Wearable and Continuous Prediction of Passage of Time Perception for Monitoring Mental Health

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Passage of time perception (POTP) linked to emotions
  - Easily quantifiable, unambiguous metric

Emotions linked to homeostatic state
  - Changes in physiological signals
  - Measured continuously and noninvasively
  - Analyze biomarkers

Goal: Develop ML models for predicting POTP based on biomarkers for real-time mental health monitoring
- Experiment: emotional short films and cognitive tasks
  - Measured ECG, SKT, EDA, RSP, PPG
  - Two wearable sensors

<table>
<thead>
<tr>
<th>Segment</th>
<th>Duration</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relaxation audio</td>
<td>3 min</td>
<td>Rest</td>
</tr>
<tr>
<td>Neutral clip</td>
<td>2 min</td>
<td>Neutral</td>
</tr>
<tr>
<td>Rest</td>
<td>2 min</td>
<td>Neutral</td>
</tr>
<tr>
<td>Fear clip</td>
<td>2 min</td>
<td>Emotional</td>
</tr>
<tr>
<td>Math task</td>
<td>3 min</td>
<td>Cognitive</td>
</tr>
<tr>
<td>Rest</td>
<td>1.5 min</td>
<td>Rest</td>
</tr>
<tr>
<td>Stroop test</td>
<td>1.5 min</td>
<td>Cognitive</td>
</tr>
<tr>
<td>Sadness clip</td>
<td>1.5 min</td>
<td>Emotional</td>
</tr>
<tr>
<td>Rest</td>
<td>3 min</td>
<td>Rest</td>
</tr>
</tbody>
</table>
• Segmented signals into 45s windows
• Extracted 80 biomarkers
• Time and frequency domain features
• Analyzed average $t_{rel}$ in each segment
  • Computed relative time error:
    $$t_{rel} = \frac{t_{correct} - t_{perceived}}{t_{correct}}$$
• Grouped segments with same POTP direction
• Performed statistical significance tests
• Compared 8 ML algorithms using Leave-n-Subjects-Out Cross-Validation
• Feature elimination
• Hyperparameter tuning
• Performed two classification tasks:
  • Experimental segment classification
  • Slow vs Fast POTP across all segments
Statistical significance of $t_{rel}$

Experimental state classification

- Average F-1 score: 79%
- F-1 score for Fast POTP: 93%
- Most important features:
  - Skin conductance gradient (SCL_gradient)
  - Skin temperature total power (SKT_TOTAL_POWER)

<table>
<thead>
<tr>
<th>Exp. state</th>
<th>Avg. $t_{rel}$</th>
<th>P-value</th>
<th>POTP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emotional</td>
<td>-16.1%</td>
<td>0.0456</td>
<td>Slow</td>
</tr>
<tr>
<td>Neutral</td>
<td>6.94%</td>
<td>0.942</td>
<td>No change</td>
</tr>
<tr>
<td>Cognitive</td>
<td>23.6%</td>
<td>2 x 10^{-5}</td>
<td>Fast</td>
</tr>
</tbody>
</table>
- F-1 score: 77.1%
- Most important biomarkers from ECG and RSP signals

Experimental State Classifier

Time Label Classifier
Concluding and Future Work

- POTP is related to emotions
- ML algorithms can predict POTP based on subjects’ biomarkers

Continuous POTP monitoring can be achieved using wearable devices

- Future work
  - Test a larger, more diverse set of subjects
  - Use longer experimental tasks