Title page

Efficiency and safety of electronic health records in Switzerland – a comparative analysis of two commercial systems in hospitals

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Abstract

Objectives: Differences in efficiency and safety between two electronic health record (systems A and B) in Swiss hospitals were investigated.

Methods: In a scenario-based usability test under experimental conditions, a total of 100 physicians at four hospitals were asked to complete typical routine tasks, like medication or imaging orders. Differences in number of mouse clicks and time-on-task as indicators of efficiency and error type, error count and rate as indicators of patient safety between hospital sites were analysed. Time-on-task and clicks were correlated with error count.

Results: There were differences in efficiency and safety between hospitals. Overall, physicians working with system B required less clicks (A: 511, B: 442, p=0.001) and time (A: 2055 sec, B: 1713 sec, p=0.055) and made fewer errors (A: 40%, B: 27%, p<0.001). No participant completed all tasks correctly. The most frequent error in medication and radiology ordering was a wrong dose and a wrong level, respectively. Time errors were particularly prevalent in laboratory orders. Higher error counts coincided with longer time-on-task (r=0.50, p <0.001) and more clicks (r=0.47, p <0.001).

Conclusions: The variations in clicks, time and errors are likely due to naïve functionality and design of the systems and differences in their implementation. The high error rates coincide with inefficiency and jeopardise patient safety and produce economic costs and burden on physicians. The results raise usability concerns with potential for severe patient harm. A deeper understanding of differences as well as regulative guidelines and policy making are needed.

INTRODUCTION

Over the recent years the digitalisation of heath care has accelerated and led to a rapid adoption and use of health information technologies (HIT) like electronic health records (EHR), computerized provider order entry (CPOE) and electronic prescribing systems (e-PS).[1–4] These technologies can improve the efficiency, safety and quality of delivering care.[5–9] For instance, easier medication ordering, less adverse drug events, a decrease in duplicate diagnostic test orders and lower costs have been reported.[8–10] But if systems are inappropriately designed, developed, implemented and applied, HIT can introduce new unintended consequences, like additional work for clinicians, unfavourable workflows, and new types of errors leading to patient safety concerns.[1,6–8,10–12] Beside potential patient harm, using complicated, incomplete, and inadequate electronic systems leads to inefficiency, frustration, and contributes to clinician burnout.[6,13–17] Benefits and risks of HIT do not only depend on system design, they have complex sociotechnical origins.[18] Mitigating HIT-related safety concerns requires a sociotechnical approach, involving health care professionals, clinical workflow and processes, the organisation and technology.[19–22] In addition, the implementation of the EHR in a specific setting involves further configuration and customisation based on workflows and interoperability with other HIT applications, which has an impact on usability and safety.[23]

Poor usability, the extent specific end-users can achieve their intended tasks with efficiency, effectiveness and satisfaction, is a prevalent contributing factor to these problems, with direct consequences for patient safety.[24–26] One way to detect health IT safety issues is conventional laboratory-based usability testing.[27] Such usability studies identify usability and safety problems and can thus contribute to improving HIT.[28,29] A few studies have studied differences in efficiency and safety between EHR systems empirically.[30,31] For example, Ratwani et al. investigated differences between two EHRs and report that physicians often make mistakes when performing tasks in the EHR. Error rates varied largely between the EHRs and their implementations in different hospitals. However, up to date there is little research regarding the impact of system performance of different EHR on safety and efficiency.[6]

In Switzerland, the federal Electronic Patient Record Law passed in 2017 and accelerated the digitalisation of the Swiss healthcare system. EHR systems in Swiss hospitals are the central repository for health information, the basis for clinical decision making and electronic prescribing. Nearly all physicians working in Swiss hospitals (91%) report to use an electronic system to store and manage patient data.[32] Given the large impact EHRs can have, it is surprising that there are no national policies to guide development, design, implementation and use of EHRs. A large number of EHR systems currently in use are outdated, offer few options for the integration of new technologies and do not match the processes of a hospital.[33] Half of clinicians are very dissatisfied with their systems mainly because of their insufficient functionality, complexity and slowness.[32] A Swiss study investigated patient safety issues of EHR systems in oncology outpatient clinics and reports that the current EHR systems do not allow adequate information management and pose a risk to patient safety.[34] In summary these observations indicate that systemic problems with EHRs observed in other countries may also exist in Switzerland. However, in contrast to the now widespread adoption of EHR systems in Swiss hospitals, their differences in safety have never been investigated. Based on the current state of research, it seems reasonable to assume that there are large differences between the systems and custom adaptions made during and after EHR implementation. As Switzerland has a small, heterogeneous and non-centralised health care system, resulting in very small markets for individual HIT vendors, the risk of relatively little investment in the usability and safety of the systems is rather high in our view. To improve the EHRs and to establish preconditions for national policies, an in-depth understanding of these variations is important to raise awareness of EHR usability and safety concerns in policymakers, hospital decision makers, vendors and researchers. The motivation for this study was to contribute to this required development.

The present study aims to analyse the efficiency and safety of two EHR systems commonly used in Switzerland and their implementation under experimental conditions. To this end, we investigated differences between and within two popular EHR systems implemented in four different hospitals with regard to their efficiency and patient safety. Indicators of safety and efficiency were correlated to understand whether higher levels of safety come at the price of less efficient systems, which may be important for economically driven HIT decisions. Physician satisfaction with their system was assessed to complement the objective measures of safety and efficiency by subjective perceptions of their users.

METHODS

Design and Setting

A scenario-based usability test using a quasi-experimental design was conducted. The study design and scenarios are based on Ratwani et al.[30] To separate the effects of EHR system and its implementation, four hospital sites (hospital sites 1-4) were included of which two each use the same EHR system (systems A and B) respectively. We chose two widely used EHR systems in Switzerland (different to those used in the study by Ratwani et al. [30]), based on publicly available information on the distribution of common EHR systems in Swiss hospitals. Potential study hospitals were selected based on their use of either of these two systems. Further inclusion criteria were the application of CPOE within the EHR and e-PS systems linked directly to the EHR. In addition, the EHR system had to be in use for at least one year. Heads of department of internal medicine of potentially eligible hospitals were approached for study participation until the four hospitals were recruited.

