

**“Sleep Disorders, EEG-Changes, Altered Cognitive Functions
– Is there a Connection with the Exposure to Mobile
Communication RF Fields?”
Stuttgart, Germany 5th - 7th November 2007**

Organized by:
FGF E.V., EMF-NET and the State Ministry of Environment,
Baden-Württemberg

Rapporteur’s Report
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Introduction

This workshop was organized by FGF E.V., EMF-NET, and the State Ministry of Environment, Baden-Württemberg. About 60 expert persons attended giving 30 lectures, each followed by open discussion over two and a half days.

Dr G. Friedrich, Managing Director of the FGF and Mr. P. Brunner, representing the State Ministry of Environment, Baden-Württemberg, made welcome and introductory remarks.

Mr. Brunner reminded us of the purpose of our meeting. 'Solid scientific knowledge' must be the basis for the evaluation of possible risks from radiofrequency exposures. He said, although the German Radiation Protection Commission concludes that there is no need to change the limits in the range of radio frequency electromagnetic fields due to evidence for potential effects found in single research projects and studies, the conference experts need to evaluate the relevance of these single results in this meeting and advise the Ministry on further research to close the existing gaps of knowledge on RF effects on sleep by further focused research [P. Brunner, 2007].

The workshop brought together representatives of the RF research groups that have worked on the topics of sleep/EEG and cognitive research and offered a public forum for open discussion of their results. This meeting continued on the progress in this area of the previous FGF, COST 281 and the State Ministry of Environment, Baden-Württemberg Workshop: 'Can electromagnetic fields used in mobile communications provoke sleep disorders?' in Immenstaad Germany 7-10 December 2003.

Introductory lectures explained the topic of the awake and sleep electroencephalograms [EEG] and the biology of sleep. They explained that medical sleep clinicians use an established international protocol to characterize, record, and score sleep polysomnograms [Rechtschaffen and Kales, 1968; Iber et al., 1999; Iber et al., 2007a; see Appendix A,B]. As well, sleep clinicians use the World Health Organisation [WHO] adopted 'International Classification of Sleep Disorders' [ICSD-2, 2005] for identifying and treating sleep disorders. Signals of base stations and mobile phones were reviewed including new technology signal measurement reports. The published EEG cognitive and sleep studies with RF exposures were reviewed and the newly conducted and ongoing studies were presented and discussed. At the end of the conference after a general discussion, overall consensus conclusions were made.

I have focused this report on the introductory lectures by two invited experts in sleep research outside of the RF research area since their presentations were most helpful for the conference purposes [see Bruner above]. Firstly, Dr M. Kiefer outlined the specifics of the nature of brain EEG recordings. Secondly, Dr Thomas Penzel outlined the methods of evaluating the polysomnography [PSG] scoring of sleep research, specifically to revise '*The American Academy of Sleep Medicine [AASM] Manual for the Scoring of Sleep and Associated Events: Rules, Terminology and Specifications*', [Iber et al., 2007a]. This thorough, open, expert evaluation [Sackett, 1993; Sackett et al., 1996; Fitch et al., 2001]

of sleep scoring methodology and evidence in the sleep publications, [Iber et al., 2007a,b], outside the RF field, may be directly applicable to designing, conducting and evaluating human RF sleep research. It is the ‘solid scientific knowledge’ we need to progress in human RF sleep research.

The human being has detectable, recordable, electroencephalogram [EEG] brain activity continuously as long as alive. The recording of the EEG is divided into wake and sleep EEG. Sleep EEG has unique features, making it easier to record as an individual is naturally unconscious in a reclined position throughout, e.g., sleeping, confined to a bed for 8 hour periods, daily. Because of the importance to RF sleep research of this unique opportunity to learn about quality polysomnographic sleep recording introduced in Dr Penzel’s presentation I have confined my rapporteur’s review mostly to quality polysomnographic sleep recording rules as revealed by the results of *The American Academy of Sleep Medicine [AASM] Manual for the Scoring of Sleep* Task Force for the revision on the R & K [1968] Sleep Recording Manual [Iber et al., 2007 a,b; Penzel et al., 2007; Silber et al., 2007] .

The rapporteur’s report ends with ‘Overall Conclusions’ and,’ Dr Brunner’s Purposes of the Workshop: Answers.’

Measuring cognitive function in the human brain with EEG

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Summary [Derived from Dr Kiefer’s slides, abstract and SAJ’s notes]

Brain function can be studied non-invasively by measuring its electrical activity on the intact scalp. The possibility to record the electroencephalogram (EEG) had been discovered in the 1920’s by the German psychiatrist and neurologist Hans Berger. The EEG arises from rhythmic changes of scalp voltages generated by a summation of post-synaptic potentials from a large number of neurons. Since its first discovery, EEG recordings have been widely used in clinical settings as a brain function test of a **gross** correlate of brain activity for monitoring and diagnostic purposes. The EEG is typically described in terms of (1) rhythmic activity and (2) transients, e.g. single events.

The rhythmic activity is divided into bands by frequency. The frequency composition of the EEG typically depends on the state of the individual (e.g., degree of alertness, sleep stage, cognitive processing); it might be altered in neurological and psychiatric disorders and is affected by certain drugs and foods such as caffeinated coffee. There is a different cognitive significance associated with each of the frequency bands. The alpha band (8-12 Hz) is recorded from electrodes at the back of the head from the visual cortex when the eyes are closed during relaxation this wave signifies cognitive inhibition, and visual relaxation. The beta band (12-30 Hz) arises from a different form of mental activity for instance, speech. The gamma band (30-100 Hz) is recorded during visual perception and object recognition. And the theta band (4-7 Hz) is associated with memory consolidation in the hippocampus in the temporal cortex.

In research settings, the EEG is used as a non-invasive technique to investigate brain function. It allows determining the orchestration of brain activity with a **high temporal resolution in the range of milliseconds** in contrast to other brain imaging techniques such as functional magnetic resonance imaging (fMRI). However, **EEG has a relatively poor spatial resolution** so that the brain electrical sources of the potentials recorded at the scalp can only be approximately identified.

With the sleep polysomnograms you only record correlation information, descriptive information, not causal information. To move to causal information you have to stimulate and record a related response. For research purposes studying awake cognitive processes, mostly the event-related potential (ERP) technique is employed. ERPs contain only electrical brain activity, which is time-locked to a stimulus or an event. Most ERP experimental paradigms involve a subject being presented with a stimulus to which an overt or covert reaction is required. There are often at least two conditions that vary in some manner of interest to the researcher. As this stimulus-response is going on, an EEG is being recorded from the subject. The ERP is obtained by extracting the event-related activity from the background EEG activity by an averaging technique in each of the trials within a certain experimental condition.

The advantage of EEG or ERP recordings in research settings is their **non-invasive nature** and their high temporal resolution so that subtle activity changes that last only a few milliseconds can be detected. EEG recordings may reveal subtle differences in brain function, which are not always accompanied by behavioral performance differences.

