The discrimination of quick Paediatric Early Warning Scores in the pre-hospital setting

Corfield, A.R.; Clerihew, L.; Stewart, E.; Staines, H.; Tough, D.; Rooney, K.D.

Published in:
Anaesthesia

DOI:
10.1111/anae.14948

Published: 01/03/2020

Document Version
Peer reviewed version

Corresponding author:

Professor Kevin Rooney

Department of Anaesthetics and Intensive Care

Royal Alexandra Hospital

Paisley

PA2 9PN

UK

Email: kevin.rooney@uws.ac.uk

The discrimination of quick Paediatric Early Warning Scores (qPEWS) in the pre-hospital setting

A. R. Corfield,[1] L. Clerihew,[2] E. Stewart,[3] H. Staines,[5] D. Tough[6] and K. D. Rooney[4]

1 Consultant, Department of Emergency Medicine, 4 Consultant, Department of Anaesthetics and Intensive Care, Royal Alexandra Hospital, Paisley, UK

2 Consultant, Department of Paediatrics, Ninewells Hospital, Dundee, UK

3 Research Associate, 4 Professor, Institute for Research in Healthcare Policy and Practice, School of Health and Life Science, Hamilton Campus, South Lanarkshire, UK

5 Director, Sigma Statistical Services, Balmullo, UK

6 Consultant Paramedic, Clinical Directorate, Scottish Ambulance Service, Edinburgh, UK

Keywords: Child Health, Pre-hospital, Critical Illness, Early Warning Scores, Patient Safety, Resource Limited

Twitter: @al_corfield; @LindaClerihew; @dahrlenetough; @kevindrooney

Summary

In our previous study, a Paediatric Early Warning Score (PEWS) could be calculated for only one fifth of 102,993 children transported by ambulance to hospital, as components other than supplemental oxygen were not reliably measured: respiratory rate 90,358 (88%); Glasgow coma score 83,648 (81%); heart rate 83,330 (81%); time to capillary reperfusion 81,685 (79%); oxygen saturation 71,372 (69%); temperature 60,402 (59%); systolic blood pressure 37,088 (36%). We tested 12 abbreviated scores with 3-5 components. Scores could be calculated for at most 74,508 (72%) children when heart rate, conscious level and respiratory rate were measured, with or without supplemental oxygen. For the primary outcome of 30 day mortality and/or admission to paediatric Intensive Care, discrimination (area under the receiving operator characteristic curve) ranged 0.69-0.80 and measured 0.75 and 0.77 for these two versions, respectively. Optimal threshold scores of 3 and 2 for these two abbreviated versions discriminated an outcome rate of 2%-3% in about one third of children from the other children who had < 1% rate of outcome.

Introduction

The utility of Paediatric Early Warning Scores (PEWS) in hospitals remains contentious, but there is growing evidence to support their role in recognising deterioration hours before a critical event in children [1-8]. One might expect that most UK paediatric units will use an early warning score following the recommendations of the UK report "Why children die" [9]. Despite their profusion only a minority of scores have been tested before their introduction into clinical practice [7, 10-15]. Within Scotland, only 2/14 paediatric early warning scores had published their retrospective testing [5, 16].

The variables used and the outcomes measured vary between scores [1, 17, 18]. However, all scores use heart rate and respiratory rate and most included oxygen saturations, supplemental oxygen and conscious level. Fewer scores included blood pressure, respiratory effort, capillary return and temperature. Clinical opinion has largely determined which variables to test [19, 20]. Variables with prognostic significance in one disease, for example bacterial or viral respiratory infections, may be inappropriately included in scores for other diseases [21, 22]. Doubt as to which variables to use has led to large multicentre studies [23]. The performance of any score depends upon the reliability with which its components are measured. In the initial bedside study all variables were recorded for only 1 in 20 children [10], the reasons for which are complex [24-26]. Variables measured infrequently and that are subject to systematic error, such as blood pressure, are more likely to impair a score's performance [20, 27, 28].

The Paediatric Early Warning Score (Scotland) was introduced with the intention of creating a single score with the ability of differentiating unwell children through the whole patient journey and creating a common language for communicating this. It is now embedded in inpatient practice in Scotland and we are keen to assess its effectiveness in the pre-hospital environment. We have previously reported that 21,202/102,993 (21%) children had all eight components of a paediatric early warning score recorded when transported by ambulance to hospital [3]. Some variables were measured less often than others, which might reflect the difficulty of measuring blood pressures in crying children, unreliable pulse oximetry in moving vehicles and a disbelief that temperature in a recently injured child might be useful. We may have compromised the utility of our early warning score in the pre-hospital environment by including some variables that cannot be reliably measured by paramedic crews in ambulances.

