

Respiratory rates observed over 15 seconds compared with rates measured using the RRate app. Practice-based evidence from an observational study of acutely ill adult medical patients during their hospital admission

I Nakitende, T Namujwiga, D Dunsmuir, JM Ansermino, L Wasingya-Kasereka & J Kellett

Abstract

Background: counting respiratory rate over 60 seconds can be impractical in a busy clinical setting.

Methods: 870 respiratory rates of 272 acutely ill medical patients estimated from observations over 15 seconds and those calculated by a computer algorithm were compared.

Results: The bias of 15 seconds of observations was 1.85 breaths per minute and 0.11 breaths per minute for the algorithm derived rate, which took 16.2 SD 8.1 seconds. The algorithm assigned 88% of respiratory rates their correct National Early Warning Score points, compared with 80% for rates from 15 seconds of observation.

Conclusion: The respiratory rates of acutely ill patients are measured nearly as quickly and more reliably by a computer algorithm than by observations over 15 seconds.

Keywords

Respiratory rate, vital signs, medical devices, quality of care, computer algorithms

Key points

1. Measuring respiratory rate is time consuming and often done poorly.
2. A computer algorithm rapidly measures respiratory nearly as well as measurements made over 60 seconds, and better than those estimated from 15 seconds of observation.
3. The performance of this simple easy to use at the bedside algorithm, which is available as a free app that runs on any android device, may compare favourably with expensive and cumbersome technology currently in development

Introduction

There is no gold standard for respiratory rate measurement as even capnography is flawed by being unable to get accurate measurements in mouth breathers, or if it becomes dislodged. On general wards the traditional method is to manually count the number of breaths for one minute.¹ However, in practice health care workers do not count respiratory rate for a whole minute, but instead often count for only 15 seconds and then multiply by four: this decreases the accuracy of respiratory rate measurement by amplifying any counting error and rounding down due to the shorter interval. Since respiratory rate is not always regular and is less frequent than, for example, heart rate, any errors in observation may be even further magnified by such

shortcuts.^{2,3} Hooker et al⁴ examined 110 ambulatory patients without cardiac or pulmonary disease and found that respiratory rates measured over 15 seconds and multiplied by 4 were 1.7 breaths per minute slower than those measured over a full minute, and in 191 patients attending an emergency department estimates over 15 seconds failed to detect 77% of rates over 20 breaths per minute when observed over 60 seconds.⁵

The difficulty of measuring rapid respiratory rates of sick children prompted the development of a mobile application (app), *RRate*, to facilitate rapid and efficient measurement of the respiratory rate.⁶ A study using videos of children breathing, where the gold standard respiratory rate was careful analysis of the videos, found that accuracy improved with the

Immaculate Nakitende¹

Teopista Namujwiga²

Dustin Dunsmuir³

J. Mark Ansermino³

Lucien Wasingya-Kasereka⁴

John Kellett⁵

on behalf of the Kitovu Hospital Study Group

1 Department of Medicine, Enrolled Nurse, Department of Medicine, Kitovu Hospital, Masaka, Uganda

2 Department of Medicine, Enrolled Midwife, Department of Medicine, Kitovu Hospital, Masaka, Uganda

3 Department of Anesthesiology, Pharmacology & Therapeutics, University of British Columbia, Vancouver, Canada,

4 Deputy Medical Director, Kitovu Hospital, Masaka, Uganda

5 Department of Emergency Medicine, Hospital of South West Jutland, Esbjerg, Denmark

Correspondence

John Kellett MD
Ballinacloy, Nenagh,
County Tipperary
Ireland
Email: jkkellett@eircom.net

Respiratory rates observed over 15 seconds compared with rates measured using the RRate app. Practice-based evidence from an observational study of acutely ill adult medical patients during their hospital admission

number of taps used in the calculation, and also if inconsistent taps were excluded. At a respiratory rate of 40 breaths per minute, the *RRate* algorithm enabled a reading that was accurate within 2.2 breaths per minute and measured within 9.9 seconds. Additionally, using videos of infants and children breathing, the *RRate* app was compared to the WHO ARI Timer and found to take a measurement a median of 52.7 seconds faster with similar accuracy.⁷ The *RRate* algorithm has never been tested in acutely ill adults, who usually have slower respiratory rates than sick children. This study compared the bias (i.e. how close the measured value is to the true value) and the precision (i.e. its statistical variance or limits of agreement) of respiratory rates of acutely ill adults estimated by the *RRate* algorithm with those estimated from 15 seconds of observation multiplied by four.

