Research

Comparison of Automated versus Manual Programming of Infusion Pumps

Julius Cuong Pham, Kathryn A. Carson, John Benson, Peter A. Doyle, Mayowa Ijagbemi, Alan Ravitz, Rhonda Wyskiel, and Grace Tran

About the Authors

Julius Cuong Pham, MD, PhD, is an associate professor in the Armstrong Institute for Patient Safety and Quality at the Johns Hopkins University School of Medicine in Baltimore, MD, and a clinical professor at the University of Hawaii School of Medicine in Honolulu. Email: jpham3@jhmi.edu

Kathryn A. Carson, ScM, is a senior research associate at the Johns Hopkins Bloomberg School of Public Health in Baltimore, MD; core faculty at the Welch Center for Prevention, Epidemiology, and Clinical Research in Baltimore, MD; and has a joint appointment in the Johns Hopkins School of Medicine. Email: kcarson@jhmi.edu

John Benson, MS, is a group supervisor and systems engineer in the Johns Hopkins University Applied Physics Laboratory in Baltimore, MD. Email: john.benson@jhuapl.edu

Intravenous (IV) medication infusion pumps (hereafter referred to as "infusion pump" or "pump") are important medical devices that enable safe and controlled delivery of IV medications. They are prolific in healthcare; approximately 90% of inpatients receive IV medications.[1] Although their benefits in controlling and improving the safety of IV medication administration are many,[2] infusion pumps carry potential for harm. Medications administered through these pumps often are potent, and the consequences of an error can be severe.[3] Recent reports of adverse events have made infusion pumps the target of close examination, with 87 pump recalls between 2005 and 2009.[4] The Food and Drug Administration (FDA) reported that the operational complexity of pumps led to 56,000 adverse drug events during a four-year period, some of which resulted in serious injuries and deaths.[4] Clinicians, engineers, and medical care providers cite infusion pumps among the most problematic medical devices used in the clinical setting.[5] A summit on infusion pump safety hosted by the Association for the Advancement of Medical Instrumentation (AAMI) and FDA in 2010 identified the following five needs: 1) standardize systems and processes for reporting, aggregating, and analyzing infusion device incidents; 2) improve the integration of infusion devices with information systems and drug libraries; 3) mitigate use errors with infusion devices; 4) improve management of multiple infusions; and 5) reconcile challenges and differences in the use environments of infusion devices.[6]

Automated Pump Programming

The full-scale integration of infusion pumps into a hospital's information technology (IT) and electronic medical record system often is referred to as automated pump programming. Such a system could potentially address the needs of systems integration (need 2 of the AAMI/FDA Infusion Device Summit) and improve usability (need 3 of the summit). Improving usability is especially relevant because a key shortcoming of current infusion pumps, based on device error reports and various studies, is poor human-machine interface design, which does not support clinical workflow.[7] Clinicians often find themselves adapting their medication administration processes to the design of the infusion pumps rather than operating a pump designed to meet their needs and clinical workflow. In concept, many of these human-machine interface design issues can be mitigated through the use of automated programming and systems integration. In fact, adoption of automated programming in current clinical practice is limited. Whether automated programming results in a performance and safety advantage over manual pump programming is unknown. To address this question, we

compared the usability of automated versus manual programming of infusion pumps in a simulated environment.

Methods

Comparative usability testing was conducted to evaluate the safety, performance, and usability of an infusion pump in manual and automated-programming modes. This study was approved by the John Hopkins University Institutional Review Board (NA_00049460).

A total of 41 nurse participants were recruited through postings on nursing listservs, social media, and word-of-mouth from Johns Hopkins Hospital Intensive Care Unit (ICU) staff. Criteria for selection included more than six months of ICU experience, currently caring for patients, and current use of infusion pumps. ICU nurses were selected because of their frequency in use of infusion pumps and high-risk medications. We did not define how many hours per week a participant had to be currently working; candidate participants who were retired or had an administrative-only role were excluded. An incentive of $150 was provided.

Nurse moderators conducted training and test sessions in one of two high-fidelity simulation laboratory spaces. Both labs used Laerdal simulated patients (i.e., manikins) with Quick Response (QR) code labels on wristbands, infusion route sites, simulated pumps mounted on IV poles, and medication bags (saline) to simulate the medications. QR code nurse ID badges also were used. Both labs enabled remote video viewing of pump manipulations for scoring purposes by a remote observer, and one lab enabled viewing through a one-way observation window.

