Impact of Frequent Interruption on Nurses' Patient-Controlled Analgesia Programming Performance

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Objective: The purpose was to add to the body of knowledge regarding the impact of interruption on acute care nurses' cognitive workload, total task completion times, nurse frustration, and medication administration error while programming a patient-controlled analgesia (PCA) pump.

Background: Data support that the severity of medication administration error increases with the number of interruptions, which is especially critical during the administration of high-risk medications. Bar code technology, interruption-free zones, and medication safety vests have been shown to decrease administration-related errors. However, there are few published data regarding the impact of number of interruptions on nurses' clinical performance during PCA programming.

Method: Nine acute care nurses completed three PCA pump programming tasks in a simulation laboratory. Programming tasks were completed under three conditions where the number of interruptions varied between two, four, and six. Outcome measures included cognitive workload (six NASA Task Load Index [NASA-TLX] subscales), total task completion time (seconds), nurse frustration (NASA-TLX Subscale 6), and PCA medication administration error (incorrect final programming).

Results: Increases in the number of interruptions were associated with significant increases in total task completion time (p = .003). We also found increases in nurses' cognitive workload, nurse frustration, and PCA pump programming errors, but these increases were not statistically significant.

Applications: Complex technology use permeates the acute care nursing practice environment. These results add new knowledge on nurses' clinical performance during PCA pump programming and high-risk medication administration.

Keywords: patient safety, medical devices and technologies, distractions and interruptions, nursing and nursing systems, simulation

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INTRODUCTION

Patient-controlled analgesia (PCA) is a widely used and effective method for the administration of analgesic medications. There are approximately 100,000 PCA pumps in use in U.S. hospitals (iData Research, 2015), with the most common use being for postoperative pain control. In 2012, there were 36.5 million patient discharges; 21.8% were surgical (Agency for Healthcare Research and Quality, 2014), computing to 5.6 million patients at 70% PCA postoperative usage. Other patient populations where PCA is useful for pain control include trauma, cancer, and burns. PCA provides patients with more control over their pain management and eliminates delays in administration, both of which can improve overall pain management (McNicol, Ferguson, & Hudcova, 2015).

PCA is most commonly administered using complex intravenous infusion devices that have been associated with a fourfold increased risk of patient injury when compared to non-PCA analgesia delivery (Hicks, Sikirica, Nelson, Schein, & Cousins, 2008). Data support that relatively high rates of serious injury or death are associated with the use of PCA, with errors frequently related to misprogramming (Hicks et al., 2008; Schein, Hicks, Nelson, Sikirica, & Doyle, 2009). The relative high risk, frequency, and cost of PCA-related error underscores the need to identify factors that contribute to PCA administration error.

An analysis in 500 U.S. hospitals showed that 6.5% of PCA administration errors resulted in significant patient harm as compared with 1.5% of generic medication error (Hicks et al., 2008). The mean cost of PCA administration error resulting in patient injury is estimated at $6,943 per case, contributing $388 million annually to the cost of U.S. health care (Meissner, Nelson, & Hicks, 2009; Palmer, Ji, & Stephens, 2014).

Distractions and interruptions occur frequently in health care settings (Redding & Robinson, 2009; Rivera-Rodriguez & Karsh, 2010). Most available data use observation to measure interruption frequency and conclude that up to two thirds of nursing tasks are interrupted (Kreckler, Catchpole, Bottomley, Handa, & McCulloch, 2008; Palese, Sartor, Costaperaria, & Bresadola, 2009). Interruption frequency observed during nurses' medication administration tasks ranges from 0.8 to 41.8 interruptions per hour (Biron, Loiselle, & Lavoie-Tremblay, 2009). Data support that the number of and severity of medication errors increase with interruption frequency (Westbrook, Woods, Rob, Dunsmuir, & Day, 2010) and that interruption is reported to contribute to PCA administration error (Hicks et al., 2008). Only one study could be found that looked at PCA programming error specifically, and it also showed that the highest rate of error occurred as a result of interruption (Ginsburg, 2004). There are few empiric data available to quantify the effect of interruption frequency on nurses during PCA programming. The findings from this study will add to the existing body of knowledge by increasing understanding of the impact of interruptions on nurses' clinical performance during PCA pump programming. We also hope this study will provide essential groundwork for future study in this important area of patient safety.