Methods

This prospective observational study was an audit carried out as part of an ongoing quality improvement project. It was performed in the 46 bed medical ward of St. Joseph's Kitovu Health Care Complex located near Masaka, Uganda, 140 km from the capital city of Kampala. Together with the 330 bed Masaka Regional Referral Government Hospital, it serves Masaka Municipality (population of 79,200) and Masaka District with a rural population of 804,300.

The audit was carried out on 272 acutely ill patients (mean age 46.0 IQR 26 - 65years) admitted between March 1st and May 23rd 2019; 143 (52.6%) were male, on admission their mean National Early Warning Score (NEWS) was 4.0 SD 3.0 (median 4.0, IQR 2-5, range 0-14), and 16 (5.9%) patients died in hospital. The hospital's standard of care requires that vital signs were recorded at least twice daily on each patient. Therefore many recordings were performed on the same patient, usually approximately 12 hours apart.

Respiratory rates were measured and recorded by a modified version of the *RRate* app,⁶ which is available free from public app stores.^{8,9} The application's screen displays a large button that is tapped every time the patient inspires, and its algorithm calculates the respiratory rate based on the interval time between taps (tap intervals). Although the algorithm is configurable from a setup page, for this study the default (and recommended) settings of 5 taps and 13% consistency was used. The respiratory rate is calculated using the median of the first 4 tap intervals (between 5 taps) that are each within $\pm 13\%$ of that median. If the first 5 taps do not satisfy this condition, the user keeps tapping and with each tap the oldest interval is replaced by the newest and the consistency check repeated.⁶

The modified version of the app provided an additional setting to determine the respiratory rate simply by counting taps over 60 seconds. An audible signal was generated by each tap and a different audible signal occurred when the respiratory rate was displayed that, depending on the settings chosen, was either an estimate made by the algorithm or the number of taps made over 60 seconds. The *RRate* application automatically stores the time of each tap so that the number of taps made using either the algorithm or at any number of seconds (<60) can be later counted.

Two nurses (IN or TN) simultaneously measured respiratory rate at the bedside using two mobile Android tablets, one configured to use the *RRate*'s algorithm and the other to measure respiratory rate over 60 seconds.

Correlation coefficients, Bland-Altman plots,¹⁰ and measures of skewness were performed in Microsoft Excel: bias is the mean difference between respiratory rate being tested and the "gold standard" rate (i.e. assumed to be the measurement counted over 60 seconds), and the 95% limits of agreement the standard deviation of the bias multiplied by 1.96. 95% confidence intervals were also calculated according to the formula of Hamilton and Stamey.¹¹ The NEWS points for each respiratory rate was calculated according to the NEWS ranges,¹² as follows: 12-20 breaths per minute (bpm) = 0 points, 9-11 bpm = 1 point, 21-24 bpm = 2 points, and ≤ 8 or ≥ 25 bpm = 3 points. We compared the number of NEWS points scored by respiratory rates determined by the *RRate* algorithm and observations over 15 seconds (counting using the first 15 seconds of raw tap times in the 60 second data and then multiplying by 4) with rates measured for the full 60 seconds.

Ethical approval of the study was obtained from the Ethics Committee of Kitovu Hospital, which conformed to the principles outlined in the Declaration of Helsinki.¹³ Since there was no study intervention the need for written consent was waived. The study is reported in accordance with the STROBE statement.¹⁴

Results

During the study period 870 recordings of respiratory rate were made. The mean respiratory rate measured over 60 seconds was 22.0 SD 5.6 bpm (IQR 18-24, median 21, range 10 to 52 breaths per minute) and a positive skew of 1.11. The Pearson correlation coefficients between the respiratory rates counted from the first 15 seconds and the *RRate* algorithm with the respiratory rate using the full 60 seconds observation were 0.80 and 0.91, respectively. The bias between the 15 seconds clinically observed respiratory rate estimate and the 60 seconds rate was 1.85 breaths

