Error in respiratory rate measurement by direct observation impacts on clinical early warning score algorithms

Andrew W Fogarty [1,2,3]
Joe West [1,3,5,6]
Mark Simmonds [3]
Dominick Shaw [2,4]
Timothy R Card [1,3,6]
Colin J Crooks [2,3,,6]

1. **Lifespan and Population Health, School of Medicine, University of Nottingham, NG5 1PB.**
2. **NIHR Nottingham Biomedical Research Centre (BRC), Nottingham University Hospitals NHS Trust and the University of Nottingham, NG7 2UH**
3. **Nottingham University Hospitals NHS Trust, NG7 2UH**
4. **Division of Respiratory Medicine, School of Medicine, University of Nottingham, NG5 1PB**
5. **East Midlands Academic Health Science Network, University of Nottingham, Nottingham, NG7 2TU**
6. **Nottingham Digestive Diseases Centre, School of Medicine, University of Nottingham, NG7 2UH**

Corresponding author: andrew.fogarty@nottingham.ac.uk

Word count: 654 words

Respiratory rate is the only vital sign that is currently measured by direct observation in many high income countries in many healthcare settings. However, when relying on direct observation by humans, values may be susceptible to measurement error. In particular, a continuous variable like respiratory rate may be inadvertently semi-categorised due to rounding and/or multiplying up counts from shorter periods to give estimated counts for a full minute.

This could have an important impact on early warning scores, as these scores rely on the aggregation of accurately measured physiological parameters to trigger specific warning thresholds. Systemic errors in the measurement of respiratory rate component could therefore negatively impact patient care if it meant a deteriorating patient did not meet the defined threshold. . 76% of UK hospital trusts receiving acute medical admissions use the National Early Warning Score -2 (NEWS-2)[12]. . Introduced in 2017, it uses six simple physiological parameters which are respiration rate, oxygen saturation, systolic blood pressure, pulse rate, level of consciousness and temperature. These are aggregated by a simple scoring system that uses pre-defined thresholds to give a composite NEWS-2 score, which is then deployed to generate triggers for review of clinical care. The threshold for respiratory rate in NEWS-2 is the step between 20 to 21 breaths per minute. We therefore examined the distribution of respiratory rate measurements around this clinically critical range for decision making.

Electronic data were available from all patients admitted to Nottingham University Hospital Trust with suspected or confirmed Covid-19 infection in 2020 to 2021. A normal distribution was generated to permit estimation of the expected number of breaths/minute values at the trigger threshold of 21 breaths/minute, and compared with the observed value (χ^2 test).

843,006 respiratory rate measurements within a range of 10 to 40 breaths per minute were observed from 9,624 patients. There were more even integers of respiratory rate measurement than odd numbers (Figure). This is likely to be an artefact of visually counting the respiratory rate for 30 seconds, and then doubling the count to give a rate/minute.

Our data show the step from a respiratory rate of 20 breaths/minute to 21 breaths/minute is associated with a large drop in the frequency of readings, with a subsequent higher number of values for the 22 breaths/minute category. The normal distribution of data (excluding the long tail to the right), shows a predicted number of readings at 20 breaths per minute of 98 406 measurements as opposed to the observed number of 125149 measurements. The comparable counts for the 21 breaths/minute readings are 10312 measurements (observed) and 32395 (expected) respectively ($p<0.0001$, χ^2 goodness of fit test, χ^2 test statistic = 14539), generating a measurement error of 214% the observed count of missing values which have been categorised else-where. These numbers are clinically important, as respiratory rates of 21 breaths/minute or over cross the pre-defined threshold and change to the NEWS-2 score which may generate a change in clinical response.

These obvious measurement errors in the recording of respiratory rate around the 20-21 breaths/minute threshold have also been observed in the USA [3]. This is likely to be a global issue that while readily apparent in clinical epidemiological datasets, is less likely to be recognised at the level of the individual patient.

This issue is another manifestation of the downside of developing composite outcome measures from healthcare system datasets [4], that while aiming to simplify complex information and make it more useful to the end-user, runs the risk of embedding and obscuring systemic errors and hence compromising patient care. Having demonstrated the issue of respiratory rate error in reducing the sensitivity of clinical early warning scores, the challenge now is to address this concern. While measuring respiratory rate manually for 60 seconds is one possibility, devices to automate measurement of respiratory rate would be a better solution, in a similar manner to how pulse measurement has changed from a manual to a more automated process.

Acknowledgements
We would like to thank the NUH Covid-19 patient safety database consortium for helping generate this resource.