The basis for developing PEWS has always been "making it easier to do the right thing and more difficult to do the wrong thing" and in paediatrics in particular, to reduce the cognitive load of applying age related values. Whilst some of the cognitive load is removed by the electronic patient report form (ePRF) in the pre-hospital setting calculating the PEWS, it could be argued that the low

rate of fully completed all eight point PEWS scores reflects that we have either not created an understanding of the need for collecting all of the vital sign parameters or not made it easier for paramedic crews thereby compromising both the utility and applicability of the PEWS score. Abbreviation of the score by reducing the number of components could increase the number of children with calculable scores.

We have therefore aimed in this paper to determine the discrimination of abbreviated versions of the paediatric early warning score for the outcomes assessed in the original paper: admission to intensive care within 48 hours of ambulance transfer or death within 30 days.

Methods

The Caldicott Guardian National Scrutiny Process for Scotland approved this study, as did the Greater Glasgow and Clyde NHS Board for research and development. We did not seek ethical approval.

The methods were outlined in the original paper [3]. Briefly, we studied all children (< 16 years) conveyed by the Scottish Ambulance Service to hospital from 2011 to 2015. We did not study children in cardiac arrest or children transferred between hospitals. We assigned risk scores of 3 and 1 for each (of seven) physiological variables if they deviated outside their 99%CI and 95%CI, respectively, adjusted for five age categories: Glasgow coma score; heart rate; systolic blood pressure; respiratory rate; pulse oxygen saturation; temperature; time to capillary reperfusion. We assigned a score of 1 if supplemental oxygen was given. We analysed the association of scores with a composite of all-cause mortality within 30 days or admission to intensive care within 48 hours of ambulance attendance, identified by linking records with the Community Health Index or NHS number. We used the physiological values recorded from the first instance that all eight variables were recorded. We did not impute missing values.

We calculated the associations of variables and their combinations with outcome, using the area under the receiver operating characteristic (AUROC) curve. For patients with all eight variables recorded, we entered variables sequentially into a multivariable binary logistic model, adding the variable that in combination with the existing model associated most with outcome, if $p<0.05$ and removing variables if $p >0.1$. The AUROC for each cumulative model was compared to using all eight components using DeLong's test. We performed sensitivity analyses of each model with and without supplemental oxygen delivery. We used SAS® software for all analyses (version 9.4, SAS Institute Inc.; Cary, NC, USA). We assumed two-sided $p < 0.05$ statistically significant. We did not test differences in the AUROC curves for different abbreviated models as the number of children (and outcomes) were different.

Results

We studied 102,993 children. The number of children who had values recorded were supplemental oxygen 102,993 (100%); Glasgow coma score 83,648 (81%); heart rate 83,330 (81%); systolic blood pressure 37,088 (36%); respiratory rate 90,358 (88%); pulse oxygen saturation 71,372 (69%); temperature 60,402 (59%); time to capillary reperfusion 81,685 (79%). All variables were recorded for 21,202 children, particularly older children (Table 1 and Fig. 1 and Supplementary Information Tables S1-3 and Figure S1).

Admission to intensive care (n = 1053) within 48 hours of ambulance transfer or death (n = 153) within 30 days was recorded for 1178 (1%) children (Supplementary Information Table S1. A model with four variables associated with outcome as much as the full model of eight variables: oxygen delivery; Glasgow coma score; heart rate; and oxygen saturation (Table 2)

All eight components of the PEWS were independent predictors of the primary outcome. However, Table 2 shows that from step 4, none of the AUROC are significantly different from that using all components. The performance of this model is compared with incomplete datasets in Table 3. The outcome rate in all model cohorts was around 1%: threshold scores discriminated children with an outcome rate < 1% (in about two thirds) from children with an outcome rate 2%-3% (in about one third, Table 3).

Discussion

We found that in an unselected population of ambulance patients, four components of the paediatric early warning score (PEWS) were as good as all eight components for discriminating between children who died within 30 days or were admitted to intensive care within 48 hours of emergency ambulance transfer to hospital: oxygen delivery; conscious level; heart rate; and oxygen saturations.

Which components of the multiple PEWS scores, in use internationally, best predicts outcome remain under debate [1, 17, 18]. The number of children in whom a modified PEWS could be calculated was trebled by reducing the number of components from eight to four, mainly because systolic blood pressure and oxygen saturation were infrequently recorded in young children. Although our data shows that each of the 8 components which contribute to the PEWS(Scotland) are independent predictors of the adverse outcomes of admission to PICU within 48 hours or death within 30 days in unselected children and young people < 16 years old transferred to hospital by ambulance, we also have demonstrated that the stepwise AUROC increases little after the first 4 components of oxygen delivery, conscious level, heart rate and oxygen saturations.