Respiratory rates observed over 15 seconds compared with rates measured using the RRate app. Practice-based evidence from an observational study of acutely ill adult medical patients during their hospital admission

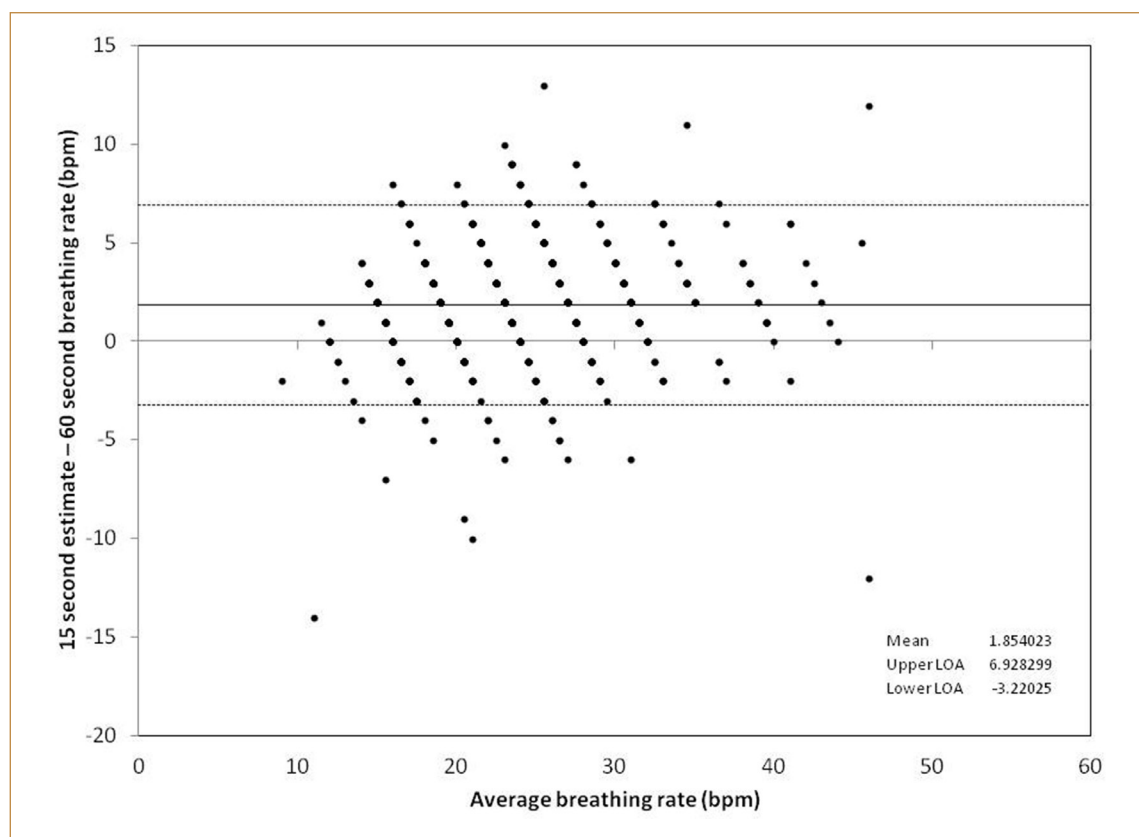


Figure 1. Bland-Altman plot for respiratory rates derived from observation for 15 seconds. Solid line shows bias (ie, mean difference between 15 second and 60 second respiratory rate); dotted line shows the limits of agreement (ie, standard deviation of mean bias times 1.96). bpm = breaths per minute.

per minute with limits of agreement of -3.22 to 6.13 breaths per minute (95% confidence interval from -3.42 to 7.13 breaths per minute), and the bias between the algorithm respiratory rate estimate and the 60 second measurement was 0.11 breaths per minute with limits of agreement of -3.39 to 3.61 breaths per minute (95% confidence interval from -3.56 to 3.78 breaths per minute). The Bland-Altman graph of respiratory rates derived from observation for 15 seconds (Figure 1) showed more outliers than the respiratory rates estimated by the *RRate* algorithm (Figure 2), and also appear as diagonal lines since all these values are divisible by four.