Smart IV Pump: Manual and Automated Programming

To evaluate automated and manual programming agnostic of any specific infusion pump manufacturer, a prototype pump was developed. In brief, the prototype pump consisted of a Samsung Galaxy 10-inch computer tablet with an active touchscreen (Figure 1) to serve as the pump user interface (Figure 2) for both automated and manual infusion modes. The user interface screen layout, color, font size, programming, and navigation features were designed based on idealized user needs derived from a previously conducted workshop with clinical, pharmacy, human factors, engineering, risk management, and regulatory stakeholders. Manual programming consisted of using the touchscreen for all pump navigation, programming, and control

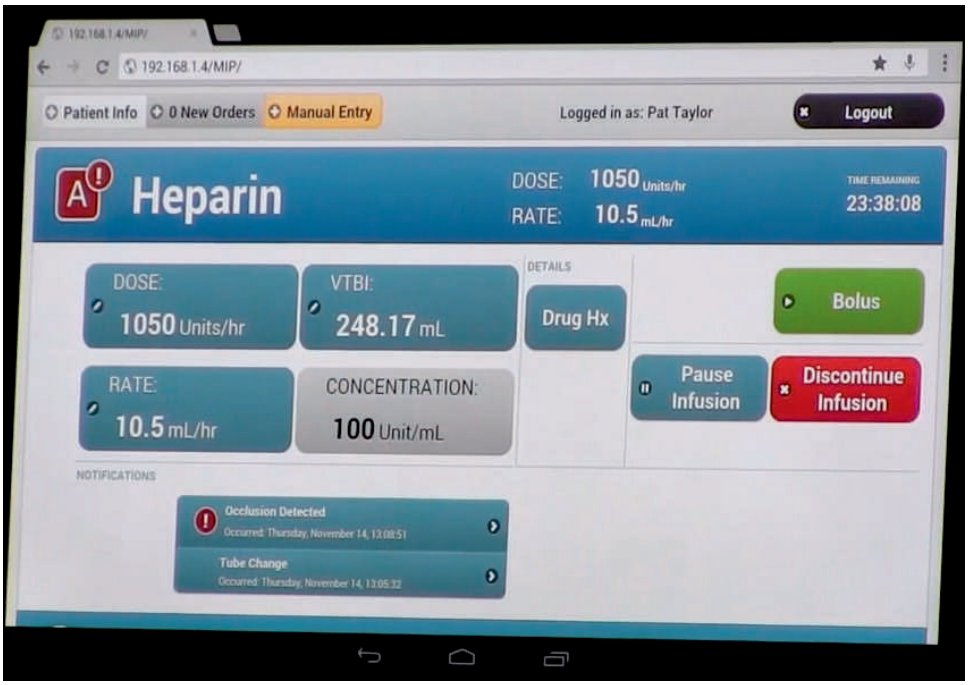

Figure 1. Sample screenshot from prototype pump interface

Peter A. Doyle, PhD, is a human factors engineer at the Johns Hopkins Hospital. Email: pdoyle6@jhmi.edu

Mayowa Ijagbemi, MPH, is a senior public health and healthcare analyst at the MITRE Corporation in McLean, VA, and was with the Armstrong Institute for Patient Safety and Quality at the Johns Hopkins University School of Medicine at the time this article was written. Email: oijagbemi@mitre.org

Alan Ravitz, MS, PE, is a principal professional staff member and health program area manager at the Johns Hopkins University Applied Physics Laboratory in Baltimore, MD. Email: alan.ravitz@jhuapl.edu

Rhonda Malone Wyskiel, RN, MSN, is patient safety innovation lead at Johns Hopkins Hospital and the Johns Hopkins Armstrong Institute for Patient Safety & Quality in Baltimore, MD. Email: rmalone1@jhmi.edu

Grace M. Tran, MS, is director of human factors safety integration in the National Center for Human Factors in Healthcare at the MedStar Institute for Innovation in Washington, DC. Email: grace.tran@medicalhfe.org.

