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Interruptions to intensive care nurses and clinical errors and procedural failures:

A controlled study of causal connection

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Abstract

Objectives. Interruptions occur frequently in the Intensive Care Unit (ICU) and are associated with errors. To date, no causal connection has been established between interruptions and errors in healthcare. It is important to know if interruptions directly cause errors before implementing interventions designed to reduce interruptions in ICUs. Our objective was to investigate whether ICU nurses who receive a higher number of workplace interruptions commit more clinical errors and procedural failures than those who receive a lower number of interruptions.

Methods. We conducted a prospective controlled trial in a high-fidelity ICU simulator. A volunteer sample of ICU nurses from a single unit prepared and administered intravenous medications for a patient manikin. Nurses received either 3 ($n = 35$) or 12 ($n = 35$) scenario-relevant interruptions and were allocated to either condition in an alternating fashion. Primary outcomes were the number of clinical errors and procedural failures committed by each nurse.

Results. The rate ratio of clinical errors committed by nurses who received 12 interruptions compared to nurses who received 3 interruptions was 2.0 (95% CI [1.41, 2.83]), $p < .001$. The rate ratio of procedural failures committed by nurses who received 12 interruptions compared to nurses who were interrupted 3 times was 1.2 (95% CI [1.05, 1.37]), $p = .006$.

Conclusions. More workplace interruptions during medication preparation and administration lead to more clinical errors and procedural failures. Reducing the frequency of interruptions may reduce the number of errors committed; however, this should be balanced against important information that interruptions communicate.

Keywords: interruptions, healthcare, simulation, intensive care

Introduction

Interruptions to healthcare workers are viewed as a common and accepted part of practice.[1] An Australian study found that interruptions occurred 14 times per hour in the Intensive Care Unit (ICU) and contributed to over a third of total communication.[2] However, interruptions are associated with increased workload,[3] increased time taken to return to and complete the interrupted task,[4 5] and an increased likelihood of abandoning the interrupted task.[6]

Importantly, interruptions have been associated with clinical errors and procedural failures.[7 8] In a large observational study of 4271 medication administrations by 98 nurses on medical wards, Westbrook et al.[8] found that 80% of medication administrations contained a clinical error or a procedural failure regardless of whether or not interrupted, and that each additional interruption was associated with a 12.7% increase in clinical errors and a 12.1% increase in procedural failures. Medical errors can not only result in patient harm, but also traumatise healthcare workers who commit them[9] and disrupt their organisations. Consequently, efforts have been made to reduce interruptions in order to reduce the likelihood of subsequent errors.

Despite the strong association reported by Westbrook et al.,[8] there is no conclusive evidence for a direct causal relationship between the number of interruptions received in the healthcare workplace and the likelihood of errors.[10] A few simulation studies point to a causal connection, but they do not directly test the hypothesis that more interruptions lead to more errors[11-13] or they are underpowered pilot studies.[14]

Given that a causal dose-response relationship has not been established with a prospective, controlled experimental design,[15] we do not know whether efforts to reduce interruptions will succeed in reducing errors.[16] Recent interventions in clinical contexts have successfully reduced the frequency of workplace interruptions, but their direct impact on

errors remains unclear.[17-19] Of greater concern is the fact that such interventions can produce unforeseen consequences. For example, when nurses wore a "do not interrupt" vest, interruptions from patients decreased whereas interruptions from other nurses increased.[20] Certain interruptions are considered an essential aspect of clinical workflow, which calls into question the effectiveness of interruption-elimination interventions.[21]

This study was designed as an efficacy trial to investigate the effect of a lower versus higher number of workplace interruptions on errors in a simulated ICU setting. Since interruptions may be impractical to eliminate entirely,[2] we chose not to incorporate a zero-interruptions condition. Nurses would receive either 1 interruption per scenario (3 in total) or 4 interruptions per scenario (12 in total). We predicted that ICU nurses who received 12 interruptions would commit significantly more clinical errors and procedural failures than nurses who received 3 interruptions.