Conscious level and heart rate might be combined with one or two other PEWS components to generate four models with similar discrimination, the additional components being: respiratory rate; respiratory rate and capillary refill; respiratory rate and oxygen saturation; or oxygen delivery and oxygen saturation. These combinations avoid the difficulty of blood pressure measurement in distressed children and may increase the speed and accuracy of recorded values [29, 30]. An important point to consider is that paediatric early warning scores are not as yet widely used in resource limited settings including the pre-hospital environment in Scotland but the benefits might be enhanced by the simplicity of measuring conscious level, heart rate and respiratory rate [31].

We are uncertain whether our results would be similar in children who do not get to hospital in an ambulance and in children in other countries. We do not know how the modified PEWS combinations would work in hospital (rather than before admission), where thresholds for scoring a physiological variable might be optimal at different values [32, 33]. Our pre-hospital model was a single set of observations, the thresholds of which might be modified if trends in scores are tested whilst children are in hospital [34].

In conclusion, the discrimination of four components of the pre-hospital paediatric early warning score was as good as eight components for the combined outcome of 30-day mortality or intensive care admission within 48 hours. A simpler version, consisting of conscious level, heart rate and respiratory rate might be tested in both primary care and resource-limited settings.

Acknowledgements

The authors would like to thank Scottish Ambulance Service staff involved in collecting the data used in this study. All authors have no conflicts to declare. This project was supported by a grant from the Laerdal Foundation for Acute Medicine, grant number 1868. Data are available for meta-analysis.

Supplementary Information

Table S1 The distribution of outcome by age.

Table S2 The distribution of outcomes and AUROC curves by age for 21,202 with complete measurements (PEWS) and for 74,508 children in whom conscious level, heart rate and respiratory rate were measured.

Table S3 The distribution of physiological measurements by age.

Figure S1 The proportion of children with complete physiological measurements by age for the PEWS and for the three variables of conscious level, heart rate and respiratory rate.

References

1. Chapman SM, Wray J, Oulton K, Peters MJ. Systematic review of paediatric track and trigger systems for hospitalised children. *Resuscitation* 2016; **109**: 87-109.

2. Lambert V, Matthews A, MacDonnell R, Fitzsimons J. Paediatric early warning systems for detecting and responding to clinical deterioration in children: a systematic review. *BMJ Open* 2017; **7**: e014497. doi: 10.1136/bmjopen-2016-014497

3. Corfield AR, Silcock D, Clerihew L, et al. Paediatric early warning scores are predictors of adverse outcome in the pre-hospital setting: a national cohort study. *Resuscitation* 2018; **133**: 153-9.

4. Roland D, Oliver A, Edwards ED, et al. Use of paediatric early warning systems in Great Britain: has there been a change of practice in the last 7 years? *Archives of Disease in Childhood* 2014; **99**: 26-9. doi.org/10.1136/archdischild-2012-302783

5. Egdell P, Finlay L, Pedley DK. The PAWS score: validation of an early warning scoring system for the initial assessment of unwell children in the emergency department. *Emergency Medical Journal* 2008; **25**: 745-9.

6. Tibballs J, Kinney S, Duke T, Oakley E, Hennessy M. Reduction of paediatric in-patient cardiac arrest and death with a medical emergency team: preliminary results. *Archives of Disease in Childhood* 2005; **90**: 1148-52.

7. Pearson G, Duncan H. Early warning systems for identifying sick children. *Paediatrics and Child Health* 2011; **21**: 230-3.

8. Monaghan, A. Detecting and managing deterioration in children. *Paediatric Nursing* 2005; **17**: 32-5.

9. Why children die: death in infants, children and young people in the UK: Part A May 2014. Royal College of Paediatrics and Child Health

10. Parshuram CS, Hutchison J, Middaugh K. Development and initial validation of the Bedside Paediatric Early Warning System score. *Critical Care* 2009; **13**: R135. doi: 10.1186/cc7998.

11. Parshuram CS, Duncan HP, Joffe AR, et al. Multicentre validation of the bedside paediatric early warning system score: a severity of illness score to detect evolving critical illness in hospitalised children. *Critical Care* 2011; **15**: R184.

