Assessing the Quality of Manual Respiratory Rate Measurements using Mobile Devices

W Karlen, M O Wiens*†*, H Gan*, D Dunsmuir*, M Chiu*‡*, G A Dumont*, J M Ansermino**

* *Electrical and Computer Engineering in Medicine Group,*
† *School of Population and Public Health,*
‡ *Faculty of Medicine,*
The University of British Columbia, Vancouver, Canada

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Abstract

We have designed a mobile device application (RRate), to provide an efficient measurement of respiratory rate with clinically acceptable accuracy. The method is based on analysis of multiple consecutive breath intervals. We investigated in this study the difference in measurement variability between breaths as a representative of recording quality. Respiratory rate of 322 children aged 0 - 12 years at a Ugandan rural health centre were recorded using the RRate mobile application, and compared to respiratory rate recordings obtained from 22 volunteers using the RRate application while observing 10 videos of children breathing in a lab setting. The variability of the recorded breaths (confidence) of both groups follow a similar Weibull distribution. However, we observed a trend towards higher variability in the data obtained in the field (median 89.7% confidence) compared to the data obtained in the laboratory setting (median 92.6% confidence). This suggests that it is more difficult to obtain consistent measurements when assessing patients in a clinical setting, and therefore the confidence in the measured respiratory rate is reduced. The mobile device application provided a respiratory rate value up to 6 times faster than the current practice of one minute counting. The measure of variability between individual measured breaths provided a powerful way to display confidence in a measurement.

1 Introduction

The Integrated Management of Childhood Illnesses (IMCI) guidelines for the diagnosis of pneumonia in children requires the accurate assessment of respiratory rate (RR) [1]. The recommended method for measuring RR is counting the number of breaths in a minute via observation. Devices such as the acute respiratory infection (ARI) timer have been introduced to time the minute while breaths are counted. In a busy clinical setting, this is a significant period of time. Any disruption means the measurement must be restarted. In addition, the manual assessment of RR is known to be inaccurate [2, 3]. This can have severe implications for pneumonia diagnosis using IMCI where a single RR threshold (e.g. 40 breaths/min for children age 1 - 5 years) determines disease status.

We have designed a mobile device application, called RRate, to provide a more efficient measurement of RR with clinically acceptable accuracy [4]. The user taps the touch screen of a mobile device each time the patient inhales and the RR is calculated iteratively from the recorded tap time intervals [5]. The digital recording of breath intervals allows for the analysis of variance between breaths within a measurement cycle. We have previously used this variability to measure and display the consistency of the measurement [4].

In a clinical setting there are no or only limited resources to assess the accuracy of the measured RR. Even if a secondary method was available, time does not permit repeated measurements. In this study we investigated if the measurement of breath variability is suitable to assess the recording quality and the confidence in the measured RR. This measure is available while the RR is assessed with RRate and does not require additional efforts from the health professional.

2 Materials & Methods

2.1 Respiratory rate calculation from tapping

The RRate application measures RR as follows: The user taps the touch screen of the mobile device each time the patient inhales. The RR is calculated iteratively from the median tap time interval $\tilde{t}$. The variation of each tap time interval t_i from $\tilde{t}$ is measured as percent difference

$$D_i = \frac{|t_i - \tilde{t}|}{\tilde{t}} \cdot 100. \quad (1)$$

If a certain number N of consecutive tap time intervals all have D within a consistency threshold Th_C, the RR is reported (Fig. 1). Otherwise, the recording of breaths is continued until the above condition is met or a previously defined maximal number of taps N_{max} is reached. The choice of parameters N and Th_C influences the duration and error of the measurement

