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Organizational and technological correlates of nurses' trust in a smart IV pump

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Abstract

The aim of this study was to understand technology and system characteristics that contribute to nurses' ratings of trust in a smart IV pump. Nurse's trust in new technologies can influence how technologies are used. Trust in technology is defined as a person's belief that a technology will not fail them. Potential outcomes of trust in technology are appropriate trust, over trust, distrust, and mistrust. Trust in technology is also related to several use specific outcomes, including appropriate use and inappropriate use such as over reliance, disuse or rejection, or misuse. Understanding trust in relation to outcomes can contribute to designs that facilitate appropriate trust in new technologies. A survey was completed by 391 nurses a year after the implementation of a new smart IV pump. The survey assessed trust in the IV pump and other elements of the sociotechnical system, individual characteristics, technology characteristics and organizational characteristics. Results show perceptions of usefulness, safety, ease of use and usability are related to ratings of trust in smart IV pumps. Other work system factors such as perception of work environment, age, experience, quality of work, and perception of work performance are also related to ratings of trust. Nurses' trust in smart IV pumps is influenced by both characteristics of the technology and the sociotechnical system. Findings from this research have implications for the design of future smart IV pumps and health systems. Recommendations for appropriately trustworthy smart IV pumps are discussed. Findings also have implications for how trust in health technologies can be measured and conceptualized in complex sociotechnical systems.

Keywords

Trust; Technology; Smart Pump; Health Organization

Introduction

In complex settings such as hospital care units, there are often unforeseen consequences that occur during the implementation of new technologies¹. As automated technologies make their way into healthcare, social and system complexities of the healthcare environment will affect whether or not these new technologies improve safety and reliability or contribute to unanticipated safety incidents and near-incidents. One example of an automated technology in health care is the smart intravenous infusion pump (smart pump) system, that are increasingly implemented in hospitals despite lacking evidence that they improve safety in medication administration^{2,3}. Many types of pumps are used in patient therapy worldwide, and both healthcare providers and patients rely on the safety and accuracy of the pumps' administration of fluids and medications. However, FDA recalls of external infusion pumps

across the market indicate a failure of this new technology to meet certain safety standards⁴. While a variety of social, technical, and system factors influence the appropriate design and effective adoption of smart pumps, this paper focuses on factors that influence users' trust, the role of users' trust in automated technology, and how trust influences user and patient outcomes.

Studies in domains outside of healthcare, dedicated to understanding different types of trust, such as social trust⁵ and technological trust⁶ support a growing knowledge base of trust, mistrust, and the effects on appropriate use of technology⁷. Trust in technology might be influenced by individual characteristics of technology, such as the technology's usability⁸, affective qualities⁹ and physical appearance¹⁰; individual user traits¹¹ or experience¹²; and the interacting social and system variables of complex work environments. Trust is relevant to human-technology interaction studies because trust has been tied to user performance, particularly with automated aspects of technologies. Parasuraman and Miller¹³ found both user performance and trust were lowered by poor automation etiquette even when the reliability of automation advice was high. Their findings indicate that the social response of technology, or how well the technology is perceived to act according to social and cultural expectations, should be considered during the design of technology. Their findings also indicate that the level of user trust in automation should be calibrated to reflect the actual capability of the automation.

Because the degree to which these variables affect levels of trust are difficult to identify, it is important to be aware of what affects trust, as well as the potential consequences of mistrust and distrust. In automation, a level of distrust may be useful for avoiding overreliance on technology¹⁴. Misuse of technology occurs when there is overreliance on the technology, while disuse refers to the rejection of technology as a viable and necessary part of workflow⁷. Both have shown to cause subsequent performance failures. Understanding how to shape users' expectations of technology reliability can affect their quality of work life¹⁵, and the success of new technology acceptance¹⁶. It is thus important to understand user trust and how it may aid in or work against the success of a human-technology system. Users' expectations of technology also depend on the user. In health care, a study by Stahl et al.¹⁷ found that nurses' response to new technology in the workplace might differ from surgeons or doctors, particularly if the new technology decreases their decision-making autonomy. Users' attitudes toward technology can also influence their use of technology¹⁸. Kjerulff et al.¹⁹ found that nurses who were anxious about using technology to perform their jobs were generally less positive toward computers, felt more stressed by their work, reported lower ratings of job satisfaction and feelings of autonomy, and tended to be older than less anxious nurses.