Method

Participants

Participants were registered nurses practicing in a tertiary ICU with a 1:1 nurse to patient ratio in Queensland, Australia, recruited via flyers and emails advertising the study internally within their unit. Research Ethics Board approval was obtained from Metro South Hospital and Health Service (HREC/16/QPAH/391) and The University of Queensland (2016001102). Inclusion criteria were ≥6 months registered nursing experience and being unaware of the study aim, to avoid expectancy effects. To conceal the study aim, participants were advised that the researchers were interested in workflow and team communication. After study completion, participants received a small gift and a debrief sheet that did not reveal the purpose of the study but requested that participants not discuss the study with others.

Sample size was based on a Cohen's d of 0.73 from our prior laboratory study (Santomauro & Sanderson, in preparation), which allowed for a minimum rate ratio of 1.44 for clinical errors between interruption conditions to be detected with 80% power and α = .025 to control for multiplicity with two primary outcome variables (clinical errors and procedural failures).

Design

A prospective, alternately-allocated parallel groups design was used to examine the effect of frequency of interruptions (3 vs. 12 interruptions) on the number of clinical errors and procedural failures. The 12-interruptions condition was based on Westbrook et al.'s[8] data showing nurses received up to 6 interruptions per medication administration and an observational study conducted in the ICU in question which found that nurses received up to 12 interruptions per hour.[22] Participants were alternately allocated to a condition of lower (3) or higher (12) number of interruptions sequentially upon enrolment. This design was chosen

due to concerns that we would not reach the desired sample size due to events outside our control and we wanted to ensure equal numbers were obtained across the two conditions.

Outcomes and measures

Primary outcomes were the number of clinical errors and procedural failures. Clinical errors were any deviation from the medication order or procedure that would result in the patient directly receiving a medication inconsistent with what they were prescribed. Procedural failures were sequencing errors, and safety or technique violations that would not directly result in a medication inconsistent with the patient's order.

Secondary outcomes included participant demographics and post-experiment surveys assessing realism of scenarios, immersion in scenarios, and level of distraction and annoyingness of the actor on 5-point Likert scales. They also included the NASA Task Load Index (NASA-TLX), a validated workload questionnaire used to assess mental, physical, and temporal demand, perceived performance, effort, and frustration on 20-point Likert scales.[23][24]

Scenario design, equipment, and delivery

Each participant performed intravenous medication preparation and administration tasks in 3 scenarios that were joined to form a continuous experience of usual ICU patient care; these scenarios always occurred in the same order. Each scenario included 1 or 2 medications and 1 or 4 interruptions (making 3 or 12 interruptions overall) and was scripted in detail and precisely timed.

Each interruption occurred at a specific time during a medication task and was designed to be disruptive, based on interruptions theory and prospective memory theory (e.g., interruptions that are longer in duration are more disruptive than interruptions that are shorter in duration,[25-27] and interruptions that occur in the middle of a task are more disruptive than interruptions that occur at any other point in a task[28-30]), and to be difficult to defer, block, or

ignore. If a participant chose not to engage with an interruption, the researchers had procedures to ensure that the interruption still occurred but in a slightly different way. For example, if the actor phoned the participant to provide some information but the participant did not answer, the actor would simply enter the room instead. Interruptions were designed with the help of local ICU nurses to be relevant to the scenario and plausible (Table 1 and Figure 1). Participants in the 3-interruptions condition received 3 interruptions that had different properties from one another (e.g., a participant in this condition would not get two phone calls). We created several combinations of 3-interruptions so that all of the interruptions were sampled in this condition. The simulation setting represented an ICU bedspace and small medication room. The room included most equipment that would typically be found at an ICU bedspace, including a bedside phone that connected to a mobile phone in the control room. The patient was simulated with a manikin (Megacode Kelly: Laerdal Global Health) voiced by a research assistant in the control room with a microphone connected to a loud speaker.