At each of the four hospital sites, usability testing was performed in a quiet room on site under the same conditions. Both hospitals with system A worked with the production environment, while the hospitals with system B used the EHR training environment that was identical to the production environment including CPU power. The same set of hypothetical patient cases was pre-installed at each site. Implementations of the two EHR systems differed between hospitals. In particular, the interfaces between the EHR and the radiology, laboratory and medication ordering systems were individually customized. The hospitals used different radiology and laboratory ordering systems linked to the EHR, but the medication ordering systems was identical within but not between hospitals with the same EHR. Furthermore, the EHR training the participating physicians received at their hospital differed in number, content and organisation of the training sessions.

Sample

Physicians working in the field of internal medicine and/or subspecialties (e.g. cardiology, oncology) in all four hospitals were eligible for participation. A quota sampling frame for level of training distribution among hospital physicians in internal medicine was developed based on the official statistics for 2019 (70% resident or attending physician, 30% senior or chief physician)[35]. Attention was also paid to gender balance.

Potential participants were recruited by a local study coordinator at each site alongside the quota sampling frame. Sample size was determined for one-way analysis of variance with four groups, based on a large effect size (f=0.35) and Alpha=0.05, Power=0.8 using G*Power 3.1.9.7 for Windows. The required sample size was 24 per hospital. Participants provided written informed consent. Physicians and all other local staff involved in the study received a voucher (approximately 55 US dollar) for their participation. The study was exempted from review by the local ethics committee (BASEC-Req-2020-00898).

Scenarios

The six scenarios used by Ratwani et al. were adapted to the Swiss context.[30] Two practicing internal medicine physicians reviewed the scenarios for plausibility and guideline conformity. The participants had to perform various typical tasks within the framework of the six clinical scenarios. The scenarios included various electronic ordering tasks, such as imaging, laboratory, medication and other typical tasks (see supplementary file A). For example, in the hypothetical case of an elderly male patient with sepsis (scenario 6), laboratory and antibiotics with a specific timing scheme had to be ordered initially. Subsequently, daily blood sugar profiles with measurements 4 times / day and insulin administration in the morning had to be ordered.

Usability testing procedure

The usability test followed a standardized procedure in each hospital. Physicians had to complete six hypothetical patient cases one by one on their own. At the beginning of the test, a standard verbal script was used to introduce the physicians to the study. Participants then answered six questions on demographics and their experiences with the EHR. The moderator presented each of the six scenarios verbally. The participants were asked to complete each clinical scenario according to their clinical practice and to perform the tasks without taking notes. The tasks were repeated a maximum of two times and no further assistance was provided. Physician-computer interactions were recorded with two cameras. One camera recorded a second screen, which was connected to the testing computer, The other recorded the mouse and hand of the participant. This installation ensured that the participant could not be identified in the video recordings. Mouse pointer and clicks were highlighted by PointerFocus® (Easy-to-Use Software). After completion of the scenarios, a debriefing was conducted and participants were asked to rate the level of satisfaction with their EHR system.

Outcome measures

To quantify the efficiency of the EHR system, the number of mouse clicks to accomplish each task was defined as primary outcome (mouse clicks) and the time to complete each task as secondary outcome (time-on-task). Mouse click count included all clicks (left, right, double). Scroll wheel adjustment, as well as the “tab” button were not considered. Data on mouse clicks and time-on-task were extracted from the video recordings. Safety of the EHR system was measured by the number of errors per task as primary outcome (error count). Error rate (percentage of errors per 100 tasks), error types and the accuracy of task completion were determined as secondary outcomes. Categories of potential types of errors, considering procedural and clinical errors for the different task types (medication, radiology, laboratory, others) were defined in advance.[36] Accuracy of task completion was defined as completion of all tasks successfully and without any error. As a global measure of provider satisfaction with the system they use, physicians were asked to rate their satisfaction on a 10-point scale ranging from “not at all satisfied” (1) to “very satisfied “ (10). After the rating, participants were asked to verbalize the positive and negative experiences of the system they use. The recordings of these statements were transcribed and used as feedback for the hospitals and EHR vendors. The results only served as a trend and were not part of the study. Thus, they are not presented in detail in this paper.

Analysis

Number and types of errors were manually extracted from entries in the EHR system made by participants. Data on mouse clicks and time-on-task were manually extracted from the video recordings. In a first step, video recordings were segmented into tasks. In a second step, time-on-task and mouse clicks were manually measured and counted for each task by a research assistant blinded to the study question. Random samples of measurements were re-evaluated by one of the authors.

Descriptive statistics are reported for sample characteristics, primary and secondary outcomes as well as participants’ experiences and satisfaction with the EHR. Sample mean and median differences between the hospitals were calculated using one-way analysis of variance and K-sample equality-of-medians test respectively. To quantify the variance between and within the hospitals and the two EHR systems (A/B) in terms of efficiency and patient safety, the outcome parameters time-on-task, mouse clicks, error count and error rate were analysed by scenario, type of task and by total tasks. Accuracy was determined as the fraction of participants who completed all tasks correctly without any error. To investigate differences between hospitals (1A, 2A, 3B, 4B) and between EHR systems (A vs. B) one-way analysis of variance was used and Bonferroni corrections for multiple tests were applied. Finally, correlation between efficiency (time-on-task, mouse clicks) and patient safety (error count) was investigated by Bravais-Pearson-Correlation. For the satisfaction ratings, the median rating and interquartile range per hospital and system were computed and a nonparametric test on the equality of medians between the two systems was performed. For all analyses, a p-Value <0.05 was considered statistically significant. STATA®, StataCorp, Version 16.1 was used for all analyses.

RESULTS

General characteristics of the participants (n=100) by hospital are reported in Table 1. There were no significant differences in participants' characteristics between hospitals. As intended by quota sampling, the sample includes approximately 70% residents and 30% senior or chief physician. Almost all participating physicians had received EHR training in some way.

Figure 1 reveals that system B was less error-prone and less time and clicks demanding for all types of tasks. Physicians working with system B required less clicks (system A 511, system B 442, p=0.001) and time (system A 2055 sec, system B 1713 sec, p=0.055) and made fewer errors (system A 40%, system B 27%, p<0.001) to complete the tasks.