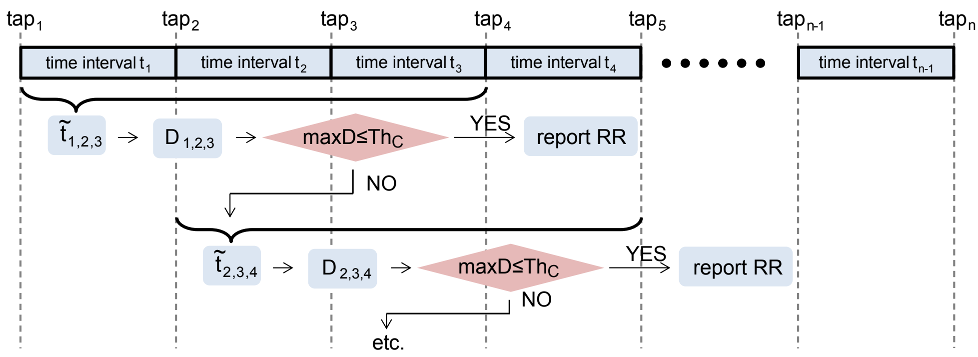

Fig. 1: Algorithm for estimating respiratory rate (RR). The median time interval $\tilde{t}$ and the percent difference D from $\tilde{t}$ are calculated for N time intervals (N = 3 in this diagram). If all D are within a threshold, the RR is reported, otherwise the next set of tap intervals is used for calculation of $\tilde{t}$ and D.

process. A larger N decreases error and makes the measurement more robust, but also increases measurement time. Similarly, a conservative Th_C decreases error, but also decreases the chance of getting a consistent tapping sequence in a given time.

2.2 Parameter optimization

Ten standard videos of children (aged 0 - 5 years) breathing with known RR were recorded [4]. The RR ranged from 17 to 59 breaths/min, and 3 cases included fast breathing (> 40 breaths/min) for the corresponding age. With ethics approval, 22 adult volunteers observed the videos and used a research version of RRate (N = ∞, Th_C = 0) for one minute. Each tap interval was recorded. These data were used to find the optimal configuration of Th_C for N = 3 and 4. This was done resolving a cost function

$$COST = E^{p95} + \tilde{E} + NRMSE \cdot w_1 \tag{2}$$

where E^{p95} is the 95^{th} percentile of the efficiency (time to complete the test), $\tilde{E}$ is the median efficiency, $NRMSE$ is the normalized root mean square error, and w_1 is a weighting factor to balance out efficiency and accuracy. The Th_C with the lowest cost for each N was selected using a 15-fold cross-validation.

2.3 Quality measure

We introduced the measure of confidence (CONF) as the quality parameter for the measurement. CONF was defined as

$$\mathrm{CONF} = 100\% - \max_{\mathrm{i}=[\mathrm{x}+1\ \mathrm{x}+\mathrm{N}]} \mathrm{D_i}. \tag{3}$$

This allowed the confidence to be maximal when the variation of tap time intervals was lowest.

2.4 Validation

As part of a larger study to investigate health outcomes following health center visits [6], a simplified version of RRate was distributed to health workers at a Ugandan level IV health centre between October 10, 2012 and January 31, 2013. This version of the application was configured to N_{max} = 4 and $Th_C = \infty$. Following patient consent, a trained research nurse interviewed the parent/guardian of each child to collect clinical data and to measure RR with RRate. The tapping was analysed post-hoc and CONF of the recordings was calculated.

3 Results

3.1 Optimization

The optimal parameter for N = 3 tap intervals was Th_C = 11%, for N = 4 it was Th_C = 14%. These configurations provided the lowest COST values and thus the best trade-off between efficiency and accuracy during the optimization phase with the standardized videos. The median CONF for N = 3 was 92.6%, for N = 4 it was 91.8%. Both CONF followed a Weibull distribution with a shape factor of 19 and the median as scaling factor. The distributions are depicted in Fig. 2 and 3 as green bold lines and the optimal thresholds Th_C as dashed lines.

3.2 Validation

RRate data were obtained from 322 children aged 0 - 12 years assessed at the Ugandan health centre. The observed RR had a median of 36.8 breaths/min ranging from 13.4 breaths/min to 107.1 breaths/min. For N = 3, a CONF better or equal than 89% was obtained for 174 (54%) cases (Fig. 2). The median CONF was 89.7%. The mean assessment time for successful cases was 5.8 s and the maximum was 16.98 s (Fig. 4, left). For N = 4, a CONF better or equal than 86% was obtained for 137 (42.5%) cases (Fig. 3). The median CONF was 83.2%.The mean assessment time for successful cases was 6.76 s and the maximum was 15.04 s (Fig. 4, right).