Inappropriate over-trust in automated technology systems also affects quality of care. For example, users that have high levels of trust in technology may develop complacency towards the abilities of the automation, creating greater potential for accidents in health settings²⁰. In a study examining how advanced practice nurses use clinical decision support systems²¹, a major predictor of system use was the nurses' level of trust in the system data. When distrust in the system occurred, it was generally followed by no system use or system use at a simplistic level, such as data entry. Furthermore, health personnel were shown to maintain levels of trust and confidence in technology even if it caused new errors, changes to work routines, and changes to the roles of the health personnel involved²². It is thus important to consider when trust is established during the introduction of a new technology in healthcare.

Trust has been found to be an important component in a framework for patient safety and maintaining a safety culture²³. This trust extends to all parts of the work system, including

the technology they use. Understanding when users trust medical technology will inform our understanding of how users may use the technology. It can also inform the design of future devices or systems that will lead to safer and more effective use of technologies in healthcare. The present study explores the relationship between nurses' perceptions of smart pump technology and trust, using data from a study that examined nurses' experiences with the implementation of a smart pump in an academic hospital²⁴. A sociotechnical system framework was used to develop hypotheses about factors that influence nurses' ratings of trust in the technology^{25,26}.

Sociotechnical systems theory describes systems as a collection of subsystems: individuals, tasks, environment, organizational elements and technology^{27–29}. Each subsystem interacts to influence the other subsystems and overall system outcomes. For example, technology can affect how workers in the system interact with one another. Attitudes towards technologies can also influence attitudes and interactions in other subsystems: negative and positive perceptions of technology may contribute to workarounds that affect worker performance³⁰, and distrust may influence how workers interact with each other, and how they accomplish various tasks, particularly if attitudes about the technology differ between workers that must use the technology collaboratively⁵.

It was expected that factors related to the functioning of the technology would be related to ratings of trust. It was also expected that the work environment and quality of working life would influence trust in the technology. Finally, based on previous research findings, it was expected that variables such as age, and nursing experience would be related to attitudes about the technology¹⁷. Results from the study showed nurses had a somewhat positive acceptance of the smart pumps that increased significantly one year after implementation, and also found several pump characteristics that influenced user acceptance, including: reliability, programming speed, perceived efficiency, error recovery, use of drug libraries, acceptable and appropriate alarm messages, and satisfaction with the pump interface. The analyses described will address factors that contributed to nurses' trust in smart IV pumps and how these characteristics may apply to trust in other medical technologies.

Method

Data collection and sample

A secondary analysis of survey data²⁴ was conducted; surveys were completed by 391 nurses one year after the implementation of a new smart IV pump in an academic hospital with a level-one trauma center. These surveys were web-based and distributed via email, with a response rate of 38%. The participants represented different levels of experience with their current job position: 19% had less than one year of experience, 49% had between 1 and 5 years experience, 21% had between 6 and 15 years experience, and 11% had over 16 years experience. Nurses who were less than 34 years old made up 45% of study participants, 26% were between 36 and 45 years old, 21% were between 46 and 54 years old, and 8% were above 54 years old. 86% of the participants had either an associates or bachelor degree in nursing, and 14% possessed graduate level degrees. The study protocol and activities were approved by university and hospital Institutional Review Boards and HIPAA (Health Insurance Portability and Accountability Act) regulations were fulfilled.

Survey Instrument

The survey instrument disseminated to participants in this study included items related to the technology, the work environment, quality of working life, performance, and demographics. The survey consisted of six sections, and each section had questions related to nurses' perceptions about their job (5 items), nurses' perceptions about smart IV pump technology,

consisted of perceived technical performance and perceived usability of smart pump questions (total 31 items), the characteristics of nurses' work environments (30 items), quality of nurses' working lives (24 items), and nurses' perceptions of their own performance (10 items). In addition, demographic information such as, age, education, experience with their present employer, experience in their present job position, and the nursing unit in which they primarily worked were obtained through the survey. Measures related to nurses' trust in the smart pump technology were also collected. A Likert scale from 1 to 7 was used in the questionnaire for the trust construct, 1 representing "strongly agree" and 7 representing "strongly disagree." Survey questions were adapted from several resources, such as the questionnaire on User Interface Satisfaction for expected/perceived technology³¹, a study by Bailey and Pearson³² for user acceptance of pump technology, and a study by Keohane et. al³³ for questions on usability. The survey instrument was used and validated by Carayon et. al²⁴.