The analysis of the accuracy of task completion showed that none of the 100 participants completed all tasks without any error. The best result was 1 error, the worst 32 errors with a median of 11 errors (IQR 8.5-16.5).

Table 2 provides an overview of the results of the primary (mouse clicks, error count) and secondary outcomes (time-on-task, error rate) by type of clinical task and hospital.

Results show that efficiency and patient safety outcomes vary largely between hospitals for specific tasks. For example, the error rate was more than doubled for radiology tasks in hospital 1A compared to 4B. Error count in laboratory related tasks was increased in hospital 2A by a factor of more than 10 compared to hospitals 3B and 4B. Contrariwise, for the medication related tasks, differences between hospitals were relatively small.

Table 3 reports outcomes by scenario. The mean number of mouse clicks differed significantly between hospitals in four out of the six scenarios. With few exceptions, EHR system B required less clicks compared to system A. Time-on-task differed only for two scenarios between hospitals. In the safety outcomes (error counts and rates), differences between hospitals were seen in three scenarios. While error rates are high across all systems, less errors were made by users of system B, and in particular in hospital 4B.

The most common types of medication order errors were wrong dose (29%), wrong start and/or stop date (28%) and an incorrect interval (22%) (see supplementary file B). Of the errors that occurred during radiology orders, 50% were due to a wrong level (for example anteroposterior vs. axial). Other frequently made radiology mistakes were the missing order of the contrast agent (16%) and a wrong localisation (14%). All radiology error types showed differences between hospitals and EHR systems. Prescribing the wrong time was by far the most common error among laboratory orders (99%) due to the significant large number made in hospital 2A. In contrast to these clinical errors, the most frequent error type of the other prescriptions was a procedural error, an incomplete order such as missing interval in the drug prescription (37%), with significantly more errors in hospital 1A compared to the other hospitals.

The results of the Bravais-Pearson correlation showed a medium strong positive correlation between error count of total tasks and time-on-task of total tasks ($r=0.50$, $p<0.001$). Likewise, error count of total tasks and mouse clicks of total tasks were positively correlated ($r=0.47$, $p<0.001$). Thus, higher error rates coincided with longer time on task and more mouse clicks.

Physicians' satisfaction with their EHR differed between EHR systems. System B was rated with a median score of 8 (IQR 7-9) in both hospitals (3B and 4B). Hospital 1A scored with a median of 5 (IQR 3-7) and hospital 2A with 6 (IQR 6-7). Overall, system A was rated significantly lower (<0.001).

DISCUSSION

In this study we generally found a high number of errors made across the different tasks regardless of hospital and system. None of the participants completed the tasks without error. Some of the errors we observed were potentially harmful, like wrong routes or toxic dosage. While the majority of errors would probably not cause severe harm or would not even reach the patient, frequent errors signal an unreliable system. For example, errors in radiology and laboratory orders often require clarification by staff causing disruptions in workflow which in turn plant new vulnerabilities into the system. Given the large differences between systems, it seems likely that improved functionality and design of EHR systems and e-PSs could reduce the frequency of these errors.[22,37] The use of human factors principles is a promising venue when re-designing EHR systems. Russ et al. recently applied human factors principles to improve alert interface design in an electronic health record.[38] Alert design was changed, for example, to present similar information always in the same column, making appearance distinctive, adding spaces between action buttons, or by eliminating scrolling functions. In a simulation study, number of prescribing errors could be reduced significantly.

Our results show that higher error rates are associated with longer time on task and more mouse clicks. Increased time and click burden for completing tasks are often due to poor usability leading to inefficient workflows or workarounds and increased cognitive load for physicians.[17] Investments in better systems could therefore also be justified on purely economic grounds. In our study, physicians working with the less error-prone and less time and clicks demanding system B were also significantly more satisfied with their system compared to users of system A. In their verbal statements after the test, users of system A claimed potential for improvement mainly in system functionality and performance. Mentioned examples included a lack of automatic transfer of data already entered or the fact that several modules cannot be opened in parallel. System interruptions and crashes were also reported. In an Arab study, physician satisfaction with their CPOE was strongly correlated with perceived attributes of the system, like easiness of locating items on the screen.[39] This indicates that user satisfaction is to some extent predictive for the usability and workflow of any system.

The better performance of system B compared to system A is likely due to a more appropriate system functionality and design, allowing a more structured and intuitive interaction with the system.[40] However, the wide variations in efficiency and safety outcomes detected in this study cannot solely be attributed to differences in EHR design. We confirm the results obtained by Ratwani et al. that differences in error rate can be observed between and within systems, i.e. due to differences in implementation in the local setting.[30] The variability within one system can be explained by local configurations and custom modifications as well as varying training and support for the physicians during and after implementation.[23,41] This may explain the differences in clicks in medication tasks between hospital 1A and 2A, for example. The better outcomes for radiology tasks of hospital 4B compared to the other hospitals highlight the impact of system-system interface on safety and efficiency.[20] For radiology, laboratory and the other prescribing orders the interfaces between EHR system and linked e-PS differed between all hospitals. It is very likely that these differences resulted in the much better findings for the radiology orders in hospital 4B and an over ten-fold higher error count in laboratory related tasks in hospital 2A compared to hospitals 3B and 4B. For example, the high rate of time errors in laboratory orders within hospital 2A seemed to result from failures to adjust predefined default times, which were not necessary at the other hospitals, and a less convenient interface from EHR system to the laboratory order system in general.

Differences in performance relative to type of task also become evident in the scenario-level analyses: for example, scenario 1 included the majority of radiology tasks, scenario 3 contained almost all laboratory orders resulting in the poor performance of hospital 2A. Thus, different systems perform better or worse in different tasks.

The most frequent type of medication errors found in our study were improper dosing and timing errors. These findings are consistent with studies, which analysed types of errors associated with e-PS or CPOE.[42–44] It is likely that one of the main underlying mechanism for these medication errors were selection errors from a drop-down menu possibly due to too many listed options in the e-PS.[7,42] The varying frequency of these error types between the hospitals is most likely due to differences in system design including system-system interface issues. For example, the most frequent procedural error, an incomplete order, was often due to an unintended loss of information. These cases occurred, for example, due to an incorrect or incomplete transfer of actually correct medication order data to a discharge prescription, which could result in a harmful use of medication after discharge.

