobiographical memory using the written procedure.

1. In the written diary condition, Mrs B did not wear SenseCam. Instead, after an interesting or non-routine event, Mr B wrote a diary of the main events. They did not view the diary that day.
2. The next day, Mr B asked his wife if she recalled the previous day's events.
3. Mr B noted Mrs B's response, which was graded as a percentage (see above).
4. After noting her responses, Mr B immediately showed Mrs B the written diary of the previous day's events. During this session, in order to replicate the SenseCam condition as far as possible, Mrs B viewed the diary approximately three times, but never more than four times. As they read the diary, they talked about the event. As far as was possible, they spent the same amount of time reading the diary and talking about the event as they had spent reviewing SenseCam

images and talking about the event. Afterwards they did not look at the diary for two days.

5. Two days later, Mr B asked his wife what she remembered of the event that had occurred a few days previously. He graded her responses and showed her the written diary.
6. Two days later, the procedure was repeated until seven trials had been completed.

In this way, over a two-week period, Mr B was able to keep a log of how many times Mrs B had viewed the diary of a recent event, and her corresponding recall of that event.

In the written diary condition, Mrs B recalled on average 40% of significant events after viewing the written diary six times. Mr B felt that undertaking a written diary was a lot of work for little reward. We therefore considered it unethical to continue with the written diary condition and it was for this reason that there are only three written diary memory trials recorded.

Assessment of long-term autobiographical memories using the written diary. After a month using the written diary, Mr B showed Mrs B the written diary events that had been created (three in total). She then did not view the diary entries for one month, and at the end of this month, Mr B tested Mrs B on her recall of all three events. He graded her responses in the manner described above. After one month without looking at the diary, Mrs B did not remember any of the events recorded with the written diary and she did not like to be asked about events she had forgotten. For this reason we did not carry out a two and three month long-term trial of Mrs B's autobiographical memory.

Written diary feedback. Mr and Mrs B were interviewed informally post-trial and asked about their experiences of using a written diary. Questions included whether the written diary was easy to use, if there were any problems with it, whether it was beneficial as a memory aid, if they would they use it again, and any other comments or suggestions.

Baseline condition

The baseline condition replicated the SenseCam and written diary conditions as far as possible. The baseline trial took place after the written diary trial and lasted one month. After an interesting or non-routine event in Mrs B's life, Mr B was asked to record Mrs B's recall of the event. The following procedure was adopted for assessing Mrs B's autobiographical memory using the baseline procedure.

1. In the baseline condition Mrs B undertook an interesting or non-routine event but did not wear SenseCam and a written diary was not recorded.
2. The next day, Mr B asked his wife if she recalled the previous day's events.
3. Mr B noted Mrs B's response, which were graded as a percentage (see above).
4. After noting her responses, no action was taken. Mr and Mrs B did not talk about the event.
5. Two days later, Mr B again asked his wife what she remembered of the event that had occurred a few days previously. Again, he graded her responses.
6. Two days later, the procedure was repeated until seven trials had been completed.

In the baseline condition, Mrs B recalled on average 2% of significant events after seven days. Again, Mr B told us that his wife did not like to be repeatedly asked about events she had forgotten. We therefore considered it unethical to continue with the baseline condition and it was for this reason that only two baseline trials are recorded. For the same reason, we did not carry out a long-term assessment of Mrs B's memory in this condition.

RESULTS

Assessment of autobiographical memory recall using SenseCam

Mr and Mrs B recorded nine key events in the first three months of the trial. Although other events were recorded, Mr and Mrs B chose not to retain the images. They were discarded for many reasons, including poor image quality or because the images were of an "easily forgettable" event. Figure 3 shows Mrs B's average percentage recall of autobiographical events one to nine, with successive SenseCam viewings. Figure 3 indicates that as the number of SenseCam viewings increased, there was a corresponding increase in Mrs B's recall of autobiographical events. Two events were not recalled well, despite regular viewings with SenseCam. Mrs B's recall of each event is summarised in Table 3.

A chi-squared analysis for linear trend shows that there is a significant improvement across SenseCam presentations, $\chi^2(1) = 62.59$, $p < .001$, indicative of a learning effect with successive SenseCam viewings. The greater the number of viewings, the higher the level of successful recall.