The ICU Electronic Medication Record (EMR) system was installed on a computer in the simulation room, with reduced functionality. A medication room separated by a partition contained a locked restricted drugs cupboard, a non-restricted drugs cupboard, drug register, materials to prepare infusions, and another computer with the EMR system.

Video was recorded and live streamed with four wall-mounted Logitech cameras and a GoPro Hero 5 recording from the participant's forehead. Audio was recorded and live streamed with a whole room microphone and lapel microphones worn by the participant and the actor. The experimental coordinator (author CS) used a microphone in the control room to communicate to the actor via an ear piece, coordinated the scenarios from the control room, and answered any questions the participant had during the simulation over the loud speaker. The actor was a nurse hired from within the unit who played a team leader (TL) who

delivered interruptions and helped participants when required (e.g., checking medications). The participant could use the bedside phone to call the TL or other personnel whenever needed. The research assistant was located in the control room to voice the patient and all of the phone-based characters.

Procedure

After providing informed consent, participants completed a demographic survey. Recording equipment was established, equipment and processes explained, and participants advised that they could ask for information or clarification at any time. Tasks not required and any deviations from typical duties were explained (e.g., participants were not required to record patient observations in the iEMR system even though this is typically required). The experimental coordinator provided a patient handover, indicated that the TL would visit shortly and left the room, leaving the participant to start their patient assessment.

The first medication of Scenario 1 was uploaded to the EMR system, and when the participant finished their patient assessment they typically checked the computer, saw the medication, and began preparing it. The TL then entered the room and prompted the participant to check the computer, if it had not been checked after the assessment. The next two scenarios unfolded with no break between them.

Participants were asked to prepare and administer each medication from start to finish before moving to the next one, otherwise it would have been difficult to deliver interruptions at the correct times. This behaviour was reinforced by uploading a new medication to the EMR system only while the participant was preparing or administering the previous medication. Other than this, participants had the freedom to carry out the tasks as they wished.

Towards the end of Scenario 3, the TL told the participant to call her when the participant was ready to go on a 'break'. This gave participants an opportunity to check

everything and perform any corrections or extra tasks they felt were important before finishing. Throughout the scenario, participants could correct any clinical errors and procedural failures they detected, or ask the TL to make corrections. After the simulation, the participant completed the NASA-TLX and answered questions about the TL and the simulation, described earlier.

The experimental coordinator recorded any clinical errors and procedural failures that were detected during scenario delivery. Pump programming, labelling, and documentation were checked for any further errors before preparing for the next participant. The whole experiment lasted 1–2.5 hours, the large variation due to participants having freedom to perform extra tasks such as patient observations throughout the scenarios.

Data analysis

Video footage was analysed with DataVyu (http://www.datavyu.org/) and exported into Microsoft Excel worksheets. A research assistant independently coded 10% of the video footage, which revealed a good level of agreement for identification of clinical errors and procedural failures, $\kappa = .79$, $p < .001$. All clinical errors and procedural failures were checked and confirmed by the research nurse, and any discrepancies or uncertainties were resolved by consulting unit or hospital policies.

Statistical analyses were conducted in IBM SPSS 22 with two-tailed tests and $\alpha = .025$ for primary outcomes analyses and $\alpha = .05$ for remaining analyses. For primary outcomes, Poisson regression with corrections for overdispersion as required was used to analyse count data (clinical errors and procedural failures). To assess and control for potential baseline imbalances in demographics, age was converted to continuous format (mean age for each category range) and education was collapsed into three categories (Diploma, Bachelor, Postgraduate). Both full regression and reduced (using backwards stepwise regression with threshold $\alpha = .10$) models were assessed for potential confounders. For secondary outcomes,

parametric tests were used for non-count data with log or square-root transformations as required according to residual diagnostics, otherwise non-parametric tests were applied. For parametric tests, residual diagnostics were conducted to assess appropriateness of model fit and autocorrelation.