Comparable with other studies, our findings highlight the impact of implementation and poor system design on usability problems, interruptions and subsequent errors.[20,22,23] These insights reveal requirements for further improvement and suggest development of national guidelines and policies, which are currently lacking in Switzerland. For example, such policies could require vendors to perform and document safety-oriented usability tests before entering the market, after local customizations are implemented or even on a regular basis. The scenarios and results of our study could be used for large scale tests of EHR safety and efficiency and also by vendors to investigate what exactly in their systems drives poor or good performance in the tasks we tested.

This study has several limitations. The usability test environment under laboratory-like conditions has the advantage that outcomes are directly comparable across sites but may have lured participants in an artificial situation with limited seriousness placed on task completion. However, in our observations we had no indication of participants' gaming or lack of interest. In addition, and contrary to real life work, participants could concentrate on the tasks and were not interrupted. It thus seems likely that our results rather underestimate true error rates. Results obtained in our sample cannot be generalized to other specialities or professional groups. Finally, our participants were current users with varying intensities of past exposure to EHR systems. A different approach would be to use novel users after a standardized time of training and usage. However, such design would possibly require long periods of time for subsequently including physicians starting to work in a hospital, in particular in smaller hospitals with little staff turnover and may also not mirror real-life. Further studies in more naturalistic settings and with various samples should be conducted.

CONCLUSION

EHR systems commonly used in Switzerland demonstrate high levels of inefficiency and patient safety hazards in all systems and wide variability between hospitals. These results should urge hospitals, vendors, safety researchers and policy makers to develop appropriate measures and requirements for safer systems designs.

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COMPETING INTERESTS

None to declare.

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AUTHOR CONTRIBUTIONS

SF and DS conceived the study and developed the research protocol. SF developed the scenarios as well as the standard script and conducted the usability test, the statistical analyses and drafted the paper. DS provided substantial contributions to the interpretation of data, gave major feedback and revised the manuscript critically. Both authors approved the final manuscript. DS is guarantor.

SUPPLEMENTARY MATERIAL

Supplementary file A and B are online.

DATA AVAILABILITY STATEMENT

The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

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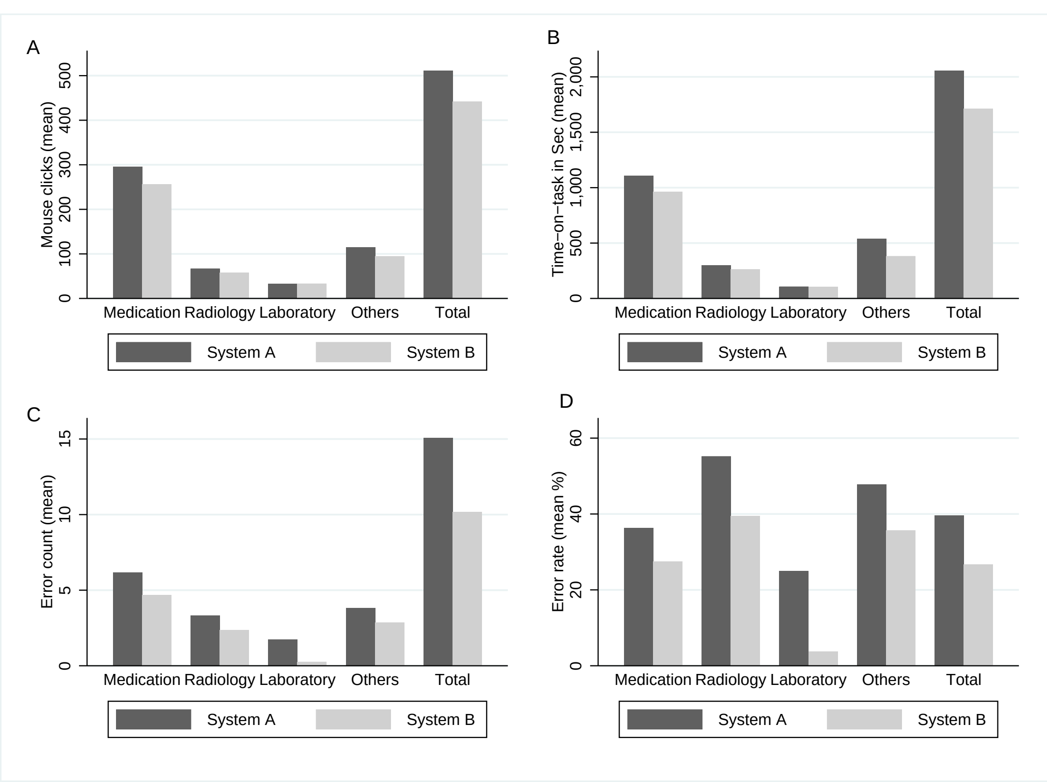
Figure legend

Figure 1: Primary and secondary outcomes by type of task/total tasks and EHR system. A: Mean mouse clicks, B: Mean time-on-task in seconds, C: Mean error count, D: Mean % error rate



A
Mouse clicks (mean)
0
100
200
300
400
500
Medication
Radiology
Laboratory
Others
Total
System A
System B
B
Time−on−task in Sec (mean)
0
500
1,000
1,500
2,000
Medication
Radiology
Laboratory
Others
Total
System A
System B
C
Error count (mean)
0
5
10
15
Medication
Radiology
Laboratory
Others
Total
System A
System B
D
Error rate (mean %)
0
20
40
60
Medication
Radiology
Laboratory
Others
Total
System A
System B

Tables

Table 1: Sample characteristics by hospital (n=100)

