Continual Screening of Patients using mHealth: The Rolling Score Concept applied to Sleep Medicine

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Sleep Apnea – A Co-Morbidity of Heart Failure

- One or more pauses in breathing during sleep

- 2 Types
  - Obstructive sleep apnea (OSA)
  - Central sleep apnea (CSA)

- Heart failure
  - Sleep Apnea remains undetected

European Heart Journal, 2015
1117 patients
Motivation

- Screening and diagnosis
  - Standardized questionnaires (Sensitivity and Specificity)
  - Polysomnography

- Independent risk factor for progression and development of heart failure\(^1\)
  - Risk assessment
  - mHealth-based telemonitoring

\(^1\)Mechanisms and Clinical Consequences of Untreated Central Sleep Apnea in Heart Failure
Costanzo M.R. et. al, Journal of the American College of Cardiology 65(1) (2015), 72-84
Risk Assessment

- Snoring
- Daytime Somnolence
- Hypertension and BMI
- Gender/Age
- Sleep Disruption
- Quality of Sleep
- Sleep Parameters

Standardized Questionnaire
- Berlin Questionnaire (BQ)
- STOP-BANG
- Pittsburgh Sleep Quality Index (PSQI)

- Sleep Tracker

Health Data Center
Standardized Questionnaires

Global Score

18

Pittsburgh Sleep Quality Index (PSQI)

[11 ≤ Global Score ≤ 21] Chronic Sleep Disorders

[ 6 ≤ Global Score ≤ 10 ] Bad Sleeper

[ 5 ≤ Global Score ] Good Sleeper
Standards Questionnaires

- Time Schedule
- Semantics
- Validation
- Combining
The **Rolling Score**

Global Score

- **5**
- **0**

Updating

- **5**
- **0**

- **6**
- **2**

- **7**

- **3**
- **2**

- **IM**

**Time Schedule**

- **I_1**
- **I_2**
- **I_3**
- **I_4**
- **I_5**

**Timeline**

- **I_M**

- Validation
- Semantics
- Merging
- Mapping
The **Rolling Score Concept**

<table>
<thead>
<tr>
<th>Standardized Questionnaires</th>
<th>Scoring</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level I:</strong> Questionnaire</td>
<td><strong>Global Score</strong></td>
</tr>
<tr>
<td>([Q_1, \ldots, Q_i, \ldots, Q_e])</td>
<td>([GS_1, \ldots, GS_i, \ldots, GS_e])</td>
</tr>
<tr>
<td><strong>Level II:</strong> Category</td>
<td><strong>Rule set 2</strong></td>
</tr>
<tr>
<td>([C_1, \ldots, C_i, \ldots, C_m])</td>
<td><strong>Category Score</strong></td>
</tr>
<tr>
<td><strong>Level III:</strong> Item</td>
<td><strong>Rule set 1</strong></td>
</tr>
<tr>
<td>([I_1, \ldots, I_i, \ldots, I_u])</td>
<td><strong>Item Score</strong></td>
</tr>
</tbody>
</table>

**Score Mapping Rule Set**

**Rolling Score**

**Classification**

**Time Schedule** \([t_0, \ldots, t_i, \ldots, t_k]\)

**Merging**

**Score Mapping Rule Set**
Feasibility Study

• 10 **healthy** volunteers

• Demographic data:
  – Average age (Min/Max): 29.1 (23/33) years
  – Gender proportion (m/f): 7/3

• **Informed Consent**

• Duration: 29 days (Dec.2015 – Jan.2016)

• **Equipment:**
  – Smartphone with **mHealth application** (Android)
  – **Sleep Tracker** Withings® *Pulse OX*

• **Compliance** of 75% necessary
Concept Implementation

Global Score

day = 0

Initial Score

Global Score

BQ
STOP-BANG
PSQI

3 $R_{\text{single}}$ $\rightarrow$ BF
$R_{\text{single}}$ $\rightarrow$ STOP-BANG
$R_{\text{single}}$ $\rightarrow$ PSQI