The mean number of taps (breaths) required by the *RRate* algorithm to estimate respiratory rate was 6.4 SD 1.9 (IQR 5-7, median 6.0, range 5 to 12), and the mean time taken was 16.2 SD 8.1 seconds (IQR 10.7 – 19.7, median 13.6, range 4.4 to 57.6 seconds). Two hundred and sixteen (24.8 %) of the respiratory rate measurements over 60 seconds scored three NEWS points, 267 (30.7 %) scored two points, 2 (0.2%) one point, and 385 (44.3 %) zero points. As the 60 second measurement was assumed to be the “gold standard” by which to correctly assign NEWS points for respiratory rate, overall 88% of the respiratory rates estimated by *RRate* algorithm were

assigned their correct NEWS points, compared with 80% of respiratory rates estimated by 15 seconds of observation. Of the 267 readings with two NEWS points according to respiratory rate measured over 60 seconds 208 (77.9%) were correctly assigned by the *RRate* algorithm, compared with 183 (68.5%) by 15 seconds of observation (Table 1).

Discussion

Major findings

This study of acutely ill patients compared respiratory rates measured by observation over 60 seconds with rates calculated using only the first 15 seconds and rates estimated by the *RRate* algorithm. The bias was just over one breath per minute for observations for 15 seconds and 0.1 breaths per minute for the *RRate* algorithm and the limits of agreement ranging from over 3 breaths slower to 7 breaths faster and from 3 breaths slower to 4 breaths faster, respectively. On average the *RRate* algorithm took just over 16 seconds to measure respiratory rate and the resulting measurement correctly assigned NEWS points for respiratory rate to 88% of observations, whereas only 80% of observations made over 15 seconds were correctly assigned.

Respiratory rates observed over 15 seconds compared with rates measured using the RRate app. Practice-based evidence from an observational study of acutely ill adult medical patients during their hospital admission