12. Joshi V, Barber R, Yates R. ManChEWS: Royal Manchester Children's Hospital early warning score. *Critical Care* 2011; **15 (Suppl 1)**: 507. doi: 10.1186/cc9927

13. Edwards ED, Powell CV, Mason BW, et al. Prospective cohort study to test the predictability of the Cardiff and Vale paediatric early warning system. *Archives of Disease in Childhood* 2009; **94**: 602–6.

14. Roland D, Davies F, Coats T. The Paediatric Observation Priority Score (POPS): outcomes of 24000 patients. *Archives of Disease in Childhood* 2014; **99**: A24.

15. Duncan HP. Survey of early identification systems to identify inpatient children at risk of physiological deterioration. *Archives of Disease in Childhood* 2007; **92**: 828–8.

16. Clements F, J. Beattie J.McIntyre, A.K. Maley, A. Wagstaff. Development and implementation of a paediatric early warning scoring system into a sick children's hospital. *Resuscitation* 2008; **77**: S32. doi:10.1016/j.resuscitation.2008.03.102

17. Chapman SM, Wray J, Oulton K, et al. The score matters; wide variation s in predictive performance of 18 paediatric track and trigger systems. *Archives of Disease in Childhood* 2017; **102**: 487–95.

18. Seiger N, Maconochie I, Oostenbrink R, Moll H. Validity of different paediatric early warning scores in the emergency department. *Pediatrics* 2013; **132**: e841-e850.

19. Cotterill S, Rowland AG, Kelly J, et al. Diagnostic accuracy of PAT-POPS and ManChEWS for admissions of children from the emergency department. *Emergency Medical Journal* 2016; **33**: 756-62.

20. Bird C, Michie C. Measuring blood pressure in children. *British Medical Journal* 2008*;* **336**: 1321. doi: 10.1136/bmj.a150.

21. Thompson M, Coad N, Harnden A, Mayon-White R, Perera R, Mant D. How well do vital signs identify children with serious infections in paediatric emergency care? *Archives of Disease in Childhood* 2009; **94**: 888-93. doi: 10.1136/adc.2009.159095.

22. Blacklock C, Mayon-White R, Coad NThompson M. Which symptoms and clinical features correctly identify serious respiratory infection in children attending a paediatric assessment unit? *Archives of Disease in Childhood* 2011; **96**: 708-14. doi: 10.1136/adc.2010.206243.,

23. Thomas-Jones E, Lloyd A, Roland D et al. A prospective, mixed-methods, before and after study to identify the evidence base for the core components of an effective Paediatric Early Warning System and the development of an implementation package containing those core recommendations for use in the UK: Paediatric early warning system - utilisation and mortality avoidance- the PUMA study protocol. *BMC Pediatr* 2018; 18(1):244

24. Sefton G, Lane S, Killen R, et al. Accuracy and efficiency of recording pediatric early warning scores using an electronic physiological surveillance system compared with traditional paper-based documentation. *Computer, Informatics, Nursing* 2017; **35**: 228-36. doi: 10.1097/CIN.0000000000000305.

25. Clifton DA, Clifton L, Sandu D, et al. 'Errors' and omissions in paper-based early warning scores: the association with changes in vital signs—a database analysis. *BMJ Open* 2015; **5:** e007376. doi: 10.1136/bmjopen-2014-007376.

26. Christofidis MJ, Hill A, Horswill MS, Watson MO. A human factors approach to observation chart design can trump health professionals' prior chart experience. *Resuscitation* 2013; **84**: 657–65.

27. Fleming S, Gill P, Jones C, et al. Validity and reliability of measurement of capillary refill time in children: a systematic review. *Archives of Disease in Childhood* 2015; **100** :239-49.

28. Jensen CS, Aagaard H, Olesen HV, Kirkegaard H. Inter-rater reliability of two paediatric early warning score tools. *European Journal of Emergency Medicine* 2019; **26**: 34-40.

29. Nolan T, Resar R, Haraden C, Griffin FA. *Improving the Reliability of Health Care.* IHI Innovation Series white paper. Boston: Institute for Healthcare Improvement; 2004. http://www.ihi.org/resources/Pages/IHIWhitePapers/ImprovingtheReliabilityofHealthCare.aspx (Last accessed 1st March 2019)

30. Thompson M, Mayon-White R, Harnden A, Perera R, McLoed D, Mant D. Using vital signs to assess children with acute infections: a survey of current practice. *British Journal of General Practice* 2008; **58**: 236-41.

31. Agulnik A, Mora Robles LN, Forbes PW, et al. Improved outcomes after successful implementation of a pediatric early warning system (PEWS) in a resource-limited pediatric oncology hospital. *Cancer* 2017; **123**: 2965-74. doi: 10.1002/cncr.30664.

