Time-Frequency Visualization of Alcohol Withdrawal Tremors

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***Abstract*— In this paper, we propose a signal processing method of assessing the severity tremors caused by alcohol withdrawal (AW) syndrome. We have developed an iOS application to calculate the Clinical Institute Withdrawal Assessment (CIWA) score which captures iPod movements using the built-in accelerometer in order to reliably estimate the tremor severity component of the score. We report on the characteristics of AW tremor, the accuracy of electronic assessment of tremor compared to expert clinician assessment, and the potential for using signal processing assessment to differentiate factitious from real tremor in patients seen in the emergency department, as well as in nurses mimicking a tremor.**

Our preliminary results are based on 84 recordings from 61 subjects (49 patients, 12 nurses). In general we found a linear relationship between energy measured by the accelerometer (in the 4.4-10 Hz range) and the expert rating of tremor severity. Additionally, we demonstrate that 75% of the recordings from patients with actual AW syndrome had a mean peak frequency higher than 7 Hz whereas only 17% of the nurses' factitious tremors were above 7 Hz, suggesting that tremor above 7 Hz could be a potential discriminator of real versus factitious tremors.

***Index Terms*— Alcohol Withdrawal, time frequency analysis, tremors, spectrogram**

I. INTRODUCTION

Alcohol withdrawal (AW) syndrome is commonly encountered in the Emergency Department (ED) [1-5] and, in its most severe form, can be life-threatening [6]. Despite its prominence, AW is often poorly managed in the ED. In a retrospective review conducted at two large urban EDs, numerous problems in clinical management were documented, including highly variable and inadequate benzodiazepine dosing, long intervals between doses, and lack of documentation of clinical signs of withdrawal [7]. Seizure rates during treatment were high, approaching 10% at one site, and the total length of stay was, on average, more than double the mean stay for non-admitted patients. Alcohol withdrawal is most commonly treated with benzodiazepines. Emergency physicians are often reluctant to treat patients in AW because: 1) These drugs can cause excessive sedation, particularly if combined with alcohol, and 2) They have high abuse potential (patients present to the ED complaining of AW but are actually drug-seeking).

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A symptom-triggered approach to the treatment of AW has the potential to improve the care of these patients in the ED [8]. In the symptom-driven therapy model, patients are regularly evaluated using a standardized assessment tool, and treated with benzodiazepines according to symptom severity. The most commonly used assessment tool is the Clinical Institute Withdrawal Assessment for Alcohol, revised (CIWA-Ar)[9]. The CIWA-Ar assesses 10 separate symptoms of AW, rating withdrawal severity on a scale from 0-67. Patients with a score ≥ 10 should be treated and re-evaluated in 1 hour until 2 sequential tests are under the treatment threshold.

Although validated in specialized alcohol treatment programs and detox facilities, the CIWA-Ar has been neither validated nor widely adopted in the ED setting. This limited acceptance is likely because: 1) Several domains assessed by the CIWA-Ar are completely subjective, making it amenable to potential manipulation by benzodiazepine-seeking patients, and 2) It is time consuming to administer. There is great need to develop a more accurate and efficient, standardized method of assessing AW severity in ED patients in order to improve the adoption of a symptom-triggered approach to AW management.

The most universally used clinical measure of AW severity is tremor. It is a key component of the CIWA-Ar. Unfortunately, existing estimates of tremor severity are subjective, and even validated scoring systems such as the CIWA-Ar use descriptors such as 'moderate' and 'severe' without qualification. A standardized tool for assessing tremor would both improve the clinical accuracy and reliability of the CIWA-Ar, and likely increase the acceptance of the CIWA-Ar in the ED, potentially improving clinical care. Accurate quantification of tremor would allow the development of shorter, more objective rating scales for the assessment of severity of AW with tremor assessment given a higher weighting [10].

To standardize the assessment of tremor in AW patients in the ED, we developed an iOS application which quantifies tremor by capturing phone movement (frequency and amplitude) in three dimensions using the built-in accelerometer. A secondary research question was whether or not it is possible to discriminate a real, involuntary AW tremor from an intentional attempt to deceive the assessor. The creation and standardization of the tremor assessment application is the first step in the eventual development of a shortened, more objective AW assessment tool specifically designed for

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ED use.

II. Clinical Tremor Assessment

In order to analyze accelerometer recordings from an iOS device held by each patient, we had to obtain clinically validated assessments of each patient. This involved standardizing the electronic tremor assessments against expert clinical opinion. Electronic tremor assessments, as measured by the accelerometer, were videotaped and compared against the standard, subjective tremor assessments of three expert clinicians according to the 7-point CIWA-Ar tremor scale (0 = no tremor, 7 = severe tremor). Data was excluded from all analyses when the tremor received a rating of 0 by all three clinicians.

