Citation for published version (APA):
The Influence of Recording Equipment on the Accuracy of Respiratory Rate Estimation from the Electrocardiogram or Pulse Oximeter

P. Charlton\textsuperscript{12} and T. Bonnici\textsuperscript{12}, D. Clifton\textsuperscript{2}, J. Alastuey\textsuperscript{1}, L. Tarassenko\textsuperscript{3}, P.J. Watkinson\textsuperscript{4}, R. Beale\textsuperscript{12}

\textsuperscript{1}King’s College London \quad \textsuperscript{2}Guy’s and St Thomas’ NHS Foundation Trust \quad \textsuperscript{3}University of Oxford \quad \textsuperscript{4}Oxford Biomedical Research Centre

\textbf{Patient monitors} filter electrocardiogram (ECG) and pulse oximeter (PPG) signals prior to output. Would respiratory rate (RR) estimates derived from these signals be more accurate if \textbf{unfiltered signals} were used?

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{Diminished modulation after filtering}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig2.png}
\caption{Respiratory Modulations}
\end{figure}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
\textbf{Signal} & \textbf{Equipment} & \textbf{Time-domain Methods} & \textbf{Frequency-domain Methods} \\
\hline
\hline
\textbf{ECG} & Minimally filtered & 3.4 (2.9 - 4.6) & 3.2 (2.6 - 4.2) & 5.7 (3.0 - 7.5) & 5.3 (3.5 - 7.4) & 6.4 (3.3 - 9.4) \\
& Tethered Monitor & 4.0 (2.6 - 5.0) & 3.2 (2.6 - 4.3) & 5.3 (3.2 - 8.9) & 4.5 (2.8 - 7.2) & 6.8 (3.9 - 10.7) \\
& Wireless Monitor & 3.9 (3.0 - 4.7) & 3.1 (2.4 - 4.2) & 5.6 (3.1 - 8.2) & 4.9 (2.8 - 7.5) & 5.9 (3.7 - 8.7) \\
\textbf{PPG} & Minimally filtered & 3.7 (2.6 - 4.5) & 3.3 (2.6 - 4.1) & 4.5 (2.3 - 6.2) & 4.9 (2.9 - 7.1) & 4.7 (3.5 - 6.8) \\
& Tethered Monitor & 3.0 (2.3 - 4.7) & 3.1 (2.6 - 4.3) & 3.2 (2.3 - 4.4) & 4.9 (2.9 - 6.7) & 5.3 (3.8 - 6.3) \\
\hline
\end{tabular}
\caption{The median (quartiles) subject-specific RMSEs of RR estimates derived from ECG and PPG signals. RR was estimated in the time and frequency domains from the three respiratory modulations: AM, FM and BW (as shown in Fig. 2).}
\end{table}

\section*{Methods}

Signal Acquisition: 42 young (18-40 years), and 16 elderly (≥ 70) healthy volunteers took part. Minimally filtered PPG and ECG signals were acquired using laboratory equipment. Filtered signals were acquired from a tethered monitor. Filtered PPG was also acquired from a wireless monitor. Reference RR was obtained from oronasal airflow and chest impedance signals.

RR Estimation: Breaths were detected from the respiratory modulations (Fig. 2) in the time-domain using 3-point peak detection. In the frequency-domain, the RR was identified as the frequency with the maximum FFT power within 6-40 bpm.

Statistical Analysis: The null hypothesis, that the difference between RMSEs obtained using laboratory and routine equipment is zero, was tested using the paired, two-sided Wilcoxon signed rank test at 5% significance level.

\section*{Results}

The null hypothesis, that filtering had no impact on accuracy of RR estimates was accepted, when using all but two of the estimation methods (Table 1). In one of these instances the filtered signals provided more accurate estimates (blue), and in the other the unfiltered signals gave higher accuracy (red).

The accuracy of RR estimates derived from PPG and ECG signals differed minimally between minimally filtered and routinely filtered signals in this healthy cohort. We found no evidence to suggest that more accurate RR estimates could be obtained from unfiltered signals in this cohort.

\section*{Conclusions}

This is part of a larger study to assess the influence of physiological and technical factors on the accuracy of algorithms for RR estimation from the ECG and PPG.

\section*{Future Work}

RR is a sensitive sign of clinical deterioration. Current practice in most UK general hospital wards is to measure RR by manually counting chest movements over approximately 30 s. However, this has been shown to be inaccurate. RR can now be estimated automatically from the PPG [1] using filtered signals from wireless sensors. RR can also be estimated from the ECG [2]. It may be possible to obtain more accurate RR estimates by analysing the signals prior to filtering (Fig. 1).

\section*{Acknowledgements}

This research was supported by the EPSRC [Grant EP/F058845/1], the National Institute for Health Research (NIHR) comprehensive Biomedical Research Centre at Guy’s & St Thomas NHS Foundation Trust, and the NIHR Oxford Biomedical Research Centre Programme. The views expressed are those of the authors and not necessarily those of the EPSRC, NHS, NIHR or Department of Health.

\section*{References}


\section*{Conclusions}

The accuracy of RR estimates derived from these signals be more accurate if \textbf{unfiltered signals} were used?