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Proposed supplements and amendments to '*A Manual of Standardized Terminology, Techniques and Scoring System for Sleep Stages of Human Subjects*', the Rechtschaffen & Kales (1968) standard

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INTRODUCTION

In 1967, the Association for the Psychophysiological Study of Sleep (APSS) chartered a committee of sleep researchers to establish a standard system for visually scoring stages of sleep. The Committee's terminology and scoring system (edited by Alan Rechtschaffen and Anthony Kales, co-Chairpersons of the Committee) were quickly adopted after its 1968 publication under the auspices of the UCLA Brain Information Service as '*A Manual of Standardized Terminology, Techniques and Scoring System for Sleep Stages of Human Subjects*'. The manual and its recommendations have been well accepted and the system has spread across the world.

The proposal to standardize recording techniques and scoring criteria was intended to increase the comparability of results reported by different investigators. Researchers who have applied the system correctly have increased the reliability of their sleep stage scoring. In the several decades since its publication, however, a number of serious areas of unreliability in the 1968 standard scoring system have been identified. In particular, researchers developing computer-based automatic sleep staging systems have encountered numerous vague and ambiguous areas in the current standard.

At the 15th Annual Meeting of the Japanese Society of Sleep Research (JSSR) in 1990, Terashima's report from the Japanese Conference for Sleep Analysis emphasized the need to re-examine the definitions of sleep stages when developing computer staging systems based on the standard scoring system. The results of multiple comparisons among institutes and laboratories using methods for automated sleep staging based on the standard scoring system were unexpectedly poor. The lowest level of congruence between automation and records staged visually using the 1968 standard system was found for Stage 1 sleep, with the second worst agreement (still less than 70%) for sleep Stages 3 and 4.

To increase both the within- and between-researcher agreement in sleep stage identification and to foster the development of computer algorithms for automatic analyses of sleep, a need for additional definitions was recognized. In 1991, the Subcommittee for Automatic Sleep Staging (SASS) was formed by the JSSR. The Subcommittee comprised 53 investigators and seven project leaders selected for their skill in scoring sleep records: S. Sugita (Chair), M. Okawa (co-Chair), T. Kobayashi, T. Hori, A. Miyasita, S. Shirakawa and Y. Atsumi. In 1995, based on their 5 year discussions, the Subcommittee proposed supplementary definitions and amendments for the Standard Scoring System to the JSSR. These proposals were reported in the *JSSR Newsletter* (1996; No. 13, February 1, pages 5–13).

In 1997, at its 22nd Annual Meeting, the JSSR restructured the SASS to form the Sleep Computing Committee (SCC). The SCC working group has now formalized Supplements and Amendments to the Standard Scoring System based upon the 1995 SASS proposals. The Committee has met several times for discussion and to test their new definitions using

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carefully selected representative polysomnographic recordings. The final JSSR Sleep Computing Committee proposals have been published in Japanese as the '*Learning Manual of PSG Chart: Polysomnogram, Sleep Stage Scoring, Interpretation*'. The Committee has now prepared the English language version of their proposals for evaluation and empirical testing by sleep researchers all over the world.

SUPPLEMENTARY AND AMENDED DEFINITIONS FOR INTERNATIONAL CRITERIA FOR SLEEP STAGE SCORING

The JSSR's proposals to supplement and amend the currently used criteria for sleep staging (*A Manual of Standardized Terminology, Techniques and Scoring System for Sleep Stages of Human Subjects*, Rechtschaffen A, Kales A (eds). BIS/BRI University of California, Los Angeles, 1968; hereafter, the 'standard criteria (SC)') are detailed below.

Movement time: MT

When research purposes are not met by the SC, different movement time criteria may be used. However, in such cases, the modified criteria should be clearly stated and the degrees of modification should not exceed those in the following examples.

Example 1

MT is judged following the SC, with the addition of scoring parts of the recording with higher muscle tones and degrees of artifact as 'gross movement' or 'movement with duration more than 50% of an epoch', and the number of such segments is reported.

Example 2

Even when an epoch fulfils the SC definition of MT, the epoch may still be scored as a stage of sleep using additional criteria (below). In this case, an SC-defined epoch of MT can simultaneously be defined as an epoch of sleep and a body movement epoch.

Examples of criteria: (i) MT epoch is scored as the same stage as the *preceding* epoch and (ii) MT epoch is scored as the same stage as the *following* epoch.

Judgement of sleep Stage 1

The following supplementary definitions are used for scoring a transition from stage wake to Stage 1 sleep. Stage 1 is not necessarily defined as a sleep onset (sleep onset is defined below).

Definition of alpha waves

Alpha waves are electroencephalographic waves with a frequency of 8 Hz or more but less than 13 Hz.