Data
Approval for this work was granted via IRAS (REC: 20/WM/0142, project ID: 282490, amendment No. SA02 20/07/21).

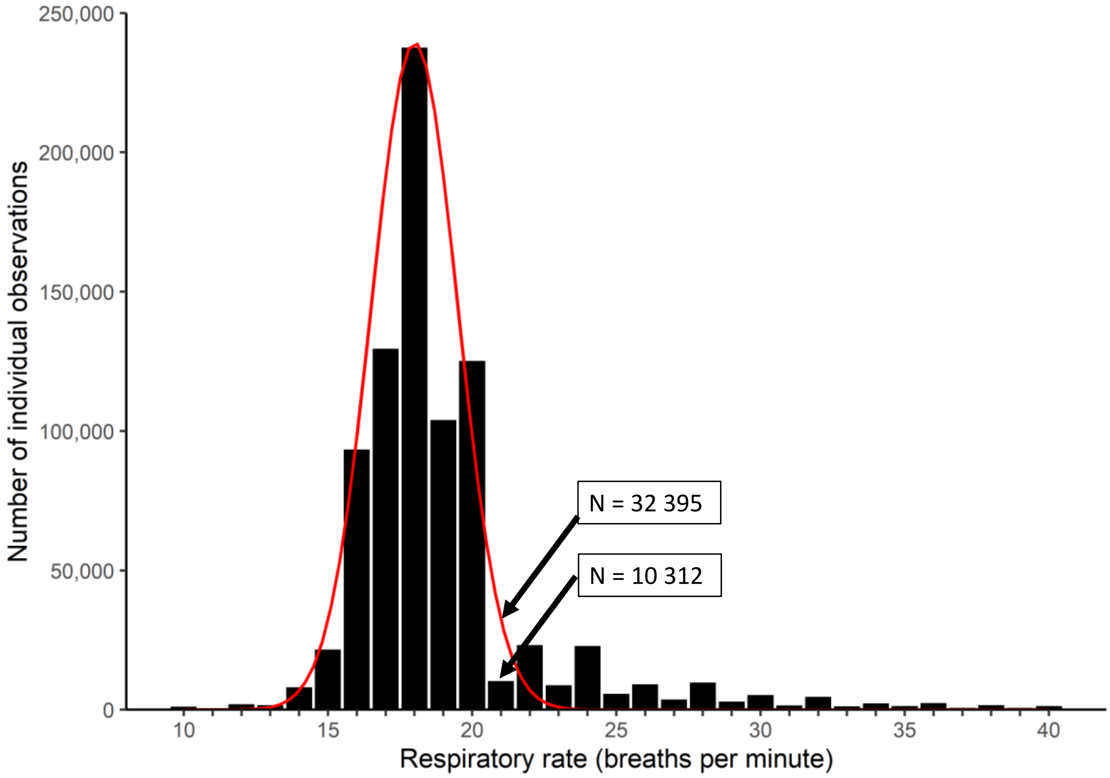
Competing interests
None of the authors have any competing interests with regard to the publication of this manuscript.

Authors' contributions
The concept was devised by AWF and DES, and used data that was collected by JW, CC, TC and MS. CC and AWF did the statistical analysis. All authors contributed to the text of the final manuscript.

Funding
University of Nottingham and Nottingham University Hospital NHS Trust.

References
1. Royal College of Physicians. National Early Warning Score (NEWS) 2. 2017;https://www.rcplondon.ac.uk/projects/outputs/national-early-warning-score-news-2 (accessed 28/2/2022)
2. NHS England. National Early Warning Score (NEWS).https://www.england.nhs.uk/ourwork/clinical-policy/sepsis/nationalearlywarningscore/ (accessed 4/3/2022)
3. Badawy J, Nguyen OK, Clark C, et al. Is everyone really breathing 20 times a minute? Assessing epidemiology and variation in recorded respiratory rate in hospitalised adults. *BMJ Qual Saf* 2017;26(10):832-36. doi: 10.1136/bmjqs-2017-006671 [published Online First: 2017/06/28]
4. Barclay M, Dixon-Woods M, Lyratzopoulos G. The problem with composite indicators. *BMJ Qual Saf* 2019;28(4):338-44. doi: 10.1136/bmjqs-2018-007798 [published Online First: 2018/08/14]

Figure. Distribution of raw data on respiratory rate for patients with suspected or clinical Covid-19 infection



Normal curve distribution using a mean of 18 breaths per minute, standard deviation 1.5 and range of 10 to 26.