Interactive Progressive-based Approach to Aid the Human Interpretation of the 12-lead Electrocardiogram

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Abstract

The 12-lead Electrocardiogram (ECG) is an important diagnostic support tool but is frequently incorrectly interpreted. This is partly due to the fact that even expert clinicians can impulsively provide a diagnosis based on first impression/intuition. It is therefore imperative to optimise how physicians interpret the 12-lead ECG. Hence, a set of interactive questions and prompts has been developed to guide an observer through a series of tasks when interpreting an ECG. This has been named 'Interactive Progressive based Interpretation' (IPI). Using this model, the 12-lead ECG is segmented into five parts and presented over five web based user interfaces. The IPI model was implemented using emerging web technologies such as HTML5. Thus, a new model has been proposed to aid ECG interpretation where observers systematically and sequentially interpret the 12-lead ECG as a series of sub-tasks. We hypothesize that this will reduce the number of errors and increase diagnostic accuracy.

1. Introduction

Cardiovascular Disease (CVD) [1] causes an estimated 17.5 million deaths each year, corresponding to 29% of annual of deaths worldwide. This figure is projected to rise to 22.2 million deaths by the year 2030 [2]. To detect CVDs, diagnostic tools are used to help the clinician make a diagnosis and to follow up with the correct treatment. The 12-lead Electrocardiogram (ECG) is a frequently used diagnostic tool for non-invasively assessing a person's heart. It is critical to the early detection of Acute Myocardial Infarction (AMI) and arrhythmias such as Atrial Fibrillation (AF) [3]. Due to the high mortality rate of CVDs it is of paramount importance to optimise the use of the ECG to help detect cardiac diseases and enable timely treatment.

Whilst the 12-lead ECG is an important diagnostic support tool it has been reported that up to 33% of ECGs are incorrectly interpreted [4]. Even expert clinicians are known to impulsively provide a diagnosis based on their first impression/intuition [5][6][7]. A typical ECG is currently presented to the reader on printed graph paper in a 12-part format (3x4 + 1R) [8]. Each part of this format contains a lead signal with each signal representing 3.33 seconds of time-series data. In addition, the rhythm strip (+1R) has a 10 second duration. It has been identified that this presentation format delivers significant cognitive load for the interpreter [9]. This overload of information can have a detrimental effect on the cognitive thinking process. A human working memory has a predetermined capacity [9], and the ECG assimilates a large number of variables comprising of 12 signals and a rhythm strip, each having multiple complexes and deflections as well as assistive computerised metrics. Thus, it is obvious that the human cognitive ability will deplete rapidly [9].

Simultaneously, the nature of ECG interpretation warrants the need for both theoretical and physiological knowledge of the myocardium and its surrounding region [10]. Interpreters need to make association between different signals to the mechanical health of the heart (often referred to as the electromechanical link). Accompanied by knowledge of its scattered characteristics and difficult-to-remember subject matter, it is a typical expectation that students, teachers and even experienced clinicians find the ECG difficult to interpret [10]. Consequently, interpreters may be able to avoid information overload through the opportunity offered by digitising the ECG and exploiting human-computer interaction principles and technologies.

In some institutions, ECG reporting is often documented using checklists. Such checklists do vary regarding their content and sequence of 'checks' depending on the institution, however they generally follow a common sequence [5][7][10][11][12][13][14]. The typical components within ECG reporting formats are: 1) heart rate, 2) rhythm analysis, 3) cardiac axis, 4) conduction times, 5) morphological features, and 6) final diagnoses.

Whilst undertaking an eye tracking experiment it was identified that ECG readers often have 'early satisfaction syndrome' when looking at all 12-leads in a single presentation, i.e. they spot an abnormality and diagnose the subject without giving appropriate consideration the remaining ECG tracings [6][15] Hence they provide a conclusion prematurely as they are 'satisfied' that they have identified the problem and subconsciously assume that co-abnormalities are not present. It was observed that even experts missed obvious lead misplacement features and ignored a number of leads.

Experts were also found to adopt an initial intuition approach to ECG interpretation, only regressing to the previously mentioned systematic approach when an obvious abnormality was not immediately identified. Thus components of the ECG reporting process may be disregarded if an obvious abnormality is spotted leading to the possibility of missing co-abnormalities during the interpretation process.

We argue that the potential to reduce ECG interpretation errors will be advanced by using interactive touch screen devices. Such devices could facilitate the development of a sequential and systematic process to aid ECG interpretation. And by limiting what an interpreter views during each stage of the interpretation, the temptation to jump to diagnostic conclusions is avoided. Furthermore, the interpreter's cognitive load is reduced due to the structuring of the large amount of data.

