Cardiopulmonary Coupling Analysis

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Slow Wave Sleep (Delta Wave)

- Slow wave sleep is correlated with **restorative** function of sleep
- Slow wave sleep is considered as **deep** sleep
Limitations of Slow Wave Sleep

• Depth criteria are arbitrary.

• Classic benzodiazepines reduce “depth” despite improving subjective and objective measures of sleep quality.

• Poor correlations with perceived sleep quality.

Conventional sleep staging based on EEG morphology gives less insight into physiologic conditions and sleep stability

Thomas RJ Cellscience Rev 2007;3:49-62
The cyclic activity of these arousal complexes in NREM sleep is termed Cyclic Alternating Pattern (CAP).

CAP is a marker for sleep instability, whereas absence of CAP (non-CAP) reflects a condition of consolidated sleep.

Terzano MG, et al. Sleep 1985;8:137-145
Cyclic Alternating Patterns (CAP)

A marker for **sleep instability**

Figure from Chokroverty S, Thomas R, Bhatt M. Atlas of Sleep Medicine 2005
Cyclic Alternating Patterns (CAP)

Unstable Sleep (CAP)

Stable Sleep (Non-CAP)
CAP and Insomnia

- 47 insomnia patients and 25 controls
- CAP rate showed significant correlation with subjective sleep quality by visual analogue scale

Cyclic Alternating Patterns (CAP)

Unstable Sleep

Figure from Dr. Robert Thomas
Non-Cyclic Alternating Patterns (Non-CAP)

Stable Sleep

Figure from Dr. Robert Thomas
CAP is Associated with Autonomic Arousal

Figure from Chokroverty S, Thomas R, Bhatt M. Atlas of Sleep Medicine 2005
Cardiopulmonary Coupling Analysis


Cardiopulmonary Coupling Analysis

Heart Rate Signal

ECG

Respiration Signal

ECG-derived Respiratory Signals (EDR)

~ 10 seconds of data
Components of Cardiopulmonary Coupling Analysis

• Respiratory-related power in heart rate signal

• Respiratory power

• Correlation between heart rate and respiratory signal
Cardiopulmonary Coupling Analysis

Figure 3—Sequential steps in the derivation of cardiopulmonary coupling measures. See Appendix for technical details. ECG refers to electrocardiogram; CAP, cyclic alternating pattern.
Association of EEG-CAP with Physiologic Parameters

Mathematically, when combining heart rate dynamics and respiration signals to determine the degree of “coupling” ...

- **EEG-CAP (unstable sleep)** is associated with **low-frequency coupling** (0.01-0.1Hz)
- **EEG-Non-CAP (stable sleep)** is associated with **high-frequency coupling** (0.1-0.4Hz)
- **REM/Wake** is associated with **very-low-frequency coupling** (<0.01Hz)

CPC Sleep Spectrogram

Non-CAP
High-Frequency Coupling
(“Stable Sleep”)

CAP
Low-Frequency Coupling
(“Unstable Sleep”)
Sleep Spectrogram in a Healthy 30-Year-Old Woman

Non-CAP
High-Frequency Coupling
(“Stable Sleep”)

CAP
Low-Frequency Coupling
(“Unstable Sleep”)

Healthy Control
### Normal CPC Sleep Parameters

<table>
<thead>
<tr>
<th>Variable</th>
<th>PSQI ( \leq ) 5 (N=82)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSQI</td>
<td>3.3 ± 1.3</td>
</tr>
<tr>
<td>Age, years</td>
<td>38.8 ± 13.0</td>
</tr>
<tr>
<td>Gender, female (%)</td>
<td>61 (74)</td>
</tr>
<tr>
<td>Epworth Sleepiness Scale</td>
<td>9.5 ± 3.9</td>
</tr>
<tr>
<td>Beck Depression Inventory</td>
<td>3.7 ± 3.9</td>
</tr>
<tr>
<td>Stable sleep index, %</td>
<td>41.2 ± 16.8</td>
</tr>
<tr>
<td>Unstable sleep index, %</td>
<td>33.9 ± 14.7</td>
</tr>
<tr>
<td>REM/Wake index, %</td>
<td>23.3 ± 7.7</td>
</tr>
<tr>
<td>Sleep duration, hours</td>
<td>6.8 ± 1.5</td>
</tr>
</tbody>
</table>
Sleep Apnea

• Signs and Symptoms
  – Loud, regular snoring
  – Daytime sleepiness
  – Hypertension

• Associated with major medical conditions

• Most common treatment
  – CPAP
The Fundamentals of Sleep and Obstructive Sleep Apnea

**Normal Breathing**
Breaths are characterized by a semi-sinusoidal wave-like pattern. Transitions from inspiration to expiration, and vice versa, are rounded and smooth.

**Flow Limitation**
The rounded inspiratory portion of the breath starts to flatten.

**Obstructive Hypopnea**
A reduction in airflow of ≥50% of baseline with a 3% desaturation OR a reduction in airflow of ≥30% with a 4% desaturation AND lasting for at least 10 seconds.*

**Obstructive Apnea**
A reduction in airflow of ≥90% of baseline lasting for at least 10 seconds.*

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**Airway Cross-section**

- No obstruction
- Partially obstructed airway
- Increasingly obstructed airway
- Completely obstructed airway

**Flow Through Airway**

- Semi-sinusoidal – unobstructed flow
- Flattening & reduced flow
- Flattening & further reduced flow
- Flat – minimal or zero flow

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Detecting Sleep Apnea

Tracking Treatment Efficacy in Sleep Apnea

# Apnea Patterns

<table>
<thead>
<tr>
<th>Airflow</th>
<th>Obstructive</th>
<th>Mixed</th>
<th>Central</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory effort</td>
<td>![Obstructive Waveform]</td>
<td>![Mixed Waveform]</td>
<td>![Central Waveform]</td>
</tr>
</tbody>
</table>
Phenotyping Sleep Apnea

Improving Sleep Stability with Tai-Chi Training

Yeh GY et al. Sleep Medicine 2008;9:527–536
Insomnia

• A perception or complaint of inadequate or poor sleep
  – Difficulty falling asleep
  – Frequent awakenings
  – Waking too early and having difficulty falling back to sleep
  – Waking unrefreshed

• A highly prevalent condition affecting as many as 48% of older persons

• Next day consequences
Insomnia Predicts Psychiatric Disorders

Insomnia Predicts Recurrence of Depression

Circadian Rhythm is **Altered** in Depression

Quantifying Insomnia

Healthy Control

Depression

Quantifying Insomnia

Stable Sleep

- High Frequency Coupling Sleep %
  - Medication-free
  - Hypnotics
  - Control

Stable Sleep Latency

- Minutes
  - Medication-free
  - Hypnotics
  - Control

Quantifying Insomnia

- Stable sleep was significantly correlated with the HAM-D insomnia (r=-0.35), and the BDI insomnia score (r=-0.33).

- REM/wakeful state was significantly correlated with the HAM-D score (r=0.42), the PSQI (r=0.31), the BDI (r=0.31), and the BDI insomnia score (r=0.41)

Quantifying Insomnia

Schramm PJ et al. Sleep Breath 2013;17:713–721
Improved Sleep Stability in Depression with Tai-Chi Exercise

Ma Y. et al. Behavioral Sleep Medicine 2016
Quantifying Stress

Quantifying Stress

Practice of Sleep Medicine

Invention

Disruptive Innovation

Polysomnography

Understanding of Sleep Apnea
Innovation in Sleep Monitoring

**Invention**

- Polysomnography

**Disruptive Innovation**

- Simplified Sleep Monitoring