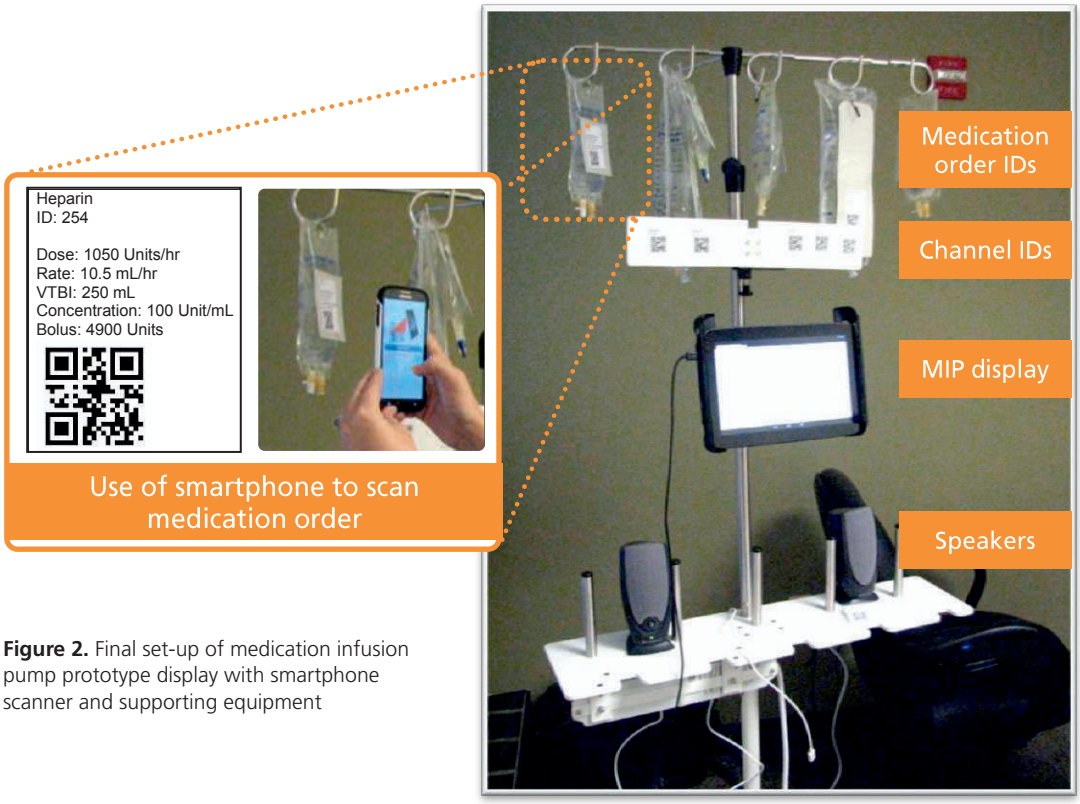

Figure 2. Final set-up of medication infusion pump prototype display with smartphone scanner and supporting equipment

activities. This included logging in and entering numeric values for dose, volume, concentration, and rate. Medications were selected from a menu but did not have these values preprogrammed or dose-limiting features. It also involved selecting a pump channel and confirming prior to initiating and stopping infusions. Automated programming consisted of wireless programming of the pump through a basic computerized provider order entry (CPOE) system controlled by the observer. Items automatically programmed included identity of the nurse, patient, medication (drug, dose, rate, volume, concentration, and bolus units, as appropriate), medication route, and the pump channel for delivery. These automated features provided a measure of dose protection. A mobile phone–based QR code scanner was used to confirm the nurse, patient, medication, and pump channel. The scanner was also used to identify a second nurse when needed to confirm correct pump settings in the context of the scenario. The navigation screen was minimally used to navigate between screens and provide final confirmation.

Training

Participants were trained on the pump prototype by completing the same training scenario in each mode during which a nurse moderator freely discussed aspects of pump use until the participant was comfortable to proceed with testing. Training sessions lasted approximately 20 minutes (range 16–30).

Scenario

During testing, the nurse moderator presented infusion tasks to participants using a randomized sequence of manual versus autoprogramming scenario mode presentations. Participants operated the pump prototype by logging in, starting infusions, starting/stopping a bolus, detecting and resolving an air-in-line alarm, performing a secondary infusion, titrating medication, and discontinuing infusions. The test scenario involved administration of lactated ringers, heparin, norepinephrine, piperacillin/tazobactam, and vancomycin over the course of 12 tasks. The observer inserted air-in-line faults into the simulator at a specific time to assess the reaction to the means for alert

notification. Tasks were subdivided into subtasks (defined as action required to achieving a task; multiple subtasks made up a task), and subtasks were divided into steps (defined as any single keystroke or scanning action). A keystroke was defined as any touch of the screen (e.g., entering "100" was coded as three keystrokes), and a scanning action was defined as an instance that requires scanning the QR code.