2. Model design

Following a literature review and input from both expert clinicians and teaching professionals in Electrocardiology, a set of interactive questions and prompts were created to direct an interpreter through a series of ECG reporting components. This process has been labelled 'Interactive Progressive based Interpretation' (IPI). The IPI model segments the 12-lead ECG into five parts and presents them in a sequence over five web-based user interfaces.

Segment 1: Rhythm strip – this user interface presents an ECG rhythm strip with the prompt: "Interpret the rhythm strip". This purpose of this page is to facilitate heart rate and rhythm analysis via relevant questions.

Segment 2: P-wave morphology – this user interface presents lead II with the prompt: "Interpret the P wave morphology". This facilitates the interpretation of ECG P-waves, which represent atrial depolarisation, conduction times, morphology and the PR intervals are assessed.

Segment 3: Limb leads – this page presents the limb leads, with the prompt: "Interpret the limb leads". This section requests the interpreter to assess the cardiac axis, ST-segment and the Q and T waves.

Segment 4: QRS morphology - the precordial leads are presented in this section with the prompt: "Interpret the QRS morphology". Again this section requests conduction times and morphology assessment. A QRS assessment is required. Through the measurement of the QT interval and the RR interval and the QTc is automatically calculated and presented. The QTc formula is illustrated in Equation 1. The cardiac axis, ST-segment and the Q and T waves also require interpretation. An image of the rhythm strip accompanies the precordial leads image to help interval assessment.

$$QTc = \frac{QT}{\sqrt{RR}} \qquad (1)$$

Segment 5: This user interface shows the complete 12-lead ECG – It requires the interpreter to assess R wave progression and lead misplacement. Finally this section requires a conclusive interpretation to be provided for the ECG.

The system model can be seen in a flow diagram in Figure 1.

3. Model implementation

In order to enable the model to be used 'ubiquitously' it has been implemented as a platform independent and device agnostic system. As such it was developed using emerging web technologies. Hypertext Mark-up Language version 5 (HTML5) was used to allow a web browser to present the webpage on any device. This is referred to as 'responsive design' where the user interface automatically adapts to the resolution of the device and the interface layout optimises to the screen's 'real estate'. Cascading Style Sheets (CSS3) was used to develop a consistent user experience. The web scripting language JavaScript, along with the JQuery library, was used to acquire reactive interactivity. This enables utilising responsive animations to enhance the user experience based on user input. All data is collected via text field entry in the application. Finally the Hypertext Pre-processing language (PHP) was used for saving these recorded values to a MySQL database that facilitates further post-processing. This data is then saved upon completion of each segment of the five-part interpretation sequence using Asynchronous Javascript and XML (AJAX).

AJAX is used to send data values to the server as it helps avoid data loss in the event of the interpretation not being completed for any practical or technical reasons. As a result some data values can be retained through the use of multiple insert queries (using Structured Query Language or SQL) that are invoked using AJAX. Figure 2 is a screen-shot of the first segment in the system. A video demonstration of the system can also be viewed online (*www.tinyurl.com/IPI-system-demo)*.