The disadvantage of EEG measurements is their low spatial resolution and the fact that they only reflect synchronous electric activity of large neural assemblies. For a fine-grained analysis, intracranial recordings of single cells are necessary. It should also be noted that contamination of EEG recordings by artifacts (eye or head movements, muscle movements, and external electrical noise) could compromise the interpretation of the data if such artifacts are not properly removed or rejected. Despite these limitations, EEG measurements are an important tool to elucidate cognitive and sleep functions in the human brain non-invasively.

Sleep - Definition, sleep stages, disorders and methods of investigation.

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Summary [Derived from Dr Penzel's slide presentation]

Humans spend a third of their life asleep. Sleep has its own internal structure with a well-programmed sequence of sleep stages. Important tasks being fulfilled during sleep are physical recreation, mental recreation, consolidation of memory, hormonal regulation, immune system activation, and restoration of performance [See: *Nature*, Issue July 2004; *Nature Insight Special Issue*, 27 Oct 2005; *Time Magazine*, July 2005]. Sleep is not a steady state of unconsciousness but has an internal structure with a cyclical time course [Penzel, 2006]. Sleep is a very dynamic and complicated behaviour. Sleep begins over the daily circadian period when core body temperature is reaching its lowest level and

ends when core body temperature is rising again [Kräuchi et al., 2007a,b]. Over the sleep period homeostasis is being restored.

The basic measurements of sleep diagnosis may include: sleep recording; sleep stage evaluation [according to Rechtschaffen and Kales, 1968] and cardiorespiratory recordings or ambulatory sleep recording.

In order to quantify sleep and sleep stages, polysomnography (PSG) is the chosen electrophysiological recording method in the sleep laboratory. The PSG recordings of sleep should include the left and right eye electromovements (electro-oculogram, EOG), the electroencephalogram (EEG, brain electrowaves recorded on the skin of the scalp), and the electromyogram submentalis (EMG of the chin muscle).

Sleep parameters such as percentages of sleep stages, latencies, wake times, and awakenings are measured. There are sequences of the sleep stages across the night from light sleep to deep sleep to rapid eye movement [REM] sleep with about 6 cycles of these periods of 90 minutes across about 8 hours of sleep. Sleep changes with age; older people have less slow wave sleep (SWS) time and more waking after sleep onset and total slow wave sleep time decreases. [See Appendix A, N3, at the end of this document]

The classification of sleep stages according to Rechtschaffen and Kales (1968) is defined as follows:

AWAKE: has beta waves and alpha waves that make up greater than 51% per recording epoch (30 seconds), with rapid eye movements and muscle tone at its highest;

REM: has theta waves with some alpha, and rapid phasic eye movement, and muscle tone at the lowest;

NREM 1: has theta waves, and alpha waves are less than <50% per epoch, and slow eye movements and muscle tone are reduced;

NREM 2: has theta waves, spindles, K-complexes, no eye movements and muscle tone is low;

NREM 3: has theta waves, delta is greater than 20% and less than 50%, there are no eye movements, and muscle tone is much lower; and

NREM 4: has theta waves, delta is greater than 50% per epoch, there are no eye movements, and muscle tone is very low.

Digital Scoring

In the revision of the Rechtschaffen and Kales (1968) Manual by *The AASM Manual for the Scoring of Sleep* [2007] expert scientific Task Force for the standard of practice of PSG recording the issue of digital acquisition, display, and analysis was addressed [Iber et al., 2007a]. ‘The evidence review suggested that computer scoring and quantitative analysis of sleep is still in the stage of development. Assessment of computer/digital capacity to mimic the well-trained visual scorer may be useful, but research is still needed to determine whether this [digital] technology will contribute new methods for understanding sleep and its disorders’ [Penzel et al., 2007].

Visual Scoring

The well-trained visual scorer of sleep PSG is still considered the most reliable method for interpretation of the recordings [Silber et al., 2007; Iber et al. 2007a]. The R & K rules are extended by aspects of cardiorespiratory polysomnography. *The AASM Manual for the Scoring of Sleep* [2007] expert Task Force recommend more EEG leads; EOG and EMG scores should be more specific; merging of stages 3 NREM and 4 NREM to N3; new abbreviations for the stages namely, W, N1, N2, N3 and R to replace awake, NREM1, NREM2, NREM3 [and NREM4] and REM, respectively; discarding the stage 'Movement'; and they recommend simplification of many context rules. They define new recommendations for sampling rates and filter settings; no automatic sleep analysis should be used. There is a new recommendation for PSG reporting and for user interfaces of computer-assisted systems (Iber et al., 2007a; See Appendix A, Appendix B, below).

The ICSD-2 [2005]

The International Classification of Sleep Disorders (ICSD-2, 2005), a primary diagnostic coding resource for clinicians and researchers in the field of sleep and sleep medicine, was produced by the American Academy of Sleep Medicine, in association with the European Sleep Research Society, the Japanese Society of Sleep Research, and the Latin American Sleep Society. The ICSD was first published in 1990 and revised in 1997. A second edition was published in 2005.

The ICSD-2 [2005] classifications of sleep disorders, complaints and symptoms include: insomnias - disorders of initiating and maintaining sleep (e.g., stress, noise, light, coffee or pain); sleep related breathing disorders; hypersomnia of other origin; circadian sleep-wake disorders; parasomnias, disorders associated with sleep (Bruxism=teeth grinding, sleep walking, lucid dreaming); sleep related movement disorders; isolated symptom and normal variants; and other sleep disorders. Appendix A lists sleep disorders associated with other medical disorders and Appendix B deals with other mental or psychiatric disorders often associated with sleep disorders [ICSD-2, 2005].

Some substances are known to disturb sleep. For example, caffeine (100-300 mg) suppresses REM and shortens sleep. Disordered breathing during sleep also causes sleep disturbances. The disturbed respiration during sleep is irregular with apneas of 60 s duration. Obstructive sleep apnea results from the collapse of the upper airways during sleep for 30 to 60 seconds for up to 400 times per night. The relaxing of upper airway muscles can be prevented by a face mask that continuously channels positive airway pressure through the nose with room air. The pneumatic pressure opens the upper airways [ICSD-2, 2005].

The 4 categories for diagnostic methods

There are 4 categories for diagnostic methods beginning with the highest level [Level I]. They are defined as follows:

Level I consists of polysomnography, with recordings of a minimum of 7 signals namely EEG, EOG, EMG, heart rate or ECG, airflow, respiratory movement, and oxygen saturation. Attendance by trained personnel is required, with the possibility of intervention during recording.

Level II consists of portable PSG recording a minimum of 7 signals namely EEG, EOG, EMG, heart rate or ECG, airflow, respiratory movement, and oxygen saturation but with no attendance by trained personnel and no intervention during recording.

Level III consists of portable sleep apnea diagnosis recordings of a minimum of 4 signals including airflow or respiratory movement, heart rate or ECG, and oxygen saturation.

Level IV: consists of continuous recording of one or two parameters.