Data Analysis

Regression analysis was used to identify the relationship between trust scores and the factors related to usefulness, safety, ease of use and usability. For some of the sections, stepwise regression analysis was used to identify the best subset model for measuring nurses' trust of smart pump technology. Regression models were also used to evaluate the relationship between demographic characteristics and trust in the smart pump technology. Simple linear regression was also used to examine the predictors of trust scores in each section. Finally, descriptive statistics were used to describe the data.

Results

The average trust score (mean 2.97, SD 1.49) indicated nurses generally trusted the smart pump technology. Approximately 68% of nurses had higher trust in the smart pump (1–3), whereas 14% of nurses did not (5–7) and 17% of nurses had neutral trust (4).

Perception of smart pump technology and trust

Model 1—Six items related to nurses' perceptions of the smart pump's technical performance were evaluated for their relationship to trust ratings, including speed of programming, reliability and durability, and noise levels (see Table 1 for the complete list). Simple linear regression was conducted with each question and the trust score. All six questions were significantly correlated and predicted the trust score (Table 1).

Stepwise regression analysis was used to identify the best model among the six items. The significant items in this model were "Speed of programming smart IV pump" and "Reliability and durability of smart IV pump" ($R^2 = 0.60$, $F_{3, 390} = 200$). This model indicates that the most parsimonious set of predictors of trust among technical performance characteristics are the perceived speed of programming smart pump and the perceived reliability and durability of the smart pump.

Model 2—In the next stage, twenty-five items related to nurses' perceived usability of smart pump technology were evaluated. These items include questions about learnability, satisfaction, memorability, efficiency, expectation, and errors. Each item was regressed on the trust score to observe its relationship with trust. All items were found to be a significant predictor of the trust score (Table 2). The result table indicates that if the pump is more efficient, easy to learn and creates less error; nurses will likely have higher trust.

Stepwise regression analysis was also conducted among these items to identify which model best fit the trust score (see Table 3). This model indicates the most parsimonious set of

predictors of trust among nurses' perceived usability of smart pump technology items (25 items).

Job characteristics, nurses' demographics and trust

Relationships between job characteristics, such as job position and length of time in their current position, were evaluated with the smart pump trust score using regression analysis. Similar trust scores were found for the different types of nursing roles, Staff RN (mean 2.98, SD 1.51) and Float/Agency RN (mean 2.62, SD 0.95) (one being highest trust and seven being lowest trust), and no significant relationship was found between the smart pump trust score and the shift that the nurse worked (i.e. day, morning, night). However, a significant relationship was found between the smart pump trust score and the length of time working with their current employer ($p=0.0303^*$, $\alpha<0.05$), or time in their current position ($p=0.0162^*$, $\alpha<0.05$). The nurses who reported less time working with their current employer and in their current position reported higher trust in the smart pump than more experienced nurses. Age was also found to be a significant predictor for the smart pump trust score ($p=0.0358^*$, $\alpha<0.05$); younger nurses (mean 2.81, SD 1.36) reported higher levels of trust than older nurses (mean 3.40, SD 1.44). There was no significant relationship between the smart pump trust score and gender ($p=0.136$) or education level of nurses ($p=0.235$).

Relationships between trust in smart pump with work environment and quality of work life factors

The questionnaire included 30 items related to the work environment, 24 items on the quality of work life, and 10 items on nurses' perception of their own performance. A simple linear regression test was used to identify any items significantly related to the smart pump trust score. Results showed that 10 items total out of 64 items, from the three constructs, were significant predictors of the trust score (Table 4).

