

A ward-based time study of paper and electronic documentation for recording vital sign observations

David Wong (corresponding author)

Leeds Institute of Data Analytics,
Worsley Building,
University of Leeds,
UK
LS2 9JT
email: d.c.wong@leeds.ac.uk

Timothy Bonnici

Kadoorie Centre for Critical Care Research and Education,
Level 3, John Radcliffe Hospital,
Headley Way,
Oxford,
UK
OX3 9DU
email: timothy.bonnici@ndm.ox.ac.uk

Julia Knight

Kadoorie Centre for Critical Care Research and Education,
Level 3, John Radcliffe Hospital,
Headley Way,
Oxford,
UK
OX3 9DU
email: julia.knight@phe.gov.uk

Stephen Gerry

Nuffield Department of Orthopaedics, Rheumatology and Musculoskeletal Sciences,
University of Oxford,
Oxford,
UK
OX3 7LD
email: stephen.gerry@csm.ox.ac.uk

James Turton

Brasenose College,
University of Oxford,
Oxford,
UK
OX1 4AJ
email: james.turton@bnc.ox.ac.uk

Peter Watkinson

Kadoorie Centre for Critical Care Research and Education,
Level 3, John Radcliffe Hospital,
Headley Way,
Oxford,
UK,
OX3 9DU
email: peter.watkinson@ndcn.ox.ac.uk

Word Count: 3303 words**Key Words:** Vital Signs, Electronic Charting, Early Warning Score, Time and Motion Studies

Abstract

Objective – To investigate time differences in recording observations and an Early Warning Score (EWS) using a traditional paper chart and a novel e-Obs system, in clinical practice.

Methods – Researchers observed the process of recording observations and EWS across three wards in two university teaching hospitals immediately before and after the introduction of the e-Obs system. The process of recording observations included both measurement and documentation of vital signs. Interruptions were timed and subtracted from the measured process duration. Multilevel modelling was used to compensate for potential confounding factors.

Results – 577 nurse events were observed (281 Paper, 296 e-Obs). The geometric mean time to take a complete set of vital signs was 215s (95% CI: 177s-262s) on paper, and 150s (95% CI: 130s-172s) electronically. The treatment effect ratio was 0.70 (95% CI: 0.57-0.85, $p < 0.001$). The treatment effect ratio in ward 1 was 0.37 (95% CI: 0.26-0.53), in ward 2 was 0.98 (95% CI: 0.70-1.38), and in ward 3 was 0.93 (95% CI: 0.66-1.33).

Discussion – Introduction of an e-Obs system was associated with a statistically significant reduction in overall time to measure and document vital signs electronically, in comparison to paper documentation. The reductions in time varied between wards and were of clinical significance on only one of three wards studied.

Conclusion – Our results suggest that the introduction of an e-Obs system may lower nursing workload in addition to increasing documentation quality.

BACKGROUND AND SIGNIFICANCE

Safe care of inpatients requires clinicians to regularly measure and document individuals' vital signs. In many hospitals, vital signs are documented on paper charts and interpreted with the aid of Early Warning Score (EWS) systems. Calculation of an EWS involves assigning an integer score to each vital sign and then aggregating the scores. The total score reflects the degree of physiological abnormality. It is used to determine whether care needs to be escalated and the frequency of subsequent observations.

Paper charts have multiple shortcomings. Errors in EWS calculation, omission of key data, and illegible handwriting contribute to the misinterpretation of paper notes.[1,2]

Computerised systems for recording vital sign observations and calculating an EWS, e-Obs systems, have previously been identified as a more effective way of identifying patients at risk of clinical deterioration.[3] The introduction of healthcare IT systems has historically been met with mixed success.[4,5] A key factor in determining end-user acceptance is the effect on workload.[6]

Evidence regarding whether e-Obs systems decrease nursing workload is mixed. In a classroom environment, Prytherch et al. demonstrated a 1.6-times reduction in the time to document vital signs and compute an EWS in comparison to pen-and-paper.[7] By contrast, Yeung et al. observed the practices of 24 nurses within a clinical setting, finding an increase in time for documenting observations electronically rather than using pen-and-paper.[8]

The effect of implementing an electronic observation and EWS system on the time taken to complete the task in clinical practice has not been studied. Oxford University Hospitals (OUH) NHS Trust planned to replace a paper chart-based EWS system with the SEND e-Obs system in a phased roll out.[9] This created the opportunity to establish the effect of the

introduction of an e-Obs system on the time taken to record vital signs observations across three wards in two university teaching hospitals.