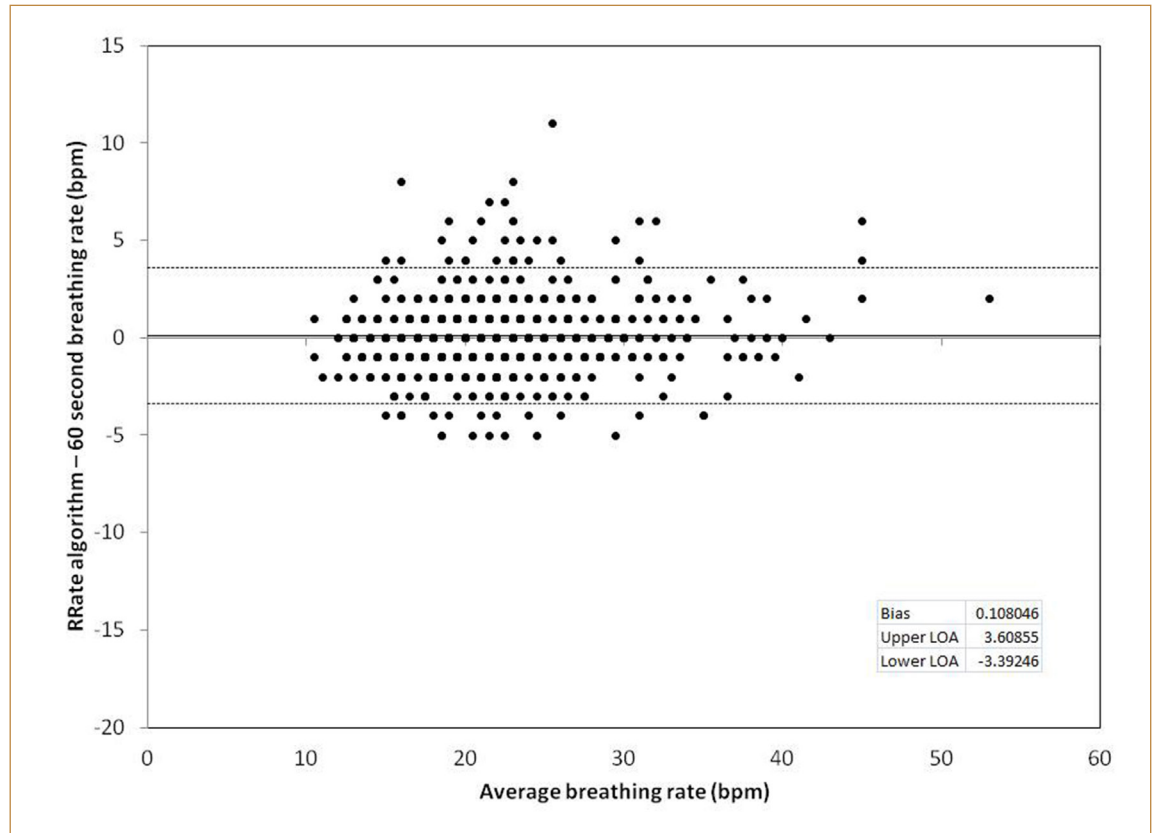


Figure 2. Bland-Altman plot for RRate algorithm derived respiratory rates. Solid line shows bias (ie, mean difference between 30 second and 60 second respiratory rate): dotted line shows the limits of agreement (ie, standard deviation of mean bias times 1.96). bpm = breaths per minute.

Limitations and strengths

This was a single centre observational study, and respiratory rates were measured simultaneously by

only two nurses and we made no attempt to compare their performance (i.e. inter-rater reliability was not measured), and in the study population, no patients

Table 1. National Early Warning Score (NEWS) points for respiratory rate assigned by the RRate algorithm and respiratory rate estimated from 15 seconds of observation

NEWS points assigned by 60 second respiratory rate measurement	NEWS points assigned by RRate algorithm respiratory rate					Total	Percent correctly assigned
	0	1	2	3			
0	336 (87.3%)	2 (0.5%)	40 (10.4%)	7 (1.8%)		385	87.30%
1	0 (0.0%)	2 (100.0%)	0 (0.0%)	0 (100.0%)		2	100.00%
2	33 (12.4%)	0 (0.0%)	208 (77.9%)	26 (9.7%)		267	77.90%
3	1 (0.5%)	0 (0.0%)	19 (8.8%)	196 (90.7%)		216	90.70%
Total	370 (42.5%)	4 (0.5%)	267 (30.7%)	229 (26.3%)		870	87.60%
NEWS points assigned by 60 second respiratory rate measurement	NEWS points assigned by measurement of respiratory rate over 15 second					Total	Percent correctly assigned
	0	1	2	3			
0	324 (84.2%)	0 (0.0%)	51 (13.2%)	10 (2.6%)		385	84.20%
1	1 (50.0%)	0 (0.0%)	0 (0.0%)	1 (50.0%)		2	0.00%
2	30 (11.2%)	0 (0.0%)	183 (68.5%)	54 (20.2%)		267	68.50%
3	4 (1.9%)	0 (0.0%)	21 (9.7%)	191 (88.4%)		216	88.40%
Total	359 (41.3%)	0 (0.0%)	255 (29.3%)	256 (29.3%)		870	80.20%

Respiratory rates observed over 15 seconds compared with rates measured using the RRate app. Practice-based evidence from an observational study of acutely ill adult medical patients during their hospital admission

scored 3 NEWS points for a slow rate as none had a respiratory rate less than 9 breaths per minute. The study also assumed that the “gold standard” for respiratory rate was its measurement over 60 seconds.

The major strengths of this study are the *RRate* app’s recording capability, and that all the measurements were on unselected acutely ill patients. The use of the *RRate* app simplified the respiratory rate measurements, such that observers did not need to keep track of a count, and all inspirations observed were automatically recorded with the date and time stamped.

Interpretation

There has to be a trade-off between the time invested in respiratory rate measurement and the clinical benefits of knowing its “true” value. This study shows that the *RRate* algorithm performs better, and nearly as quickly, as 15 seconds of simple observation. This was true despite the fact that estimating the respiratory rate from 15 seconds of observation was greatly facilitated by using the *RRate* application to track the timing of “taps”, which almost certainly provided more accurate timing of the observed respirations over 15 seconds than would have been possible using a watch with a second hand. Additionally, this 15 second count of respiratory rate was derived from the first 15 seconds of the reference 60 second value, while the *RRate* algorithm was used on a separate tablet.

