Quantifying Opioid Withdrawal through Cardio-mechanical Variability using Multi-modal Wearable Sensors

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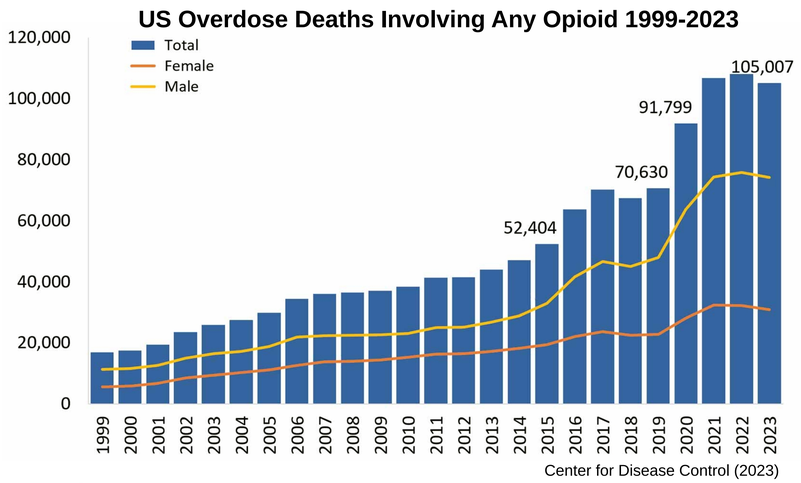
Introduction

- Over 26.8 million people are living with opioid use disorder globally with the majority of those affected in the United States.
- Opioid use related deaths is expected to result in more than 700,000 drug related deaths in the US by 2025.



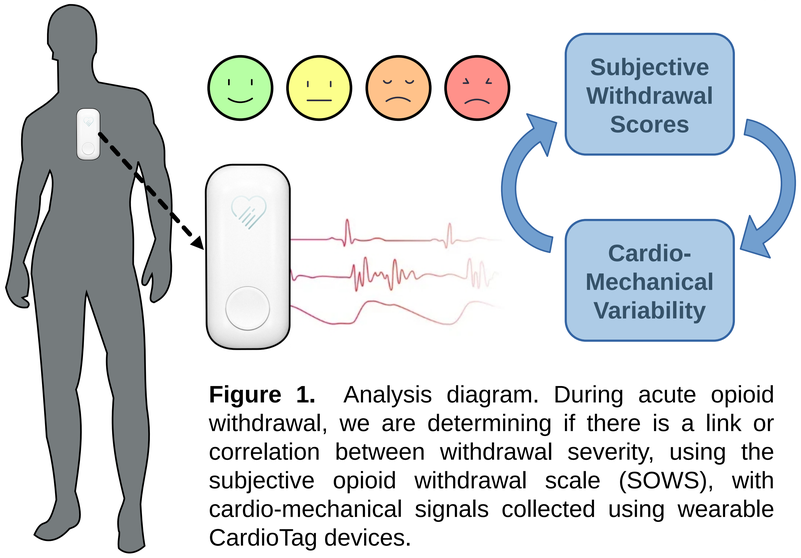


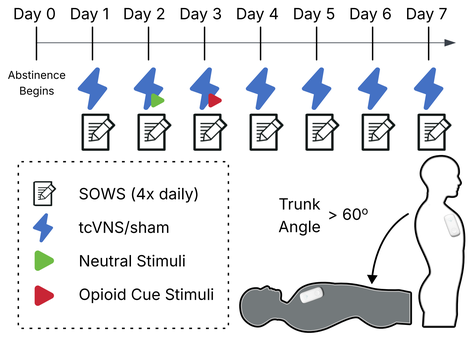
Figure 1. Analysis diagram. During acute opioid withdrawal, we are determining if there is a link or correlation between withdrawal severity, using the subjective opioid withdrawal scale (SOWS), with cardio-mechanical signals collected using wearable CardioTag devices.

Objective

Investigated a novel method for correlating dynamic time warping (DTW) distances of raw cardio-mechanical signals during 60-minute windows prior to measuring subjective opioid scores using SOWS.

Methods

Figure 2. Subjective opioid withdrawal scales (SOWS) and wearable cardiac signals, continuous electrocardiogram (ECG), seismocardiogram (SCG), and photoplethysmogram (PPG), were collected over a 7-day double-blind study exploring effects of transcutaneous cervical vagus nerve stimulation (tcVNS) vs. sham on patients with opioid use disorder (OUD). Signals for analysis are taken for patients in a supine position. Four times each day, tcVNS/sham stimulation and SOWS were administered. Days 2 and 3 consists of Biopac signal acquisition and blood draws during a neutral/opioid cue stimuli protocol.