Study Purpose and Aims

The purpose of this study was to measure the impact of interruption frequency on acute care nurses' cognitive workload, total task completion times, nurse frustration, and medication administration error while programming a PCA pump. We hypothesized that increases in the number of interruptions during PCA programming would be associated with increases in cognitive workload, total task completion time, nurse frustration, and PCA medication administration error. Our aims were as follows:

1. Determine the impact of interruptions on nurses' cognitive workload as measured by the NASA Task Load Index (NASA-TLX).
2. Determine the impact of interruptions on nurses' PCA programming total task completion time.
3. Determine the impact of interruptions on nurses' frustration during PCA programming as measured by the NASA-TLX Frustration subscale.
4. Determine the impact of interruptions on nurses' PCA medication administration error.

METHOD

Design

Institutional review board (IRB) approval was obtained from Nova Southeastern University and the University of Central Florida. A one-way repeated-measures analysis of variance (RM-ANOVA) was used for data analyses. The independent variable included three levels of interruptions: Conditions 2 (two interruptions), 4 (four interruptions), and 6 (six interruptions).

There were three continuous dependent variables: cognitive workload (NASA-TLX), programming total task completion time (measured in seconds), and nurse frustration (NASA-TLX Subscale 6). The fourth outcome variable, PCA medication administration error, was dichotomous and defined as either correct or incorrect final programming for each of the three programming tasks.

Setting

This study was conducted in the Nova Southeastern University Anesthesia Assistant high-fidelity patient simulation laboratory. High-fidelity simulation is a well-researched method and is the most common method used to study human–machine interactions with therapeutic medical devices (Dieckmann, Gaba, & Rall, 2007; LeBlanc, Manser, Weinger, Musson, & Howard, 2011). The realistic nature of high-fidelity simulation laboratory studies and the "as-if" concept can create a suspension of disbelief during simulation where participants respond as if they were practicing in a real clinical setting (Dieckmann et al., 2007). Testing interruptions in a real clinical setting would have created obvious and unethical safety and confidentiality concerns. The laboratory was arranged to simulate an adult inpatient medical-surgical nursing environment and was viewed via one-way glass to limit intrusiveness of the research assistant who was video-recording the study. Recording equipment was discreetly located in the laboratory, and all sessions were recorded using both audio and video for data verification and additional analyses as needed.

Sample and Recruitment

Nine experienced adult medical-surgical registered nurses (RN) from throughout west central Florida were recruited for participation. Eligibility criteria included (a) being employed for 24 or more hours per week on average in a medical-surgical unit, (b) a minimum of 6 months of experience in adult medical-surgical nursing, and (c) reported regular PCA use of at least four shifts per month. Recruitment e-mails were distributed by the principal investigator (PI) to hospital-based medical-surgical nurse managers in west central Florida, and nurses interested in participating were instructed to contact the PI directly by phone. The first nine nurses who met inclusion criteria were accepted and scheduled for data collection. Completion of the study protocol took approximately 1.5 hr, and a $45 prepaid retail gift card was provided as an incentive.

Power Analysis and Sample Size

Sample sizes in comparable empirical clinical usability studies range from six to 24 (Liu & Osvalder, 2004; Trbovich, Pinkney, Cafazzo, & Easty, 2010). A statistical power of .80 is generally considered acceptable in usability testing, and effect sizes between small and moderate are often not practically meaningful (Nielsen, 1997). Small sample sizes are a known limitation in many current usability studies (Campoe, Barnett, & Byers, 2012; Wiklund, Kendler, & Strochlic, 2011).

Sample size was calculated using G*Power (Buchner, Erdfelder, & Faul, 1997) Version 3.1.5. Assuming a power of .80, alpha of .05, repetitions of three, and within-subjects correlation of .90, a sample size of seven was needed to detect a moderate effect size (Cohen's $f = .25$) for RM-ANOVA, a priori. We anticipated 10% attrition and using 10% missing data as a cutoff, so a total sample size of nine nurses was sought to balance feasibility, current shortcomings in comparable studies, and minimum sample size needed to detect a moderate effect.

Instruments and Measures

Interruption. Participants were instructed to complete the three PCA programming tasks as if they were caring for a real patient. Participants heard a prerecorded interruption, "Excuse me, could you please assist me?" that was intended to simulate the most common interruption in health care: interpersonal communication. All interruptions required participants to stop the PCA and turn toward a computer screen placed on a table approximately 5 feet away. At the computer screen, each nurse responded to one simple, unique question, such as "What day of the week is today?" "What is the brand name of the PCA you are programming today?" and "Did you see a movie at the theater in the last 30 days?" Each nurse submitted a response, then returned to the PCA programming task. Unpredictable, forced interruption followed by a computer-based secondary task with contextual similarity has been used successfully in other interruption research to simulate cognitive processes (Eatchel, Kramer, & Drews, 2012; Monk, 2004).