[ASDA, 1994; Chesson et al., 2003; Note Chesson is also co-author of *The AASM Manual for the Scoring of Sleep*, 2007]

Ambulatory Sleep Investigation [Portable, non-laboratory, recording]

There are systems for ambulatory one channel sleep recording including ambulatory PSG (e.g., Embla), ambulatory EEG recording, special systems for sleep apnea, Quisi, and Biosomnia. But with one to two channel EEG sleep recording, no standardised leads, no visual inspection and automatic analysis, the ambulatory sleep recording has limitations because of lack of supervision, video, correction of electrodes and raw data and quality control. The discussion of ambulatory sleep recording is relevant to the interpretation of some of the RF sleep research reported at the Workshop (See the discussion below of the presentation by Leitgeb et al., 2007)

Penzel's Conclusions

1. Quantitative [digital] sleep analysis can give an objective diagnosis of sleep disorders but there is no accepted defined digital recording or scoring procedure and there are no estimates of the validity or reliability of the various digital recording methods.
2. There are, however, gold standards for the cardiorespiratory PSG and the visual evaluation of the sleep recording.
3. A limited [ambulatory] sleep recording with a one channel EEG gives only limited and not reliable results.
4. There are well-defined sleep disorders that are now part of ICSD-2 [2005] coding with eight main groups.
5. There are contradictory results on the influence of RF on sleep and the effects are much smaller than effects of known sleep disorders.

Dr Penzel's presentation was followed by many questions focusing on the variability of sleep recordings and the likely measurement limitations that would make recording, small RF effects near impossible. What is the variability of polysomnograms across a month for any one individual? What is the error in measurement, the natural variability of the EEG? How do you control for all the external factors such as caffeine consumption, alcohol consumption, noise, and emotional factors that are known to cause large enough effects to be detectable? Would caffeine or noise be a good positive control? How likely is it to

pick up small effects if the natural variability in polysomnograms is large? In that case, since the effects of RF on sleep appear to be small, would it be a poor endpoint to study?

Dr Penzel agreed it would be difficult to pick up small RF effects in polysomnograms and he agreed noise [or caffeine] could be a positive control.

Further Comments on the AASM Sleep Recording Evaluation [2007]: SAJ

[This added section is derived from further sleep papers, many kindly recommended by Drs Thomas Penzel and Blanka Pophof to SAJ.]

‘The AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology, and Technical Specifications’

Iber et al., [2007a,b] have revised the sleep scoring Manual of Rechtschaffen and Kales, [1968] with new scoring rules based on literature review and expert consensus on the evidence. The PSG scoring evidence behind the rules in ‘*The AASM Manual for the Scoring of Sleep*’ was presented in seven white papers in a special edition [March 2007, Volume 3 Issue 2] of ‘The Journal of Clinical Sleep Medicine’ [JCSM] [Iber et al., 2007b]. “*The AASM Manual for the Scoring of Sleep and Associated Events: Rules, Terminology, and Technical Specifications*” was published separately [Iber et al., 2007a]. Dr Iber was chairman of the Steering Committee of the revision Task Force. The revision Task Force topics were digital analysis and reporting parameters [chair T. Penzel], visual scoring [chair M Silber], arousal [chair M Bonnet], cardiac events [chair M Caples], movements [chair A Walters], respiratory events [chair S Redine], and pediatric scoring [chair MM Grigg-Damberger]. The charge of *The AASM Manual for the Scoring of Sleep* Task Forces was to develop reference material to support the development of a more comprehensive Scoring Manual. The Task Forces participated in consensus decision making for revision of *The AASM Manual for the Scoring of Sleep* [Iber et al., 2007a,b]. Similar chairs, Task Forces and procedures were followed for the earlier [Iber et al., 1999] revision of Rechtschaffen and Kales [1968] [R & K]. Standardized evidence tables (which can be accessed on the web at www.aasmnet.org) were prepared and evidence levels assigned to each study [Iber et al., 2007b; Silber et al., 2007; Penzel et al., 2007].

The revision of the R & K method of sleep recording as specified in the revised *AASM Manual for the Scoring of Sleep* [2007] was an iterative process; future editions of the Manual will undoubtedly require a reexamination of evidence to address the rapidly evolving science of the metrics for sleep recording [Iber et al., 2007a, b].

The AASM Manual for the Scoring of Sleep [2007] Task Forces openly reviewed the evidence for the accuracy of their scoring methods and this is most helpful to us reviewing the RF sleep research to use their results as the basis for, and a guide to, reviewing the quality of RF sleep recording evidence. Below I focus on digital and visual recording methods.

Digital Scoring:

Excerpted digital scoring comments below arise from a chapter on ‘Sleep’ by Dr Achermann and from a chapter on the ‘Sleep Laboratory’ by Dr Penzel in the recent book

‘*Wiley Encyclopedia of Biomedical Engineering*’ [2006]. The digital scoring excerpts also come from the white paper of *The AASM Manual for the Scoring of Sleep* [2007] Task Force on digital scoring chaired by Dr Penzel [Penzel et al., 2007] and the section in *The AASM Manual for the Scoring of Sleep* [Iber et al., 2007a] on digital scoring rules. [See Appendix B, addendum recommended digital specifications, below]

No optimum method of digital recording has been identified. The methods are based on rules, neural networks, or fuzzy logic approaches. All methods try to mimic the visual classification of Rechtschaffen and Kales [1968]. Algorithms based on sleep EEG alone have difficulties distinguishing wake, sleep stage 1, and REM sleep [Penzel, 2006; Iber et al., 2007a].

‘It is important to note that spectral analysis is a mathematical approach to quantify the EEG and does not provide a biophysical model of EEG generation. The sleep EEG is a non-stationary signal with typical changes in total power as a function of the non-REM-REM sleep cycle. Nevertheless, by selecting short epochs in which the parameters of interest vary little, the requirements for stationarity may be fulfilled (quasi-stationarity). The choice of the epoch length is a compromise between frequency resolution and stationarity. For spectral analysis, [of an entire night’s sleep] epochs of 2 s to 10 s usually are used ’ [Achermann, 2006].

‘A shortcoming of spectral analysis is the loss of temporal information. The frequency spectra do not indicate the time point of a specific change within the analyzed interval. In an effort to overcome this shortcoming, Gabor (1946) adapted the Fourier transform so that only short sections of the signal are analyzed at a time. This technique is called short-time Fourier transform (STFT). STFT is a compromise between time- and frequency-based views of the signal; time and frequency resolution are fixed’ [Achermann, 2006].

Validity and reliability of digital analysis: *The AASM Manual for the Scoring of Sleep* [2007] Task Force consensus: ‘While [digital] findings suggest discernible relationships between sophisticated computerized EEG parameters and both normal and abnormal sleep, the understanding is minimal at this time. Much more work is needed in this area before the sleep specialist will have an acceptable [digital] clinical tool.’ ‘.validation remains a question. It is critical that the [digital] measurements reflect details about extant phenomena and not artifact...The continued variation and non-sinusoidal nature of EEG can, in some cases, generate information that does not really exist’ [Penzel et al., 2007].