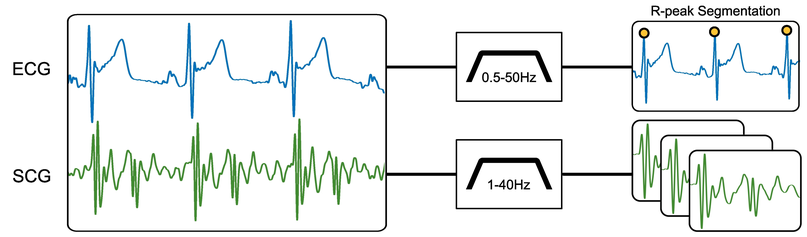


Figure 3. Signal preprocessing pipeline. The raw ECG signal is band-pass filtered between 0.5-50 Hz, while the SCG is filtered between 1-40 Hz. Key R-peaks are then identified in the ECG, which serve as fiduciary markers to segment the continuous SCG waveform into discrete, beat-by-beat cycles.

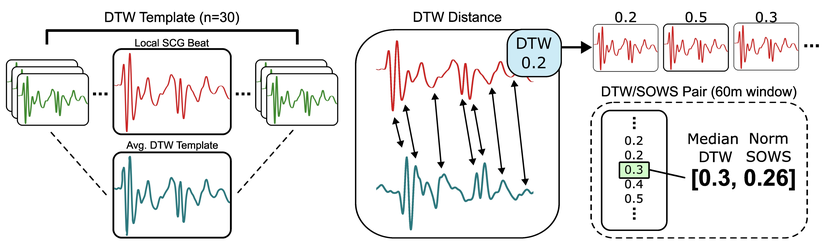
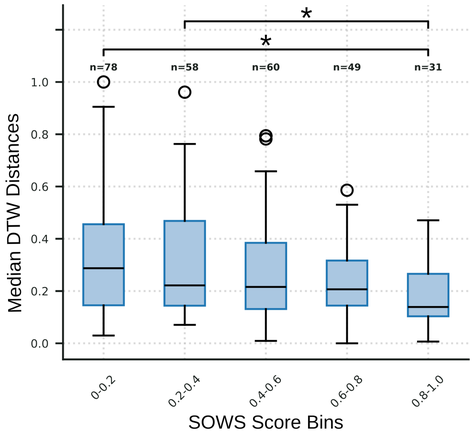


Figure 4. Pipeline for quantifying morphological changes in SCG heartbeats. First, a representative template heartbeat is created by averaging a moving window of 30 beats. The DTW distance is then computed by measuring the similarity between this template and the local individual heartbeat. This process is repeated continuously. The final output is a feature pair associated with a SOWS, consisting of the survey's score and the median of all normalized DTW distances calculated within the 60-minute window immediately prior to the survey.

Results and Conclusions

Figure 5. Box-plot showing the average median DTW distances for 60 minutes of raw beat-segmented SCG signals prior to each normalized SOWS score across all available time-points and patients (n=13). Distance decreases (higher beat similarity) as SOWS increases (higher withdrawal). Table below shows statistics across SOWS bins for associated SCG DTW scores.



SOWS	Count	Mean ± Std	Median	Min	Max	IQR
0-0.2	78	0.32 ± 0.22	0.287	0.030	1.000	0.310
0.2-0.4	58	0.31 ± 0.21	0.222	0.071	0.961	0.324
0.4-0.6	60	0.27 ± 0.19	0.216	0.009	0.794	0.253
0.6-0.8	49	0.24 ± 0.14	0.207	0.000	0.586	0.172
0.8-1.0	31	0.19 ± 0.12	0.139	0.007	0.471	0.163

Conclusions

- Successfully differentiated between high and low states of opioid withdrawal using DTW distances of SCG signals collected via an FDA-approved, wearable CardioTag device
- System demonstrates significant potential for acute withdrawal alerts to support inpatient care
- Potential for remote patient monitoring and timely telehealth interventions for enhanced outpatient care
- Can guide the administration of medications for opioid use disorder (MOUD)
- Provides quantitative metrics to evaluate the effectiveness of current and future opioid prevention techniques and medications

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