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1 The CamNtech Sleep/Wake Algorithms

1.1 Introduction

Actigraphy has become an established and valued tool for sleep and circadian rhythm analysis over extended periods.
It should be noted that actigraphy data alone cannot be used to distinguish between sleep and immobility, however many validation studies of actigraphs have been performed **[Morgenthaler[1] et al]** showing the efficacy of actigraphy.
The CamNtech system is based upon threshold algorithms that are found within the public domain. The sleep/wake algorithms have been validated with a 30 second epoch hence protocol design should adhere to this setting wherever possible.

1.2 Sleep/Wake Scoring

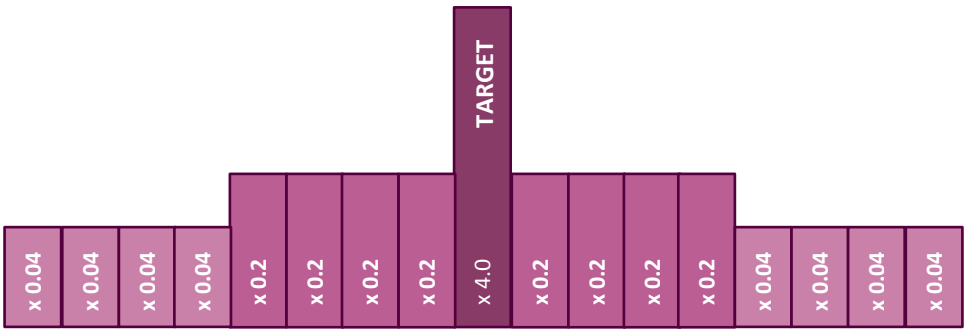
The sleep/wake algorithm uses a threshold to score each epoch of activity within the selected period as either sleep or wake. A 'score' is created by totalizing the epoch in question and those surrounding it using weighting factors based upon the epoch length.
If this score is above the sensitivity threshold, then the epoch is scored as wake, otherwise it is scored as sleep.

Wake = Activity Score > Threshold Value
Sleep = Activity Score <= Threshold Value

The threshold is adjustable between three settings (low, medium and high).
The activity score is dependent upon the sampling epoch for the data.
The following figures show the weighting factors applied for each different sampling epoch:

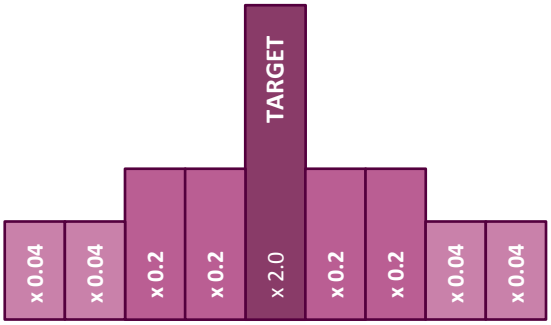
1.2.1 Activity score when using a 15 second epoch

With a 15 second epoch, the 'target' epoch (i.e. the one being scored as sleep or wake) is multiplied by 4, the epochs within 2 minutes of the target are multiplied by the factors as shown in the figure below. The activity score is the sum of these weighted values.



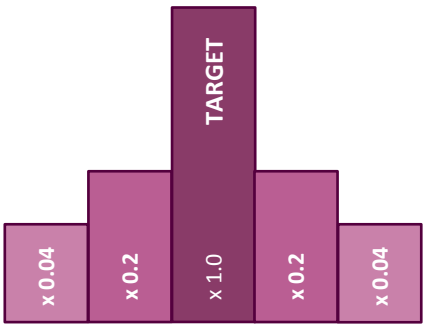
1.2.2 Activity score when using a 30 second epoch

With a 30 second epoch, the 'target' epoch (i.e. the one being scored as sleep or wake) is multiplied by 2, the epochs within 2 minutes of the target are multiplied by the factors as shown in the figure below. The activity score is the sum of these weighted values.



1.2.3 Activity score when using a 1 minute epoch

With a 1 minute epoch, the 'target' epoch (i.e. the one being scored as sleep or wake) is multiplied by 1, the epochs within 2 minutes of the target are multiplied by the factors as shown in the figure below. The activity score is the sum of these weighted values.



1.2.4 The Threshold Values

The Activity Score for each epoch is then compared to the threshold to determine if the epoch is to be scored as wake or sleep. The 'Sensitivity' setting in the software allows for 3 different settings as follows:

Sensitivity Setting	Threshold Value
Low	*80*
Medium	*40*
High	*20*

The **Validation**[2] of the MotionWatch was performed using HIGH sensitivity. This is the default setting for the software.