‘Some computer based systems [quantitative EEG measures, fast Fourier transformation (FFT), period amplitude analysis (PAA), spectral analysis, zero crossings for frequency bands,] allow users to modify analysis settings. If users with limited knowledge modify these settings, it is not clear whether scoring results will be valid. Studies of software provided by manufacturers, independent investigators, and by national funding sources will be needed to assure clinically valid information’ [Penzel et al., 2007].

Digital scoring conclusions

1. No optimum method of digital recording has been identified.
2. Much more work is needed to validate digital recording before the sleep specialist will have an acceptable clinical tool.
3. *The AASM Manual for the Scoring of Sleep* sets out recommended digital recording methods as a first step to see if these methods may lead to accumulating evidence to support their validation in the future [see Appendix B].

Visual Scoring:

The visual scoring excerpts below come from the white paper of *The AASM Manual for the Scoring of Sleep* [2007] Task Force on visual scoring chaired by Dr Silber [Silber et al., 2007] and the section in *The AASM Manual for the Scoring of Sleep* [Iber et al., 2007a] on visual scoring rules. [See also Appendix A, on visual scoring rules, below]

Inter-rater and intra-rater reliability overall:

With the 1968 Rechtschaffen and Kales (R & K) sleep scoring Manual, the well-trained visual scorer of the sleep PSG is still considered the most reliable method for interpretation of the recordings (Silber et al., 2007). ‘The AASM Visual Scoring Task Force concluded that inter-rater and intra-rater reliability were substantial for staging of records as a whole with the use of the R & K montages [up to and over 90% agreement]. This suggested that the R & K method could be used as a basis for a revised scoring system’ [Silber et al., 2007].

Inter-rater and intra-rater reliability of each sleep stage:

Greatest inter-rater accuracy was achieved for REM sleep followed by stage 2 sleep. Lowest reliability was found for stage 1 sleep, while reliability for wake and slow wave sleep [SWS] was moderate. Similar results were noted in the one study examining intra-rater reliability [Danker-Hopfe et al., 2004]. ‘It was concluded that scoring rules for stage 1 and SWS sleep needed reassessment’ [Silber et al., 2007].

EEG electrode placement: (sleep characteristics at specific scalp locations)

‘Evidence from these studies suggests that sleep spindle activity is optimally recorded with central electrodes, while K complexes and delta activity are optimally recorded with frontal electrodes. The predominant localization of alpha rhythm over the posterior head regions, and especially the occipital cortex, has been unchallenged since the days of the early EEG pioneers’ [Silber et al., 2007].

Failure to record frontal activity may result in reduced identification of K complexes and thus inaccurate scoring of stage 2 sleep, especially in older subjects, and the absence of an occipital derivation may hamper the determination of sleep onset. As a result, the Task Force determined through the consensus process that a minimum of three EEG derivations will be required, sampling activity from the frontal, central, and occipital regions. ...It was also recommended that appropriate backup electrodes for each standard electrode be applied in case of electrode malfunction during the sleep study’ [Silber et al., 2007].

EOG electrodes (placement):

The R & K Manual recommended at least two electro-oculogram (EOG) derivations to record eye movements during sleep [Silber et al., 2007].

EMG electrodes (placement):

Given the uniformly accepted practice of using EMG derivations specified in the R & K Manual, the Task Force recommended continuation of the standard bipolar single chin surface EMG derivation. Chin EMG should be recorded from electrodes placed above and below the chin with a backup electrode placed below the chin close to the primary electrode [Silber et al., 2007].

Scoring epochs:

A recommendation was made to retain the traditional epoch based scoring method. The group also voted to recommend that an epoch length of 30 seconds continue to be used for stage scoring, finding no compelling evidence to change it [Silber et al., 2007].

Sleep stage terminology revision [Silber et al., 2007]:

Stage W (Wakefulness)

Stage N1 (NREM 1 sleep)

Stage N2 (NREM 2 sleep)

Stage N3 (NREM 3 sleep)

Stage R (REM sleep)

[See Appendix A, on visual rules for scoring of sleep stages W, N1, N2, N3, R, excerpted from *The AASM Manual for the Scoring of Sleep*, Iber et al., 2007 a].

Visual scoring conclusions

1. 'No visual based scoring system will ever be perfect, as all methods are limited by the physiology of the human eye and visual cortex [alpha wave artifacts], individual differences in scoring experience, and the ability to detect events viewed using a 30-second epoch' [Sibler et al., 2007]. Nevertheless, Silber et al., found it is possible to develop a rigorous, biologically valid visual scoring system that can be applied meaningfully in clinical and research settings.
2. 'The new scoring system is presented as a step forward along this path' [Silber et al., 2007].
3. 'Studies are needed to test the reliability of the new rules. Future advances in technology may require modification of these rules with time' [Sibler et al., 2007].

RF Sleep Review Based on the Quality of RF Sleep Recording Evidence –SAJ [Iber et al., 2007a,b; Penzel, 2006; Penzel et al., 2007; Silber et al., 2007].

Digital scoring in RF sleep studies

In accordance with the lack of validation of the digital sleep recording methodology in the clinical sleep studies [Achermann 2006; Penzel, 2006; Penzel et al., 2007; Iber et al., 2007a], the various digital methodologies employed by sleep researchers using RF

exposures, (i.e. Borbély et al., [1999], Huber et al., [2000], [2003], Regel et al., [2007], Loughran et al., [2005]), must also be considered presently unvalidated and consequently their associated digital sleep data must also be considered unvalidated. Algorithms based on sleep EEG alone have difficulties distinguishing wake, sleep stage 1, and REM sleep [Penzel, 2006; Iber et al., 2007a]. [See Appendix B: In order to move forward in *The AASM Manual for the Scoring of Sleep* the first digital recording recommended rules are specified; they have been created, by consensus, to incorporate set techniques to facilitate a process for revision if accumulating evidence supports their utility’ [Iber et al., 2007a].]

RF scoring artifact problems

We must take into consideration that the analysis of the sleep EEG first requires the removal of artifacts [Silber et al., 2007; Penzel et al., 2007; Iber et al., 2007a; Kiefer, 2007 above; Penzel, 2007 above]. The digital sleep recorders have particular difficulty removing these artifacts from their automated digital records [Achermann, 2006; Penzel 2006; Penzel et al., 2007; Iber et al., 2007a].

There may be ECG, EOG, and EMG artifacts in the EEG signal. As much as possible, these influences have to be removed. ‘Automated [digital] sleep analysis primarily focuses on the sleep EEG signal. Several analysis algorithms restrict themselves to the analysis of one EEG only but the recording from at least 6 electrodes is required for accuracy of EEG recording [R & K, 1968; Iber et al., 2007a]. The definition of sleep stages, according to the recommendations of Rechtschaffen and Kales, do require the interpretation of EOG and EMG in addition’ [Penzel, 2006]. *The AASM Manual for the Scoring of Sleep* recommends at least 7 polysomnograms to be recorded [Iber et al., 2007a]. [See Appendix A and B, below]. Thus, digital scoring does not record sufficient information to remove the artifacts to accurately score sleeping.