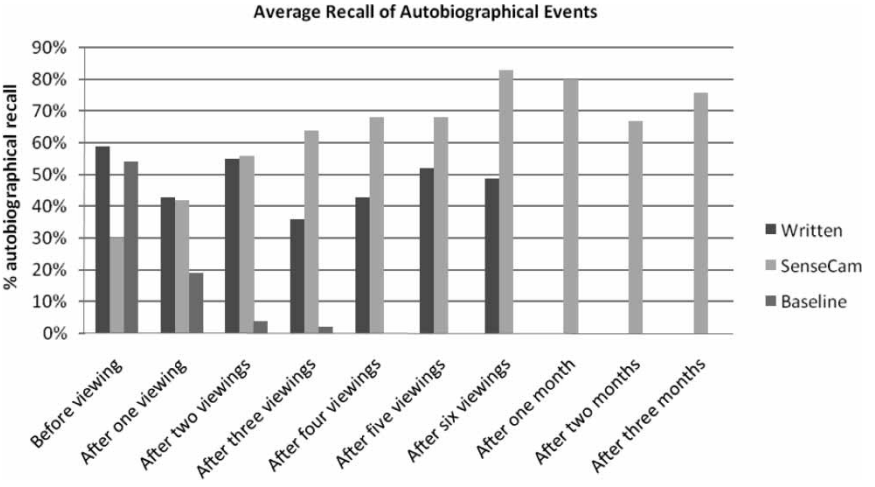

Figure 3. Mrs B's mean percentage recall of autobiographical events, at different time periods, for baseline, written diary and SenseCam conditions.

Long-term assessment of autobiographical memories using SenseCam

Figure 3 shows Mrs B's average percentage recall of autobiographical events one to nine after intervals of one month, two months and three months, without further viewings of the SenseCam images. Details of Mrs B's long-term recall of autobiographical events in the SenseCam

TABLE 3
Mrs B's recall of autobiographical events using SenseCam

Event number	*Recall prior to viewing images (%)*	*After one viewing (%)*	*After two viewings (%)*	*After three viewings (%)*	*After four viewings (%)*	*After five viewings (%)*	*After six viewings (%)*
1	10	50	60	65	80	90	100
2	0	50	70	80	90	80	90
3	0	0	0	10	0	25	20
4	100	90	90	100	70	90	90
5	60	50	60	80	80	80	95
6	50	50	80	50	80	50	95
7	20	20	60	80	100	80	90
8	20	60	70	90	100	95	90
9	10	10	10	20	10	20	80

TABLE 4
Mrs B's long-term recall of autobiographical events using SenseCam

Event number	*Recall with no additional viewing of SenseCam images for 1 month (%)*	*Recall with no additional viewing of SenseCam images for 2 months (%)*	*Recall with no additional viewing of SenseCam images for 3 months (%)*
1	100	100	95
2	80	60	90
3	10	20	Mr B no longer testing
4	100	95	80
5	80	100	90
6	70	80	65
7	100	90	40
8	100	40	70
9	80	20	Mr B no longer testing
Average recall across nine events	**80**	**67**	**76**

condition can be seen in Table 4. In the SenseCam condition, the results of the long-term recall trial indicate that after one month without viewing the images, Mrs B was able to recall 70% or more of eight of the nine autobiographical events. She was only able to recall 10% of event three. After two months without viewing the images, Mrs B's recall was more variable, but she was able to remember 60% or more of six of the nine autobiographical events. After three months without viewing SenseCam images, Mrs B recalled 76% of the seven SenseCam events on which she was tested. Note, therefore, that recall with SenseCam remains high even after three months, despite the fact that no additional viewing of the images took place in the interim period and the events had occurred up to 11 months previously.

Assessment of autobiographical memory recall using written diary

Mr B recorded three key events using a written diary. Figure 3 shows Mrs B's average percentage recall of autobiographical events one to three after successive written diary viewings. Figure 3 indicates that relative to Mrs B's recall the day after each event occurred ("Before viewing" column), Mrs B's overall recall with successive written diary viewings reduced. Mrs B's recall of each event is summarised in Table 5.