1.3 Mobile/Immobile Scoring

An additional level of scoring is applied to determine if each epoch is mobile (contains activity counts) or immobile (no activity counts). A threshold is utilized to ensure that very small background activity is not scored as mobile. The threshold is based upon the epoch for the stored data and is applied as follows;

Epoch Setting	Threshold Value
15 Seconds	*<1 count*
30 Seconds	*< 2 counts*
1 Minute	*<4 counts*

1.4 Sleep Start Calculation

The sleep start calculation is based upon the assumption that the subject will have little or no movement in the period shortly after they have fallen asleep.
The period used to determine sleep start is 10 minutes, hence at a 1 minute epoch, we test 10 epochs and at a 15 second epoch, we test 40 epochs.
We use a threshold value to classify sleep/wake within this test which is **totally independent** of the sleep/wake scoring during the analysis period. The threshold is set depending upon the epoch as follows:

Epoch Setting	Threshold Value
15 Seconds	*1.5 counts**
30 Seconds	*3 counts*
1 Minute	*6 counts*

*In practice this will be 2 counts

Additionally, we allow some epochs to be above the threshold within the test period; the number of epochs allowed is also dependent upon the epoch as follows:

Epoch Setting	Counts Allowed Above Threshold
15 Seconds	*7*
30 Seconds	*2*
1 Minute	*1*

The process then begins by looking at the first **10 minute** period following the Bed Time. Each epoch is tested against the threshold as described above. The number of epochs exceeding the threshold is counted. If the number of epochs exceeding the threshold is greater than the 'allowed' number from above, then the process is repeated with the start point 1 minute forward from the bed time.
This process continues until a 10 minute block is found that satisfies both the threshold and allowed counts criteria. The Sleep Start is then marked as the **START** of this 10 minute period.

1.5 Sleep End Calculation

The sleep end calculation works in a similar manner to sleep start, except that we look for a period of **5 minutes before the Got-up time** that satisfies the test criteria. The thresholds are the same as those for the sleep start. The allowed counts differ as follows:

Epoch Setting	Counts Allowed Above Threshold
15 Seconds	*11*
30 Seconds	*5*
1 Minute	*2*

The process then begins by looking at the **5 minute** period before the Got-up Time. Each epoch is tested against the threshold as described above. The number of epochs exceeding the threshold is counted. If the number of epochs exceeding the threshold is greater than the 'allowed' number from above, then the process is repeated with the start point 1 minute backward from the get up time.
This process continues until a 5 minute block is found that satisfies both the threshold and allowed counts criteria. The Sleep End is then marked as the **END** of this 5 minute period.

2 The Sleep Parameters

Time in bed	The total elapsed time between the “Lights Out” and “Got Up” times.
Assumed sleep	The total elapsed time between the “Fell Asleep” and “Woke Up” times.
Actual sleep time	The total time spent in sleep according to the epoch-by-epoch wake/sleep categorisation.
Actual sleep %	Actual sleep time expressed as a percentage of the assumed sleep time.
Actual wake time	The total time spent in wake according to the epoch-by-epoch wake/sleep categorisation.
Actual wake %	Actual wake time expressed as a percentage of the assumed sleep time.
Sleep efficiency %	Actual sleep time expressed as a percentage of time in bed.
Sleep latency	The time between “Lights Out” and “Fell Asleep”.
Sleep bouts	The number of contiguous sections categorised as sleep in the epoch-by-epoch wake/sleep categorisation.
Wake bouts	The number of contiguous sections categorised as wake in the epoch-by-epoch wake/sleep categorisation.
Mean sleep bout	The average length of each of the sleep bouts.
Mean wake bout	The average length of each of the wake bouts.
Immobile mins	The total time categorised as Immobile in the epoch-by-epoch mobile/immobile categorisation.
Immobile time %	The immobile time expressed as a percentage of the assumed sleep time.
Mobile mins	The total time categorised as mobile in the epoch-by-epoch mobile/immobile categorisation.
Mobile time (%)	The mobile time expressed as a percentage of the assumed sleep time.
Immobile bouts	The number of contiguous sections categorised as immobile in the epoch-by-epoch mobile/immobile categorisation.
Mean immobile bout	The average length of each of the immobile bouts.
Immobile bouts <=1min	The number of immobile bouts which were less than or equal to one minute in length.
Immobile bouts <=1min %	The number of immobile bouts less than or equal to one minute expressed as a percentage of the total number of immobile bouts.
Total activity score	The total of all the activity counts during the assumed sleep period.
Mean activity per epoch	The total activity score divided by the number of epochs in the assumed sleep period. Note that this result will be expected to scale depending on the length of the epoch.
Mean nonzero activity per epoch	The total activity score divided by the number of epochs with greater than zero activity in the assumed sleep period. Note that this result will be expected to scale depending on the length of the epoch.
Fragmentation Index	The sum of the “Mobile time (%)” and the “Immobile bouts <=1min (%)”. This is an indication of the degree of fragmentation of the sleep period, and can be used as an indication of sleep quality (or the lack of it).