Discussion

Bivariate regression analysis indicated that all of six items related to technical performance of the smart pump significantly influences nurses' trust in the smart pump (Table 1). The stepwise regression analysis helped identify the most effective predictors of trust scores among those six items. The most parsimonious set of predictors of trust among technical performance are "speed of programming smart pump" and "reliability and durability of smart pump". This implies nurses who perceive the smart pump to be slow, unreliable, and not durable are less likely to trust the smart pump than nurses who perceive the smart pump to be fast, reliable, and durable. All other items related to nurses' interactions with the smart pump's features were analyzed in terms of the nurses' trust in smart pump technology. The results showed all items including efficiency, errors, memorability, learnability, and satisfaction with the interaction were significantly associated with nurses' trust in the smart pump technology (Table 2). Stepwise regression illustrated the most parsimonious set of predictors (seven) among these 25 items (Table 3). These predictors include two items from satisfaction, three items from efficiency, and one item from error and learnability constructs. For example, nurses who perceived that the smart pump increased safety of care, gave appropriate alarms, were satisfied with their interaction with the smart pump, thought the smart pump was easy to learn, was easy to operate, functioned as expected, and were confident in responding to alert messages, were more likely to rate a higher level of trust in the smart pump than nurses who felt the converse. These findings are congruent with other studies that found technology characteristics, such as usability, related to trust³⁴ and associated constructs, such as acceptance.

Results also illustrated relationships between trust scores and nurses' demographics. The length of time working with the current employer and time in their current position was significantly related to trust ratings. The nurses with less work experience tended to have more trust than more experienced nurses in smart pump technology. Age was also a significant predictor; younger nurses reported higher levels of trust than older nurses. The analysis showed that all of the younger nurses stated higher trust in smart pump technology (mean=2.81, SD 1.36). However, we can observe several older nurses stated lower trust (distrust) (mean =3.40, SD 1.44) in smart pump technology. Other studies support these findings; Stahl et al.¹⁷ report that older nurses may have higher levels of trust in themselves, or be more skeptical of new devices, while younger nurses who have more experience with new technologies or are trained using similar technologies may be more vulnerable to over trust. No significant relationship was observed between trust score and education level of nurses as well as gender of nurses. Future work should explore the demographic characteristics related to trust and the potential outcomes related to inappropriate trust calibration²⁰. Future research should also explore the demographic factors that contribute to an appropriate balance between trust in one's self and technologies.

The data indicate that some of the items related to characteristics of nurses' work environments and quality of work life influence their trust in smart IV pumps (Table 4). Nurses who reported higher influence over their work environment tended to have higher trust in the smart pump. In addition, nurses' reported fatigue levels were significantly related to trust levels in the smart pump ($p=0.0391$ *), where nurses who reported higher levels of fatigue tended to have higher trust in the smart pump (mean 2.33, SD 1.15) than the nurses who reported lower levels of fatigue (mean 3.2, SD 1.57). Although burnout, or physical/mental breakdown caused by overwork or stress, was not found to be a significant predictor of smart pump trust ratings, there is a difference in the level of trust between completely burned out nurses (mean 1.8, SD 0.44) and nurses with no symptoms of burnout (mean 2.93, SD 1.47). Nurses who felt they did not have enough time to complete patient care tasks safely tended to have higher trust in the smart pump (mean 2.7, SD 1.3) than nurses who stated they have enough time to complete patient care tasks safely (mean 3.1, SD 1.5). These findings indicate that nurses who feel they have a higher sense of control at work, and work environments that lead to burnout may result in technology over-trust.

Many of this study's limitations reside in the constructs explored. First, interpersonal relationships were not assessed in this study and several studies have found interpersonal and group attitudes about technologies to influence trust³⁵. The survey methods used could be expanded in future studies to provide greater insight into nurses' cognitive and emotional assessments of the pump's physical design³⁶ and better inform the role of aesthetics in ratings of trust³⁷. These methods are widely used in other domains, but have not been widely used in healthcare. Finally, the timing of trust assessments during new technology implementation should be considered in future studies. If an assessment is conducted at an early phase, users' engagement and optimistic attitudes may influence the way they describe the new system²². The data used in this study were collected one year after initial smart pump implementation.

Conclusions

The aim of this study was to understand the technology and system factors that contribute to nurses' trust in a smart IV pump. Three system elements associated with nurses' trust assessments were found: technology characteristics, individual user characteristics, and organization characteristics. These findings support a measure of trust in technology rooted in sociotechnical systems theory³⁸.