A chi-squared analysis for linear trend indicates that there was no trend effect across written diary viewings, $\chi^2(1) = 0.29$, $p > .6$. Mrs B's recall

TABLE 5
Mrs B's recall of autobiographical events recorded by written diary

Event number	*Recall prior to viewing images (%)*	*After one viewing (%)*	*After two viewings (%)*	*After three viewings (%)*	*After four viewings (%)*	*After five viewings (%)*	*After six viewings (%)*
1	40	64	52	0	20	44	40
2	100	12	72	56	60	72	64
3	36	52	40	52	48	40	44

with increasing viewings was variable, with an overall reduction in recall with successive written diary viewings.

Long-term assessment of autobiographical memories using written diary

The results of the long-term recall trial in the written diary condition indicate that after one month without viewing the diary, Mrs B was unable to recall any of the three autobiographical events.

Comparison between SenseCam and written diary

There was a difference in average recall per viewing between SenseCam and the written diary, $\chi^2(1) = 13.10$, $p < .001$. Mrs B recalled more about the events that were recorded by SenseCam than she did about the events recorded by the written diary.

Assessment of autobiographical memory recall using no memory aids (baseline condition)

Mr B recorded two key events in the baseline condition. Figure 3 shows Mrs B's average percentage recall of two autobiographical events with no memory aids. Mrs B's recall declined across time. On average, she had 2% recall of the events seven days after they occurred. Mrs B's recall of each event is summarised in Table 6.

SenseCam feedback

Mr and Mrs B generally considered that SenseCam was a useful autobiographical memory aid, and that it was primarily helpful for remembering non-routine events, such as trips, holidays, meeting new acquaintances, etc. Mr B reported that he could now more readily share past experiences with Mrs B, and she in turn felt less anxious about remembering key events as she knew she would be able to view SenseCam images at a later date.

TABLE 6
Mrs B's recall of significant events in baseline condition

Event number	*Recall prior to viewing images (%)*	*After one viewing (%)*	*After two viewings (%)*	*After three viewings (%)*	*After four viewings (%)*	*After five viewings (%)*	*After six viewings (%)*
1	8	6	0	0	0	0	0
2	100	32	8	4	0	0	0

Mr B made some specific suggestions relating to the camera itself, such as image quality in poor light, battery power, preference for higher positioning of SenseCam rather than at chest level, etc. Some of his suggestions have been incorporated into the latest version of SenseCam (Hodges et al., 2006).

Written diary feedback

Mrs B did not remember using the written diary as an aid to recall and was unable to comment. Mr B reported that he would not choose to use a written diary to aid his wife's memory. He gave four main reasons for favouring SenseCam over a written diary. First, the improvements in recall using SenseCam were greater than the benefits of using a written diary, in terms of his wife's recollection of significant events. Second, he indicated that both he and his wife found it more pleasurable and "stimulating" to look at images than to view a written diary. Third, the SenseCam movie allowed his wife to view the entire day quickly and without effort. Fourth, Mr B felt that there was often benefit to be gained from the large number of images captured by SenseCam because some of these images were of highly relevant events. In short, Mr B felt that the written diary was a great deal of effort for little reward and stated that he and his wife would not have the motivation to use it on a regular basis.

DISCUSSION

We were able to demonstrate the benefits of using a wearable, automated camera for autobiographical memory in a patient with severe memory impairment following limbic encephalitis. After viewing SenseCam images, our patient was able to recall approximately 80% of recent, personally experienced events. Retention of events was maintained in the long-term, 11 months afterwards and without viewing SenseCam images for three months. In a control condition, after using a written diary, our patient was able to remember on average 49% of an event; after one month with no diary readings she had no recall of the same events. Mrs B's exceptional

recall with SenseCam cannot be attributed to spontaneous recovery because the SenseCam trial took place before the written diary and baseline conditions.

At the theoretical level, our findings can be seen to highlight the importance of re-consolidation/rehearsal factors in long-term retention of episodic memories. However, it may first be worth briefly noting encoding factors that may have been operating. It is possible that when Mrs B wore SenseCam she was aware that important events would be captured, and this reduced her anxiety about her memory and freed her cognitive resources to focus on the event. This is unlikely, as on the one occasion when Mrs B wore SenseCam and the batteries ran out without her realising it, Mrs B had no recall of the event. Conversely, one might argue that if the patient realises that the event will be recorded for later review, he/she will spend less effort/time trying to retain the information at the time. In the case of post-encoding factors, it may be more likely that the images themselves provided potent cues to aid memory consolidation and recall, though it should be borne in mind that the first recall in a series of recall attempts was uncued.