Artifacts can occur as a result of many causes. Electrode lead movements are a common cause. Electrode impedance changes result in waves that can be misinterpreted. Degrading electrode impedance over the course of the night significantly affects EMG signal quality, which is difficult to recognize with automatic analysis [Penzel, 2006, 2007; Penzel et al., 2007].

Furthermore, an artifact unique to RF studies may occur when the RF exposure takes place with the electrodes attached to the subject’s head. In this exposure scenario, it is possible for the RF energy to interact with the recording electrodes producing artifacts in the measurement [Foster, 2007; Tattersall et al., Rostock, Sept 2006/ London ICES Conference, March 2007; Angelone et al., 2004; Chou and Guy, 1979].

Alpha band results

The stage NREM 1 sleep [N1] with alpha rhythm has the worst scoring agreement [Penzel et al., 2007; Danker-Hopfe et al., 2004; Iber et al., 2007a; also see Appendix A]. Where the number of subjects is well below 60, the reliability of the reports is decreased markedly [Penzel et al., 2007].

These factors lower the quality of the reports of alpha band effects [i.e. Borbély 1999; Hubel et al.; 2000; 2003; Regel et al., 2007; Loughran et al., 2005]. Overall, in these RF studies, the alpha band effects are small, variable and may lack scoring validity. The health consequences are unknown and are not identifiable in the visible scoring range of sleep disorders [ICSD-2, 2005] for instance as compared to the effects of caffeine on sleep.

There were several presentations at the Workshop reporting no effect of RF exposure on the alpha band [i.e. Danker-Hopfe et al., 2007; Sauter et al., 2007; Wiholm et al., 2007; Hinrichs et al., 2007; Hinrichs et al., 2005; de Seze 2007; Besset et al., 2005].

Visual Scoring of PSGs according to R & K [1968] during RF exposure

Loughran et al., [2005]

Loughran et al., [2005] have reported using the visual scoring method of R& K, 1968. However their number of electrodes for scoring sleep EEG is 2 [C₄-A₁ and C₃-A₂] whereas *The AASM Manual for the Scoring of Sleep* [following R & K 1968] recommends six, [F₄-M₁, C₄-M₁ and O₂ M₁ [on the left side of the scalp], with backup electrodes at F₃-M₂, C₃-M₂ and O₁ M₂, [on the right side of the scalp]. Loughran et al., [2005] appear to have recorded with one central-anterior [central, top] electrode on the left side of the scalp and one central-anterior electrode on the right side and did not report recording from frontal-medial [FM], central-medial [CM] and occipital-medial [OM] electrodes as specified by *The AASM Manual for the Scoring of Sleep* [Iber et al., 2007a]. This may result in limitations and distortions in their EEG recorded data. ‘Evidence from these studies suggests that sleep spindle activity is optimally recorded with central electrodes [C], while K complexes and delta activity are optimally recorded with frontal [F] electrodes [see Appendix A]. The predominant localization of alpha rhythm over the posterior head regions, and especially the occipital cortex [O], has been unchallenged since the days of the early EEG pioneers’ [Silber et al., 2007].

Considering Loughran et al., [2005] reported their visually scored data shows no effects except on REM sleep onset, this could be due to the lack electrodes over the frontal and posterior regions. This could account for their reporting an effect in the first REM onset [with a large standard deviation].

There is presently no validation for Loughran et al.’s, [2005] digitized scoring method and analyses [Iber et al., 2007a; Penzel et al., 2007] that suggest an effect on enhancing power in the 11.5–12.25 Hz frequency range. This reported effect could be a result of recording only with electrodes over the central region since ‘sleep spindles with frequency 11-16 Hz are usually maximal in amplitude over the central regions’ [Silber et al., 2007]. In their favour, Loughran et al., [2005] had a subject number of 50, which is near to the recommended number of around 60 subjects for sleep studies [Penzel et al., 2007]. They also used both visual and digital scoring allowing some possible cross validation of the digital scores. In the future, following the visible sleep scoring rules of

The AASM Manual for the Scoring of Sleep could improve this research to the level of validated reports [Iber et al., 2007a].

Danker-Hopfe et al., [2007]

In ongoing RF exposure during sleep, Danker-Hopfe et al., [2007] are using the R & K visual recording method in their sleep laboratory with 30 subjects. The subject level is well below 60. Danker-Hopfe et al., have previously published sleep research [not in the RF field] that was judged level one [Danker-Hopfe et al., 2004] by the Visual Scoring Task Force [Silber et al., 2007; see Appendix, Table 3].

A possible, but *unproven [Foster and Repacholi 2004; IEEE 95.1- 2005; ICNIRP 1998], reservation in regard to Danker-Hopfe et al., RF sleep on-going research is that they did not report using the same 8 Hz signal modulation that some groups report may be source of biological effects of GSM modulated 900 MHz signals [Bach Andersen group, 2007; Achermann / Kuster group, 2007].

* There is no established biophysical reason to expect a more likely biological non-thermal effect of RF with an amplitude modulated signal than a continuous wave signal at the same exposure level, below guideline limits [Foster and Repacholi 2004; IEEE 95.1-2005; ICNIRP 1998].

Hinrichs et al., [2005]

Hinrichs et al., [2005] also report that they used the R & K [1968] visual recording method in their sleep laboratory, with 14 subjects exposed to a GSM 1800, 1736 Hz base site signal. They have acquired 8 EEG signals. It would require an expert RF Sleep Task Force to evaluate whether the polysomnograms recorded in this paper included the 7 different types of signals suggested for level 1 diagnosis [see the Penzel summary above, page 7]. They found no effects on sleep.

Leitgeb et al., [2007]

Leitgeb et al. [2007] reported, in ambulatory RF sleep studies, sleep onset effects in 14% [6 subjects] of a possible 43 subjects. This work is presently unpublished, and tentative comment below is based his presentation. Considering the reports of *The AASM Manual for the Scoring of Sleep* Task Force, stage one sleep, is the most unreliable to score [Silber et al., 2007a] and ambulatory sleep recordings are not considered reliable sleep evidence [See Penzel summary above, page 7, re: limitations of ambulatory recordings]. As noted below, about 10-20 % of the population has little or no alpha rhythm [Appendix A, N1] and this is the way to identify sleep onset. This natural lack of alpha rhythm could result in a failure to record sleep onset accurately in 14% of his subjects. Also 'inward anger' of 'electrosensitive' persons could affect sleep onset [See 'Emotional measurements' below Kräuchi et al., 2007a]. The tentative RF effect on sleep onset, [Leitgeb et al., 2007], reported is much less than for instance the effect of caffeine on sleep. This appears to be at most, a small, weak, unreliable report of an RF effect on sleep.