Interruptions. All participants began with a practice session (PS) of the three programming tasks without interruption. Once the PS was complete, to mitigate for order bias, the order of the three interruption conditions (2, 4, and 6) was randomized.

1. The PS was free of interruptions, which is typical of medical device usability studies (Campoe et al., 2012; Rubin, 2008; Wiklund et al., 2011).
2. Experimental Condition 2 contained two "planted" interruptions per 10-min task scenario, once every 5 min. This level of interruption represents the mean rate of interruptions typically experienced by nurses in actual clinical environments (Biron et al., 2009). The mean calculated interruption frequency was 6.7 to 15 events per hour, or roughly one to two interruptions every 10 min.
3. Experimental Condition 4 contained four "planted" interruptions per 10-min task scenario, once every 2.5 min. Condition 4 simulates the rate of interruption found by Westbrook et al. (2010) to double the risk of medication error.
4. Experimental Condition 6 contained six "planted" interruptions per 10-min scenario, once every 1.5 min. This frequency represents the maximum

TABLE 1: Patient-Controlled Analgesia (PCA) Programming Tasks

Task 1. Initial pump setup
Subtask 1a. Pump setup with continuous mode programming
Subtask 1b. Initiation of loading (bolus) dose
Subtask 1c. Verify treatment
Subtask 1d. Initiation of infusion
Task 2. Change PCA orders: Basal PCA
Subtask 2a. Pump setup with continuous mode programming
Subtask 2b. Initiation of loading (bolus) dose
Subtask 2c. Verify treatment
Subtask 2d. Initiation of infusion
Task 3. Change PCA orders: Continuous initial programming
Subtask 3a. Pump setup with continuous mode programming
Subtask 3b. Initiation of loading (bolus) dose
Subtask 3c. Verify treatment
Subtask 3d. Initiation of infusion

range of 41.8 interruption events per hour identified by Biron et al. (2009).

PCA pump. The PCA pump holds prefilled or standard syringes and can be programmed in three different modes: PCA only, basal plus PCA, or continuous basal rate.

PCA programming tasks. Using instructions from the PCA pump operator's manual, three commonly used PCA programming tasks were developed: (a) PCA only with bolus, (b) PCA basal with bolus, and (c) PCA continuous with bolus. Details of each programming task and associated subtasks are shown in Table 1. To control for any variation related to task order, participants always completed the tasks and subtasks in the same order.

NASA-TLX. The NASA-TLX is a widely used multidimensional assessment tool for the measurement of subjective workload. Although originally developed at NASA's Ames Research Center for use in aviation, it has become an important tool in human factors research (Hart, 2006; Hart & Staveland, 1988). Part 1 (raw scores) of the NASA-TLX consists of six individual subscales measuring mental demand, physical demand, temporal demand, performance, effort, and frustration. Subscale raw scores can be used individually or in combination to assess participants' cognitive experiences during task performance (Hart, 2006). Each subscale uses an interval scale ranging from *low* (1) to *high* (20), and subscales can be summed in various combinations to create combined scores, with higher scores indicating higher perceived cognitive workload.

The NASA-TLX has been used widely in health care and for usability testing in the simulated environment by a variety of users, including nurses (Hart & Staveland, 1988; Hoonakker et al., 2011; Weigl, Müller, Vincent, Angerer, & Sevdalis, 2012). The NASA-TLX tool is reliable and valid for cognitive workload assessment in intensive care unit nurses, with a reported test–retest reliability of 0.77 and a high concurrent validity (.73–.79; Hoonakker et al., 2011).

Cognitive workload. Cognitive workload was measured using the six subscales of the NASA-TLX.

Nurse frustration. Nurse frustration was measured using the NASA-TLX Frustration subscale (Subscale 6).

Total task completion time. Total task completion time was measured in seconds. Prior to data analyses, the time spent attending to the interruptions was subtracted from all three experimental interruption conditions (2, 4, and 6) so that only actual programming time was used in the analyses.

Programming error. Programming error was dichotomously defined as either correct or incorrect final programming for each of the three programming tasks.