Mrs B reported that seeing the beginning of a clip brought memories "flooding back" without necessarily having to view further images, suggesting that she was remembering the event itself rather the movie clip, something that was confirmed by Mr B, who said that his wife was able to recall details of events not contained in the images. It also suggests that the visual images themselves provided a potent cue to recall. Autobiographical memory is thought to be rich in visual imagery (Brewer, 1986, 1988). Brewer (1988) found that more than 80% of randomly sampled memories consisted of visual images and others have found comparable results (Whitten & Leonard, 1981). Brewer (1986) also proposed that the retrieval of a visual image distinguishes autobiographical memory from autobiographical knowledge; that is, visual images enable a person to recollect or relive an event, rather than simply know of an event. Similarly, although the neuroanatomy of autobiographical memory has yet to be clearly defined, behavioural and neuropsychological data indicate that the brain regions underlying visual memory are an important part of the network that subserves autobiographical memory. For example, the destruction of the visual association cortex is associated with an impairment of visual memory which often results in significant retrograde amnesia (see Greenberg & Rubin, 2003, for a review). On the basis of neuropsychological and neuroimaging studies (electroencephalograph and functional magnetic resonance imaging), Conway (2005) has proposed that the hippocampus might function as an important link between anterior (prefrontal anterior-temporal) and posterior (temporo-occipital) memory systems, both of which subserve autobiographical memory. In addition, SenseCam is different from standard photographic diaries in that it produces a form of movie taken from the

point of view of the wearer. When the images are played back, the patient is able to see a concise time-lapse movie of their day, which may be similar to how they experienced it. It is possible therefore that SenseCam produces images that are close in nature to visual autobiographical memories and hence provides a powerful consolidation boost for the hippocampus and related memory structures.

Mrs B did not recall all of the autobiographical events recorded by SenseCam. For example, she remembered little of events three and nine. When discussing his wife's lack of recall for these events, Mr B said that they were "not memorable", in that they were "boring" to her. Mr B described them as "dreary days walking through dreary little towns . . . Nothing stood out". Similarly, Mr and Mrs B did not think it necessary to record routine or mundane daily events. We agree that it is unlikely that SenseCam would be of benefit in recording day-to-day actions that are of low salience and familiar, as these are not recalled by people with intact memory functioning in the longer-term (Conway, 2005; Canli, Desmond, Zhao & Gabrieli, 2002; Linton, 2000).

When wearing SenseCam, Mrs B's subjective levels of anxiety reduced. In particular, she felt more confident about her memory and therefore more able to relax at social events. This concurs with evidence presented by Tate (2000), who notes that a lack of confidence in memory-impaired people can lead to an avoidance of high-risk situations where failure may be more likely to occur. Mrs B also stated that her increased confidence led to improved self-esteem and less frustration at home. Her husband's delight in sharing experiences with his wife supports theories that propose that memory may serve a social as well as a personal function (Hyman, 2000).

It is interesting to note that Mrs B's memory also improved (albeit less so and not in the longer-term) through the systematic use of a written diary. This suggests that in both the written diary and the SenseCam conditions, regular reviewing of the images/diary coupled with the process of talking through the events, facilitated recall or consolidation of autobiographical memories that had already been encoded. Similarly, intermittent SenseCam and written diary viewings could be characterised as a form of spaced repetition, in which learning trials are distributed over a period of time, allowing for gradual consolidation and reconsolidation of memories. This form of spaced presentation is thought to be an effective way of improving learning (Landauer & Bjork, 1978). Another, less likely reason is that Mrs B's recall is impaired by her mild executive dysfunction, and that viewing the images or the written diary allowed her to organise her search strategies more effectively.

In order for SenseCam to be effective, the presence of a motivated spouse or carer is likely in many cases to be important. For example, it would be difficult to envisage a markedly amnesic patient remembering not only to use the SenseCam, but also to upload the images and to review them

regularly. Although this process could be prompted with external memory aids and further consolidated through the use of procedural memory, the initial process may require a carer to encourage its use. The patients themselves must also be happy to use the camera and ideally there should be a strong working alliance with the family, especially while any initial problems with the use of the technology are ironed out. The constructive criticism offered by Mr B in terms of the usability of the camera has largely been addressed in a new version of SenseCam (Hodges et al., 2006), and these hardware issues are continuing to be evaluated.