A. Subjects

Accelerometer data were collected from 49 patients presenting to an urban ED with AW symptoms and from 12 nurses deliberately mimicking an AW tremor (factitious). Subjects were instructed to hold the iPod in their hand with their palm facing upward while fully extending their arm. Data was collected over a 20 second window at a sampling rate of 70 samples per second. Initially data was collected only from each patient's right hand (21 patients), but we subsequently modified our methods to include an assessment of each hand after noticing significant variability between hands (28 patients). Data saving errors occurred in 7 cases, leaving a total of 84 recordings.
For analysis purposes, participants were subdivided into four categories: 1) Real Characteristic Tremor (mild); 2) Real Characteristic Tremor (moderate/severe); 3) Potentially Factitious/Atypical Tremor (patient); and 4) Factitious (nurse). To do so, experienced observers reviewed patients' tremor videos and categorized each tremor as either a typical, mild tremor; a typical moderate/severe tremor; or a potentially factitious, atypical tremor. Twenty seven were classified as real, characteristic mild tremors; seventeen were classified as real, characteristic, moderate/severe tremors; and five were flagged as potentially factitious or atypical.

III. Time-Frequency Analysis

Often with biologically derived periodic signals such as speech, heart signals, or body motion, a time-frequency view can provide unique insight [11]. We use spectrograms in this paper in order to better understand the nature and type of tremors. Data was collected using the 3-axis accelerometer on iPods for 20 seconds with a sampling rate at around 70 Hz, with only the magnitude of the accelerations being used. We then computed short-time Fourier transforms (STFTs) with window lengths of 4 s with 90% overlap. The peak frequency (in the 0.3-13 Hz range) of each window was used for tremor detection analysis, as shown below:

$$V(n) = \underset{1<k<50}{\operatorname{argmax}} |X_n(k)| \tag{1}$$

where $X_n(k)$ is the STFT of window n at frequency k. We define the mean peak frequency μ as:

$$\mu = \frac{1}{N}\sum_{n=1}^{N} V(n) \tag{2}$$

and, the RMSE (relative to the mean) as:

$$\sigma = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(V(n)-\mu)^2} \tag{3}$$

We also define consistency as how stable the frequency is from one window to the next, and is quantitatively defined as:

$$C = \frac{1}{N-1}\sum_{n=2}^{N}|V(n)-V(n-1)| \tag{4}$$

Our first goal was to electronically quantify tremor severity in patients in AW. Figure 1 illustrates the relationship between the CIWA-Ar tremor severity score and the energy in the signal. Energy here is defined as the sum of time frequency blocks in the 4.4-10 Hz range (i.e., the tremor frequency range). As can be shown, there is a general linear relationship such that the higher the CIWA-Ar tremor severity score, the higher the energy in the tremor signal.

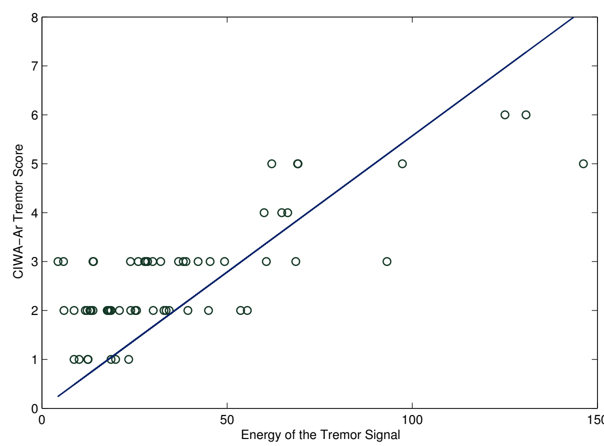

Fig. 1: Relation between CIWA-Ar Tremor Score and Energy of the Tremor Signal

With respect to differentiating real from factitious tremors, based on our evaluation of the 84 spectrograms, one key feature became evident. Figures 2 demonstrates the average energy of the tremor signal versus mean peak frequency. As demonstrated by this figure, the mean peak frequency is a potentially useful indicator of typical versus factitious tremors. For example, frequencies higher than 7 Hz are more indicative of real tremors; 75% of 'real' tremors had a mean peak frequency higher than 7 Hz. On the other hand, only 17% of nurses' tremors were above this cut-off. There were 5 patients with atypical/possibly factitious tremors who were assessed, and 5 out of 9 recordings from them (56%) also fell below the 7 Hz frequency. A variety of other features could be observed, including energy consistency and change of acceleration angle. However, for the purposes of this paper we focused on the peak frequency.