Results

Demographics

Seventy-two nurses volunteered to participate; one subsequently declined due to use of video recording, and one was excluded due to loss of blinding prior to participation. Demographic characteristics of the 70 nurses were similar across both groups, although participants who received 12 interruptions had more experience in the current ICU than participants who received 3 interruptions (Table 2).

Participants in the 3-interruptions condition received all 3 interruptions. However, 4 participants in the 12-interruptions condition received 11 interruptions instead of 12. In these situations, an interruption was missed due to technical issues such as the alarm on the monitor not sounding, or because the participant completed the primary interrupting task much faster than anticipated.

Although the interruptions were designed to be difficult to block, defer, or ignore, participants were free to deal with them as they pleased. Two participants blocked one interruption, one participant multi-tasked one interruption, and the rest engaged or deferred all interruptions.

Primary outcomes

Nurses who received 12 interruptions committed clinical errors 2.0 times (95% CI [1.41, 2.83]) more frequently than nurses who received 3 interruptions. Nurses who received 12 interruptions committed procedural failures 1.2 times (95% CI [1.05, 1.37]) more frequently than nurses who were interrupted 3 times (Table 3).

After controlling for baseline demographic imbalances, the rate ratio of clinical errors and procedural failures between interruption conditions were not substantially affected (2.1, 95% CI [1.45, 2.07], $p < .001$ and 1.2, 95% CI [1.00, 1.33], $p = .049$, respectively) and none of the demographic covariates were statistically significant in either the full or reduced

models. Backwards stepwise regressions conducted independently due to multicollinearity for age ($p = .017$), years experience as a registered nurse ($p = .007$), and years experience in the current ICU ($p = .009$) identified all three as statistically significant covariates in the procedural failures analysis – but there was minimal impact on the rate ratio of procedural failures committed by nurses across interruption conditions (1.2, 95% CI [1.00, 1.32], $p = .043$). The strongest association was in the years experience as a registered nurse, which showed that procedural failures increased by 1.2% (95% CI [0.0, 2.0%]) with every year increase in participant nursing experience.

Post-hoc exploratory analyses

When errors that were subsequently corrected were removed from the analysis, participants who were interrupted 12 times still committed more clinical errors and procedural failures than participants who were interrupted 3 times (Table 3).

There were no statistically significant differences between conditions in NASA-TLX scores, or in ratings of TL distraction or annoyance, scenario realism (*Mdn* = 4, *IQR* = 3-5) or immersion (*Mdn* = 3, *IQR* = 2-4) on 5-point Likert scales.

Participants who received 12 interruptions had an extra opportunity (interruption #7) to commit a clinical error compared to participants who received 3 interruptions. It was not possible to deliver interruption #7 to participants in the 3-interruptions condition because they only received one interruption per scenario, and it followed logically from the previous interruption within the same scenario (interruption #6). Because interruption #7 had the potential to lead to a specific clinical error, participants who received this interruption (i.e., all participants who received 12 interruptions) may have had unfairly inflated error rates. When clinical errors that resulted directly from this interruption were removed, the rate ratio decreased but the results remained statistically significant (Table 3).

In a subgroup analysis, procedural failures were sorted into four categories: documentation errors (e.g., documenting medication administrations incorrectly); incorrect/omission errors (doing something incorrectly or not at all); labelling errors (incorrect information written on line/bag/syringe labels); and nonaseptic technique (e.g., not swabbing the connection port for 15 seconds). Interruption frequency was a significant predictor only of nonaseptic technique: participants who were interrupted 12 times used nonaseptic technique more frequently than participants who were interrupted 3 times (Table 3).