Summary on the quality of RF sleep recording

1. Although the rapporteur's report is not the appropriate format to re-evaluate the entire RF sleep literature according to *The AASM Manual for the Scoring of Sleep* Task Forces' findings, with this brief introduction above, it is already clear that their findings [Iber et al., 2007a; Penzel et al., 2007; Silber et al., 2007] highlight the weaknesses of the RF sleep research methodology.
2. During the workshop several expert speakers reviewed the RF sleep literature [i.e. Loughran et al., 2007; Hämäläinen, 2007; Danker-Hopfe et al., 2007] with various evaluation criteria. But, in the future, once the ongoing RF sleep research is published, an expert RF Sleep Task Force may undertake a complete evaluation, by using the reliable and validated scoring criteria as set out by *The AASM Manual for the Scoring of Sleep* white papers and *The AASM Manual for the Scoring of Sleep* to reach a consensus scientific conclusion, and make expert recommendations and rules for future RF sleep research.

General Discussion/Consensus Statement [Leader Dr. Jürgen Kiefer]

During the concluding Workshop discussion, three questions related to these sleep and cognitive EEG studies were discussed and an answer to each question was developed based on a consensus of the participants attending the final session of the Workshop.

- 1) Are there any proven effects? There are no proven effects on either cognition or sleep. Generally there are both negative and positive results that are not replicated [by different laboratories].
- 2) What is the relevance of the present results to human health? None of the positive results are established evidence and all appear to be very small effects. Although there was disagreement, it was generally agreed that none of the small positive effects if established appear to be of any likely health consequence.
- 3) Mechanisms? There are no known mechanisms by which low level RF exposure below ICNIRP limits could cause effects on sleep or cognition. Above limits, heat is the known mechanism that could affect human cognition or sleep. Further research would be of greater importance if a new mechanism could be identified.

Future Developments –Considerations [SAJ]

Electrodes

New wireless recording techniques are now being investigated in sleep laboratories to free the patient from the leads between the body and a head-box or a bedside box. Efforts are underway to develop sensors with integrated wireless data transmission, which allows even less wires on the body. Efforts are being made to improve sensors and electrodes (e.g., dry electrodes) in order to minimize artifacts caused by movements and low impedance [Penzel, 2006]. Possible RF interaction artifacts with the electrodes require elucidation and elimination [Foster, 2007].

The AASM Manual for the Scoring of Sleep [2007] rules of visual scoring

In the medical clinical sleep field, as a result of the fact that considerable differences between visual sleep scoring and automated sleep analysis are always reported, none of the current automated sleep analysis methods has been accepted as an alternative for visual sleep analysis [Penzel, 2006]. Thus future RF sleep researchers could be required to follow *The AASM Manual for the Scoring of Sleep* rules of visual scoring of sleep EEG recordings to achieve validated sleep reports [Iber et al., 2007a; See Appendix A].

The AASM Manual for the Scoring of Sleep [2007] recommendations for digital scoring

If digital scoring of RF sleep recordings is desired, it could be done as set out in *The AASM Manual for the Scoring of Sleep*, [Iber et al., 2007a; III Technical and Digital Specifications; See Appendix B], in parallel with the visual scoring, as set out by *The AASM Manual for the Scoring of Sleep*, [Iber et al., 2007a; See Appendix A], to allow for cross validation of digital methods. In such a way, they would incorporate digital techniques that may in the future lead to ‘accumulating evidence to support their utility’ [Iber et al., 2007a].

RF Exposures

Future sleep researchers using RF exposures need to establish by international consensus standard exposure protocols for GSM 900, 1800 and UMTS [and emerging technology signals] and use them in the same way among inter-laboratory replications. Presently each sleep study laboratory has had their own exposure protocols making study comparison and interpretation difficult.

Additional points:

1) Temperature measurements.

In *The AASM Manual for the Scoring of Sleep* [Iber et al., 2007a], thermoregulation measurements over the sleep night are not required.

The human circadian rhythm of the core body temperature is relevant to sleep onset latency and thus influences N1; it is also relevant to sleep duration. The core body temperature and distal [skin temperatures] and their ratio and changes are relevant to sleep onset latency and the duration of the sleep.

Sleep duration is longest when in sync with circadian rhythm of the core body temperature. ‘Sleep is then typically initiated on the declining portion of the core body temperature [CBT] curve when its rate of change, and body heat loss, is maximal. In the morning when heat production is dominant over heat loss, CBT increases, as does the propensity to wake-up.... These preferred zones for falling asleep and for waking up have a profound effect on sleep duration — sleep length is maximal (circa 14 h) when sleep is

initiated around the CBT maximum. All these findings indicate that sleep propensity and sleep duration are tightly coupled with the thermoregulatory system. However, in contrast to the sophistication of sleep EEG analyses, including spectral decomposition of the EEG-signal, the thermoregulatory system has not been adequately studied in parallel [Kräuchi, 2007b].

‘Body heat loss before lights off, via selective vasodilatation of distal skin regions, promotes sleepiness and the rapid onset of sleep. This thermophysiological effect represents the cement between the circadian clock and the sleep–wake cycle, and in turn determines phase of entrainment and sleep onset latency. These interrelationships have been recently studied in a particular subset of the general population, mainly women, who suffer from cold hands and feet (the so-called vasospastic syndrome, VS). Women with VS exhibit not only a lower capacity to lose heat during the daytime but also a prolonged sleep onset latency, a disturbed phase of entrainment of the circadian clock with respect to the sleep–wake cycle and psychologically, a disposition to turn experienced anger inwards. This naturalistic model leads us to a more general conclusion that regulation of distal skin blood flow may have clinical relevance for insomnia, in particular sleep onset insomnia’ [Kräuchi 2007a].

Disorders of the circadian rhythm are relevant; the recording of core body temperature can give insights on the actual circadian phase of the patient. Core body temperature [CBT] is closely linked to the circadian system and its recording will allow conclusions on jet lag, delayed, or advanced sleep phase problems [Penzel, 2006].

Since an established mechanism of RF bioeffects is heating, it would be relevant to maintain and report the sleep recording room temperature and air circulation and also measure core body temperatures and distal skin temperatures of subjects throughout the sleep period.

2. The Emotional Measurements

Sleep is a desired state of unconsciousness, a state of disconnection, expecting to be restored and comforted upon awakening many hours later [Iber et al., 2007a].

“Sleep that knits up the ravell’d sleeve of care,
The death of each day’s life, sore labour’s bath,
Balm of hurt minds, great nature’s second course,
Chief nourisher in life’s feast”
[Macbeth Act II Sc ii. Shakespeare, ~1606].

These three authors [Kräuchi, Iber and Shakespeare] spanning some 400 years suggest one dimension of sleep not yet recorded in *The AASM Manual for the Scoring of Sleep* revision of the R& K Sleep Scoring Manual that may influence sleep scores, the emotional context [‘anger inwards’ ‘the comforter’ ‘the balm of hurt minds’] in which we sleep [Iber et al., 2007a]. Kräuchi [2007a] suggests above an impact on sleep scoring of prolonged sleep onset in women who turn anger inward.

Presently *The AASM Manual for the Scoring of Sleep* does not record emotional measurements but they may be relevant to a delayed sleep onset [N1]. The idiopathic environmental intolerant [IEI] ‘electrosensitive’ persons in sleep recording may have inward anger and thus delayed sleep onset. Should emotional state before sleep be recorded in RF sleep studies?