3 Comments on some sleep parameters

3.1 Immobile phases

This value is low if there have been long periods of uninterrupted sleep and is therefore a measure of sleep quality. If the value is high it is indicative of more disrupted sleep.
If there is high proportion of phases of 1 minute duration (Percentage Immobility) then this is highly suggestive of disrupted sleep in the form of micro-arousals as encountered in Sleep Apnoea.

3.2 Number of Minutes Moving

This is the converse of Number of Minutes Immobile. The higher this value the more disrupted the sleep.

3.3 Fragmentation Index

This index is sometimes referred to as Movement (MI) and Fragmentation (FI) index because it is equal to: Percentage of Minutes Moving + Percentage Immobility. This index is a proven and very good indication of disrupted or restless sleep. A fragmentation index of >50 is considered bad. <20 is considered to be very good.
Aubert-Tulkens[3] et al used this index to screen patient for sleep apnea–hypoapnea. The MI and FI reflect different sleep characteristics. A raised MI occurs when sleep and immobility is interrupted by nocturnal awakenings. A high MI can exist with a low FI if, once asleep the individual remains immobile for prolonged periods. By contrast in OSAS the periodic arousals caused by respiratory events increase both the MI and FI. Accordingly, Aubert-Tulken et al found that the variable with the least overlap between controls and patients was the sum of MI and FI. This had a sensitivity of 89% and a specificity of 95% for diagnosing sleep apnea syndrome when using all night PSG as a reference standard.

3.4 Sleep and Wake Bouts

The number of sleep bouts is low if the sleep is of good quality (i.e. long uninterrupted periods) and higher if it is of poor quality. Wake bouts are the converse of sleep bouts.

3.5 Sleep Efficiency

This is equal to “Actual Sleep Time” divided by “Time in Bed” and is a well recognized measure of sleep quality. However it needs to be interpreted carefully when comparing with PSG results.
In a sleep laboratory Bed Time is when the lights are switched off. If a user at home marks a Bed Time and then reads for an hour before switching off the lights the Time in Bed will be longer than that worked out in a sleep lab. Hence actigraphy will yield lower sleep efficiency than PSG.
Conversely actigraphy can also yield higher sleep efficiency than PSG in the following situations. (a) the Actual Sleep Time of subjects who are studied in a sleep laboratory for the first time sleep is lower than it would be at home primarily due to the new environment and discomfort from recording instrumentation; (b) subjects with disturbed sleep lie quietly in bed for long periods of time and their wakefulness is not always detected by actigraphy.

4 References

[1] *Timothy Morgenthaler, MD, Cathy Alessi, MD, Leah Friedman, PhD, Judith Owens, MD, Vishesh Kapur, MD Brian Boehlecke, MD, Terry Brown, DO, Andrew Chesson, Jr., MD, Jack Coleman, MD, Teofilo Lee-Chiong, MD, Jeffrey Pancer, DDS, Todd J. Swick, MD.* ***Practice Parameters for the Use of Actigraphy in the Assessment of Sleep and Sleep Disorders: An Update for 2007.*** *Standards of Practice Committee, American Academy of Sleep Medicine*

[2] *Maxime ELBAZ , Kevin YAUY , Arnaud METLAINE , Monica MARTONI , Damien LEGER.* ***Validation of a new Actigraph MotionWatch versus Polysomnography on 70 healthy and suspected sleep disordered subjects.***

[3] *Aubert-Tulkens G, Culee C, Harmant-Van Rijckevorsel K, Rodenstein DO.* ***Ambulatory evaluation of sleep disturbance and therapeutic effects in sleep apnea syndrome by wrist activity monitoring****. Am Rev Respir Dis 1987; 136: 851-856*