METHODS

We conducted a before-and-after observational study between November 2014 and December 2015 on three medical in-patient wards, in two university teaching hospitals that form part of the OUH NHS Foundation Trust. We used time-motion methods to measure the time to take and document patients' vital signs.

The study was approved as a service evaluation for OUH Foundation Trust (Datix :3196).

Aim

The primary objective of this study was to determine whether the introduction of an e-Obs system alters the time required to record a complete set of vital sign observations.

Pre-Intervention

Prior to the intervention, patients' vital signs data were recorded onto the existing paper observation chart.[10] The vital signs recorded on the chart were: Heart Rate (HR), Respiratory Rate (RR), Blood Pressure (BP), Temperature (Temp), Oxygen Saturations (SpO2), Oxygen Therapy, and Consciousness via the Glasgow Coma Score (GCS) or AVPU score. The chart was routinely kept in the patient's nursing folder, alongside other care plans and charts. Nursing folders of all patients on the ward were located at the nursing stations, rather than at the bedside, on all observed wards.

Intervention

The paper chart was replaced with an e-Obs system, SEND, a description of which has previously been published.[9] In brief, the SEND application is accessed using a tablet mounted on a roll-stand alongside the vital signs monitor. Patients are identified by scanning a barcode on their ID wristband. Vital sign data are manually entered using the tablet's touchscreen. The vital signs are graphically charted as they are entered, allowing easy comparison with previously entered data. Upon completion, all data are transmitted immediately to a central server, and the system provides clinical advice based on the automatically calculated EWS.

Data Collection Procedures

Two clinically-trained observers watched nurses on the study wards before and after the intervention. We collected ward-level data, including staff levels, staff seniority, and ward specialty at the start of the study, and monitored for any changes throughout the study period. Staff seniority was categorised as: 'Care Support Workers and Student Nurses', 'Nurses' (NHS Band 5) and 'Senior Nurses' (NHS Band 6 and above).

Nurses undertaking observation sets were observed Monday to Friday between 9a.m. – 5p.m. Nurses were aware that they were being observed and had the opportunity to refuse consent to being observed prior to each observation.

On each ward observations were conducted over two five-week periods, one before and one after the implementation of SEND. The pre-implementation period occurred 16 to 9 weeks prior to implementation of the e-Obs system. The post-implementation period took place 4 to 8 weeks thereafter. The pre- and post-implementation periods were separated by

8 to 12 weeks. We chose this separation to allow for the training and bedding-in effects of the intervention while minimising the risks of confounder variables such as changes in staff population.

Our decision to measure the time of nursing tasks follows the precedent of previous studies.[11-13] We divided the observation recording process into two sub-tasks: *View Chart* and *Take Vital Signs*. *View Chart* was defined as the task of locating the chart and “opening” the chart ready to record vital signs. *Take Vital Signs* was defined as the task of measuring and documenting vital signs. We defined actions that marked the start and end of the tasks as shown in Table 1.

Task	Times	Control (paper chart)	Intervention (SEND e-Obs)
View Chart	Start (i)	Nurse arrives at the notes source (e.g. at the nursing station)	No equivalent (notes stored in database)
	Finish (i)	Nurse has finished collecting all the sets of notes required for the observation and has all sets of notes in hand	No equivalent (notes stored in database)
	Start (ii)	Nurse is at the patient’s bedside and touches the notes to open them	Nurse scans the patient’s wristband identifier to access their SEND record
	Finish (ii)	Vital sign chart is open at the bedside	Vital sign chart is visible to nurse

Take Vital Signs	Start	First piece of vital sign monitoring equipment is attached to patient	
	Finish	Nurse completes the final piece of documentation on the paper vital sign chart	Nurse presses 'Save Obs' to submit a set of vital signs in SEND

Table 1: Definitions of task time points in the pre-intervention and intervention groups. The View Chart task consists of two mutually exclusive time periods. These relate to (i) locating the nursing notes within a ward (ii) locating the observation chart within the nursing notes

Tasks may be interrupted due to competing events that require attention from the observed nurse. We defined an *Interruption* as anything that caused an on-going task to be halted. All *Interruptions* were timed and classified (see supplementary material for further details).

All data were recorded electronically in real-time on tablet devices using bespoke software developed for the study. The software contained timers for each task and for *Interruptions* that allowed concurrent tasks and *Interruptions* to be accurately recorded. The software also had rules to ensure logical consistency such as preventing the start of an *Interruption* when no other task was in progress.