The number of tasks completed correctly (i.e., any task that had the potential for an error but did not contain one) varied across participants, depending on how they did their work. An error rate was computed for each participant to account for this variation. The number of tasks performed incorrectly (clinical errors and procedural failures) was totalled and divided by the total number of tasks performed (correctly and incorrectly). Participants who were interrupted 12 times had significantly higher error rates than participants who were interrupted 3 times (Table 3). We also considered whether receiving a high number of interruptions would result in more opportunities to commit errors (i.e., by requiring the participant to complete more tasks in general). For example, nurses who received 12 interruptions may have been required to wash their hands more often than nurses who received 3 interruptions (due to the extra interrupting tasks). However, we found no difference in the number of tasks done correctly between participants who were interrupted 12 times compared to 3 times.

To explore whether an increase in the number of interruptions lead to more severe clinical errors and/or procedural failures, all clinical errors and procedural failures were categorized into one of five severity ratings (Table 4). Categories of clinical errors were taken from Westbrook et al.,[8] and categories of procedural failures were adapted from the clinical

error categories. All severity ratings were checked and confirmed by the research nurse and nursing professor. Two independent subject matter experts rated a sample of clinical errors and procedural failures and the ratings of all errors were adjusted accordingly before performing the analyses. The average severity of procedural failures did not differ between interruption conditions; however, clinical errors committed by participants in the 12-interruptions condition were more severe than clinical errors committed by participants in the 3-interruptions condition (Table 3).

Discussion

Summary of findings

Nurses who received a higher number of interruptions during medication preparation and administration tasks committed more clinical errors and procedural failures than nurses who received a lower number of interruptions. This study therefore demonstrates a prospective dose-response relationship between interruptions, clinical errors and procedural failures.[15] The findings provide further evidence to support the hypothesis that there is a causal relationship between interruptions and errors, and they fill a previously noted gap in the literature.[10 16] Our results strengthen observational research showing an association only[7 8] and empirical research that uses quasi-experimental methods or small samples only.[12-14]

Westbrook et al.'s[8] estimated risk data for clinical errors suggest a rate ratio of 1.4 when comparing nurses who received 1 interruption and 4 interruptions per medication – a rate lower than but comparable to that found in the current study (2.0) when comparing 1 interruption versus 4 interruptions per scenario. The rate ratio may be higher in our study because the interruptions were designed to be maximally disruptive. When considering only the most severe errors, Westbrook et al. report a rate ratio of 2.0 when comparing nurses who received 0 interruptions and 4 interruptions per medication, which is more comparable to our rate ratio of 1 versus 4 interruptions per scenario.

We used an alternately-allocated parallel groups design for pragmatic reasons, but compared to randomized designs, they are more susceptible to selection biases and confounding. The potential for selection biases were minimised by blinded allocation; participants were scheduled by a senior nurse blinded to both study aims and interruption condition without the involvement of the research team. In addition, participants were scheduled to testing sessions at relatively short notice because of unpredictable shift changes and unit workload, and participants in each condition were equally likely to be tested in the morning or afternoon. Controlling for baseline imbalances in demographics using full and

reduced regression models did not substantively change the conclusions or effect sizes. Furthermore, residual diagnostics did not show evidence of autocorrelation, suggesting that participants' performance did not systematically improve or worsen as the experiment progressed. Thus, our findings are unlikely to be due to bias or confounding.

The effect of interruptions on clinical errors held even when participants subsequently corrected some errors. However, the corrections could have been made at any point in the simulation, so in principle the initial error could have already reached the patient before it was detected. For example, a participant may start an intravenous infusion without priming the tubing with fluid, but only realise the error once air has already entered the patient's blood stream. The clinical errors observed mostly related to the medication rate and dose. The effects of interruptions on procedural failure counts was driven by the increase in violations of aseptic technique with more interruptions. Given that interrupted tasks may be done faster than uninterrupted tasks,[31] interrupted nurses may have performed tasks more quickly by omitting perceived tedious steps such as hand washing or reducing the time taken to swab insertion ports. A further procedural failure was forgetting to ask the TL to check required components of the medication preparation and administration process. This failure potentially facilitated a clinical error—for example, not asking the TL to check a drug calculation and then administering the wrong dose.