		Hospital 1A (n=25)	Hospital 2A (n=26)	Hospital 3B (n=24)	Hospital 4B (n=25)	p-Value
Sex, n (%)	Female	12 (48)	16 (62)	14 (58)	16 (64)	0.675
	Male	13 (52)	10 (38)	10 (42)	9 (36)	
Mean age, yrs (SD)		33.8 (9.7)	37.5 (9.1)	36.5 (6.8)	40.2 (9.3)	0.096
Role, n (%)	Resident or Attending physician	17 (68)	17 (65)	17 (71)	18 (72)	0.957
	Senior or Chief physician	8 (32)	9 (35)	7 (29)	7 (28)	
Median experience with EHR, months (IQR)		12 (10-20)	22.5 (12-47)	17 (3-38)	45 (13-77)	0.166

Table 2: Results of one-way analysis of variance for primary and secondary outcomes by type of task/total task and hospital

Type of task/total tasks and hospital over all scenarios		Mouse clicks Mean (SD)	Time-on-task (Sec) Mean (SD)	Error count Mean (SD)	Error rate Mean % (SD)
Med (17 tasks)	Hospital 1A (n=25)	262.2 (59.2)	975.1 (404.6)	5.6 (4.9)	32.7 (28.9)
	Hospital 2A (n=26)	327.6 (73.0)	1236.7 (336.0)	6.8 (4.1)	39.8 (24.0)
	Hospital 3B (n=24)	255.2 (69.2)	943.5 (383.2)	4.3 (2.6)	25.0 (15.5)
	Hospital 4B (n=25)	257.2 (63.2)	980.8 (417.2)	5.1 (3.2)	29.9 (18.6)
p-Value		<0.001 [a,d,e,$]	0.028 [d]	0.132	0.132
Rad (6 tasks)	Hospital 1A (n=25)	54.3 (12.1)	212.8 (93.4)	3.6 (2.0)	59.3 (33.7)
	Hospital 2A (n=26)	79.7 (21.8)	381.8 (304.2)	3.1 (1.4)	51.3 (24.0)
	Hospital 3B (n=24)	73.1 (14.4)	335.0 (158.8)	3.5 (1.7)	58.3 (27.8)
	Hospital 4B (n=25)	44.0 (7.9)	193.5 (68.9)	1.3 (0.9)	21.3 (15.6)
p-Value		<0.001 [a,b,e,f,$]	<0.001 [a,c,e,f]	<0.001 [c,e,f,$]	<0.001 [c,e,f,$]
Lab (7 tasks)	Hospital 1A (n=25)	32.0 (4.9)	78.0 (36.2)	0.4 (1.3)	5.1 (17.9)
	Hospital 2A (n=26)	34.2 (15.8)	134.4 (60.0)	3.1 (3.3)	44.0 (47.2)
	Hospital 3B (n=24)	35.3 (10.8)	121.4 (44.5)	0.2 (0.4)	3.0 (5.9)
	Hospital 4B (n=25)	31.6 (9.0)	90.1 (37.1)	0.3 (0.5)	4.6 (6.8)
p-Value		0.568	<0.001 [a,b,e]	<0.001 [a,d,e,$]	<0.001 [a,d,e,$]
Other (8 tasks)	Hospital 1A (n=25)	110.4 (44.1)	468.7 (647.2)	4.2 (1.9)	52.0 (23.6)
	Hospital 2A (n=26)	119.5 (30.4)	608.1 (687.2)	3.5 (1.7)	43.8 (20.7)
	Hospital 3B (n=24)	92.0 (25.6)	370.3 (163.5)	2.7 (1.6)	33.3 (19.4)
	Hospital 4B (n=25)	96.6 (25.3)	394.6 (170.0)	3.0 (1.6)	38.0 (19.6)
p-Value		0.012 [d,$]	0.313	0.015 [b,$]	0.015 [b,$]
Total (38 tasks)	Hospital 1A	458.8 (105.9)	1736.5 (1061.8)	13.6 (5.8)	35.9 (15.3)
	Hospital 2A	561.0 (105.0)	2360.9 (1002.1)	16.4 (7.1)	43.2 (18.8)
	Hospital 3B	455.6 (91.1)	1770.5 (1061.8)	10.6 (4.1)	28.0 (10.7)
	Hospital 4B	429.4 (86.0)	1659.0 (627.3)	9.7 (4.8)	25.6 (12.6)
p-Value		<0.001 [a,d,e,$]	0.015 [e]	<0.001 [d,e,$]	<0.001 [d,e,$]

Med – Medication, Rad – Radiology, Lab – Laboratory
Superscripted letters indicate results of Bonferroni adjusted tests for mean differences between sites:
[a] Hospital 1A vs Hospital 2A, [b] Hospital 1A vs Hospital 3B, [c] Hospital 1A vs Hospital 4B
[d] Hospital 2A vs Hospital 3B, [e] Hospital 2A vs Hospital 4B, [f] Hospital 3B vs Hospital 4B,
[$] System A vs System B,
Details of the scenarios are provided in supplementary file A.

Table 3: Results of one-way analysis of variance for primary and secondary outcomes by scenario and hospital