Definition of a vertex sharp wave (V-wave)

A vertex sharp wave is a sharp waveform distinguished from background activities at or near Cz (C3, C4), with an amplitude of 75 μV or greater, and with a frequency of at least 5 Hz but no more than 14 Hz.

Slow eye movements

Slow eye movements (SEM) can be difficult to detect in recordings that were not made using long time constants. The following definitions are considered to apply for recordings made under recommended conditions. Slow eye movements waveforms do not manifest saccade-like sharp, abrupt, movements. Rather, SEM are smooth sinusoidal eye movements with amplitudes of 100 μV or more, and 10 s or less in duration.

Time constant: Longer time constants of 1.5 s or more are recommended to minimize deformations of SEM signals and to enhance the detection of SEM.

Amplification: Amplification of 200 μV/5 mm is recommended. This amplification allows observation of subtle eye movements without appreciably increasing the likelihood of signals saturating the amplifier.

Derivation: Monopolar recordings from both outer canthi are recommended to distinguish eye movements from contamination such as superimposition of electroencephalographic (EEG)waveforms.

Supplements for poor alpha wave subjects: For subjects whose central EEG alpha waves during resting wakefulness occupy less than 50% of the analysis epoch when the eyes are closed, one of the following criteria should be used to judge Stage 1 sleep. When using these exception criteria, the resting wake EEG should be recorded both before bedtime and after awakening from all-night sleep recording along with observations to confirm that subjects are behaviorally awake.

1. In subjects whose occipital EEG alpha activity occupy more than 50% of the analysis epoch during wakefulness with eyes closed, SC should be applied.
2. Electroencephalogram of various frequencies but less than 8 Hz and 20 μV or more in amplitude,

which is considered as EEG, suggesting lower vigilance level comparing resting wake with eyes closed condition, occupies more than 50%. In the absence of true alpha band activity, alpha-like activity in EEG frequencies below 8 Hz may be used to suggest lower vigilance levels when it is of 20 μV or greater amplitude, increases during resting wakefulness with the eyes closed, and occupies 50% or more of an epoch.
3. When the preceding criteria (2) are applied, confirmation of SEM activity is also recommended.

Judgement of sleep Stage 2

The following supplementary definitions of the K-complex should be considered.

1. The K-complex waveform begins with the abrupt onset of a negative sharp wave, which is immediately followed by a high amplitude positive slow wave. Polyphasic (notched) negative-positive waves are sometimes observed just before the onset of the negative K-complex sharp wave. The duration of a K-complex must be longer than 0.5 s. Its peak-to-peak amplitude must be greater than 200 μV. Waveforms must be visually distinct from background EEG activities; and a waveform should not be identified as a K-complex if it occurs within 5 s preceding or following high voltage delta waves (defined below). The K-complex waveform may or may not be accompanied by sleep spindle activity (defined below). Termination of a K-complex is identified by the peak of a trailing negative wave, which follows the major positive component, neglecting other overlapping waves (Fig. 1).
2. Sleep spindles are defined as trains of 12–16 Hz waves of 10 μV or greater amplitude, composed of at least six consecutive waves, or a train duration longer than 0.5 s. The appearance of the waveform train is not specified in the definition (i.e. a 'spindle' shape is not a requirement for identification as a sleep spindle). Although the mean frequency of a single train of waves can be used as a single descriptor for identified sleep spindles, its use must be clearly reported. Similarly, if a different amplitude threshold is used to identify sleep spindle activity, the threshold value must be clearly reported.

Definition of sleep onset

Sleep onset may be defined as necessary for research purposes, but should include the first epoch scored as one of the standard sleep Stages (1, 2, 3, 4, or REM) after the lights are darkened or a subject goes to bed. Researchers must report their definition of sleep onset. Researchers are expected to specify the sleep stage criteria used for the judgement of sleep onset, including all criteria for the duration of sleep stage(s), its (their) duration, and the time course of sleep etc. as in the following examples.