The total number of tasks that the participants performed correctly did not differ across conditions. This finding suggests that the interruptions did not increase the number of tasks completed and therefore were not simply providing more opportunities for mistakes.

Participant age, nursing experience, and ICU experience were associated with a small increase in the frequency of procedural failures but not clinical errors. A similar effect was observed in Westbrook et al.'s study,[8] with 1% (95% CI [0.6, 1.4%]) higher rate of procedural failures per year of nursing experience, compared to the 1% (95% CI [0.0, 2.0%])

in the current study. Although counterintuitive, this effect can be explained by the model of Dynamic Safety.[32] Procedural failures that do not result in overt accidents reinforce the incorrect action, especially in the long term. Therefore, nurses with many years of experience may be more likely to commit procedural failures because they have not observed any consequence for that action.

Participants who were interrupted 12 times committed more severe clinical errors than participants who were interrupted 3 times. This supports Westbrook et al.'s[8] finding that the risk of committing a major error (rating of 3-5) increases with the number of interruptions received. However, although we found a difference in the number of procedural failures across interruption conditions, we did not find a difference in severity ratings of procedural failures. The most common procedural failure was nonaseptic technique, which was given a severity rating of 5 out of 5 due to its potential to lead to a blood infection. Thus, the average procedural failure severity rating was 4 out of 5, revealing a potential ceiling effect that may have concealed any differences in severity between the two conditions.

Limitations

The research has several limitations that may affect the representativeness of the study and the generalizability of the findings. First, we did not randomly allocate participants to each condition. Future studies in this area should ideally be randomized, but in the present study with alternate-allocation the findings did not appear to be the result of bias or confounding.

Second, as with all simulation research, participants were aware they were being watched and recorded. As a result, participants' behaviour may not reflect their behaviour in clinical practice. A concern was that participants might feel uncomfortable deferring or blocking interruptions while being recorded, but our participants' high rates of accepting the interruptions are similar to those found in natural settings.[33] [34]

Third, the frequency of clinical errors and procedural failures may have been artificially inflated if participants were nervous and/or working in an unfamiliar environment, and we did not collect baseline error rates with no interruptions. Although the rates of errors and failures in our study appear high, our findings are consistent with Westbrook et al.'s[8] observational data suggesting that baseline error rates are high. Using a similar classification for errors, they found that 25% of uninterrupted medication administrations contained clinical errors and 70% of uninterrupted medication administrations contained procedural failures.

Fourth, the simulation room and scenarios contained several unique qualities compared with the ICU in question. (1) The room was similar to an 'isolation room' in the ICU, whereas most of the ICU bed-spaces are in an open plan where nurses can easily approach neighbouring nurses. (2) The medication room is not normally so close to the bedspace and is accessed via swipe card rather than a partition. (3) Efforts were made to include interruptions that were representative of authentic workplace interruptions, but there were some that we could not simulate. For example, interruptions often come from the nurse at the adjacent bedspace but this would have required a larger simulation room and additional actors. (4) We assessed the impact of interruptions on medication preparation and administration tasks only. It is not clear whether interruptions would lead to errors during other nursing tasks.

Applications and future directions

Because more interruptions can cause more errors, reducing or eliminating interruptions could be an effective step towards reducing errors. However, attempts to enforce zero interruptions have led to unanticipated consequences.[20,35] Researchers are shifting from a viewpoint that all interruptions are inherently undesirable, to acknowledging that many interruptions are essential for the work system to function.[1,22,34,36-38] In our scenarios, every interruption could be considered necessary. Instead, interruption-reduction interventions should target interruptions that increase risk or that do not add value,[22,38] but

interruptions that facilitate good coordination of the work system should be preserved. One possibility is to develop nurses' resilience to interruptions with system-based changes such as visual timers and cues.[13 39] Interruption management strategies could also be used to mitigate the negative effects of interruptions.[37]

Our findings reflect ICU environments and other critical care/emergency departments – whether they are generalizable to other settings with different nurse and patient characteristics is not known.