Data Collection

Participants completed a demographics questionnaire to indicate age, sex, height, years of ICU experience, current employment in an academic versus nonacademic environment, familiarity with different infusion pump types, and current use of various mobile technology devices. We did not set minimum criteria or quantify the amount of use of mobile technology devices. We simply learned that the participants used such devices using the question, "What type of personal devices do you use?"

To observe task completion, a human factors engineer remotely monitored the participant's performance using a camera image on a large display and reviewed videotaped recordings. An error was defined as any deviation from the correct action on the participant's first attempt. This included starting in the wrong mode, entering wrong data regardless of the possible ultimate effect on delivery of medication, considerable delay in subtask completion (>15 seconds), conducting a wrong sequence to complete a task or skipping a subtask, and any instance of retyping with exception of the first letter of input for user ID (as happened frequently). An adverse event was defined as an error that resulted in actual incorrect delivery of medication, dose, or volume to the patient; delivery of correct medication to the incorrect patient; or delivery of correct medication via an incorrect route. To assess interobserver reliability, a second human factors engineer independently scored a sample of 10 videos, representing five participants, across four of the five test days, both labs, and five different test moderators. The variance rate between the two engineers was 2.19% and 1.20% for the automated and manual modes, respectively.

After each scenario, the observer interviewed the participant using a structured interview form (results not shown) to learn about the acceptability and safety of the prototype pump features. The participant completed a self-administered 15-question survey addressing their perceptions of each programming mode. Responses to the post-task survey were scored on a five-point Likert-type scale. Participants also completed a NASA Task Load Index (NASA-TLX)[8] form to assess perceived workload.

Individual components of the NASA-TLX scores were combined to create a single composite score as an indication of total workload demand. Workload components were assigned different weights to reflect their varying contributions to the composite score. The weighting scheme was determined through study team group consensus.[8] The components were given the following weights: performance (0.333), frustration (0.267), mental demand (0.200), effort (0.133), temporal demand (0.067), and physical demand (0.00).

Data Analysis

Demographic and experience characteristics of participants were summarized using counts and percentages for categorical measures and means (±SDs) for continuous measures. Comparison of autoprogramming and manual modes was analyzed by the number and duration of subtasks completed. Responses to the post-task survey and NASA-TLX scores for manual and automated programming were summarized using means (±SDs) and were compared across methods using paired *t* tests. Fisher's exact tests compared categorical data, and McNemar's test compared the number of participants without an error on the two modes. Statistical analyses were performed using SAS version 9.3 (SAS Institute, Cary, NC). All tests were two-sided, and significance was set at $P < 0.05$.

Results

Participants were predominantly female (83%) with an average age of 32 ± 7.5 years (Table 1). They had a median of six years of professional experience, four years employed at their current institution, and six years of

Characteristic	Participants No. (%)
n	41
Age (years), mean ± SD	32.0 ± 7.5
Age >29 years	21 (51)
Male sex	7 (17)
Height (in), mean ± SD	66.5 ± 3.6
Height ≤65 in	17 (41)
Electronic personal devices used	
Cell phone	1 (2)
Cell phone and tablet	1 (2)
Smart phone	14 (34)
Smart phone and tablet	25 (61)
Years of experience, median (interquartile range)	
Professional	6 (3.5–12)
At current institution	4 (2–7)
With pump	6 (3.5–12)
Vision	
No assistive devices	16 (39)
Distance only	22 (54)
Reading	3 (7)
Takes medication that might cause drowsiness	1 (2)
Pump experience (years)	
<2	2 (5)
2–5	17 (41)
>5	22 (54)
Academic institution	37 (90)
Intensive care unit experience (years)	
<2	9 (22)
2–5	15 (37)
>5	17 (41)
Pump use frequency	
2–3 times per month	1 (2)
2–3 times per week	1 (2)
Daily	39 (95)
Pump type	
Manufacturer 1	35 (85)
Manufacturer 2	1 (2)
Manufacturer 3	2 (5)
Manufacturers 1 and 2	3 (7)

Table 1. Demographics and experience characteristics of study participants

pump experience. Approximately 90% of the participants worked in an academic institution, 95% used infusion pumps daily, and 85% reported familiarity with the infusion pumps of manufacturer 1. Participants also had smartphone (34%) and/or tablet experience (61%). A summary of the results is shown in Table 1.

Task Completion

The manual programming required 100 subtasks, consisting of 180 steps, further broken down into 180 keystrokes and zero scanning actions. The automated programming required 73 subtasks, consisting of 89 steps, further broken down into 68 keystrokes and 21 scanning actions.