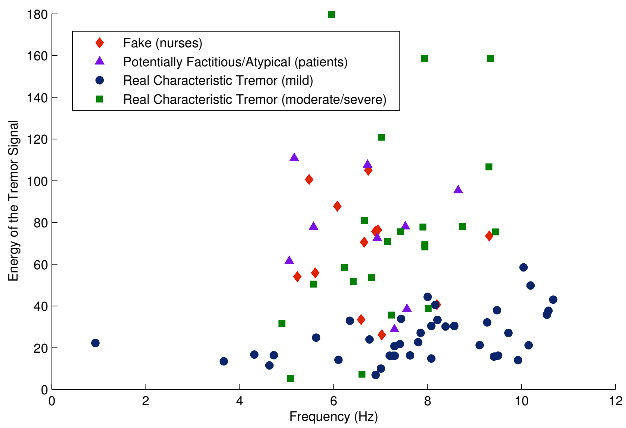

Fig. 2: Average Energy of the Tremor Signal in [4.4 - 10] Hz vs. Mean Peak Frequency of the Tremor Signals.

IV. Discussion

The primary goal of this study is to objectively quantify tremor severity in patients in acute AW. Differentiating real from factitious tremors is an important part of assessing tremor severity. Currently, tremors are assessed visually by a health care professional and the CIWA-Ar score associated with the tremor severity can be subjective. In previous work directed at developing a shortened version of the CIWA-Ar [10], we discovered surprising variability in the inter-rater reliability of tremor. Anecdotal information collected since our original study confirms that the assessment of tremor severity is quite variable, depending on clinical experience with AW. This is especially important as the turnover of nursing staff is high and EDs are increasingly staffed by younger and less experienced personnel, and it is these nursing staff who primarily assess withdrawal severity. The simple quantification of tremor using a standardized electronic tool is a novel and innovative idea with hospital-wide applicability in the evaluation of AW. Such a system could potentially even help non-clinical staff at withdrawal management facilities decide when to send patients to hospital for treatment. Our preliminary results are promising; we found that there was a linear relationship between the CIWA-Ar tremor rating and the energy in the tremor signal such that the higher the CIWA-Ar severity score, the greater the energy in the 4.4-10 Hz range. Additional signal processing may be useful for filtering the data in order to reduce the variance around this line.

With respect to differentiating real versus factitious tremors, the goal of this paper is to provide an initial answer as to whether classification is possible based on the electronic tremor recordings. We found that 75% of the recordings from patients with AW syndrome had a mean peak tremor frequency higher than 7 Hz, whereas only 17% of nurses mimicking AW tremor had a tremor with a frequency in this range, suggesting that tremor above 7 Hz could be a potential discriminator of real versus factitious AW tremors. Notably, the selection of the range of mean peak frequency was visually done based on evaluating the spectrograms of patients and nurses mimicking AW tremors. If the peak frequency cut-off was changed to 7.1 Hz, 50% of these potentially factitious tremors would have been captured in the low frequency range without affecting the percentage of 'real' tremors falling above the cut-off. More data from patients' who are potentially 'faking' an AW tremor are needed to evaluate if there is a meaningful difference between a cut-off of 7 versus 7.1 Hz.

Of course, it is impossible to ascertain, with certainty, that tremors classified as 'real' were in fact legitimate AW tremors; likewise, it is possible that patients' tremors classified as 'suspicious/factitious' were in fact legitimate. The experienced observers did their best to identify potentially factitious tremors based on atypical or uncharacteristic tremor features (e.g., movement in only one axis), which, in practice, is all clinicians have to rely on in order to differentiate genuine from factitious tremors. This emphasizes the importance of our current investigation, which seeks to characterize typical AW tremors, and to identify useful features for distinguishing real from factitious tremors.

It should be noted that this is a very simple, preliminary view of this data, with our goal being to characterize the type tremor recordings that are observed in actual AW patients. Obviously, further data analysis, including machine learning or support vector machines, could provide significant improvements in classification. Finally, investigation into the effects of handedness is ongoing.

V. Examples

Figures 3 and 4 illustrate spectrogram examples of the tremor recordings. Figure 3 shows a patient with actual tremors, with a dominant and consistent frequency at 9.7 Hz and an RMSE of 0.3 Hz. On the other hand, Figure 4 illustrates a factitious tremor without a consistent frequency peak. In this case the mean peak frequency is 6.3 Hz which is not in our range and, based on our empirically determined cut-off of 7 Hz, would identify the tremor as factitious.