Observer Training

We used high fidelity simulation to train the study observers prior to data collection. Testing scenarios included a mix of paper-based and SEND-based vital sign recording as well as a variety of *Interruptions*. In each scenario, the observers were asked to record study data using the data collection software. The two additional independent, who took no further part in the study, concurrently recording study data, also using the data collection software.

Inter-observer variability was assessed by calculating the range of times for each task, for each scenario. A high value for the range, with respect to the mean task time, would indicate uncertainty in when tasks should be started or stopped, or problems with the data capture software. Unconscious bias was assessed by ranking the observers (fastest to slowest) for each task within each scenario. Consistently high or low rankings indicated an unconscious propensity to be faster or slower than the true time.

In the event of high inter-observer variability or evidence of unconscious bias we planned to retrain observers and repeat the scenarios. The results and analysis of the scenarios are available as online supplementary material.

Analysis of Outcome Measures

Outcomes

The primary outcome was the difference in *Task Completion* Time: the time to take a set of vital sign observations and compute an early warning score. This was calculated as the sum of times required to complete View Chart and Take Vital Signs, excluding the duration of any concurrent tasks and Interruptions.

The secondary outcome measures were the differences in times to complete the View Chart and Take Vital Signs sub-tasks pre- and post-intervention. Ward level analysis was undertaken post-hoc.

Outcome Analysis

We limited analysis a priori to observations where all of the vital signs were documented and an EWS score was calculated.

We assessed time differences using a linear mixed effects model. The first level of the model was a fixed-slope random intercept linear regression to take into account the clustering of multiple observations by the same nurse. The number of Interruptions and nurse seniority were identified as potential confounders and included as covariates in the model.

The second level of the model used a random slope and random intercept to account for differences between wards. Non-normal distribution data were log-transformed prior to analysis. We assessed the validity of the transformation by checking the normality of the model residual distributions (available as supplementary material). The back-transformation of logarithmic values means that all times and confidence intervals are presented as geometric means. The effect size is then calculated as the ratio of geometric means pre- and post-intervention.

Statistical analysis was performed using SAS software, version 9.4.[14]

RESULTS

606 sets of vital sign recordings were observed during the study period. We excluded 29 incomplete observation sets from analysis. Of the 29, 6 were missing one vital sign, 3 were missing multiple vital signs, and 20 were missing EWS scores for at least one vital sign. We analysed 281/297 (94.6%) paper observations and 296/309 (95.8%) e-Obs. 153 to 280 observations were taken per ward across both periods (Table 2). The majority of staff observed were Band 5 nurses. Full details are shown in Table 2.

Ward	Ward 1		Ward 2		Ward 3	
Specialty	Medicine: Infectious Diseases		Medicine: Haematology		Medicine: Acute General	
Number of nursing staff trained to record vital signs	32		33		29	
Study phase	Before	After	Before	After	Before	After
Senior Nurses observed	1	2	3	1	0	1
Nurses observed	9	12	21	22	9	13
Care Support Workers and Student Nurses observed	4	2	1	4	2	3
Total	14 (44%)	16 (50%)	25 (76%)	27 (82%)	11 (38%)	17 (59%)
Total Observations	86	67	139	141	86	86
Complete Observations	79	66	133	132	84	83

Table 2: Ward-level data for the three study wards.

The geometric mean Task Completion Time was lower using e-Obs 150s (95% CI: 130s-172s) than when charting on paper 215s (95% CI: 177s-262s). The overall treatment effect ratio was 0.70 (95% CI: 0.57-0.85, $p < 0.001$) (Table 3), equivalent to a 30% reduction in time for the e-Obs system compared to the paper system.

At an individual ward level, the treatment effect ratio was 0.37 (95% CI: 0.26-0.53, $p < 0.001$) in Ward 1, equivalent to a 63% reduction in time. In Ward 2, the treatment effect ratio was 0.98 (95% CI: 0.70-1.38, $p = 0.91$), equivalent to a 2% reduction in time. This corresponded to

a Task Completion Time of 204s (95% CI: 146s-285s) pre-intervention and 200s (95% CI: 159s-253s) post-intervention. In Ward 3 the treatment effect ratio was 0.93 (95% CI: 0.66-1.33, $p=0.70$), equivalent to a 7% reduction in time. This corresponded to a Task Completion Time of 153s (95% CI: 109s-216s) pre-intervention and 143s (95% CI: 112s-183s) post-intervention. The treatment effect ratios on Wards 2 and 3 were not significant (Ward 2: 0.98, 95% CI: 0.70s-1.38s, $p=0.91$; ward 3: 0.93, 95% CI: 0.66s-1.33s, $p=0.70$).