Demographic data. The following demographic data were collected: age, gender, ethnicity, nursing education, years of nursing experience, employment status, current medical-surgical nursing unit of hospital, frequency of PCA use, and self-reported level of comfort with PCA use.

Study Procedures

1. All participants completed the informed consent, gave permission for audio-video (AV) recording, were oriented to the simulation laboratory, and completed the demographic questionnaire.
2. Each participant received a 15-min training session on the PCA pump, including general functionality and instructions on each programming task. All participants were trained prior to the practice session by the PI, who was an experienced RN trained by the manufacturer's representative with the study PCA. Training was conducted according to the PCA pump manufacturer recommendations, and the manufacturer provided a quick training guide, which was available to study participants during PCA programming.
3. Participants then entered the simulation environment and were asked to complete all three PCA programming tasks as if they were in a real clinical setting. This step served as their PS, also providing a return demonstration of the training and orientation to the simulation laboratory experience.
4. For each of the Experimental Conditions 2, 4, and 6, participants were instructed to acknowledge and attend to each of the interruptions as they occurred, which began once the nurse stopped interaction with the PCA pump.
5. Each participant completed the three programming tasks under the first randomly selected interruption condition: 2, 4, or 6. The NASA-TLX was then administered. This procedure was repeated for each of the three interruption conditions in random order. Participants were given a 5-min break between each of the interruption conditions.

Ethical Considerations

Recruitment began once formal IRB approval had been obtained. Nurses who agreed to participate completed the informed consent with the PI at Nova Southeastern University on the day of the study. Participants were informed verbally regarding the study purpose, expectations of participants, and study risks and benefits, and were given a copy of their signed consent form. Confidentiality was maintained by assigning subject numbers to each participant.

RESULTS

Data Analysis

SPSS Version 23 was used for data analyses.

Participant Demographics

Nine female medical-surgical nurse participants completed the study, and their descriptive data are summarized in Table 2. Six participants self-reported feeling "very comfortable" with the use of a PCA device; almost half reported using a PCA device at least a few times a month in their workplace (n = 4; 44%). Five participants (56%) had no current experience with the PCA pump used in the study.

Aim 1: Determine the Impact of Interruptions on Nurses' Cognitive Workload as Measured by the NASA-TLX

A one-way RM-ANOVA was calculated comparing total cognitive workload scores for the NASA-TLX across the three interruption conditions: 2, 4, and 6. Although the mean total cognitive workload scores increased in a linear pattern with the number of interruptions (Figure 1), 26.0 (Condition 2), 31.6 (Condition 4), and 36.7 (Condition 6), no significant effect was found, $F(2, 16) = 0.967$, $p > .05$. This trend is shown in Figure 1.

Aim 2: Determine the Impact of Interruptions on Nurses' PCA Total Task Completion Time

A one-way RM-ANOVA was calculated comparing the total task completion times (programming task time only, in seconds) across the three interruption conditions. Because Mauchly's test of sphericity was not significant ($p = .346$), significance testing for sphericity assumed was reported. A significant effect was found, $F(2, 16) = 8.5$, $p = .003$. A limitation of SPSS is the inability to perform post hoc analyses for within-subjects comparisons. Thus, follow-up

TABLE 2: Participant Demographic Information

Variable	*n*	%	*M*	*SD*
Gender				
Female	9	100		
Ethnicity				
Black or African American	3	33		
Hispanic or Latino	2	22		
Caucasian	4	44		
Highest level of nursing education				
Associate degree in nursing	4	44		
Baccalaureate degree in nursing	5	56		
Age			36.22	6.76
Years practicing as a registered nurse			5.94	5.46
Type of unit				
Combination of medical and surgical patients	6	67		
Medical patients only	2	22		
Surgical patients only	1	11		
Specialty of medical-surgical unit				
Cardiac	1	11		
Cardiac-vascular-neurology	1	11		
Neurology	1	11		
Oncology	1	11		
Telemetry	1	11		
OB/GYN-surgery	4	44		