32. Hoffmann F, Schmalhofer M, Lehner M, Zimatschek S, Grote V, Reiter K. Comparison of the AVPU scale and the pediatric GCS in pre-hospital setting. *Pre-hospital Emergency Care* 2016; **20**: 493-8

33. Bonafide, Christopher P et al. Development of heart and respiratory rate percentile curves for hospitalized children *Pediatrics* vol. 131,4 (2013): e1150-7.

34. Jarvis SW, Kovacs C, Briggs J, et al. Are observation selection methods important when comparing early warning score performance? *Resuscitation* 2015; **90**: 1-6. doi: 10.1016/j.resuscitation.2015.01.033.

Table 1 The rates combinations of variables were recorded for 102,993 children transferred to hospital by ambulance.

GCS	HR	RR	Temp	CRT	SpO_2	SBP	O_2	Number
X	X	X						74,508 (72%)
X	X	X		X				66,449 (65%)
X	X	X			X			64,202 (62%)
X	X	X	X					51,007 (50%)
	X	X	X	X				48,242 (47%)
X		X	X	X				47,588 (46%)
X	X		X	X				47,028 (46%)
X	X	X	X	X				45,734 (44%)
X	X	X	X	X	X	X	X	21,202 (21%)

CRT, capillary refill time; GCS, Glasgow coma score; HR, heart rate; O_2, supplemental oxygen; RR, respiratory rate; SBP, systolic blood pressure; SpO_2, oxygen saturation; Temp, temperature.

Table 2 Stepwise entry and retention of variables in the paediatric early warning score model

Step	Variable	Entry p value	Cumulative AUROC	Retention p value
1	Oxygen delivery	< 0.0001	0.69	-
2	Glasgow coma score	< 0.0001	0.75	< 0.0001
3	Heart rate	< 0.0001	0.79	0.013
4	Oxygen saturations	< 0.0001	0.80	0.080
5	Systolic blood pressure	0.0053	0.81	0.43
6	Respiratory rate	0.022	0.81	0.48
7	Temperature	0.049	0.81	0.96
8	Capillary refill time	0.043	0.81	-

AUROC, area under the receiving operator characteristic curve.

Table 3 The performance of different models for how variables recorded for 102,993 children transported by ambulance to hospital associated with subsequent admission to paediatric intensive care (48 h) or death (30 days).

Variables	Number	Events	AUROC	Threshold				
				Value	Sensitivity	Specificity	PPV	NPV
GCS, HR, RR	74,508	799	0.75	3	0.66	0.74	2.7%	99.5%
GCS, HR, RR, O_2	74,508	799	0.77	2	0.75	0.67	2.4%	99.6%
GCS, HR, SpO_2, O_2	67,265	728	0.78	2	0.76	0.69	2.6%	99.6%
GCS, HR, RR, CRT	66,449	684	0.75	3	0.66	0.74	2.6%	99.5%
GCS, HR, RR, CRT, O_2	66,449	684	0.77	2	0.76	0.67	2.3%	99.6%
GCS, HR, RR, SpO_2	64,202	679	0.79	3	0.74	0.70	2.6%	99.6%
GCS, HR, RR, SpO_2, O_2	64,202	679	0.80	4	0.67	0.80	3.4%	99.6%
GCS, HR, RR, Temp	51,007	513	0.74	3	0.72	0.68	2.2%	99.6%
HR, RR, Temp, CRT	48,242	492	0.69	2	0.68	0.63	1.9%	99.5%
GCS, RR, Temp, CRT	47,588	461	0.72	3	0.55	0.83	3.1%	99.5%
GCS, HR, Temp, CRT	47,028	474	0.73	3	0.68	0.72	2.4%	99.5%
GCS, HR, RR, Temp, CRT	45,734	450	0.75	3	0.72	0.68	2.2%	99.6%
GCS, HR, SpO_2, O_2*	21,202	176	0.80	5	0.71	0.78	2.7%	99.7%

*For the 21,202 children for whom all eight variables were recorded.

AUROC, area under the receiving operator characteristic curve; CRT, capillary refill time; GCS, Glasgow coma score; HR, heart rate; O_2, supplemental oxygen; RR, respiratory rate; SBP, systolic blood pressure; SpO_2, oxygen saturation; Temp, temperature.

Figure 1 The proportion of 102,993 children transported by ambulance to hospital who had eight physiological variables recorded, categorised by age: pulse oxygen saturation (———); respiratory rate (———); heart rate (———); Glasgow coma score (———); time to capillary reperfusion (———); temperature (———); systolic blood pressure (———); supplemental oxygen (———).