Comparison	Paper: Geo Mean (95% CI)	e-Obs: Geo Mean (95% CI)	Geometric Mean Ratio (95% CI)	P-value
Ward 1	319s (225s, 451s)	117s (92s, 150s)	0.37 (0.26, 0.53)	<0.001
Ward 2	204s (146s, 285s)	200s (159s, 253s)	0.98 (0.70, 1.38)	0.91
Ward 3	153s (109s, 216s)	143s (112s, 183s)	0.93 (0.66, 1.33)	0.70
overall	215s (177s, 262s)	150s (130s, 172s)	0.70 (0.57, 0.85)	<0.001

Table 3: Model outputs for a random offset multi-level linear regression model in which Level 1 = nurse, level 2 = ward. A geometric mean ratio <1 implies that the time for observations using e-Obs is less than on paper. The model accounts for correlation between multiple observations of the same nurse.

Of the two sub-tasks, View Chart and Take Vital Signs, we observed the greatest time savings in the latter. The geometric mean (95% CI) time to complete the View Chart task was 18s (13s-27s) before the intervention and 13s (10s-17s) after the introduction of SEND (treatment effect ratio 0.36, $p=0.052$). The geometric mean (95% CI) time to complete the Take Vital Signs task was 194s (156s-241s) on paper and 140s (120s-164s) using the e-Obs system (treatment effect ratio 0.72, $p=0.005$).

DISCUSSION

Our study, conducted in a real-world environment, demonstrates that documentation of vital signs using a well-designed e-Obs system can be faster than paper charting. We observed a statistically significant reduction in Task Completion Time in the studied sample. The reduction remained significant, even after accounting for variation in ward, individual nursing behaviour, nursing seniority, and number of Interruptions.

Sub-group analysis by ward highlighted that the size of the time saving may vary considerably between individual wards. We observed a clinically significant reduction in geometric mean Task Completion Time on Ward 1 from 345s to 114s, whereas time savings on Wards 2 and 3 were smaller and less clinically relevant (Table 3)

Introduction of an e-Obs system was also associated with a reduced variability in the time taken to record vital signs. It seems likely that the system was driving a standardisation in the process of recording and documenting vital signs. Process standardisation is recognised to be associated with improved quality of care.[15]

The main time saving occurred in the “take vital signs” sub-task. This occurred despite the SEND system including a timer to encourage clinical staff to count respiratory rate over a full sixty seconds. Respiratory rate is known to be a particularly important indicator of adverse clinical events,[16] and longer measurement periods have been associated with increased data accuracy.[17]

The success of time-motion methods depends on how the observed tasks are defined.[18] In this case, we attempted to only measure the direct effect of e-Obs observation chart recall and vital sign data entry and EWS calculation. In doing so, we may have under-estimated the

true overall time-saving of e-Obs. For instance, the SEND e-Obs system may reduce the amount of travel required to take observations by ensuring that the equipment and documentation devices are always in the same location. We chose not to include this measure, as the outcome would be highly dependent on local ward organisation, rather than the introduction of e-Obs.

Increased efficiency is not the only benefit of an e-Obs system. SEND incorporates a number of features designed to reduce error. In common with other e-Obs systems,[7, 19] SEND automatically calculates EWS scores, thereby eliminating EWS calculation errors. Such errors may delay timely identification of patients at risk of deterioration.[20] Furthermore, the system identified patients using barcodes on their identification wristbands. Patient identification via barcodes has been associated with error reductions in other clinical settings, including drug prescribing and blood transfusion.[21, 22]

Limitations

The sampling of vital signs recording sessions across the three wards was uneven. We chose to observe for a fixed period before and after intervention to minimise confounding from time-dependent covariates. However, variation in practice between wards led to over-sampling in ward 2 and under-sampling in ward 1 and 3. As the largest time savings occurred where the fewest samples were taken (Ward 1), the likely effect of our sampling differences is to underestimate the effects on Task Completion Time.

During observation sessions, we aimed to observe all observations taken. In order to be present at the bedside we could only study vital signs recording when the ward nurse agreed to being observed. We did not observe observation recording practice outside weekday working hours. The choice of 9am-5pm weekdays to undertake the study was

pragmatic, given researcher availability and the need to minimise the impact of the study on the wards. It is theoretically possible that observation recording is systematically biased according to time of day although this does not seem likely.