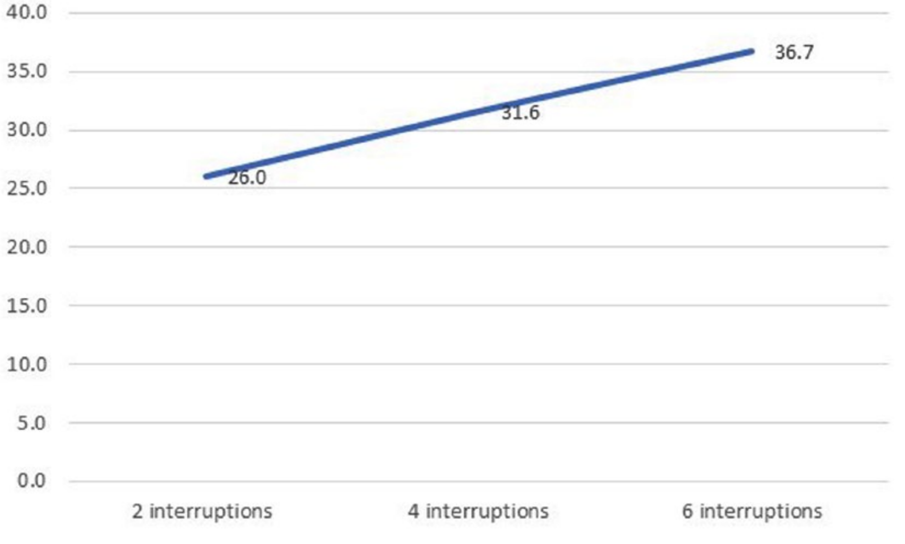

Figure 1. Total cognitive workload scores for each interruption condition.

TABLE 3: Results of Follow-Up Protected *t* Tests

Comparison	*df*	*p* (Two Tailed)
Interruption frequency 2 – interruption frequency 4	8	.073
Interruption frequency 2 – interruption frequency 6	8	.00
Interruption frequency 4 – interruption frequency 6	8	.15

protected *t* tests with a significance level of $p \leq .017$ (0.05/3) to adjust for multiple comparisons and protect against a Type 1 error were used. The follow-up protected *t* tests revealed that total task time in seconds increased significantly ($p < .001$) between two interruptions ($M = 282.11$, $SD = 73.25$, Condition 2) and six interruptions ($M = 366.44$, $SD = 74.68$, Condition 6). No significant differences were found among the other two comparisons (Table 3).

Aim 3: Determine the Impact of Interruptions on Nurses' Frustration During PCA Programming as Measured by the NASA-TLX Frustration Subscale

A one-way RM-ANOVA was calculated comparing nurse frustration (NASA-TLX Subscale 6) across the three interruption conditions. No significant effect was found, $F(2, 16) = 2.65$, $p > .05$. No significant differences existed in nurse frustration between two interruptions ($M = 3.56$, $SD = 1.80$), four interruptions ($M = 6.44$, $SD = 5.0$), and six interruptions ($M = 6.11$, $SD = 3.7$).

Aim 4: Determine the Impact of Interruptions on Nurses' PCA Medication Administration Error

PCA programming error was defined as either correct or incorrect PCA pump programming for each of the three programming tasks. Our study design provided a total of nine opportunities for error for each participant (3 programming tasks × 3 experimental interruption conditions). Thus, the total opportunity for error per interruption condition was 81 (9 participants × 9 opportunities for error). We found a total of 10 errors (overall 4.12%) in final PCA pump programming. There was one error during Condition 2 (1.27%), seven errors during Condition 4 (8.64%), and two errors during Condition 6 (2.47%). Details of each error are highlighted in Table 4.

DISCUSSION

Although we found a positive relationship between the number of interruptions and perceived cognitive workload, these results were not significant. The failure to reach statistical significance may have been due to the small sample size and/or variability in the data.

After accounting for the time it took nurses to address the planned interruptions, we found a significant increase in total task completion time associated with an increase in the number of interruptions (from two to six). This finding suggests that the increased number of interruptions may have a negative impact on nurses' overall task performance during high-risk PCA medication administration. It is possible that some of the measured performance may have been related to previous clinical experience with the PCA pump or from memorization of the initial PCA programming steps. It is also possible that these findings are related to a concept known as resumption lag, which is the time needed to resume a task after an interruption. Previous research in the intensive care unit supports that longer interruptions can result in longer resumption lag time (Grundgeiger, Sanderson, MacDougall, & Venkatesh, 2010).