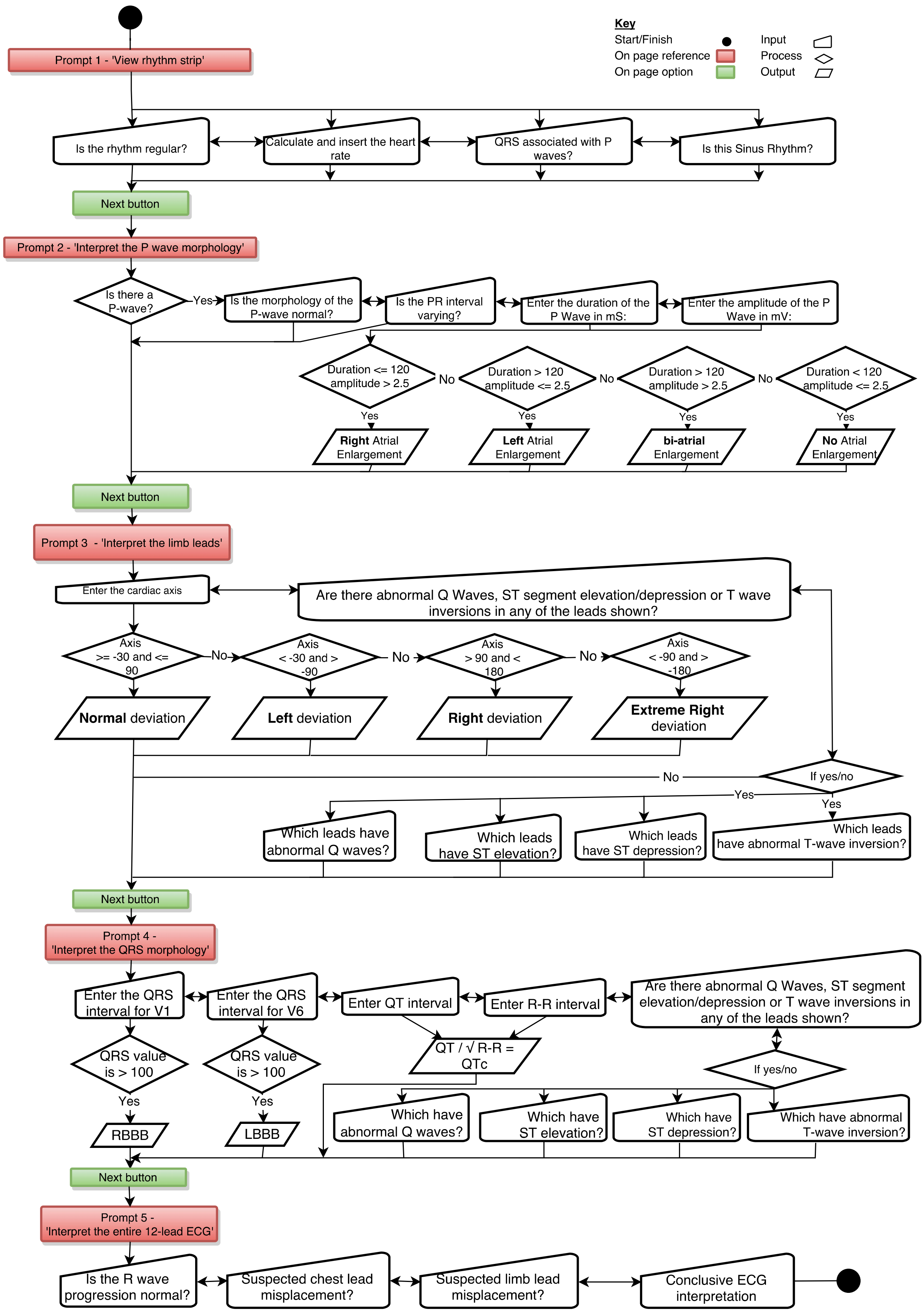

Figure 1. IPI system modal illustrating the five step sequential process

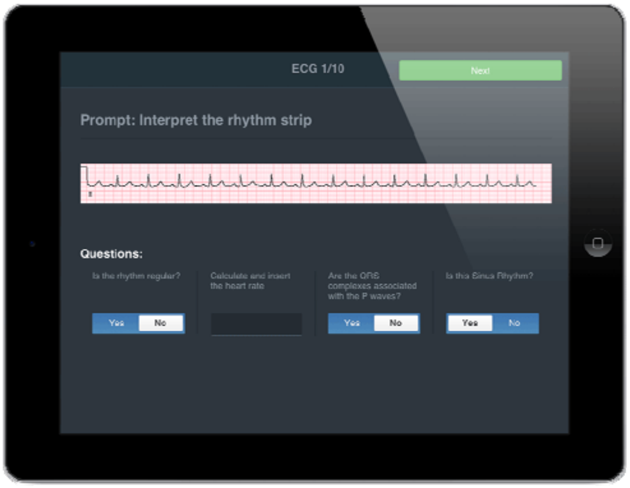

Figure 2. Implementation of the IPI system using web technologies

4. Conclusion

We believe that the potential to reduce ECG interpretation errors can be partly achieved using clinician-friendly interactive touch screen systems that assist the interpreter in their decision-making processes. Hence, we have developed a new model to aid ECG interpretation where interpreters are systematically guided to sequentially interpret the 12-lead ECG as a series of sub-tasks. We hypothesize that this will reduce information overload and cognitive load and thus reduce the number of interpretation errors whilst increasing diagnostic accuracy. This hypothesis forms the basis of future research.

5. Further research

An enhancement to the proposed system could be the implementation of a feature that automatically digitises and segments an ECG using coordinates for each lead. This is done manually for the IPI system at present.

Similarly another potential development to this study could involve the signal transformation of individual leads to assess if signal transformations can improve accuracy or efficiency in ECG interpretation.

A final potential addition to this study is the development of a rule-based system to assist the interpreter's final diagnoses. This could be achieved through rules being developed assessing the inputted data received from the interpreters; the relevant ECG diagnoses' would then be appropriately filtered and presented to the user upon completion.

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