Overall Conclusions

I have confined my rapporteur’s review mostly to quality polysomnographic sleep recording rules as revealed by evaluation of clinical sleep research by the American Academy of Sleep Medicine [AASM] Task Force [Iber et al., 2007a,b] for the revision of the R & K [1968] Sleep Recording Manual as introduced by Dr T. Penzel because of the ‘rules’ great importance to RF sleep research.

1) General comments on brain electroencephalogram recordings

- The advantage of EEG and ERP recordings is their non-invasive nature and their high temporal resolution so that subtle activity changes which last only a few milliseconds can be detected. EEG recordings may reveal subtle differences in brain function, which are not always accompanied by behavioral performance differences.
- The disadvantage of EEG measurements is their low spatial resolution since the location in the brain of the electrical potentials recorded at the scalp can only be approximately identified. And the potentials only reflect synchronous electric activity of large neural assemblies.

2) *The AASM Manual for the Scoring of Sleep* [2007]

- The R and K, [1968] Sleep Recording Manual was revised in 2007 [*The AASM Manual for the Scoring of Sleep*, Iber et al., 2007a]. The AASM expert Task Forces [Iber et al., 2007a,b] evaluated the sleep evidence for the accuracy of their scoring methods and this information could be most helpful in future evaluation and planning of RF sleep research.
- Visual sleep scoring remains the preferred reliable and valid method [90% agreement] but the new small changes in *The AASM Manual for the Scoring of Sleep* [2007] need validation.
- Computer/digitized scoring of sleep is not yet an established method; any such method requires future validation [Iber et al., 2007a].
- The AASM Task Force found Stage N1 [NREM1-alpha rhythm] sleep scoring is the least reliable record of all the sleep stages and scoring of stage R [REM] is the most reliable.

3) Summary of RF studies presented at the Workshop

- Some RF sleep studies appear to follow the visual scoring methodology in the R and K [1968] Manual at least to some extent [i.e. Danker-Hopfe et al., 2007; Hinrichs et al., 2005; Loughran et al., 2005]. These visual studies mostly show no effect of RF exposure on sleep.
- Replicated visual scoring RF sleep results that follow the R & K, [1968], scoring rules would be a valid level of scientific evidence (see the AASM Task Forces’ publications).

- Digital recordings of sleep scores provide weak reports (see the AASM Task Forces' publications) and presently lack validity. Many of the digital scoring RF sleep studies report various positive small effects of RF on sleep.
- There are no proven effects of RF exposure on either cognition or sleep EEGs. Generally there are both negative and positive results that are not replicated [by different laboratories].
- None of the positive results are established evidence and appear to be very small, and of much less significance to health than, for instance, caffeine before sleep. The RF positive sleep results are much smaller than any of the sleep disorder effects identified in the ICSD-2, 2005: The International Classification of Sleep Disorders.
- Although there was disagreement, it was generally agreed that none of the small positive effects if established appear to be of any likely health consequence.

4) Future research

- Researchers would be well advised to use *The AASM Manual for the Scoring of Sleep* [2007] Task Forces' evaluation results and visual scoring rules to guide the design of quality RF sleep recording studies.
- Future RF sleep replication studies should be designed using RF signal exposures with characteristics specified on the basis of consensus among international experts.
- RF researchers could investigate the usefulness of new wireless recording techniques now being investigated for sleep laboratory use in order to free the patient from the leads between the body and a head-box or a bedside box. This could help minimize electrode artifacts. RF electrode interaction artifacts require expert investigation and elimination.
- Improvement in thermal measurements during sleep recording could advance the quality of sleep recording overall and may be essential in sleep research during RF exposures.

Dr Brunner's, Purposes of the Workshop: Answers [SAJ]:

1. RF sleep researchers could build 'solid scientific knowledge' about the effect of RF exposures on EEG through the use of *The American Academy of Sleep Medicine [AASM] Manual for the Scoring of Sleep* visual scoring rules that give well-validated scientific evidence [90% agreement] [Iber et al., 2007a,b].

2. 'The relevance of the single RF positive studies on EEG' has been evaluated. The RF EEG experts at the workshop reached the consensus conclusion that the reports of potential RF effects found in single EEG research projects are not validated, are variable, weak and of small and unknown health concerns, [and less than i.e. the effects of caffeine on sleep, less than the effects of Sleep Disorders identified in the ICDS-2, 2005]. The Workshop results affirm the opinion of the German Radiation Protection Commission that there is no need to change the limits in the range of radio frequency electromagnetic fields.

3. The consensus advice to the Ministry on further research to close the existing gaps of knowledge on RF effects on EEG would be that at present results are not of sufficient

quality to make a strong conclusion. Once ongoing RF sleep research is published an expert Task Force could evaluate the RF EEG literature, guided by *The AASM Manual for the Scoring of Sleep* [2007] visible scoring rules and guided by international dosimetry experts, using consensus conclusions.

If such a future RF Sleep Task Force concludes there is still a lack of quality RF sleep research literature to make a strong conclusion then future replicated quality research on sleep EEG may be warranted and is feasible. It is feasible because we have validated visual rules for sleep EEG scoring in *The AASM Manual for the Scoring of Sleep*, [Iber et al., 2007a]. Such an RF Sleep Task Force could also draw up rules for future RF research with validated methods on the basis of solid science, by consensus.

Solid Science Research would include, for instance:

Validated visual scoring of sleep following the rules of *The AASM Manual for the Scoring of Sleep* [Iber et al., 2007a], recording electrodes verified to be free from RF interference and artefacts, RF exposures that are agreed by international consensus to measure relevant human exposures, and room and body thermal measurements throughout the sleep period, testing around 60 subjects. The work should be conducted in a recognised international medical clinical facility by sleep medicine clinicians with the support of radio engineers and simultaneously replicated in another independent expert sleep recording medical clinical facility, by similar staff.

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Note: Appendix A and Appendix B are attached to give a brief sample to the reader of the extensive visual sleep scoring rules and digital recommendations that are defined in the 59 page 'AASM Manual for the Scoring of Sleep and Associated Events, Rules Terminology and Technical Specifications' [Iber et al., 2007a].

Appendix A

Excerpts from: IV Visual Rules from *The AASM Manual for the Scoring of Sleep and Associated Events. Rules Terminology and Technical Specifications*, [Iber et al., 2007a, pages 23-31] and [Silber et al., 2007].

Defining the wake-sleep boundary: Criteria for stages W and N1

Proposed criteria for stages W and N1 in subjects who are good alpha rhythm generators (80%-90% of the population) are largely unchanged, and sleep onset is defined as the start of the first epoch of sleep other than stage W. The “alpha rhythm” is an electrical rhythm which oscillates at a frequency of 8-13 Hz generated over the occipital scalp regions in humans during a state of relaxed wakefulness with eyes closed [Berger, 1929]. The issue of definition of stage N1 and sleep onset in subjects who generate little or no alpha rhythm (10%-20% of the population) was carefully considered. This group most probably accounts for the low inter- and intra-rater reliability for scoring of stage 1 sleep. Through the consensus voting process, the Task Force chose to concentrate on the development of slow eye movements in the EOG as the best measure of early sleep in the absence of any visually discernable alterations in EEG [no alpha waves] [Silber et al., 2007; Iber et al., 2007a].