4 Discussion

We have developed an RR estimation method based on recording breath intervals through tapping of a touch screen on a mo-

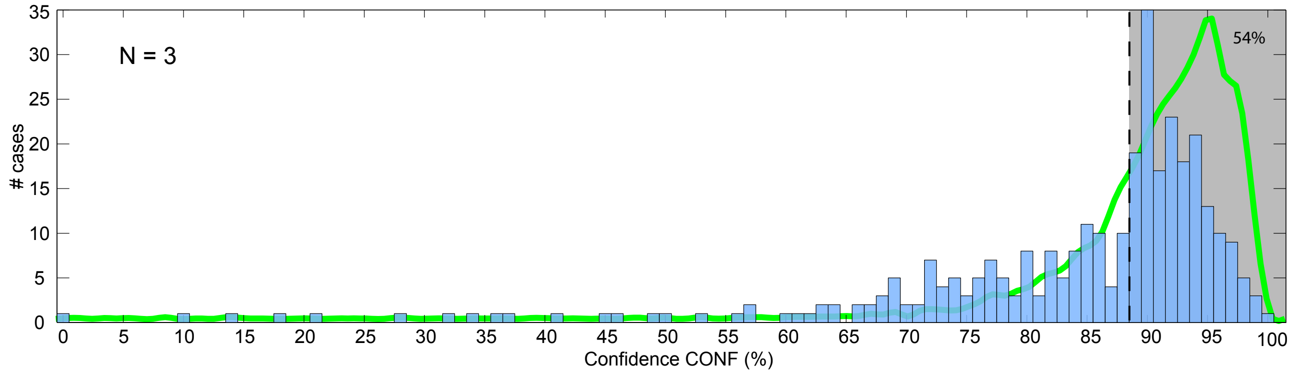

Fig. 2: Distribution of confidence measures for 322 assessments using N = 3 tapping intervals. The optimal consistency threshold Th_C obtained from standardized videos (green distribution curve) is shown by the dashed vertical line. Measurements within the grey shaded area would be reported by the RRate application.

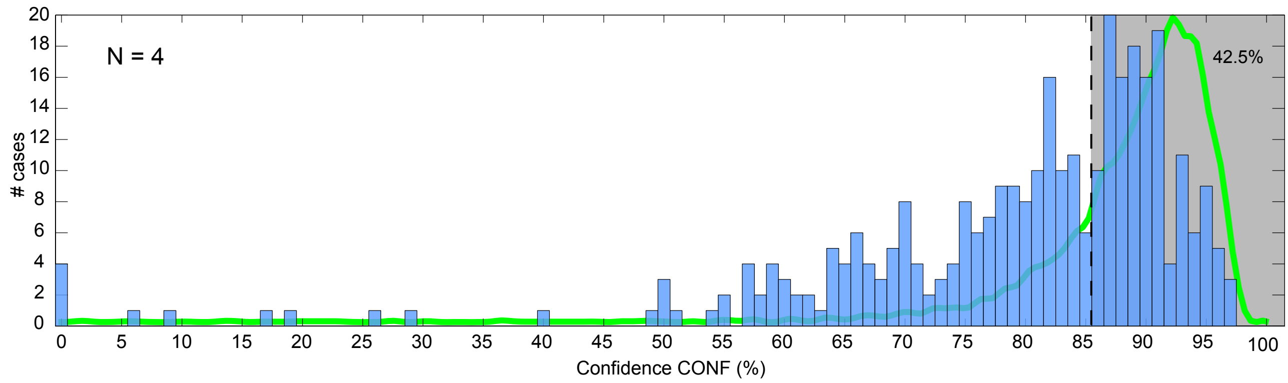

Fig. 3: Distribution of confidence measures for 322 assessments using N = 4 tapping intervals. The optimal consistency threshold Th_C obtained from standardized videos (green distribution curve) is shown by the dashed vertical line. Measurements within the grey shaded area would be reported by the RRate application.

bile device. Processing of individual breath intervals allows for shorter measurement times compared to traditional one minute observation as the RR can be computed iteratively [4]. In this study we were interested in whether the variation of recorded breath intervals is representative of the measurement quality.

From measurements obtained from subjects observing standardized videos with known RR while using a mobile device application implementing the RR estimation method we were able to determine the optimal parameter settings. These settings keep assessment time minimal and measurements accurate. As expected, when increasing the number of breaths that contribute to the RR calculation the consistency threshold Th_C increased as well, allowing more variation in tap time intervals. This was a necessary consequence of the optimization cost function in order to keep the assessment time stable.