Timeline

day = 29$^{\text{th}}$

End Score

Global Score

BQ
STOP-BANG
PSQI
# Rolling Score Questionnaire

<table>
<thead>
<tr>
<th>Category C</th>
<th>Number of Items $I$</th>
<th>Category $\tilde{C}$ (Number of Items $I$)</th>
<th>Number of Items $\bar{I}$</th>
<th>Time Schedule $t_i$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snoring</td>
<td>$1/5^*$</td>
<td>Snoring (8)</td>
<td>4</td>
<td>Mon.</td>
</tr>
<tr>
<td>Observed</td>
<td>1</td>
<td>Snoring (8)</td>
<td>4</td>
<td>Mon.</td>
</tr>
<tr>
<td>Sleep Disturbances</td>
<td>9</td>
<td>Sleep Disturbances (8)</td>
<td>8</td>
<td>Tue.</td>
</tr>
<tr>
<td>Sleep Medication</td>
<td>1</td>
<td>Sleep Medication (1)</td>
<td>1</td>
<td>Wed.</td>
</tr>
<tr>
<td>Daytime Somnolence</td>
<td>$1/3/2^*$</td>
<td>Daytime Somnolence (6)</td>
<td>4</td>
<td>Thu.</td>
</tr>
<tr>
<td>Sleep Latency</td>
<td>2</td>
<td>Weekly Quantifiable (5)</td>
<td>5</td>
<td>Fri.</td>
</tr>
<tr>
<td>Sleep Duration</td>
<td>1</td>
<td>Weekly Quantifiable (5)</td>
<td>5</td>
<td>Fri.</td>
</tr>
<tr>
<td>Sleep Efficiency</td>
<td>$2^{**}$</td>
<td>Weekly Quantifiable (5)</td>
<td>5</td>
<td>Fri.</td>
</tr>
<tr>
<td>Blood Pressure</td>
<td>2</td>
<td>Monthly Quantifiable (4)</td>
<td>3</td>
<td>Every 28$^{th}$ after start</td>
</tr>
<tr>
<td>BMI</td>
<td>1</td>
<td>Monthly Quantifiable (4)</td>
<td>3</td>
<td>Every 28$^{th}$ after start</td>
</tr>
<tr>
<td>Neck size</td>
<td>1</td>
<td>Monthly Quantifiable (4)</td>
<td>3</td>
<td>Every 28$^{th}$ after start</td>
</tr>
<tr>
<td>Sleep Quality</td>
<td>1</td>
<td>Sleep Quality (1)</td>
<td>1</td>
<td>Every 28$^{th}$ after start</td>
</tr>
<tr>
<td>Age/Gender</td>
<td>2</td>
<td>Age/Gender (2)</td>
<td>2</td>
<td>At start</td>
</tr>
</tbody>
</table>

* Order: STOP-BANG/BQ/PSQI ** One item of category Sleep Duration for GSi calculation necessary
The **Rolling Score**

- **Rolling Score of Subject 09**

![Graph showing Rolling Score over time](image)

Average relative **difference** between RS and **standardized score**

\[
\Delta_{rel} = \frac{1}{n} \sum_{k=1}^{n} \frac{|G_{Sk} - \text{End Score}_{k}|}{mSR} \times 100 \% 
\]

- \(n\) ... # of observations
- \(mSR\) ... max. Score Range
The **Rolling Score**

### Mean, standard deviation and $\Delta_{rel}$ of joined and single $GS_i$ and *End Score*, * joined questionnaires

<table>
<thead>
<tr>
<th></th>
<th>GS*</th>
<th>GS</th>
<th>End Score</th>
<th>$\Delta_{rel}$*</th>
<th>$\Delta_{rel}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BQ</td>
<td>0.4 ±0.5</td>
<td>0.4 ±0.5</td>
<td>0.5 ±0.5</td>
<td>3.3%</td>
<td>3.3%</td>
</tr>
<tr>
<td>STOP BANG</td>
<td>0.4 ±0.8</td>
<td>0.4 ±0.8</td>
<td>0.4 ±0.8</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>PSQI</td>
<td>4.7 ±2.2</td>
<td>3.9 ±2.3</td>
<td>4.5 ±2.1</td>
<td>6.7%</td>
<td>6.7%</td>
</tr>
</tbody>
</table>
Quantification of Items

- **Differences** in *Sleep Parameters* between subjective estimations and objective measurements

- One subject **excluded** from analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sleep Latency [min]</td>
<td>11.6</td>
<td>± 20.0</td>
<td>0.8</td>
<td>96.8</td>
</tr>
<tr>
<td>Sleep Duration [h]</td>
<td>0.8</td>
<td>± 0.8</td>
<td>0.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Sleep Efficiency [%]</td>
<td>9.1</td>
<td>± 5.4</td>
<td>2.9</td>
<td>20.8</td>
</tr>
</tbody>
</table>
Merging

PSQI - Assessment period of 1 month

During the past week [...]?

Algorithm - Arithmetic Mean
Discussion

- **Differences** between the *Rolling Score* and the *Standardized Global Score* (≤ 10\%)\(^1\) showing promising results in the context of a feasibility study

- Small **temporal variances**

Sources:
- "**Intraobserver-Variabilities**“ of certain categories
- **Granularity** of the scoring system
- Subject was **uncertain** in regards to the respond
- Expected Bias: **Sensor data** may had an **influence** on the answers of corresponding **items**

\(^1\)A content validated questionnaire for assessment of self reported venous blood sampling practices  
K. Bölenius et. al, BMC Research Notes 5(1) (2015), 39
Conclusion

- **New risk assessment** approach „The Rolling Score Concept“
- Deviations of scores are in a **reasonable range** (≤ 10%)
- **General validation** must be performed to confirm the **diagnostic benefit**

Outlook

- **Application** of *Rolling Score Concept* to **heart failure patients**
- **Substitution** of items by **sensor data** and mapping measurements to scoring system by specific algorithm
- Application to other **standardized questionnaires**