Scenario (Sc) and hospital		Mouse clicks Mean (SD)	Time-on-task (Sec) Mean (SD)	Error count Mean (SD)	Error rate Mean % (SD)
Sc1	Hospital 1A (n=25)	51.0 (11.2)	282.9 (491.3)	3.2 (1.7)	52.7 (28.3)
	Hospital 2A (n=26)	65.0 (10.5)	415.6 (646.1)	2.6 (1.2)	43.6 (20.0)
	Hospital 3B (n=24)	57.0 (17.6)	244.5 (115.7)	2.5 (1.2)	41.7 (19.7)
	Hospital 4B (n=25)	55.8 (25.2)	244.2 (138.9)	1.3 (1.1)	21.3 (18.3)
p-Value		0.035 [a]	0.418	<0.001 [c,e,f,$]	<0.001 [c,e,f,$]
Sc2	Hospital 1A (n=25)	52.3 (22.3)	154.8 (87.4)	1.3 (1.3)	42.7 (43.6)
	Hospital 2A (n=26)	47.1 (19.3)	234.7 (300.2)	0.4 (0.9)	11.5 (28.2)
	Hospital 3B (n=24)	47.1 (10.9)	196.5 (132.9)	0.7 (0.8)	23.6 (26.9)
	Hospital 4B (n=25)	39.8 (11.3)	151.1 (46.8)	0.4 (0.7)	14.7 (21.7)
p-Value		0.070	0.274	0.003 [a,c]	0.003 [a,c]
Sc3	Hospital 1A (n=25)	63.9 (21.1)	203.0 (109.0)	0.8 (1.6)	6.9 (14.2)
	Hospital 2A (n=26)	108.0 (29.1)	422.0 (152.4)	5.2 (3.4)	47.2 (30.8)
	Hospital 3B (n=24)	101.1 (34.3)	356.9 (148.6)	1.5 (1.2)	14.0 (10.7)
	Hospital 4B (n=25)	76.0 (19.6)	274.8 (136.2)	1.4 (1.3)	12.7 (11.4)
p-Value		<0.001 [a,b,e,f]	<0.001 [a,b,e]	<0.001 [a,d,e,$]	<0.001 [a,d,e,$]
Sc4	Hospital 1A (n=25)	79.9 (30.8)	284.2 (164.7)	4.5 (2.2)	75.3 (36.0)
	Hospital 2A (n=26)	111.3 (52.5)	368.2 (173.7)	3.2 (2.3)	53.8 (37.8)
	Hospital 3B (n=24)	63.0 (13.1)	270.0 (78.2)	2.8 (2.1)	47.2 (35.3)
	Hospital 4B (n=25)	60.4 (14.1)	244.5 (64.0)	3.5 (2.49)	58.7 (41.4)
p-Value		<0.001 [a,d,e,$]	0.007 [e]	0.064	0.064
Sc5	Hospital 1A (n=25)	151.6 (39.1)	590.5 (253.1)	2.3 (2.1)	38.0 (35.2)
	Hospital 2A (n=26)	156.5 (54.1)	636.5 (231.0)	2.8 (2.0)	46.8 (33.7)
	Hospital 3B (n=24)	121.2 (43.6)	463.5 (273.5)	1.7 (1.1)	28.5 (18.7)
	Hospital 4B (n=25)	126.9 (43.2)	494.4 (230.6)	2.0 (1.3)	34.0 (21.8)
p-Value		0.014 [d,$]	0.051	0.143	0.143
Sc6	Hospital 1A (n=25)	59.9 (27.0)	221.2 (164.2)	1.6 (1.8)	27.3 (30.8)
	Hospital 2A (n=26)	73.2 (16.9)	284.0 (126.1)	2.2 (2.1)	37.2 (34.7)
	Hospital 3B (n=24)	66.2 (15.7)	238.9 (90.5)	1.3 (1.6)	22.2 (25.9)
	Hospital 4B (n=25)	70.4 (18.5)	250.2 (133.1)	1.0 (1.2)	17.3 (20.7)
p-Value		0.103	0.3815	0.088	0.088

Sc – scenario, Sec - seconds
Superscripted letters indicate results of Bonferroni adjusted tests for mean differences between sites:
[a] Hospital 1A vs Hospital 2A, [b] Hospital 1A vs Hospital 3B, [c] Hospital 1A vs Hospital 4B
[d] Hospital 2A vs Hospital 3B, [e] Hospital 2A vs Hospital 4B, [f] Hospital 3B vs Hospital 4B,
[$] System A vs System B,
Details of the scenarios are provided in supplementary file A.

Supplementary File A: Scenarios

Scenario 1: Fall with a medial femoral neck fracture

Please open the case of Ms. Lina Betschart, born 2 May 1933, or case number XX.

Introduction

An 87-year-old female patient, Ms. Betschart, fell during the night on her way to the toilet. When the nurse arrived, Ms. Betschart was lying on the floor and was not able to stand up due to pain in her right hip. In the clinical examination, the right leg was noticeably shortened and rotated outwards. There was also swelling and haematoma over the left wrist with peripheral blood supply, motor and sensory functions intact.

Initial measures

Ask the nurse to provide IV access. In the meantime, order the following:

- Peripheral venous catheter (PVC)
- Morphine in doses of 1mg IV, as needed

Order immediately!

Imaging is also required. Order the following X-rays:

- Pelvic x-ray, deep-centered
- Proximal femur, right axial
- Left wrist in two levels
  Question: Exclusion of fractures?

Order immediately!

Further measures and procedures

The x-ray shows a medial femoral neck fracture on the right (Type Garden III). The fracture must be treated surgically as soon as possible. The surgical colleagues take the patient over for further treatment.

- Transfer Ms. Betschart to the surgical department and order that the patient must remain fasting from now.

Order immediately!

Scenario 2: Disc herniation

Please open the case of Mr. Marcus Silberschmied, born 23 October 1978, or case number XX.

Introduction

A 42-year-old male patient, Mr. Silberschmied, has been admitted for pain management and further diagnostics (MRI) due to months-long, now immobilising pain in the lumbar spine area. During the clinical examination, a slight weakness in the left leg (M4) and sensory disturbances were evident, but no symptoms of cauda equina.

Initial measures

Managing the pain is very difficult. Discuss the possibility of infiltration anaesthesia with the patient and promise to send a colleague in orthopaedics or neurosurgery to assess him. Order the following:

- MRI of lumbar spine
  Question: Disc herniation?
- Consil with colleagues in orthopaedics / neurosurgery.

Order immediately!

Further measures and procedures

The MRI shows an L4/5 disc herniation on the left. Following the infiltration and further adjustment of the pain medication, there is a clear improvement in the symptoms. Prepare for Mr. Silversmith to be discharged.

He requires a prescription for

- Tizanidine (Sirdalud®) 2mg 3 times / day, i.e. for a pack of 30 tablets

Issue the prescription now!

Scenario 3: Chest pain

Please open the case of Mr. Antonio Da Silva, born 3 February 1961, or case number XX.

Introduction

59-year-old Mr. Da Silva was complaining of chest pain radiating to his left arm, accompanied by dyspnoea. The pain feels similar to his last heart attack. The initial ECG shows normal sinus rhythm with nonspecific ST wave abnormalities.

Initial measures

Order the following laboratory tests:

- Blood count
- Chemistry: Na, K, creatinine
- Troponin

Order immediately!