The shape of the distribution curve of confidence values followed a similar pattern throughout all 4 studied cases. There was an observed left shift towards lower confidence when switching from N = 3 to N = 4. This is explained by the fact that it is harder to maintain consistency with an increased number of taps. There was also a clear left shift of the peak distribution of approximately 5% from the data obtained by the standardized videos to the data obtained in the field. This suggests that there was an increase in difficulty in obtaining consistent tapping, resulting in lower CONF when assessing patients in a busy setting. Therefore, the optimal thresholds Th_C determined by the video data may be too conservative, although the peaks of the CONF distributions were still included in the accepted portion of the distributions.

The number of measurements in the field study that were validated as good quality by the consistency threshold was relatively low (54% for N = 3, 42.5% for N = 4). This is explained by the fact that measurements were limited to 4 tap time intervals (5 taps) in total. The chances of obtaining an accurate measurement with high confidence could easily be increased by changing to real-time feedback (Th_C not set to ∞) and increase N_{max}. With the current setting, only two (one for N = 4) chances to obtain an accurate reading per patient were available to the health worker. The settings change would come at the expense of longer measurement times.

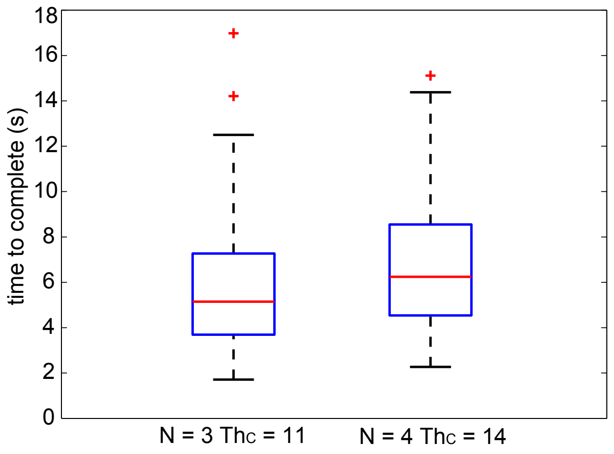

Fig. 4: Distribution (boxplot) of completion times for 322 assessments using N = 3 (left) and N = 4 (right) tapping intervals. The median is reported as a horizontal red bar and the whiskers depict the extreme values within 1.5 of the interquartile range. Crosses are outliers.

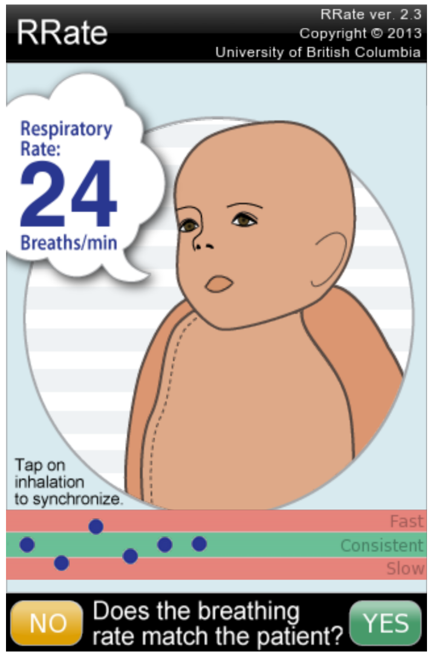

Fig. 5: Screenshot of the result screen of RRate. Along with the RR in breaths/min, an animated infant breathing at the measured RR is shown. At the bottom of the screen the recoded tap intervals (blue dots) and the deviation from the median are displayed.

To further improve the quality of the RR measurement, we have included a feedback screen in the RRate application, featuring not only the RR as an absolute number, but also an animated infant breathing at the given RR and a graph displaying the performed taps and their relative variation in time (Fig 5). Both features support the health worker in comparing the RRate application result with their real-time observation of the child. This is further facilitated by a yes/no question that automatically restarts the measurement procedure if the user does not feel the RRate application is accurately representing the clinical situation. Such feedback features were not available in the one minute observation methods and the RRate version used in this study. This represents an important step in increasing reliability of measurements. These feedback options are still the subject of our research endeavours and will require further validation of effectiveness.

5 Conclusion

RRate is a simple application for efficient and accurate measurement of RR. It is available as a free download [5]. It provides acceptable RR results up to 6 times faster than the current practice of one minute counting. The measure of variability between individual measured breaths provides a powerful way to display confidence of a measurement at no additional cost.

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