Conclusion

This is the first prospective controlled study to test the hypothesis that more interruptions lead to more clinical errors and procedural failures in a simulated ICU environment. Our findings point to a dose-response relationship between interruptions and errors; the prospective nature of the finding increases our confidence in a causal connection. Reducing the frequency of interruptions may lead to a reduction in errors, but may also result in unexpected consequences to the wider work system. Researchers could shift their focus to making necessary interruptions safer by increasing the resilience of the work system, while also seeking ways to reduce interruptions that do not contribute to work coordination.

Conflicts of Interest

None.

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Figure 1. Example image of interruption #6. Participant (left) finds blood collection materials at the request of the team leader (right).

Table 1. *Descriptions of each interruption and the associated primary task that was interrupted.*

Scenario and Interruption	Medication	Interruption description	Primary task at time of interruption
Scenario 1			
1	Saline fluids	TL asks if there is anything she can get participant from the medication room. Expectation: participant requests heparin or TL offers to get heparin	Preparing fluids infusion
2	Insulin infusion	Patient complains of discomfort from the central line on his neck. Expectation: participant readjusts position of lines	Consulting insulin infusion rate algorithm
3	Insulin infusion	TL asks if patient has had a chest X-ray, and tells participant to call radiology to follow up. Expectation: participant calls radiology	Preparing insulin infusion
4	Insulin infusion	Monitor alarms because oxygen saturation drops to 70%. Expectation: participant silences alarm and re-attaches pulse oximeter peg to patient's finger (TL removed prior when participant was not looking)	Programming insulin infusion pump
Scenario 2			
5	Heparin infusion/ bolus	In charge nurse calls to offer an early shift finish and asks how everything is going. Expectation: participant accepts phone call	Consulting heparin policy and calculating infusion rate and bolus dose
6	Heparin infusion/ bolus	TL notifies participant that one of the patient's blood tests wasn't collected properly and offers to re-take it as well as a blood gas (for blood sugar level). TL asks participant where the blood collection tubes are. Expectation: participant hands the materials to TL	Preparing heparin infusion/bolus

Scenario and Interruption	Medication	Interruption description	Primary task at time of interruption
7	Heparin infusion/ bolus	TL calls to inform participant that the patient's BSL has dropped significantly (results from blood gas). Expectation: participant consults insulin algorithm and reduces infusion rate	Programming heparin infusion pump OR pushing heparin bolus (whichever came first)
8	Heparin infusion/ bolus	Patient cries out in pain. Expectation participant attends to patient and asks follow up questions	Programming heparin infusion pump OR pushing heparin bolus (whichever came second)
Scenario 3			
9	Fentanyl PCA	TL2 (watching patient while participant is in medication room) peeks into medication room to ask if participant can hand her some paracetamol for patient who is still complaining of pain. Expectation: participant either gives paracetamol to TL2 or has discussion about why they should wait for PCA first	Preparing fentanyl PCA in medication room
10	Fentanyl PCA	TL forgot to bring a PCA pump so TL2 offers to retrieve one. Expectation: TL and participant have a conversation as they wait for the pump	Preparing fentanyl PCA
11	Fentanyl PCA	TL answers phone call from patient's daughter and asks participant to speak to her. Expectation: participant speaks to daughter who is very anxious	Programming PCA pump
12	Fentanyl PCA	TL receives a call that the patient's wife is in the waiting room and asks participant if she can bring the wife in. Expectation: participant answers TL's question	Providing patient education about PCA pump

Note: TL = team leader, TL2 = second team leader, BSL = blood sugar level, PCA = patient-controlled analgesia.