Figures 5 and 6 show misclassified examples from our data. Figure 5 shows a real tremor with a mean peak frequency of 5.6 Hz. This would be incorrectly classified as a factitious tremor. Figure 6 illustrates a factitious tremor with a mean peak frequency of 8.3 Hz. This would be classified, based on our rules, incorrectly as a real tremor.

VI. Conclusion

Alcohol and alcohol-related illness are among the most common health issues resulting in emergency department visits around the world [2]. The ability to provide better, more efficient care for patients in AW literally has global implications.

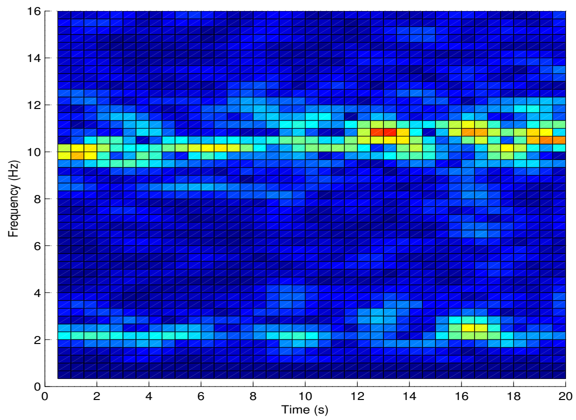

Fig. 3: A clearly identifiable example of a real tremor.

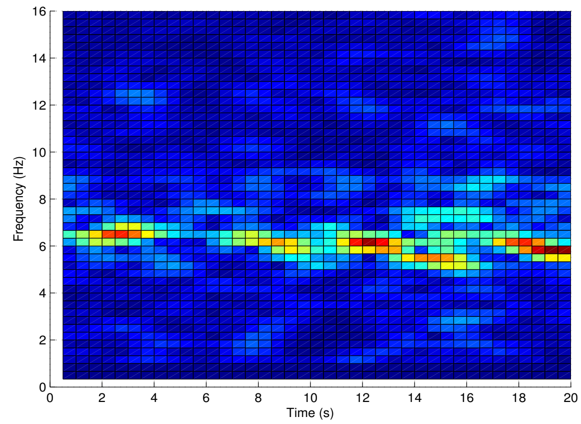

Fig. 5: A misclassified example of a real tremor.

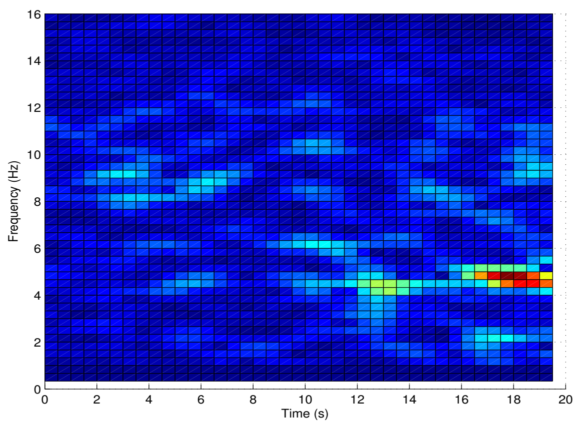

Fig. 4: A clearly identifiable example of a factitious tremor.

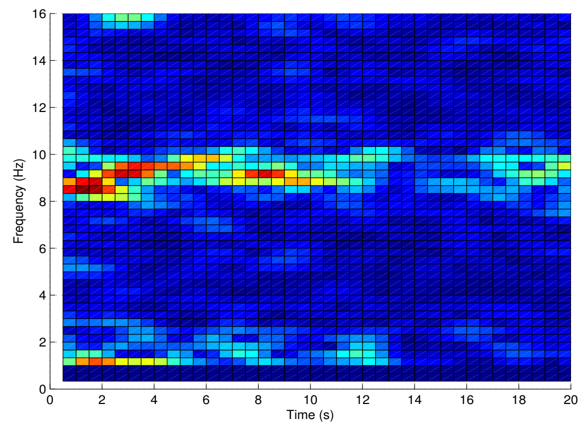

Fig. 6: A misclassified example of a factitious tremor.

Our preliminary results suggest that there is a linear relationship between subjective tremor rating and energy in the tremor signal. In addition, mean peak frequency appears to be a useful feature for differentiating real from factitious tremors; 75% of the recordings from patients with actual AW syndrome had a mean peak tremor frequency higher than 7 Hz whereas only 17% of the nurses' factitious tremors were above 7 Hz. This is a preliminary data set based on only 49 subjects. With further and more detailed analysis, it may be possible to tighten the relationship between CIWA-Ar score and energy in the signal and to more accurately differentiate factitious tremors from real ones. We are currently obtaining additional data from more subjects.

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