Since SenseCam autonomously captures images, it has particular benefits for acquired and degenerative brain injured patients, enabling them to record their experiences without operating equipment and without conscious thought. For example, the memory-impaired person does not have to remember to capture an image and a patient with executive dysfunction does not have to plan ahead or think flexibly. It allows a person to truly participate in an event without having to pause to capture the moment.

We hypothesise that, in addition to aiding autobiographical memory, SenseCam has a number of further benefits for brain injured patients: First, SenseCam may provide the means of getting information on the frequency, type and nature of a patient's memory lapses or cognitive deficits that would help inform a treatment programme or aid research into autobiographical memory deficits. Second, SenseCam may have the potential to be used as a source of images that could interface with a virtual reality system to train people with impaired memories to use strategies to aid their memory. Third, SenseCam may aid therapy by enabling people with memory impairment to recall specific events that have triggered an emotional reaction (anger, sadness, anxiety etc.), to re-evaluate situations that cause them distress (SenseCam could be coupled with a device that monitors physiological recordings, such as skin conductance and heart-rate, for this purpose), to challenge biased recall of events or to organise their executive strategies more effectively. Fourth, SenseCam could be used to evaluate the effectiveness of rehabilitation programmes with patients with brain injury, by monitoring their behaviour. Fifth, SenseCam may provide useful stimuli for studies of autobiographical memory using functional imaging techniques such as functional magnetic resonance imaging (fMRI) or positron emission tomography (PET). Sixth, SenseCam may help to define time windows during which a particular memory lapse has occurred, such as forgetting where something has been put, and then make it easier for a patient to rectify the memory lapse. Finally, SenseCam images may provide useful stimuli for studying autobiographical and episodic memory more generally, for example answering questions such as, "How quickly do we forget?" and "How does memory change with age?"

Current limitations with SenseCam include the absence of sound information and the time taken to upload, access and combine particular image segments. Another limiting factor is that the viewing software runs on a standard desktop or laptop PC, which may be unfamiliar or anxiety-provoking for some people. Further control studies need to be carried out, including an examination of the benefits of SenseCam compared to a photographic diary or a diary that uses a commercial video camera, to shed light on factors such as contextual richness of reminder cues. Since the written diary was stopped after a short period of time, restricting the number of data points gathered, it may be worth comparing SenseCam with more extensive written diary records. It is possible that in future years SenseCam may be integrated with mobile phone or electronic diary technology. Since many patients with limbic encephalitis have as a residual feature of their condition focal memory deficits, with relatively preserved insight and motivation, SenseCam may be particularly suited for this population. Further research using a range of objective measures of everyday memory functioning is needed to evaluate the usefulness of SenseCam in aiding memory and rehabilitation with patients with acquired and degenerative brain pathology.

REFERENCES

Brewer, W. F. (1986). What is autobiographical memory? In D. Rubin (Ed.), *Autobiographical memory* (pp. 25–49). Cambridge: Cambridge University Press.

Brewer, W. F. (1988). Qualitative analysis of the recalls of randomly sampled autobiographical events. In M. M. Gruneberg, P. E. Morris, & R. N. Sykes (Eds.), *Practical aspects of memory: Current research and issues* (Vol. 1, pp. 263–268). Chichester, UK: Wiley.

Canli, T., Desmond, J. E., Zhao, Z., & Gabrieli, J. D. E. (2002). Sex differences in the neural basis of emotional memories. *Proceedings for the National Academy of Sciences of the United States of America*, *99*, 10789–10794.

Clare, L., & Woods, B. (2001). Editorial: A role for cognitive rehabilitation in dementia care. *Neuropsychological Rehabilitation*, *11*(3), 193–196.

Conway, M. A. (2005). Memory and the self. *Journal of Memory and Language*, *53*, 594–628.

Corsellis, J. A. N., Goldberg, G. J., & Norton, A. R. (1968). "Limbic encephalitis" and its association with carcinoma. *Brain*, *91*, 481–496.