Measurement of the primary outcome measure could have been affected by the fact that participants were aware that they were being observed. Being under scrutiny can stimulate an improvement in performance, the Hawthorne effect.[23] Another potential source of bias in time-motion studies comes from the *demand effect*, in which participants aim to please the study investigators. However, participants were not aware of the study objectives at the time of consent.

Before-and-after studies are limited in their ability to account for temporal variations in confounding variables. The lack of a control cohort, in which the intervention is never received, hampers the modelling of confounding effects.[24] Due to the practicalities of rolling out e-Obs to the hospitals, alternative study methodologies were not possible. We limited the effect of temporal variations in confounding variables by observing nurses over a relatively short period close to the time of the intervention. We did not observe any external changes that could have plausibly affected the efficiency of vital sign recording.

Relevance to other work

Three studies have compared electronic with paper vital signs entry. Vital sign recording took longer in a hospital recording vital signs into an electronic patient record in comparison to two hospitals that recorded vital signs on paper.[8] In contrast, two studies suggest that vital sign entry using electronic devices at the bedside is more time efficient than using paper.[25,26] None of these studies reported calculation of an EWS.

Two previous studies have used selected observation sets to assess the effect of an e-Obs

system (VitalPAC TM; System C) on the time to record vital signs and calculate an early warning score. Time savings were seen in comparison to paper in a classroom-based study.[7] All the fictitious vital signs sets used in this study scored >0 on the EWS system. This contrasts with the clinical environment, where the majority of vital sign score zero.[27] Consequently, the time to calculate the EWS manually may have been higher than in our study. Mohammed et al. found marginal improvements for nurses inputting ten vignettes with the e-Obs system after initial training. However, inputting the same ten vignettes was on average over ten seconds quicker than paper after the nurses had used the e-Obs system for four weeks in clinical practice.[28] This improvement is similar to the smallest median ward change found in our study.

Our study adds to previous findings by observing the use of an e-Obs system in clinical practice, with real patients. The study sample size was much larger than previous comparable work in this area.

CONCLUSIONS

In our three-ward study e-Obs was associated with a statistically significant reduction in the overall time to record vital sign observations and calculate an EWS, when compared with paper. In subgroup analysis, the time saved varied by ward. These variations may be due to differences in ward practice and require further investigation.

The results of this study, taken in conjunction with previous work, supports the assertion that a well-designed system can save significant amounts of time in clinical practice. These time-savings, in addition to the data quality benefits of electronic systems, present a convincing case for the adoption of e-Obs systems as part of routine inpatient care.

ACKNOWLEDGMENTS

We thank Soubera Yousefi and David Vallance for their help in collecting observation data during the study.

FUNDING STATEMENT

This work was supported by the NIHR Biomedical Research Centre (Oxford). PW is employed by the OUH NHS Trust. DW (grant: DFRWAO00), JK, TB were funded by the NIHR Biomedical Research Centre.

COMPETING INTERESTS STATEMENT

DW, JK, TB and PW were part of the team that developed SEND.

CONTRIBUTORSHIP STATEMENT

PW, JK, DW conceived and designed the study. DW, TB and JK acquired the study data. DW, JT, SG and TB analysed and interpreted the data. All authors were involved in drafting and critically revising the article and have approved the final version for submission.