Defining stage N2

The N2 sleep stage is characterized by low amplitude mixed frequency background with two morphologically distinct waveforms superimposed: K complexes and sleep spindles. The presence of these waveforms defines stage N2 sleep. The Task Force voted to define a K complex as a well delineated negative sharp wave immediately followed by a positive component standing out from the background EEG with total duration ≥ 0.5 seconds. Sleep spindles are comprised of a group of rhythmic waves which progressively increase and then gradually decrease in amplitude. Following review of the literature, the Task Force voted to define a sleep spindle as a train of distinct waves with frequency 11-16 Hz (most commonly 12-14 Hz) with a duration ≥ 0.5 seconds, usually maximal in amplitude over the central regions [Silber et al., 2007; Iber et al., 2007a].

Defining slow wave sleep: Stage N3

‘Stage N3 represents slow wave sleep and replaces the R & K nomenclature of stage 3 and stage 4 sleep’ [Iber et al., 2007a]. Slow wave sleep is high voltage [$> 75 \mu\text{V}$, $< 2\text{Hz}$] delta activity. Stages 3 and 4 are the only stages in which the R & K Manual specifies amplitude criteria. This was felt to be important, as there were no distinctive morphological features of slow waves in contrast to K complexes and sleep spindles. The R & K Manual defines the low frequency filter setting as a time constant not shorter than 0.3 seconds. ‘After about age 40 years -age-related drops in amplitude or spectral power have been noted in the theta, alpha, and spindle frequency bands, suggesting that this is a nonspecific phenomenon.’. ‘Both the Visual Scoring Task Force and the Geriatric Task Force voted to retain the $75 \mu\text{V}$ criterion for all ages. Data discussed earlier in the EEG derivation section indicate that slow wave amplitude is higher when recorded by frontal compared to central derivations. As a result, the Task Force voted to recommend the use of a frontal rather than a central derivation to measure slow wave amplitude. Since no

evidence could be found to indicate validity or biological significance in the subdivision of SWS into stages 3 and 4 based on the percentage slow waves in each epoch, they voted not to subdivide SWS. The group found no reasons to change from the current definition of stage 3 sleep. It was therefore recommended that stage N3 sleep be scored when 20% or more of an epoch consists of waves of 0.5-2 Hz frequencies with peak-to-peak amplitude $>75 \mu\text{V}$ in the frontal derivation' [Silber et al., 2007; Iber et al., 2007a].

Defining sleep stage R (formerly REM sleep)

'As discussed earlier, inter- and intra-rater reliability for scoring according to R & K rules is highest for R sleep compared to other stages. The Task Force addressed scoring of the onset and termination of periods of stage R sleep by consensus voting, with the aim of simplifying the current rules and giving clear guidelines for most circumstances. In summary, stage R sleep commences when chin EMG tone falls, unless K complexes or spindles persist, in which case stage N2 persists until rapid eye movements develop. If chin EMG tone is low in stage N2 as well as R sleep, the transition to Stage R occurs after the last K complex or spindle' [Silber et al., 2007; Iber et al., 2007a].

Appendix B

Excerpts from: III Technical Digital Specifications from *The AASM Manual for the Scoring of Sleep and Associated Events. Rules Terminology and Technical Specifications*, [Iber et al., 2007a]

The AASM Manual for the Scoring of Sleep RE: New Digital Recording Recommendations [Quoted from AASM, Iber et al., 2007a]

'Quantitative electroencephalography, cyclic alternating pattern, and methods characterizing autonomic events have not been incorporated [in *The AASM Manual for the Scoring of Sleep*] although a process for revision has been created to incorporate techniques if accumulating evidence supports their utility' [Iber et al., 2007a].

These recommendations are found in the section 'III Technical and Digital Specifications'. They list the following recommendations in Sections A, B, C and D [See brief quotes below from *The AASM Manual for the Scoring of Sleep*, Iber et al., 2007a pages 20-21].

'A. 'Digital Specifications for Routine PSG Recordings [Notes]'

' The recommended practice includes the maximum electrode impedances [5 K Ω], minimum digital resolution [12 bits per sample], sampling rate for EEG, EOG, EMG, ECG [desirable 500 Hz, minimal 200 Hz]; there are also specifications for sampling rates of airflow, nasal pressure, oximetry, esophageal pressure, body position, snoring sounds, and ribcage and abdominal movements. There are specifications for routinely recorded low frequency and high frequency filter settings for EEG, EOG, EMG ECG, respiration and snoring.'

‘B. Digital PSG Recording Features: Recommended are the following 7 features:’

1. A toggle switch permitting visual on screen standard 50uV DC calibration signal for all channels to demonstrate polarity, amplitude and time constant settings for each recorded parameter.
2. A separate 50/60 Hz filter control for each channel.
3. The capability of selecting sampling rates for each channel.
4. A method of measuring actual individual electrode impedance against a reference.
5. The capability of retaining and viewing the data in the exact manner in which it was recorded by the attending technologist [i.e. retain and display all derivation changes, sensitivity adjustments, filter settings, temporal resolution].
6. The capability of retaining and viewing the data in the exact manner it appeared when it was scored by the scoring technologist [i.e., retain and display all derivation changes, sensitivity adjustments, filter settings, temporal resolution].
7. A filter design for data collection which functionally simulates or replicates conventional [analog-style] frequency response curves rather than removing all activity and harmonics within the specified bandwidth.’

‘C. Rules for PSG Display and Display Manipulation: Systems must include 10 listed PSG features.’

‘Features 1-4 are recommended

1. Resolution of a digital screen and video card must be at least 1600 X 1200 for display and scoring of raw PSG data
2. Histogram with stage, respiratory events, leg movement events, O₂ saturation, and arousals, with cursor positioning on histogram and ability to jump to the page
3. Ability to view a screen on a time scale ranging from the entire night to windows as small as 5 seconds
4. Recorded video data must be synchronized with PSG data and have an accuracy of at least one video frame per second.

PSG features 5-10 are optional:

10. Fast Fourier Transformation or spectral analysis on specifiable interval (omitting segments marked as data artifact).’

‘D. Digital Analysis of PSG.’

‘Digital systems must include the ability to:

1. Identify whether sleep stage scoring was performed visually or computed by the system. [Recommended]’

‘Digital systems should include the capability to turn off and on, as demanded, highlighting for: 2-4 [Optional]

2. Patterns identifying sleep stage decisions [i.e., sleep spindle, K complex, alpha, delta].
3. Patterns identifying the respiratory analysis (for example apneas, hypopneas, desaturations)

4. Patterns identifying the movement analysis (for example periodic limb movements of sleep).’

[Quoted from AASM, Iber et al., 2007a]

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