In addition, order the following:

- Chest X-ray in 2 levels
  Question: Pneumothorax?
- Single dose of acetylsalicylic acid (Aspegic®) 250mg IV.

Order now!

Further measures and procedures

A nurse informs you that the patient's saturation has dropped to 90%. In addition, you have received the laboratory results indicating that troponin is slightly increased.

Order the following:

- Oxygen 2L / min
- Heparin bolus of 5000 IU as IV injection, thereafter continuously 30,000 IU / day
- Troponin test to be repeated in 3 hours

Order now!

Scenario 4: Abdominal pain

Please open the case of Mrs. Sarah Huber, born 30 June 1994, or case number XX.

Introduction

A 26-year-old female patient, Ms. Huber, was hospitalised the previous day due to febrile gastroenteritis with dehydration. Food and fluid intake was almost impossible due to nausea. The most recent clinical examination showed new signs of clear guarding over the right lower abdomen with increasing inflammation values, giving rise to suspicion of appendicitis.

Initial measures

Order the following:

- Metoclopramide (Paspertin®, Primperan®) 10mg 3 times / day IV
- Metamizole (Novalgin®) 1g IV, single dose
- CT of the abdomen with IV and oral contrast agent
  Question: Appendicits?

Order immediately!

Further measures and procedures

Appendicitis is ruled out on the basis of the CT scan. In the further course of hospitalisation, there is a clear regression of all symptoms and the patient is able to eat and drink again.

Discharge the patient with the following prescription:

- Metoclopramide (Paspertin®, Primperan®) 10mg PO max. 3 times / day, as needed
- Ciprofloxacin (Ciproxin®) 500mg every 12 hours for a further 2 days

Issue the prescription now!

Scenario 5: COPD

Please open the case of Ms. Susanne Nötzli, born 1 May 1968, or case number XX.

Introduction

A 52-year-old female patient, Ms. Nötzli, was hospitalised the previous day due to an exacerbation of known COPD. Acute dyspnea continues to reoccur following admission. The physical examination reveals ubiquitous wheezing with prolonged expiration, a breathing rate of 22 and an oxygen saturation of 87% in room air.

Initial measures

Prescribe the following medication:

- Salbutamol and ipratropium bromide (Dospir®, Ipramol®) for inhalation immediately, then 4 times / day as a regular medication
- Methylprednisolone (Solu-Medrol®) 40mg IV, single dose

Order now!

Further measures and procedures

A regression of the symptoms is observed.

For the following day, order:

- Prednisone (Spiricort®) 60mg, to be reduced by 10mg every 2 days for a total of 12 days

Order now!

Check the patient's other medication and intensify therapeutic measures.

Order the following:

- ULTIBRO® Breezhaler 110mcg / 50mcg 1 time / day
- Physiotherapy prescription for respiratory therapy
- Bottle blowing

Order now!

Scenario 6: Sepsis

Please open the case of Mr. Hubert Graf, born 13 July 1937, or case number XX.

Introduction

An 83-year-old male patient, Mr. Graf, was referred by the family doctor 3 days ago with a cough and fever. The x-ray showed pneumonia. During therapy with co-amoxicillin, however, there is a further deterioration in condition with hypotonic blood pressure values and a further increase in inflammation values. There is a query regarding a lung infection with atypical bacteria.

Initial measures

Order the following:

- Legionella Ag in urine
- Ringer's bolus of 2000ml over 2 hours

Order immediately!

Adjust antibiotic therapy as follows:

- Ceftriaxone (Rocephin®) 2g IV once daily, first dose immediately
- Clarithromycin (Klacid®) 500mg PO every 12 hours, first dose immediately

Order now!

Further measures and procedures

Following the administration of the IV fluid bolus, Mr. Graf's blood pressure is back in the normal range.

The repeat blood sugar checks show constant hyperglycemic values, always requiring correction.

Order the following:

- Daily blood sugar profile with measurements 4 times / day
- Insulin glargine (Lantus®) 10U in the morning

Order now!

Supplementary File B: Results of oneway analysis of variance for error types per participant by hospital

Error types by type of tasks and hospital			Total (N=100)	Hospital 1A (n=25)	Hospital 2A (n=26)	Hospital 3B (n=24)	Hospital 4B (n=25)	p value
Med	Wrong drug agent	n(%)	4 (100)	1 (25.0)	1 (25.0)	1 (25.0)	1 (25.0)	
		Mean(SD)	0.04 (0.00)	0.04 (0.20)	0.04 (0.20)	0.04 (0.20)	0.04 (0.20)	1.000
	Wrong dose	n(%)	159	31 (19.5)	60 (37.7)	31 (19.5)	37 (23.3)	
		Mean(SD)	1.59 (1.39)	1.24 (1.30)	2.31 (1.46)	1.29 (1.30)	1.48 (1.29)	0.019 [a]
	Wrong route	n(%)	25 (100)	7 (28.0)	10 (40.0)	6 (24.0)	2 (8.0)	
		Mean(SD)	0.25 (0.52)	0.28 (0.46)	0.38 (0.75)	0.25 (0.44)	0.08 (0.28)	0.213
	Wrong start and/or stop date	n(%)	154 (100)	40 (26.0)	37 (24.0)	32 (20.8)	45 (29.2)	
		Mean(SD)	1.54 (1.28)	1.60 (1.19)	1.42 (1.36)	1.33 (1.13)	1.8 (1.44)	0.595
	Wrong interval	n(%)	122 (100)	28 (22.9)	32 (26.2)	28 (22.9)	34 (27.8)	
		Mean(SD)	1.22 (1.14)	1.12 (1.17)	1.23 (1.39)	1.17 (1.01)	1.36 (0.99)	0.895
	Order technically incomplete	n(%)	1 (100)	1 (100)	0	0	0	
		Mean(SD)	0.01 (0.10)	0.04 (0.20)	0	0	0	0.396
	Other error	n(%)	79 (100)	31 (39.2)	36 (45.6)	4 (5.1)	8 (10.1)	
		Mean(SD)	0.79 (1.44)	1.24 (2.09)	1.38 (1.55)	0.17 (0.48)	0.32 (0.48)	0.002 [b,d,e,$]
	Duplicate order	n	16	6	4	3	3	
	Regular and on demand medication confused	n	9	4	2	1	2	
	"Current" and "Discharge" sections confused*	n	40	19	21	0	0	