The scenario was completed in 648.6 seconds (s) in automated programming mode compared with 515.6 s in manual mode ($P < 0.001$; Table 2). The average number of errors (2.07 vs. 2.05, $P = 0.64$) and adverse events (0.15 vs. 0.20, $P = 0.73$) per participant was similar between the two modes. There was no difference in proportion of tasks completed (97.9 vs. 97.2, $P = 0.17$). A significant proportion of the errors in automated programming was due to the initial login process (95% vs. 89%, $P = 0.02$). Additional results are presented in Table 2.

NASA-TLX

Results from the NASA-TLX survey are shown in Table 3. When asked, "How successful were you in accomplishing what you were asked to do?," participants rated their performance to be higher in autoprogramming mode than in manual mode (20.7 vs. 28.9, $P < 0.01$; Table 3). Autoprogramming was associated with less mental demand (33.8 vs. 39.4 on NASA-TLX, $P = 0.02$), compared with manual programming. The overall task load was similar between the two modes (28.3 vs. 31.1, $P = 0.08$).

Composite NASA-TLX scores were also analyzed by participant characteristics (Table 4). Height effects were observed, wherein taller participants (>65 in) indicated lower workload demands in the autoprogramming mode compared with infusion pump use in the manual mode ($P < 0.01$). Although not statistically different, shorter participants (≤65 in), on the contrary, reported higher workload demand in the autoprogramming mode.

Post-task Survey

Post-task survey results (Table 5) indicated that automated programming was rated higher than manual programming in preventing misinterpretation of physician orders (4.3 vs. 3.1 on Likert-type scale, $P < 0.01$), reducing programming errors (4.2 vs. 2.9, $P < 0.01$), and preventing calculation errors (4.3 vs. 3.7, $P = 0.03$). Although the graphical user interface was the same in both modes, participants felt that the autoprogramming mode had a higher degree of displaying drug concentration options ($P < 0.001$). Other results from the post-task survey are shown in Table 5.

Discussion

We compared task performance, perceived safety, and perceived workload of a prototype infusion pump in automated and manual programming modes. Automated programming was associated with less mental workload and better perceptions of safety by the participants. Manual programming was associated with similar rates of task completion and less time to task completion.

A primary premise of the study and concern of healthcare providers, manufacturers, and patients is the safe delivery of IV medications. We found that systems integration of the pump and its associated automated programming improved the safety profile of the system. Automated pump programming decreased the total number of steps required to complete the scenario. Programming of medication, dose, concentration, and rate were entirely eliminated from the task sequence; errors for these tasks were due to challenges with selecting the medication order. Although not statistically significant (most likely due to small sample size), the number of adverse events per participant was lower and the number of participants without an error was higher for automated programming. Moreover, participants largely felt automated programming was safer (less misinterpretation of physician orders, less programming errors, less calculation errors). This was not surprising, given the proportion of IV medication errors associated with pump programming.[9] On the other hand, automated programming may not be able to mitigate certain errors. Tasks such as emergency bolus dosing and dose titration are currently not available with automated programming. These tasks still require manual programming even with automated programming available. In our study, the error rate was similar between the two modes for these tasks, which emphasizes the importance of designing safe manual programming, even in the setting of automated programming.

Finally, certain automated programming tasks were entirely unique and new. Tasks such as login, association of patient/medication/pump/IV site, and second nurse verification are not often required with manual programming. These tasks were

