Supplementary Information - Rapidly detecting disorder in rhythmic biological signals: a spectral entropy measure to identify cardiac arrhythmias

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This Supplementary Information accompanies the paper titled, 'Rapidly detecting disorder in rhythmic biological signals: a spectral entropy measure to identify cardiac arrhythmias', and contains images of the electrocardiograms referred to in the text (Sections IV A and B) and bibliography. They represent examples where we believe the annotations provided as part of the MIT-BIH atrial fibrillation database to be incorrect, and where rhythms other than atrial fibrillation and atrial flutter are present in patient electrocardiograms.

I. ELECTROCARDIOGRAM (ECG) FIGURES

The following figures are obtained using the Chart-O-Matic facility on the physionet website [1] for patients comprising the MIT-BIH atrial fibrillation database (afdb). We give selected example electrocardiograms (ECGs) to illustrate the point under consideration and stress that there are additional times that could have been used for demonstrative purposes. The rhythm assessments to which we are comparing are provided as annotations included as part of the afdb. For other examples of ECGs corresponding to the rhythms given here, see Bennett [2].

A. Disagreements with Annotations

Rhythm assessments have been questioned before [3]; here we give explicit examples from the afdb where we believe the ECG suggests a rhythm different from that given by the annotation. The figures and ideas in this section pertain to Section IV A of the main paper.

1. *Instances where atrial fibrillation has been missed in annotations*

We observe in Patients 08219 (Fig. 1) and 08434 (Fig. 2) periods of atrial fibrillation that we believe to have been missed in the annotations but are correctly identified by our detection algorithm. Cases such as these serve to negatively impact the results of the algorithm unfairly; however, we note that such instances comprise a small proportion of the afdb.

FIG. 1: ECG for Patient 08219, starting at 11,880s for a 10s duration. This period is denoted as being neither atrial fibrillation or atrial flutter in the provided annotation, while we believe the ECG to suggest that the patient is experiencing atrial fibrillation.

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FIG. 2: ECG for Patient 08434, starting at 9,504s for a 10s duration. This period is denoted as being neither atrial fibrillation or atrial flutter in the provided annotation, while we believe the ECG to suggest that the patient is experiencing atrial fibrillation.

2. Instances where atrial flutter has been missed in annotations

Atrial flutter may have been misannotated in Patients 04936 (Fig. 3) and 08219 (Fig. 4). This unreliability of rhythm assessment, compounded with the limited number of periods of atrial flutter in the database, prevents us from drawing meaningful quantitative conclusions regarding the success of the detection algorithm in identifying flutter. Despite this, we believe that the spectral entropy is in principle still capable of identifying flutter.

FIG. 3: ECG for Patient 04936, starting at 7,347s for a 10s duration. This period is denoted as being neither atrial fibrillation or atrial flutter in the provided annotation, while we believe the ECG to suggest that the patient is experiencing atrial flutter.

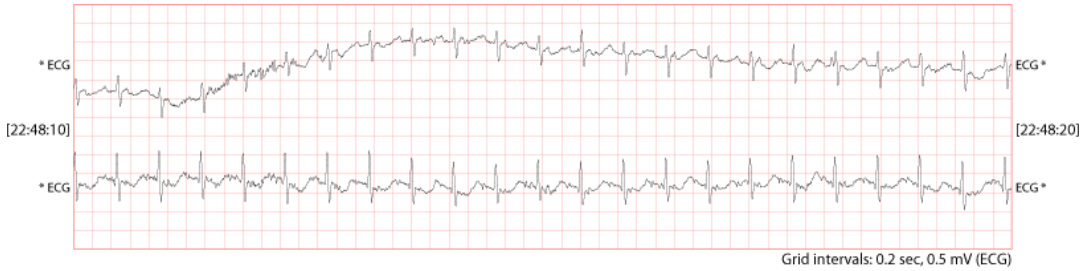

FIG. 4: ECG for Patient 08219, starting at 10,090s for a 10s duration. This period is denoted as being neither atrial fibrillation or atrial flutter in the provided annotation, while we believe the ECG to suggest that the patient is experiencing atrial flutter.