REFERENCES

- [1] Wilson SJ, Wong D, Clifton DA et al. Track and trigger in an emergency department: an observational evaluation study. *Emerg Med J* 2012;30(3):186
- [2] Subbe CP, Gao H, Harrison DA. Reproducibility of physiological track-and-trigger warning systems for identifying at-risk patients on the ward. *Intensive Care Med* 2007;33:619-624.
- [3] Smith GB, Prytherch DR, Schmidt P et al. Hospital-wide physiological surveillance—a new approach to the early identification and management of the sick patient. *Resuscitation* 2006;71(1):19–28.
- [4] Nguyen, L, Bellucci E, Nguyen LT. Electronic health records implementation: an evaluation of information system impact and contingency factors. *Int J Med Inform* 2014;83(11):779-796.
- [5] Bossen C, Jensen LG, Udsen FW. Evaluation of a comprehensive EHR based on the DeLone and McLean model for IS success: Approach, results, and success factors. *Int J Med Inform* 2013;82(10):940-953.
- [6] Pynoo B, Devolder P, Voet T et al. Assessing hospital physicians' acceptance of clinical information systems: A review of the relevant literature. *Psychologica Belgica* 2013;53(2).
- [7] Prytherch DR, Smith GB, Schmidt P et al. Calculating early warning scores—a classroom comparison of pen and paper and hand-held computer methods. *Resuscitation* 2006;70(2):173–178
- [8] Yeung MS, Lapinsky SE, Granton JT, Doran DM, Cafazzo JA. Examining nursing vital signs documentation workflow: barriers and opportunities in general internal medicine units. *Journ Clin Nurs* 2012;21(7-8):975-982
- [9] Wong D., Bonnici T., Knight J., Morgan L., Coombes P., Watkinson P. SEND: A System for Electronic Notification and Documentation. *BMC Med Inform Decis Mak* 2015;15:68
- [10] Tarassenko L, Clifton DA, Pinsky MR, Hravnak MT, Woods JR, Watkinson PJ. Centile-based early warning scores derived from statistical distributions of vital signs. *Resuscitation* 2011;82(8):1013–1018
- [11] Potter P, Wolf L, Boxerman S et al. Understanding the cognitive work of nursing in the acute care environment. *J Nurs Adm* 2005;35(7-8):327-335
- [12] Wolf LD, Potter P, Sledge JA, Boxerman SB, Grayson D, Evanoff B. Describing nurses' work: combining quantitative and qualitative analysis. *Human Factors* 2006;48(1):5-14
- [13] Hendrick A, Chow MP, Skierczynski BA, Lu Z. A 36-Hospital Time and Motion Study: How Do Medical-Surgical Nurses Spend Their Time? *The Permanente Journal* 2008;12(3):25
- [14] Base SAS 9.4, SAS Institute Inc., Cary, NC.
- [15] Batalden PB, Davidoff F. What is “quality improvement” and how can it transform healthcare? *Qual Saf Health Care* 2007; 16:2-3
- [16] Cretikos MA, Bellomo R, Hillman K, Chen J, Finfer S, Flabouris A. Respiratory rate: the neglected vital sign. *Med J Aust* 2008;188(11): 657.

- [17] Simoes, EA, Roark R, Berman S, Esler LL, and Murphy J. Respiratory rate: measurement of variability over time and accuracy at different counting periods. *Arch Dis Child* 1991;66(10):1199-1203.
- [18] Zheng K, Guo MH, Hanauer DA. Using the time and motion method to study clinical work processes and workflow: methodological inconsistencies and a call for standardized research. *J Am Med Inform Assoc* 2011;18(5):704-710.
- [19] Pullinger R, Wilson S, Way R, et al. Implementing an electronic observation and early warning score chart in the emergency department: a feasibility study. *Emerg Med J* (2016).
http://journals.lww.com/euro-emergencymed/Abstract/publishahead/Implementing_an_electronic_observation_and_early.99344.aspx (accessed 31 Aug 2016)
- [20] Smith AF, Oakey RJ. Incidence and significance of errors in a patient 'track and trigger' system during an epidemic of Legionnaires' disease: retrospective casenote analysis." *Anaesthesia* 2006;61(3):222-228.
- [21] Poon, EG, Keohane CA, Yoon CS et al. Effect of bar-code technology on the safety of medication administration. *N Engl J Med* 2010;362(18):1698-1707.
- [22] Turner CL, Casbard AC, Murphy MF. Barcode technology: its role in increasing the safety of blood transfusion. *Transfusion*;2003;43:1200-9
- [23] McCambridge J, Witton J, Elbourne DR. Systematic review of the Hawthorne effect: new concepts are needed to study research participation effects. *J Clin Epidemiol* 2014;67(3):267-77.
- [24] Goodacre S. Uncontrolled before-after studies: discouraged by Cochrane and the EMJ. *Emerg Med J* 2015;32(7):507-508.
- [25] Meccariello M, Perkins P, Quigley LG, Rock A, Qiu J. Vital Time Savings: Evaluating the Use of an Automated Vital Signs Documentation System on a Medical/Surgical Unit. *J Healthc Inf Manag* 2010;24(4):46-51
- [26] Wager KA, Schaffner MJ, Foulois B, Swanson Kazley A, Parker C, Walo H. Comparison of the quality and timeliness of vital signs data using three different data-entry devices. *CIN: Computers, Informatics, Nursing* 2010;28(4):205-212
- [27] 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(7): e007376.
- [28] Mohammed M, Hayton R, Clement G, Smith G, Prytherch D. Improving accuracy and efficiency of early warning scores in acute care. *British Journal of Nursing* 2009;18 (1):18-24.