Task/Action Type	Manual Programming Mean ± SD	Automated Programming Mean ± SD	*P**
Time to scenario completion (start to end), seconds	516 ± 80.9	649 ± 130	<0.001
Overall subtasks completed (%)	97.9 ± 2.0	97.2 ± 3.4	0.17
By task (%)			
Initial login	95.2 ± 6.8	89.0 ± 13.7	0.02
Task 1: administer heparin	97.8 ± 3.9	96.7 ± 11.8	0.55
Task 2: administer lactated ringers	100	98.8 ± 4.4	0.08
Task 3: administer vancomycin	98.5 ± 4.2	98.4 ± 5.0	0.85
Task 4: administer piperacillin	97.6 ± 4.4	97.6 ± 4.9	0.99
Task 5: bolus heparin	98.5 ± 5.3	99.0 ± 4.4	0.66
Task 6: discontinue piperacillin	99.2 ± 5.2	99.2 ± 5.3	0.99
Task 7: increase lactated ringers	97.6 ± 7.5	96.3 ± 10.5	0.42
Task 8: setup lactated ringers as carrier	99.1 ± 3.3	95.9 ± 9.7	0.05
Task 9: administer norepinephrine	97.6 ± 4.9	98.0 ± 5.5	0.68
Task 10: change norepinephrine dose to 0.04 µg/kg/min	98.8 ± 5.5	98.2 ± 6.6	0.66
Task 11: change norepinephrine dose to 0.12 µg/kg/min	97.6 ± 7.5	98.2 ± 6.6	0.66
Task 12: discontinue all medications	95.1 ± 21.8	97.0 ± 16.0	0.47
By action type (%)			
Login	92.3 ± 11.7	86.2 ± 18.2	0.11
Submit/confirm	99.2 ± 2.2	99.3 ± 3.5	0.82
Select patient	95.1 ± 18.7	96.3 ± 13.2	0.71
Navigate menu	98.5 ± 3.2	98.1 ± 4.2	0.65
Input medication name	98.7 ± 3.0	97.4 ± 5.4	0.18
Input dose	94.7 ± 9.5	97.6 ± 15.6	0.34
Input volume	98.4 ± 5.0	—	
Input concentration	97.6 ± 10.9	—	
Select bag	—	98.8 ± 4.4	
Input route	—	93.9 ± 20.0	
Select channel	98.4 ± 5.0	98.0 ± 5.5	0.74
Second nurse verification	—	95.1 ± 21.8	
Start infusion	98.8 ± 4.4	99.2 ± 5.2	0.57
Stop infusion	98.4 ± 7.3	99.2 ± 5.2	0.32
Input rate	96.3 ± 6.4	95.1 ± 14.1	0.50
Setup secondary infusion	100	100	—
Respond to alert	100	97.6 ± 10.9	0.16
Change dose	93.9 ± 16.6	93.9 ± 16.6	0.99
No. errors† per participant	2.05 ± 1.99	2.07 ± 2.50	0.64
No. adverse events‡ per participant	0.20 ± 0.46	0.15 ± 0.36	0.73
No. (%) of participants without an error	9 (22)	12 (29)	0.35

Table 2. Medication infusion pump simulation task completion by method. Task refers to the process of administering a specific drug. **P* value from paired *t* test, except for number of participants without an error (McNemar's test). †Error: any deviation from the correct action on the participant's first attempt. ‡Adverse event: error that resulted in actual incorrect delivery of medication, dose, or volume to the patient; delivery of correct medication to the incorrect patient; and delivery of correct medication via an incorrect route.

NASA Task Load Index	Manual Programming Mean ± SD	Automated Programming Mean ± SD	*P**
n	40	41	
Composite (weighted)	31.1 ± 15.4	28.3 ± 15.7	0.08
Mental demand	39.4 ± 21.2	33.8 ± 18.6	0.02
Physical demand	21.8 ± 18.1	23.8 ± 20.1	0.47
Temporal demand	31.4 ± 19.8	31.0 ± 21.8	0.76
Performance	28.9 ± 19.7	20.7 ± 15.9	<0.01
Effort	35.3 ± 18.3	32.6 ± 22.7	0.24
Frustration	25.5 ± 19.1	30.9 ± 27.5	0.17

Table 3. NASA Task Load Index scores by method **P* value from paired t test for n = 40 with both types of entry. Composite: weighted summation of mental, physical, temporal, performance, effort, and frustration. Performance is reverse coded, where 0 is perfect performance and 100 is failure.

unfamiliar for many of the participants; "login" was the source of the majority of errors in automated programming. This is consistent with prior limited studies evaluating automated pump programming.[10] These errors would be would be expected to decrease as participants gained familiarity with automated programming. Although more studies should be conducted before recommending widespread adoption of automated programming, the system holds promise for a closed-loop medication delivery.[10]

In terms of task performance, the results were mixed. Automated programming was more time consuming (649 vs. 516 s), more frustrating (per NASA-TLX), and harder to use (per post-task survey) than manual programming. In debriefing with participants, this was due to lack of familiarity with automated programming and technical challenges with the scanner. All of the participants were experienced with manual programming, while none were familiar with automated programming. The "additional steps" of logging in and scanning the components led to frustration, especially when the equipment had technical challenges. The prototype used a cell phone camera as the QR scanner. In some cases, the phone did not readily read the QR code. In other cases, delays in wireless connectivity occurred. This combination of challenges led to increases in time, frustration, and difficulty in use. Usability likely would improve as familiarity with the automated programming system increased and with a more usable QR scanner and further refinements through an iterative design process. Similar patterns have been demonstrated with implementation of CPOE systems.[11,12] On the other hand, automated programming was less mentally demanding and associated with overall better performance (per NASA-TLX), an important factor for clinicians facing many mental demands in the course of work.