	Order unfeasible	n	6	1	4	0	1	
	Order deleted after completion	n	1	1	0	0	0	
	Wrong application form	n	7	0	5	0	2	
Rad	Wrong imaging type		0	0	0	0	0	
	Wrong site	n(%)	10 (100)	3 (30.0)	3 (30.0)	2 (20.0)	2 (20.0)	
		Mean(SD)	0.10 (0.33)	0.12 (0.33)	0.12 (0.43)	0.08 (0.28)	0.08 (0.28)	0.962
	Wrong level	n(%)	143 (100)	37 (25.9)	37 (25.9)	49 (34.3)	20 (13.9)	
		Mean(SD)	1.43 (1.02)	1.48 (0.65)	1.42 (0.76)	2.04 (1.52)	0.80 (0.50)	<0.001 [f]
	Wrong localisation	n(%)	40 (100)	18 (45.0)	5 (12.5)	15 (37.5)	2 (5.0)	
		Mean(SD)	0.40 (0.57)	0.72 (0.61)	0.19 (0.40)	0.63 (0.65)	0.08 (0.28)	<0.001 [a,c,d,f]
	Missing contrast agent	n(%)	46 (100)	19 (41.3)	13 (28.3)	10 (21.7)	4 (8.7)	
		Mean(SD)	0.46 (0.50=	0.76 (0.44)	0.50 (0.51)	0.42 (0.50)	0.16 (0.37)	<0.001 [c,e,$]
	Order technically incomplete	n(%)	1 (100)	1 (100.0)	0	0	0	
		Mean(SD)	0.01 (0.10)	0.04 (0.20)	0	0	0	0.396
	Wrong or missing order question	n(%)	16 (100)	8 (50.0)	4 (25.0)	3 (18.7)	1 (6.3)	
		Mean(SD)	0.16 (0.69)	0.32 (1.25)	0.15 (0.46)	0.13 (0.34)	0.04 (0.20)	0.548
	Wrong time		0	0	0	0	0	
	Other error	n(%)	29 (100)	3 (10.3)	18 (62.2)	5 (17.2)	3 (10.3)	
		Mean(SD)	0.29 (0.48)	0.12 (0.33)	0.69 (0.55)	0.21 (0.41)	0.12 (0.33)	<0.001 [a,d,e,$]
Rad	Duplicate order	n	6	1	1	1	3	
	Additional image	n	19	2	13	4	0	
	Additional level	n	4	0	4	0	0	

Lab	Wrong parameter		0	0	0	0	0	
	Wrong time	n(%)	82 (100)	0	71 (86.6)	4 (4.9)	7 (8.5)	
		Mean(SD)	0.82 (1.91)	0	2.73 (3.00)	0.17 (0.38)	0.28 (0.46)	<0.001 [a,d,e,$]
	Order technically incomplete	n(%)	5 (100)	0	5 (100.0)	0	0	
		Mean(SD)	0.05 (0.50)	0	0.19 (0.98)	0	0	0.421
	Other error	n(%)	6 (100)	2 (33.3)	2 (33.3)	1 (16.7)	1 (16.7)	
		Mean(SD)	0.06 (0.76)	0.08 (0.28)	0.08 (0.39)	0.04 (0.20)	0.04 (0.20)	0.930
	Additional parameter	n	4	1	2	0	1	
	Duplicate order	n	2	1	0	1	0	
Others	Wrong order type	n(%)	3 (100)	1 (33.3)	1 (33.3)	1 (33.3)	0	
		Mean(SD)	0.03 (0.17)	0.04 (0.20)	0.04 (0.20)	0.04 (0.20)	0	0.800
	Wrong time	n(%)	43 (100)	18 (41.9)	3 (7.0)	5 (11.6)	17 39.5)	
		Mean(SD)	0.43 (0.61)	0.72 (0.46)	0.12 (0.33)	0.21 (0.41)	0.68 (0.85)	<0.001 [a,b,,e,f]
	Order incomplete	n(%)	126 (100)	52 (41.3)	21 (16.7)	30 (23.8)	23 (18.2)	
		Mean(SD)	1.26 (0.95)	2.08 (1.04)	0.81 (0.63)	1.25 (1.04)	0.92 (0.70)	<0.001 [a,b,c]
	Order technically incomplete	n(%)	1 (100)	0	1 (100.0)	0	0	
		Mean(SD)	0.01 (0.10)	0	0.04 (0.12)	0	0	0.421
	Wrong interval	n(%)	76 (100)	24 (31.6)	15 (19.7)	21 (27.6)	16 (21.1)	
		Mean(SD)	0.76 (0.64)	0.96 (0.54)	0.58 (0.64)	0.86 (0.54)	0.64 (0.57)	0.097
	Other error	n(%)	86 (100)	9 (10.5)	50 (58.1)	7 (8.1)	20 (23.3)	
		Mean(SD)	0.86 (1.30)	0.36 (0.57)	1.92 (1.01)	0.29 (0.55)	0.80 (0.71)	<0.001 [a,d,e,$]

	Order not required	n	5	3	2	0	0
	Wrong receiver	n	11	5	2	1	3
	Duplicate Prescription	n	1	1	0	0	0
	Order in wrong place	n	2	0	0	1	1
	Regular and on demand medication confused or ambiguous	n	11	0	10	0	1
	Wrong or missing route	n	21	0	1	5	15
	Wrong rate	n	16	0	16	0	0
	"Current" and "Discharge" sections confused*	n	3	0	3	0	0
	Wrong dose	n	16	0	16	0	0

Med – Medication, Rad – Radiology, Lab – Laboratory, n – number, *system A specific error
Superscripted letters indicate results of Bonferroni adjusted tests for mean differences between sites:
[a] Hospital 1A vs Hospital 2A, [b] Hospital 1A vs Hospital 3B, [c] Hospital 1A vs Hospital 4B
[d] Hospital 2A vs Hospital 3B, [e] Hospital 2A vs Hospital 4B, [f] Hospital 3B vs Hospital 4B
[$] System A vs System B