Table 2. *Participant demographics across conditions.*

Demographic		3-interruptions (n = 35)	12-interruptions (n = 35)
Age	20-25 years	5	7
	26-30	11	6
	31-34	6	9
	35-40	6	2
	41-44	3	5
	45+	4	6
Gender	Male	13	10
	Female	22	25
Education	Diploma	2	3
	Bachelor	18	14
	Graduate certificate	13	14
	Graduate diploma	1	0
	Masters (coursework)	1	3
	Masters (research)	0	1
Experience (in years)	Registered nurse: median (IQR)	8 (5-11)	9 (6-16)
	Current ICU: median (IQR)	3 (1-6)	6 (2-8)

Note: Values are number of participants, except for experience reported in mean (SD) years.

Table 3. Descriptive statistics for primary and secondary outcomes under 3-interruptions and 12-interruptions conditions.

Dependent variable	3-interruptions		12-interruptions				
	Mean	95% CI	Mean	95% CI	Ratio	95% CI	p value
Clinical errors (total)	1.4	[0.99, 1.75]	2.7	[2.19, 3.29]	2.0	[1.41, 2.83]	< .001[a]
With corrected errors removed	1.1	[0.67, 1.45]	1.9	[1.35, 2.42]	1.8	[1.19, 2.67]	.005[a]
With interruption #7 errors removed	1.4	[0.99, 1.75]	2.2	[1.70, 2.70]	1.6	[1.12, 2.30]	.010[a]
Procedural failures (total)	35.3	[31.74, 38.95]	42.5	[38.65, 46.32]	1.2	[1.05, 1.37]	.006[a]
With corrected failures removed	34.0	[30.49, 37.51]	40.7	[37.22, 44.21]	1.2	[1.05, 1.36]	.006[a]
Documentation (5% of total)	1.7	[1.10, 2.27]	2.3	[1.79, 2.78]	1.4	[0.92, 1.99]	.121[a]
Incorrect/omission (9% of total)	3.3	[2.67, 3.96]	3.9	[3.25, 4.58]	1.2	[0.92, 1.52]	.190[a]
Labelling (17% of total)	6.6	[5.60, 7.60]	6.7	[5.70, 7.67]	1.1	[0.83, 1.24]	.902[a]
Nonaseptic (69% of total)	23.7	[20.99, 26.50]	29.6	[26.50, 32.70]	1.3	[1.07, 1.45]	.004[a]
Tasks done correctly	86.3	[82.80, 89.78]	83.7	[79.94, 87.49]	-	-	.313[b]
Error rate (%)[c]	29.7	[26.94, 32.35]	35.0	[32.16, 37.81]	-	-	.007[b]
Severity ratings (out of 5)	Mdn	IQR	Mdn	IQR			p value
Clinical errors	1.67	1-2	2.00	1-2	-	-	.031[d]
Procedural failures	4.00	4-4	4.05	4-4	-	-	.242[d]

[a] = analysed with Poisson regression.
[b] = analysed with independent samples t-test.
[c] Error rate = (tasks performed incorrectly / total tasks) * 100.
[d] = analysed with Mann-Whitney U test.

Table 4. Description of clinical error and procedural failure severity ratings.

Severity Rating	Clinical error description	Procedural failure description
1	Incident is likely to have little or no effect on the patient	Action is not best practice/procedure, but is unlikely to have any future consequence
2	Incident is likely to lead to an increase in level of care (e.g., review, investigations, or referral to another clinician)	Action may lead to an increase in level of care (e.g., review, investigations, or referral to another clinician), but not in isolation
3	Incident is likely to lead to a permanent reduction in bodily functioning leading to, e.g., increased length of stay; surgical intervention	Action may lead to a permanent reduction in bodily functioning leading to, e.g., increased length of stay; surgical intervention, but not in isolation
4	Incident is likely to lead to a major permanent loss of function	Action may lead to a major permanent loss of function, but not in isolation
5	Incident is likely to lead to death	Action may lead to death, but not in isolation