Despite these early promising results of automated pump programming, many challenges to its widespread adoption remain. Clinical studies comparing the usability and performance of these systems in real-world scenarios should be performed to understand their incremental benefits over existing systems. Areas of inquiry include the safety benefits of automated pump programming, the workflow/efficiency benefits of these systems, and the new challenges to implementation. Moreover, setting up these systems involves many technical challenges. Interfaces between the IT system, CPOE, and smart pumps are not standardized and fraught with potential challenges. What are the time and resources required to integrate such products into various CPOE and other IT systems? Future technological developments should target ways to make integrating these systems seamless (i.e., plug and play). Finally, purchasing of this equipment and creating the necessary infrastructure can be cost prohibitive in most healthcare organizations.[10] Future technological and business development should target ways to make automated pump programming financially feasible.

Limitations

This study involved several potential limitations. First, these results were based on simulation of common medication infusion scenarios in a simulation center. How these results compare with those performed in a real-world setting with real patients is unclear. The advantage of the simulation was that we could study participants performing the exact same scenario using two modes in a controlled setting. Moreover, we could observe and collect information about task performance and usability.

Second, these results are based on a prototype pump. Whether these results are

applicable to real-world pumps in practice today is unclear. The prototype IV pump had two notable differences compared with commercially available pumps today. The touchscreen provided a larger surface for display of both controls and status information, using color and functional grouping for an intuitive layout. The larger screen enabled simultaneous display of status information for five pump channels, a bolus option, an alert line, and indications for medications infused secondary to a primary medication. The prototype also required association of the provider (i.e., login). This is not required on many commercially available pumps today. The prototype was used to allow full control of the simulation. Building a prototype that could be easily manipulated would allow testing of different human-machine interface features. Moreover, the intent was to test a pump that was agnostic to current commercial models. It is possible that the performance and usability outcomes reported here resulted from the specific prototype features we developed. To control this potential limitation, the prototype interface was replicated in the two modes as closely as possible, with the exception of features that enabled automated programming.

Third, the vast majority of our participants (90%) worked at an academic medical center and were familiar with one proprietary pump. It is possible that these results would be different with a population of participants working in a community setting or who were familiar with different pumps.

Conclusion

We compared the task performance, perceived safety, and perceived workload of automated versus manual programming of an infusion pump in a simulated setting. We found automated programming to have better perceptions of safety and workload, though task completion was more time consuming. Error and adverse event rates were similar between the two modes. Some of the errors and technical challenges to automated programming resulted from lack of familiarity with the system. Further testing of automated pump programming in the clinical setting is needed to identify value and vulnerabilities in the system and how this can be mitigated through design. ■

	NASA Task Load Index (Composite)		
Characteristic	Manual Data Entry Mean ± SD	Automated Data Entry Mean ± SD	*P**
Age (years)			
20-29	30.2 ± 12.1	27.2 ± 14.7	0.24
30-53	32.0 ± 18.4	29.4 ± 17.0	0.22
Sex			
Male	26.0 ± 20.7	24.9 ± 23.0	0.59
Female	32.2 ± 14.2	29.0 ± 14.2	0.10
Height (in)			
>65	29.0 ± 14.8	23.1 ± 11.8	0.004
≤65	33.9 ± 16.1	35.6 ± 17.9	0.56
Electronic personal devices used			
Cell phone	12.3 ± †	13.0 ± †	**
Cell phone and tablet	13.0 ± †	10.0 ± †	**
Smart phone	26.8 ± 13.5	23.8 ± 11.4	0.27
Smart phone and tablet	35.1 ± 15.5	32.1 ± 17.1	0.20
Professional experience (years)			
<2	27.5 ± 8.7	17.2 ± 4.0	0.20
2–4	29.1 ± 13.6	23.5 ± 13.2	0.05
>4	32.7 ± 17.1	32.2 ± 16.8	0.64
Experience at current institution (years)			
<2	30.6 ± 14.6	28.2 ± 19.8	0.61
2–4	28.2 ± 13.1	22.4 ± 12.2	0.06
>4	33.7 ± 17.7	32.9 ± 15.9	0.59
Vision			
No assistive devices	37.6 ± 17.6	33.1 ± 15.0	0.08
Distance only	26.9 ± 11.9	25.6 ± 16.7	0.40
Reading	25.4 ± 17.2	22.7 ± 4.7	0.80
Takes medication that might cause drowsiness			
Yes	40.0 ± †	34.0 ± †	**
No	30.9 ± 15.5	28.2 ± 15.9	0.10