Although 60 seconds is the recommended time period over which respiratory rate should be measured, the optimal period of time has not been established,¹⁵ and it is unclear if the extra time required to measure respiratory rate over 60 seconds is of clinical benefit. Although the *RRate* algorithm will incorrectly assign NEWS points for respiratory rate to 12% of observations, the majority of these incorrect assignments would not have had catastrophic clinical consequences: only one (0.5%) of the 216 observations with a 60 second respiratory rate over 24 breaths per minute was assigned zero NEWS points, and remaining 19(8.8%) observations were all assigned 2 points.

In a previous study¹⁶ we found that only half of 60 second respiratory rates over 24 breaths per minute (i.e. a rate that scores 3 NEWS points) were identified by 15 seconds of observation, compared with 88% in this study. There is no obvious explanation for this: proportionately more of the patients in this study had 60 second respiratory rates >24 breaths per minute (i.e. 24.8% versus 6.4%), and it may be that the two nurses that performed the study have become more skilled at using the *RRate* app and, therefore, performed more consistent tapping that provided more accurate 15 second estimates of respiratory

rate. Alternatively, patients in these two cohorts may have suffered from different conditions that increased their respiratory rates. The *RRate* application detects inconsistencies or variations in respiratory rate, and it took from 4.4 to 57.6 seconds before 5 consistent breaths were detected. It is not clear what the clinical significance is for an inconsistent rate of breathing. One might have expected that, as with heart rate,¹⁷ sick patients would have less variability in their respiratory rate than healthy ones, who would be more likely to have their breathing influenced by external environmental distractions. On the other hand, periodic breathing is a well recognised feature of severe illnesses such as heart failure and stroke.^{18,19}

General clinical relevance

The main advantages of measuring the respiratory rate by the *RRate* app are speed and simplicity, which are obtained at the cost of a slight reduction in performance. It compares favourably with technology currently available for the measurement of respiratory rate. Recently a camera-based prototype application (CBPA) for measuring respiratory rate has been reported, which takes 60 seconds to make a measurement and has a bias of 1.75 breaths per minute and limits of agreement of approximately -6 and 9 breaths per minute.²⁰ Apart from this prototype, other devices that measure respiratory rate take time and trouble to apply.²¹ The *RRate* could be a quick, convenient method of selecting patients for whom the application of these devices would be justified.

Conclusion

Practice-based evidence shows that respiratory rates of acutely ill adult patients are measured nearly as quickly and more reliably by a novel computer algorithm using screen taps than by observations made over 15 seconds and multiplied by four.

Author’s contributions

Teopista Namujwiga and Immaculate Nakitende collecting the data

John Kellett and Lucien Wasingya-Kasereka designed the study and analysed and interpreted the data, assisted by J. Mark Ansermino and Dustin Dunsmuir who also extensively revised and edited the text and provided technical support for data collection.

Funding and Conflict of interest statement

All costs were borne by the authors. John Kellett is a major shareholder, director and chief medical officer of Tapa Healthcare DAC. The other authors have no potential conflicts of interest.

Respiratory rates observed over 15 seconds compared with rates measured using the RRate app. Practice-based evidence from an observational study of acutely ill adult medical patients during their hospital admission

Acknowledgements

The authors wish to acknowledge and thank Tapa Healthcare DAC (Dundalk, Ireland) for the complimentary use of their Rapid Electronic Assessment Data System (READS). They would acknowledge and thank Jeffrey Bone MSc for his

statistical advice, and Alan Murray for his generous donation of IT support.

List of abbreviations

NEWS = National Early Warning Score.