Gorniak, R. J. T., Young, G. S., Wiese, D. E., Marty, F. M., & Schwartz, R. B. (2006). MR imaging of human herpes virus-6-associated encephalitis in 4 patients with anterograde amnesia after allogenic hematopoietic stem-cell transplantation. *American Journal of Neuroradiology*, *27*, 887–891.

Greenberg, D. L., & Rubin, D. C. (2003). The neuropsychology of autobiographical memory. *Cortex*, *39*, 687–728.

Hodges, S., Williams, L., Berry, E., Izadi, S., Srinivasan, I., Butler, A., Smyth, G., Kapur, N., & Wood, K. (2006). SenseCam: A retrospective memory aid. In P. Dourish & A. Friday (Eds.), *Ubicomp, LNCS 4206* (pp. 177–193). Berlin, Heidelberg: Springer-Verlag.

Hyman, I. E. Jr. (2000). Conversational remembering. In U. Neisser & I. E. Hyman, Jr. (Eds.), *Memory observed: Remembering in natural contexts.* (2nd ed., pp. 457–471). New York: Worth Publishers.

Kapur, N., Barker, S., Burrows, E., Ellison, D., Brice, J., Illis, L., Scholey, K., Colbourn, C., Wilson, B., & Loates, M. (1994). Herpes simplex encephalitis: Long-term MRI and neuropsychological profile. *Journal of Neurology, Neurosurgery and Psychiatry*, *57*, 1334–1342.

Kapur, N., Glisky, E. L., & Wilson, B. A. (2002). External memory aids and computers in memory rehabilitation. In A. D. Baddeley, M. D. Kopelman, & B. A. Wilson (Eds.), *The handbook of memory disorders.* (2nd ed., pp. 757–784). Chichester, UK: John Wiley.

Kime, S. K., Lamb, D. G., & Wilson, B. A. (1996). Use of a comprehensive programme of external cueing to enhance procedural memory in a patient with dense amnesia. *Brain Injury*, *10*(1), 17–25.

Landauer, T. K., & Bjork, R. A. (1978). Optimum rehearsal patterns and name learning. In M. M. Gruneberg, P. E. Morris, & R. N. Sykes (Eds.), *Practical aspects of memory* (pp. 625–632). London: Academic Press.

Linton, M. (2000). Transformations of memory in everyday life. In U. Neisser & I. E. Hyman, Jr. (Eds.), *Memory observed. Remembering in natural contexts.* (2nd ed., pp. 117–118). New York: Worth Publishers.

Nelson, K. (1993). The psychological and social origins of autobiographical memory. *Psychological Science*, *4*, 7–14.

Oddy, M., & Cogan, J. (2004). Coping with severe memory impairment. *Neuropsychological Rehabilitation*, *14*(5), 481–494.

Rose, F. C., & Symonds, C. P. (1960). Persistent memory defect following encephalitis. *Brain*, *83*, 195–212.

Spence, R. (2001). Rapid, serial and visual: A presentation technique with potential. *Information visualization* (pp. 13-19). Harlow, UK: Addison-Wesley.

Tate, R. L. (2000). Emotional and social consequences of memory disorders. In A. D. Baddeley, M. D. Kopelman, & B. A. Wilson (Eds.), *The handbook of memory disorders.* (2nd ed., pp. 786–805). Chichester, UK: John Wiley.

Vincent, A., & Bien, C. G. (2005). Temporal lobe seizures, amnesia and auto-antibodies - identifying a potentially reversible form of non-paraneoplastic limbic encephalitis. *Epileptic Disorders*, *7*, 77–179.

Whitten, W. B., & Leonard, J. M. (1981). Directed search through autobiographical memory. *Memory and Cognition*, *9*, 566–579.

Wilson, B. A., Emslie, H. C., Quirk, K., & Evans, J. J. (2001). Reducing everyday memory and planning problems by means of a paging system: A randomised control crossover study. *Journal of Neurology, Neurosurgery and Psychiatry*, *70*, 477–482.

Wilson, B. A., Evans, J. J., Emslie, H., & Malinek, V. (1997). Evaluation of NeuroPage: A new memory aid. *Journal of Neurology, Neurosurgery and Psychiatry*, *63*, 113–115.