Table 4. Composite NASA Task Load Index by method, stratified by subject characteristics. **P* value from paired *t* test within each characteristic. †Response from only one participant; result could not be analyzed.

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Question	Likert-Type Rating		
	Manual Programming Mean ± SD	Automated Programming Mean ± SD	*P**
1. To what degree does the simulated pump prevent overriding of safety features?	3.2 ± 1.3	3.5 ± 1.0	0.14
2. To what degree does the simulated pump prevent misinterpretation of a physician's order?	3.1 ± 1.4	4.3 ± 1.1	<0.001
3. To what degree does the simulated pump reduce programming errors?	2.9 ± 1.1	4.2 ± 0.9	<0.001
4. To what degree does the simulated pump prevent the need to reprogram the pump after a bolus?	4.2 ± 1.2	4.4 ± 1.1	0.35
5. To what degree does the simulated pump prevent errors in calculating conversions?	3.7 ± 1.2	4.3 ± 1.1	0.03
6. To what degree does the simulated pump provide a workflow that matches the user workflow?	4.0 ± 0.8	3.7 ± 1.1	0.10
7. To what degree does the simulated pump display easy to read content and format?	4.5 ± 0.9	4.4 ± 0.9	0.26
8. To what degree does the pump control accuracy of weight data derived from primary source?	4.1 ± 1.1	4.3 ± 1.0	0.11
9. To what degree does the pump provide adequate visual cues for selection options?	4.4 ± 0.9	4.4 ± 0.8	0.69
10. To what degree does the pump prominently display drug concentration options?	3.5 ± 1.4	4.2 ± 1.1	<0.001
11. To what degree does the pump provide adequate cues to read pump status during use?	4.4 ± 0.8	4.5 ± 0.9	0.25
12. Please rate the sensitivity of the touchscreen compared with current methods of infusing medications.	2.7 ± 0.8	2.5 ± 0.8	0.13
13. Please rate the overall ease of using this mode compared with what you currently use at your hospital?	4.1 ± 0.9	3.4 ± 1.4	0.01
14. Please rate your degree of confidence in administering infusions with what you currently use at your hospital?†	4.7 ± 0.5†	4.7 ± 0.7†	0.80†
15. Please rate your degree of confidence in administering infusions with this mode of the simulated pump.	4.2 ± 0.7	4.2 ± 0.9	0.99

Table 5. Post-task survey, by mode. Responses were based on a five-point Likert-type rating scale, where 1 is "not at all" and 5 is "to a great degree" (questions 1–11); where 1 is "too insensitive" and 5 is "too sensitive" (question 12); where 1 is "difficult" and 5 is "very easy" (question 13); and where 1 is "not confident" and 5 is "very confident" (questions 14 and 15). **P* value from paired *t* test. †Same question for both modes; expected same response.

previously with Johns Hopkins University School of Medicine); Adjhaporn Khunlertkit, PhD (human factors engineer, Johns Hopkins University School of Medicine); Namrata Shrestha (project manager, Johns Hopkins University Applied Physics Laboratory); and Michael Ruffolo (computer engineer, Johns Hopkins University Applied Physics Laboratory).

References

1. **Sensmeier J.** Transform workflow through selective implementation. *Nurs Manage*. 2004;35(12):46–51.
2. **Carayon P, Hundt AS, Wetterneck TB.** Nurses' acceptance of smart IV pump technology. *Int J Med Inform*. 2010;79(6):401–11.
3. **Keohane CA, Hayes J, Saniuk C, et al.** Intravenous medication safety and smart infusion systems: lessons learned and future opportunities. *J Infus Nurs*. 2005;28(5):321–8.
4. **Food and Drug Administration.** White Paper: Infusion Pump Improvement Initiative. Available at: www.fda.gov/MedicalDevices/ProductsandMedicalProcedures/GeneralHospitalDevicesandSupplies/InfusionPumps/ucm205424.htm. Accessed April 8, 2016.