The technology characteristic items found to predict trust ratings suggest that well-designed devices may be positively associated with trust in the device. Design considerations based on the technological influencers on trust could include the speed of programming, reliability and durability, noise, alarming, navigation, learnability, and automation transparency. Organizational correlates were also found, and changes to the work environment that prevent worker fatigue and discourage worker over-confidence could be implemented to support appropriate reliance and effective use of technologies meant to improve safety. Design considerations based on the organizational influencers on trust could include worker autonomy, team culture, worker fatigue (staffing, scheduling, workload), and time to complete tasks. In addition, understanding how individual characteristics (e.g. previous experience with technology) may influence trust in technology can inform organizational policies or training programs that are relevant to the nurses who work there.

Considering the system elements that affect nurses' trust in technology is the first step to safe and effective use of existing technology. Research has shown appropriate reliance on technology is influenced by the users' trust in technology^{6,14}. For the human-machine team performance to surpass their individual performances, appropriate reliance on technology must be obtained. This is particularly critical for devices that are increasingly "smart" and increasingly automated. Increasing automation in the workplace may inadvertently affect workload, increase complacency, result in skill degradation, and decrease situational awareness³⁹. The findings presented here can inform the design of healthcare work organizations and healthcare technologies, to avoid the consequences of misaligned trust in technology.

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Table 1

Adjusted R-squared and significance from simple linear regression analyses for perceived technical performance of the smart pump technology items and trust

Construct	Item	Mean (SD)	R square	Significance (p)
Technical Performance	Speed of programming smart IV pump (Too slow to Fast enough)	5.52 (2.35)	0.231	.000 ***
Technical Performance	Reliability and durability of smart IV pump (Unreliable to Reliable)	6.08 (2.09)	0.303	.000 ***
Technical Performance	Smart IV pumps tend to be (Noisy to Quiet)	5.16 (2.59)	0.063	.000 ***
Technical Performance	Alert messages for the drug library (Useless to Useful)	6.20 (2.01)	0.111	.000 ***
Technical Performance	Air-in-line alarms (Annoying to Useful)	3.41 (3.2)	0.048	.000 ***
Technical Performance	Beeps resulting from a delay (Annoying to Useful)	3.36 (3.18)	0.041	.000 ***

Note =

*
p< 0.05

**
p< 0.01

p<0.001

Table 2

R-squared from simple linear regressions on perceived usability items and trust in the smart IV pump features.

Construct (Likert scale)	Item	Mean (SD)	R squared	Significance (p)
Satisfaction (0–9)	How would you rate your interaction with the smart IV pump: Difficult to Easy	6.44 (2.28)	0.226	.000 ***
Satisfaction (0–9)	How would you rate your interaction with the smart IV pump: Frustrating to Satisfying	5.63 (2.13)	0.286	.000 ***
Satisfaction (0–9)	How would you rate your interaction with the smart IV pump: Rigid to Flexible	5.78 (2.07)	0.228	.000 ***
Satisfaction (0–9)	Your level of confidence in responding alert messages (Not confident to Confident)	6.71 (1.86)	0.084	.000 ***
Learnability (0–9)	Learning to operate the smart pump (Difficult to Easy)	6.57 (2.01)	0.037	.000 ***
Learnability (0–9)	Exploring new features by trial and error (Difficult to Easy)	5.95 (2.26)	0.046	.000 ***
Learnability (0–9)	Knowing the available channel labels (Difficult to Easy)	6.07 (2.28)	0.055	.000 ***
Learnability (0–9)	Navigating through the programming software (Difficult to Easy)	5.75 (2.13)	0.066	.000 ***
Learnability (0–9)	Designed for all levels of users (Never to Always)	5.78 (1.89)	0.171	.000 ***
Memorability (0–9)	Remembering medications in the drug library (Difficult to Easy)	5.66 (2.30)	0.051	.000 ***
Expectation (0–9)	Supplemental training materials (Confusing to Clear)	5.11 (1.96)	0.108	.000 ***
Errors (0–9)	Correcting your mistakes (Difficult to Easy)	5.74 (2.09)	0.127	.000 ***
Errors (0–9)	Alarm messages for pump functioning (Frustrating to Acceptable)	5.48 (2.63)	0.109	.000 ***
Errors (1–7)	Alert messages for the drug library (Frustrating to Acceptable)	6.18 (2.02)	0.099	.000 ***
Errors (1–7)	It is able to give appropriate alarm	3.06 (1.55)	0.447	.000 ***
Efficiency (1–7)	It enables me to accomplish the task quickly	3.30 (1.54)	0.365	.000 ***
Efficiency (1–7)	It improves the quality of care I provide	3.03 (1.51)	0.414	.000 ***
Efficiency (1–7)	It improves the safety of care I provide	2.63 (1.55)	0.493	.000 ***
Efficiency (1–7)	It enhances my effectiveness on the job	3.12 (1.52)	0.431	.000 ***
Efficiency (1–7)	It makes it easier to do my job	3.23 (1.58)	0.376	.000 ***
Efficiency (1–7)	It increases the safety of care provided to our patient	2.68 (1.65)	0.507	.000 ***
Efficiency (1–7)	Patients and their families feel they receive safer care	3.65 (1.51)	0.215	.000 ***
Efficiency (1–7)	The pump is easy to use in emergency situation	3.96 (1.77)	0.213	.000 ***
Efficiency (0–9)	Tasks can be performed in a straightforward manner (Never to Always)	5.77 (2.07)	0.235	.000 ***
Efficiency (0–9)	Smart IV pump functions as I expect (Never to Always)	6.05 (1.82)	0.280	.000 ***