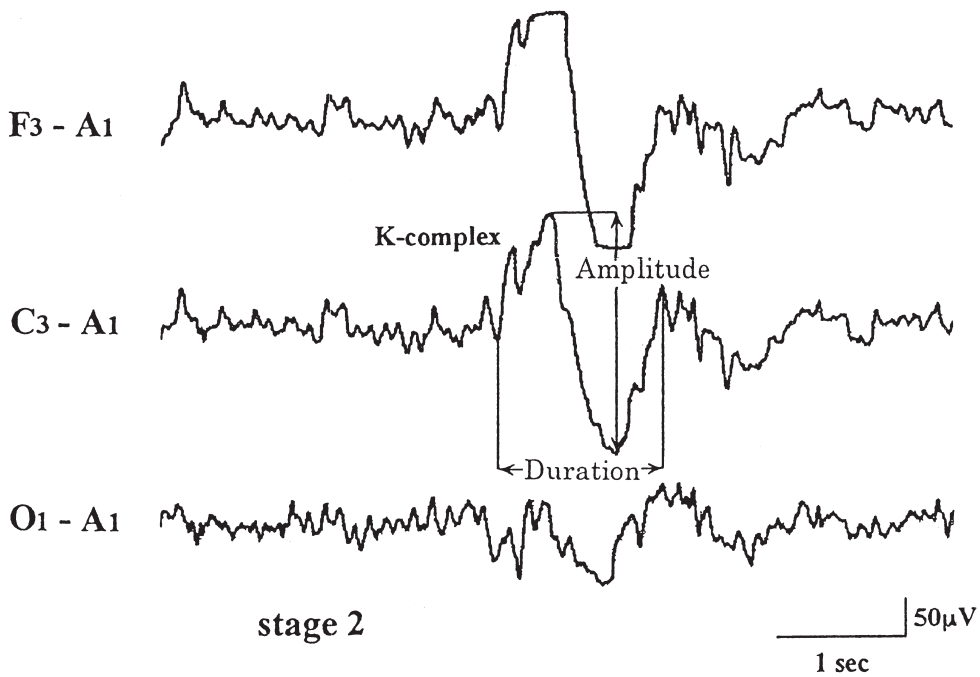

Figure 1. Onset and termination of K-complex

1. In this example, the first epoch judged as one of the sleep stages is defined to be sleep onset. However, if the first stage is Stage 1, the epoch can be judged as sleep onset only if it is followed by consecutive epochs of sleep stages 2, 3, 4 or REM.
2. In this example, the first epoch judged as one of the sleep stages is defined to be sleep onset. However, if the first stage is Stage 1, the epoch is judged as sleep onset on the condition that Stage 1 or the other stages continue for a specific length of time (e.g. 3 or 5 min).
3. In this example, the first epoch judged as sleep Stages 2, 3, 4, or REM is defined to be sleep onset. (A definition to attach importance on the appearance of Stage 2.)
4. In this example, the first epoch judged as sleep Stages 2, 3, 4, or REM is defined to be sleep onset. However, the epoch is judged as sleep onset on the condition that sleep Stages 2, 3, 4 or REM, follows for a specific duration (e.g. 3 or 5 min).
5. The expressions of 'Stage 1' or 'Stage 2' in the example definitions can be modified to use 'vertex sharp wave' or 'sleep spindle' criteria as desired.

Judgement of Stages 3 and 4

If slow waves with frequencies below 2 Hz and with amplitudes greater 75 μV occupy between 20 and 50% of an epoch, that epoch is judged as Stage 3 sleep. If the slow waves occupy more than 50% of an epoch, that epoch is judged as Stage 4 sleep. However, because these definitions do not contain any descriptions of complex composite waveforms, it can often be difficult to judge Stages 3 and 4 under the SC.

1. We add the following supplements to the definition of high amplitude slow waves given above.
   (i) When the combined period of two contiguous EEG waveforms is 0.5 s or longer (i.e. the frequency of the composite wave is 2 Hz or lower), that wave complex can be scored as one slow wave if the amplitudes of the two waves satisfy the requirement $B \geq A/2$ (Fig. 2).
   (ii) When fast waves appear superimposed on a slow wave, the amplitude of the slow wave is still measured from peak-to-peak, including the superimposed waves.
   (iii) The onset of an individual slow wave must follow a trough satisfying the requirement $B \leq A/2$ (Fig. 3).
2. When bursts of slow wave activity precede or accompany an arousal response or high amplitude EMG (e.g. body movements), those bursts should *not* be considered slow waves for EEG stage scoring, but as one form of the arousal response. Such portions of a record should be considered part of the preceding or following epoch when stage scoring. Furthermore, the terms 'movement arousal' or 'EEG arousal' are recommended over the general term 'arousal response', following the definition of American Sleep Disorders Association (EEG arousal: scoring rules and examples. *Sleep* 1992; **15**: 173–184).

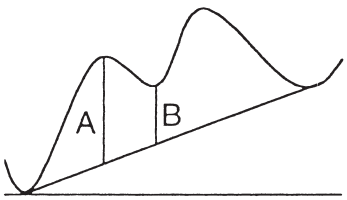

Figure 2.

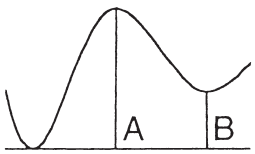

Figure 3.

Judgement of stage REM

Addition of the following supplement to the definition of rapid eye movements (REMs)

The same time constant, gain, electrode placements and montage can be used to record both SEM and REM. The REM waveform must appear as a saccadic movement, with rapid changes in angular velocity at the onset and termination of eye movement. Since small eye movements often appear during the transitions to and from REM sleep, a low amplitude criterion of 40 μV or greater (1 mm pen deflection under above-mentioned recording condition) is recommended. In recordings at 15 mm/s (or the equivalent digital display), REM activity should be identifiable as a 45° or greater angular departure from the baseline. Researchers should specifically report any modifications to the above-mentioned criteria.