B. Other Rhythms

The unreliability of parts of the annotations still does not account for all false predictions produced by the detection algorithm. We suggest the presence of other rhythms within the afdb to be an additional factor that needs to be considered. The figures and ideas in this section pertain to Section IV B of the main paper.

1. *Instances of fib-flutter*

Fib-flutter denotes periods where the rhythm transitions in quick succession between atrial fibrillation and flutter [4]. Such behavior naturally causes the variance to increase (thereby exceeding the standard deviation threshold in the algorithm for classification as atrial fibrillation) and one might question whether it is still appropriate to classify those periods as standard atrial fibrillation. We identify in the ECG of Patient 04936 (Figs. 5 and 6) periods of fib-flutter which likely accounts for the high proportion of false negative results.

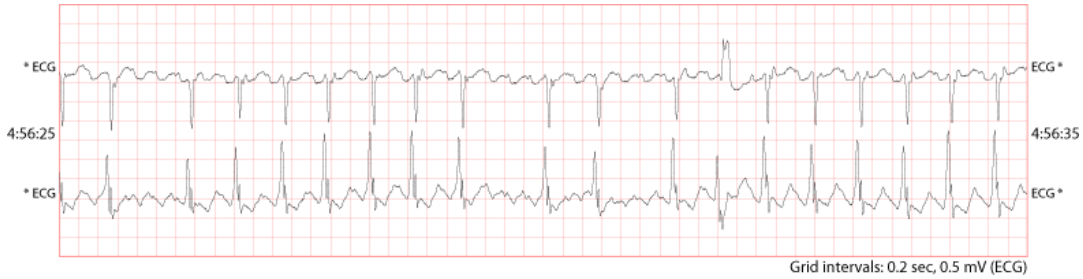

FIG. 5: ECG for Patient 04936, starting at 17,785s for a 10s duration. This period is denoted as being atrial fibrillation in the provided annotation, while we believe the ECG to suggest that the patient is experiencing fib-flutter.

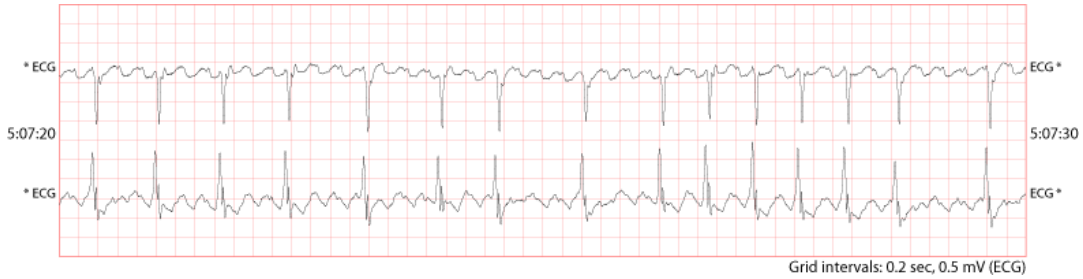

FIG. 6: ECG for Patient 04936, starting at 18,440s for a 10s duration. This period is denoted as being atrial fibrillation in the provided annotation, while we believe the ECG to suggest that the patient is experiencing fib-flutter.

2. *Instances of sinus arrest*

Sinus arrest occurs when the sinoatrial node fails to fire, resulting in increased irregularity of the heart rhythm, whilst still retaining QRS complexes indicative of normal sinus rhythm; this condition (along with sinus arrhythmia) is likely responsible for the high proportion of false positives seen in Patient 05091 (Fig. 7).

FIG. 7: ECG for Patient 05091, starting at 6,714s for a 10s duration. This period is denoted as being neither atrial fibrillation or atrial flutter in the provided annotation, while we believe the ECG to suggest that the patient is experiencing sinus arrest.

[1] Data from www.physionet.org; see A.L. Goldberger et al., Circulation **101**, 215 (2000).
[2] D. H. Bennett, Cardiac Arrhythmias Sixth Edition, Arnold (2002).
[3] K. Tateno and L. Glass, Computers in Cardiology **27**, 391 (2000); K. Tateno and L. Glass, Med. Bio. Eng. Comput. **39**, 664 (2001).
[4] G. Horvath, J. J. Goldberger and A. H. Kadish, J. Card. ElecPhys. **11**, 849 (2000).