Note =

*
p<0.05**
p<0.01***
p<0.001

Table 3

Stepwise regression analyses for model 2: perceived usability of smart pump and trust

Predictor	Estimate	Standard Error	t value	P values
Intercept	1.464	0.284	5.145	.000***
It increases the safety of care provided to our patient	0.380	0.040	9.33	.000***
It is able to give an appropriate alarm	0.323	0.037	8.522	.000***
The interaction with the smart IV pump (Frustrating to Satisfying)	−0.065	0.028	−2.289	0.022 *
Learning to operate the smart pump (Difficult to Easy)	0.069	0.027	2.51	0.012 *
Tasks can be performed in a straightforward manner (Never to Always)	−0.101	0.034	−2.987	0.003 **
Smart IV pump functions as I expect (Never to Always)	0.080	0.030	2.603	0.009 **
Your level of confidence in responding to alert messages (Not confident to Confident)	−0.090	0.041	−2.173	0.030 *

Note:

~p<0.1

*
p<0.05**
p<0.01***
p<0.001. $R^2=0.63$, $F_7, 386=98.44$

Table 4

R-squared and significance from simple linear regression analyses for work environment and quality of work with trust

Construct	Item	Mean (SD)	R squared	Significance
Characteristics of nurses' work environment	How much influence do you have over the availability of supplies and equipment you need to do your work?	3.20 (1.08)	0.029	.000***
Characteristics of nurses' work environment	How much influence do you have over the order in which you perform tasks at work?	3.81 (0.93)	0.017	0.010*
Characteristics of nurses' work environment	How much influence do you have over the decisions concerning which individuals in your work area do which tasks?	2.94 (1.10)	0.013	0.025*
Characteristics of nurses' work environment	How much influence do you have over the decisions as to when things will be done in your work area?	2.83 (1.02)	0.014	0.020*
Characteristics of nurses' work environment	How much influence do you have over the policies, procedures, and performance in your work area?	2.45 (1.05)	0.012	0.032*
Characteristics of nurses' work environment	How much influence do you have over the availability of materials you need to do your work?	2.69 (0.99)	0.036	.000***
Quality of working life	In my work I like to feel I am making some effort, not just for myself but for the hospital as well.	4.02 (0.76)	0.011	0.041*
Quality of working life	Using your own definition of "burnout", select the statement that most closely describes how you feel.	2.13 (0.72)	0.010	0.050*
Quality of working life	How you have been feeling during the past week (Fatigue)?	2.75 (1.03)	0.446	0.039*
Nurses' perception about their performance	I have enough time to complete patient care tasks safely.	3.67 (0.79)	0.012	0.033*

Note=

*
p< 0.05

**
p< 0.01

p<0.001.