Interruptions during medication administration have been reported as a source of nurse frustration (Sørensen & Brahe, 2014). Although we did find differences in frustration scores across the three interruption conditions, those differences were not significant. More research is needed, as our study is the first known study to report specifically on nurse frustration levels during PCA use in relation to frequent interruption. Knowledge regarding frustration describing the users' experience could be used to help device designers and manufacturers better understand user needs, limitations, and expectations. PCA devices designed for use in the expected use environment should anticipate high rates of interruption and the potential for user frustration.

TABLE 4: Summary of Patient-Controlled Analgesia Programming Errors

Error Description	Clinical Impact	Number of Errors per Condition	Error %
Condition 2		1	1.23
Entered and delivered wrong dose	Overdosing narcotic		
Condition 4		7	8.64
Entered and delivered wrong bolus amount	Overdosing narcotic		
Entered and delivered wrong 1-hr dose limit	Overdosing narcotic		
Redelivered bolus	Overdosing narcotic		
Redelivered bolus	Overdosing narcotic		
Entered wrong 1-hour dose limit	Overdosing narcotic		
Entered and delivered wrong bolus amount	Overdosing narcotic		
Failed to deliver bolus dose	Under-dosing narcotic		
Condition 6		2	2.47
Redelivered bolus	Overdosing narcotic		
Redelivered bolus	Overdosing narcotic		
Total number of errors = 10			
Mean errors = 4.12			

The PCA administration error found is of particular concern. Although an overall error rate of 4.12% may not seem high, the 10 errors we found in the simulation laboratory translates to potentially 10 patients who would have received incorrect narcotic dosing in the actual clinical setting. PCA programming is a high-risk task in which programming should be error free. We found that only three of nine nurses had error-free PCA programming, with five nurses making one error each and one nurse making a total of five errors. Four of the nurses were current users of the PCA pump being used in the study, including the nurse who made five errors. If we correct for the multiple errors made by one user, the overall error rate of current users was 0.75 as compared with 0.6 for nurses who were not familiar with the PCA pump prior to participation in the study. Thus, there was no difference in error rate based on previous PCA pump use. In all cases, most of the errors (n = 8) occurred immediately after being interrupted, a finding worthy of continued study. Even more concerning, nine of the 10 errors resulted in an overdosing of narcotics; only one resulted in underdosing. Overdosing of narcotics is a serious patient safety issue that can result in significant patient morbidity or even death.

Limitations

This study has several limitations. First, the within-groups design was limited because it can be difficult for the researcher to control for learning effects despite the use of planned training and random order of the interruption conditions. Training and the initial programming session was intended to allow time for all study participants to become familiar with the PCA device, tasks, and measurement tools. Four of the nine participants had past experience with the PCA pump used in the study. It is unclear if nurses' previous experience may have affected study outcomes, if training for the nurses who had not previously used the PCA pump was sufficient, or if training on the NASA-TLX was sufficient. It is also possible that results could vary with the use of a different brand of PCA pump.

During the nurses' performance in the simulation laboratory, the PI was directly present and a one-way glass window was used for observing and recording task performance with audiovisual equipment. This limitation is a factor in all simulation research. The presence of the PI and audio-video technology may have influenced nurses' performance, including task times and error rates, or nurses may have modified their behavior under the testing conditions. The PCA programming tasks and mental workload conditions were representative of the real clinical setting, but the study was conducted in a simulation laboratory. Even considering the suspension-of-disbelief construct that is known to occur during high-fidelity medical simulation, it is possible that the nature and frequency of planted interruptions and PCA programming tasks may not have been perceived as realistic.

CONCLUSION

These findings are relevant to nursing practice, stakeholders who design and manufacture PCA pumps, and overall patient safety. Although research in this area is just beginning, PCA pumps deliver some of the most high-risk medications available for use in acute care. Complex technology use permeates acute care nursing practice, and there is a dearth of research describing the nurses' work during complex device interactions. Improved understanding of the factors that can affect the overall use of PCA pumps in general, and PCA pump programming error in particular, has the potential to make a positive impact on patient care. These results add to the body of knowledge on interruptions and clinical nurse performance and provide the foundation for further study in this important area of patient safety. Future research should include replication of this study with a larger sample of participants.

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KEY POINTS

- The impact of interruption on nurses' patient-controlled analgesia (PCA) programming has not been reported in current literature.
- This study reports the work of acute care nurses during PCA device use with attention to the high-risk, high-consequence PCA interaction.
- This study adds to the body of knowledge on acute care nurses' cognitive workload, total task completion times, nurse frustration, and medication administration error while programming a PCA pump and provides groundwork for future study in these areas.

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