Addition of the following definition of twitches (phasic EMG activity)

A twitch is defined as a skin-recorded EMG discharge with duration shorter than 0.5 s, or the EMG dis-

charge accompanying the contraction of a single muscle unit. The term 'these transient changes may be disregarded' in the standard manual (p. 8) is ambiguous. Therefore, the muscle activities satisfying the above-mentioned definition of twitch may be disregarded, while a transient increase in tonic EMG not satisfying the definition may be regarded as a sign of movement arousal.

Supplements and modifications for distinguishing the end of and interruptions of stage REM

Rechtschaffen and Kales (1968) discussed the difficulty of identifying the onset of REM sleep:

> A special case frequently arises where a movement arousal interrupts the continuity of stage REM, the mental-submental EMG quickly reverts to the stage REM level following the movement arousal, the EEG remains relatively low voltage, mixed frequency, and there is a resumption of REMs or change to stage 2 one or more epochs following the movement arousal. The problem is whether to score the interval following the movement arousal and the resumption of REMs or change to stage 2 as stage 1 or stage REM. (p.10, Part C).

The general guidelines for distinguishing between Stage 1 and stage REM support little more than scorer judgement. The following partially modified guidelines have been arranged to aid the discrimination of Stage 1 from REM sleep.

The following cases justify scoring as stage 1:

(i) epochs follow long or intense movement arousals;
(ii) epochs contain slow eye movements;
(iii) epochs contain persisting alpha activity following a movement arousal;
(iv) epochs contain well-formed vertex spikes;
(v) epochs contain waveforms similar to, but not fulfilling the definitions of sleep spindles or K-complexes. Such cases may be considered as supporting evidence that the interval between the movement arousal and unambiguous Stage 2 or REM has been Stage 1.

The following case justifies scoring as stage REM:

(i) epochs contain well-formed saw-tooth waves.

Definitions of sleep parameters

The following definitions of sleep parameters frequently used in sleep science and sleep medicine are listed for reference.

1. Total recording time (TRT): The duration of time from the start to the end of a recording.
2. Time in bed (TIB): The duration of time from 'lights out' to final awakening.
3. Total sleep time (TST): The amount of actual sleep time in a recording.
4. Sleep efficiency (SE): The ratio of total sleep time to time in bed (i.e. $(\mathrm{TST} \div \mathrm{TIB}) \times 100$).
5. Sleep period time (SPT): The duration of time from sleep onset to final awakening.
6. Time spent in each of the sleep stages based on total recording time (TRT).
   TS1: Time spent in Stage 1.
   TS2: Time spent in Stage 2.
   TS3: Time spent in Stage 3.
   TS4: Time spent in Stage 4.
   TSR: Time spent in stage REM.
7. Percentage of the sleep stages.
   (i) Percentage of the sleep stages based on sleep period time (SPT).
   %SW: Percentage of stage W.
   %S1: Percentage of Stage 1.
   %S2: Percentage of Stage 2.
   %S3: Percentage of Stage 3.
   %S4: Percentage of Stage 4.
   %SR: Percentage of stage REM.
   (ii) Percentage of the sleep stages based on total sleep time (TST).
   %S1: Percentage of Stage 1.
   %S2: Percentage of Stage 2.
   %S3: Percentage of Stage 3.
   %S4: Percentage of Stage 4.
   %SR: Percentage of stage REM.
8. Wake time after sleep onset (WASO), intermittent awakening: The total time spent awake during sleep period time (SPT).
9. Number of arousals: The number of arousals occurring in sleep period time (SPT).
10. Number of stage shifts: The number of occasions of sleep stages shifting from one to another.
11. Sleep latency: The duration of time from 'lights out', or bedtime, to the onset of sleep.
12. REM sleep latency: The interval from sleep onset to the first appearance of stage REM sleep in a recording.
13. REM activity: REM activity is identified as one or more REM in a unit of time and often expressed as the total number of such units.
14. REM density: REM density is a function that expresses the frequency of eye movements per unit of time during stage REM.
15. Number of REM episodes: The number of REM episodes that appear during sleep period time. If REM sleep continues with interruptions by wake

or other sleep stages, such REM episodes are considered as a single REM episode when the interruption is less than 15 min.

16. Sleep cycle: The first sleep cycle is the period from sleep onset to the end of the first REM sleep episode. Later sleep cycles are defined as the periods from the end of a REM sleep episode to the end of the subsequent REM sleep episode.
17. REM sleep interval: The REM sleep interval is the interval between the end of a REM sleep episode and the beginning of the subsequent REM sleep episode. Time awake is generally excepted from the interval.