References

1. Strauß R, Ewig S, Richter K, König T, Heller G, Bauer T. The prognostic significance of respiratory rate in patients with pneumonia: a retrospective analysis of data from 705 928 hospitalized patients in Germany from 2010–2012. *Deutsches Ärzteblatt International* 2014;**111**:503–8
2. Badawy J, Nguyen OK, Clark C, Halm EA, Makam AN. Is everyone really breathing 20 times a minute? Assessing epidemiology and variation in recorded respiratory rate in hospitalised adults. *BMJ Qual Saf*. 2017;**26**:832–836.
3. Semler MW, Stover DG, Copland AP, Hong G, Johnson MJ, Kriss MS, et al. Flash mob research: a single-day, multicenter, resident-directed study of respiratory rate. *Chest*. 2013;**143**:1740–1744.
4. Hooker EA, O'Brien DJ, Danzl DF, Barefoot JA, Brown JE. Respiratory rates in emergency department patients. *The Journal of emergency medicine* 1989;**7**:129–132.
5. Bianchi W, Dugas AF, Hsieh YH, Saheed M, Hill P, Lindauer C, Rothman RE. Revitalizing a vital sign: improving detection of tachypnea at primary triage. *Annals of emergency medicine* 2013;**61**:37–43.
6. Karlen W, Gan H, Chiu M, Dunsmuir D, Zhou G, Dumont GA, et al. Improving the Accuracy and Efficiency of Respiratory Rate Measurements in Children Using Mobile Devices. *PLoS ONE* 2014; **9**(6): e99266. doi:10.1371/journal.pone.0099266
7. Gan H, Karlen W, Dunsmuir D, Zhou G, Chiu M, Dumont GA, Ansermino JM. The Performance of a Mobile Phone Respiratory Rate Counter Compared to the WHO ARI Timer. *Journal of Healthcare Engineering* 2015;**6**(4):691–704.
8. RRate on iTunes AppStore website. Available: <https://itunes.apple.com/ca/app/rrate/id581390517>. Accessed 2019 Jan 14.
9. RRate on Google Play website. Available: <https://play.google.com/store/apps/details?id=ca.bccw.rrate>. Accessed 2019 Jan 14.
10. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;**1**(8476):307–310.
11. Hamilton C, Stamey J. Using Bland-Altman to assess agreement between two medical devices – don't for the confidence intervals! *Journal of Clinical Monitoring and Computing* 2007;**21**:331–333
12. Royal College of Physicians (RCP). National Early Warning Score (NEWS): Standardising the Assessment of Acute Illness Severity in the NHS. Report of a Working Party. London: RCP; 2012.
13. World Medical Association. World Medical Association Declaration of Helsinki: ethical principles for medical research involving human subjects. *JAMA* 2013; **310**:2191–4.
14. Vandembroucke JP, von Elm E, Altman DG, Gotsche PC, Mulrow CD, Pocock SJ, et al. Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): explanation and elaboration. *Epidemiology*. 2007;**18**:805–835.
15. Hill A, Kelly E, Horswill MS, Watson MO. The effects of awareness and count duration on adult respiratory rate measurements: An experimental study. *J Clin Nurs*. 2018;**27**:546–554.
16. Rimbi M, Dunsmuir D, Ansermino JM, Nakitende I, Namujwiga T, and Kellett J, on behalf of the Kitovu Hospital Study Group. Respiratory rates observed over 15 and 30 s compared with rates measured over 60 s: practice-based evidence from an observational study of acutely ill adult medical patients during hospital admission. *QJM*. 2019;**112**(7):513–517.
17. Buchman TG, Stein PK, Goldstein B. Heart rate variability in critical illness and critical care. *Curr Opin Crit Care*. 2002;**4**:311–5.
18. Hermann DM, Siccoli M, Kirov P, Gugger M, Bassetti CL. Central Periodic Breathing During Sleep in Acute Ischemic Stroke. *Stroke* 2007;**38**:1082–1084
19. McGee S. Cheyne-Stokes Breathing and Reduced Ejection Fraction. *American Journal of Medicine* 2013;**126**:536–540
20. Achermann S, Caspar M, Wirth C, Becker C, Rocque M, Kirenko I, Schlack A, Dutilh G, Bingisser R, Nickel CH. Contact-free monitoring of respiratory rates for triage of patients presenting to the emergency department. *Resuscitation* 2019;**137**:154–155.
21. Subbe CP, Kinsella S. Continuous Monitoring of Respiratory Rate in Emergency Admissions: Evaluation of the RespiSense™ Sensor in Acute Care Compared to the Industry Standard and Gold Standard. *Sensors* 2018, **18**, 2700; doi:10.3390/s18082700