Usability Aspects Reduce Design Complexity and Help Prevent Use-Related Errors in ICU Ventilators*

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Abstract

The complexity of the user interface design of critical healthcare devices may lead to use-related errors. Involving users as co-creators to design simple user interfaces for critical healthcare systems helps reduce user-related errors and, ultimately, lowers the risk to life. The participation of co-creators is effective in reducing the design and process complexity while developing the experimental prototype, which may help reduce cognitive load. A usability evaluation was conducted to assess the users' perceptions and real experiences with the experimental prototype in actual settings. The participants involved in this study were requested to perform tasks on an experimental prototype and a questionnaire survey was used to gather the participants' feedback. The results reveal that the interface design increases the user perception of usability by minimizing complexities in design because a strong association between design aspects and system simplicity was observed. The findings provide valuable insight both practically and theoretically to improve the reliability and usability of critical healthcare devices.

Keywords

Critical healthcare devices, Design complexity, End User Development, Participatory design, Usability, User interfaces

1. Introduction

Interface design is crucial in developing an effective interaction between systems and users. However, poor information organization and design complexity may lead to use-related errors. Besides errors, design complexity also increases the information processing time [1]. The cost of the errors may depend on the type of interaction, situation, and context of use. Most of the use-related errors are due to poor interaction and design quality. Coldewey et al. [2] observed that complex user interface design is a source of errors in critical healthcare devices. They further suggested that standardization in the design of interfaces can help to reduce the complexity and use-related errors. Likewise, Jorien et al. [3] state that most incidents while using the healthcare devices reported in the literature are use-related errors. It was also appeared that approximately 50 percent of adverse ventilator events were caused by human use errors [4]. Jiang et al. [4] argue that poor and complex user interface design of critical healthcare devices is the main cause of use-related errors. The World Health Organization (WHO) highlighted that the interface designs of healthcare devices are often complex, difficult to learn, and inappropriate for the situation in which it is adapted to be used [3]. Accordingly to IEC 62366-1 [3, 2] International Standard Organization (ISO) stresses to the manufacturers to ensure the health care devices should be easy and simple to use to minimize use-related errors because reducing the chance of risk increases patient safety. In the Intensive Care Unit (ICU), various healthcare devices (i.e., ventilator system, electrocardiogram

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ECG, monitoring systems, and ventilator system) are utilized to observe the patient's health conditions and statistics. These devices are operated through controls, dialogues, and buttons to facilitate patients in critical situations. It is necessary to pay more attention to cognitive ergonomics/human factors by improving the usability of functional and interaction processes while developing critical healthcare devices [5, 6, 3].

Appropriate design approaches, well-matured development methodologies, and robust Artificial Intelligence (AI) techniques are paramount in designing and developing healthcare devices to build usable, reliable, and trustworthy technologies [7, 8]. Therefore, the blend of user-centric design approaches in relation to "Participatory Design (PD) and End-User Development (EUD)", is considered cost-effective and suitable for developing reliable and customizable systems. [9, 10]. The PD emphasizes the participation and potential contribution of end users as co-creators in the design and development process, ensuring that the intended systems meet users' requirements and expectations [9, 11, 12]. Like PD, EUD requires the involved user to support system customization in the design and development process [10].

The current study aims to employ the relevant design methodologies with modifications to develop usable software systems that meet user requirements and to assess the perceived usability or perception of the user interface developed using the proposed methodology for critical healthcare devices, focusing on ventilators, which are a necessary part of ICUs that provide respiratory support to unstable patients. Their crucial role makes the accuracy of ventilation functions and settings very critical using the adopted methodology (See Figure 1).

In the foundation research, it is important to study the users' experiences with the ventilators. How these experiences, technological fear, poor interaction, and design quality influence their adaptation. The findings helped define the problem and involve the appropriate procedures and relevant users while developing the prototype. The PD approach was adopted to create the design of the prototype of a ventilator. Because the PD empowered the user to participate actively and welcome their feedback during the design and development phase. Their participation as co-creators was important to reduce unnecessary content and be useful to simplify the functional and interaction process through continuous feedback or design iteration. Later, a tool was developed to assess the perceived usability and to explore the user experiences and perceptions about the experimental prototype in actual settings. The objective usability includes only limited measures (i.e., errors, clicks, and task time) to evaluate ventilators in artificial environments such as usability labs. Numerous studies have been conducted to investigate ways to minimize human errors. [4, 13, 14, 5, 15, 16]. However, only a few studies have discussed design strategies to minimize design complexity, cognitive load, errors, or other patient risks. The modified assessment (subjective/perceived usability) tool was observed to be more useful in gathering the users' perceptions in an actual setting, providing more insight into the users' experiences, and seeking important design strategies to ensure simplicity. Therefore, it is important to explore how PD improves the perception of usability by reducing design complexity, which may help clinicians prevent errors in critical situations.

The paper is structured as follows: Section 2 provides the literature review or background, Section 3 outlines the research methodology and experimental design, and Section 4 presents the results and analysis of the experimental data. Finally, the paper concludes with discussions, limitations, and potential directions for future research.

2. Related Work

Using careful design strategies and development methodologies along with consistent user participation during its development is crucial to building effective interfaces of healthcare devices to ensure reliability and efficiency. Feedback from domain experts and users to organize the features, functionality, and information is mandatory to deal with critical situations. The methodologies that discuss the active participation of users and stakeholders in designing and assessing critical healthcare devices may provide more insight into details about the system services, usage context, and situations in which the system should work efficiently. Because the design strategies that strictly follow guidelines related to

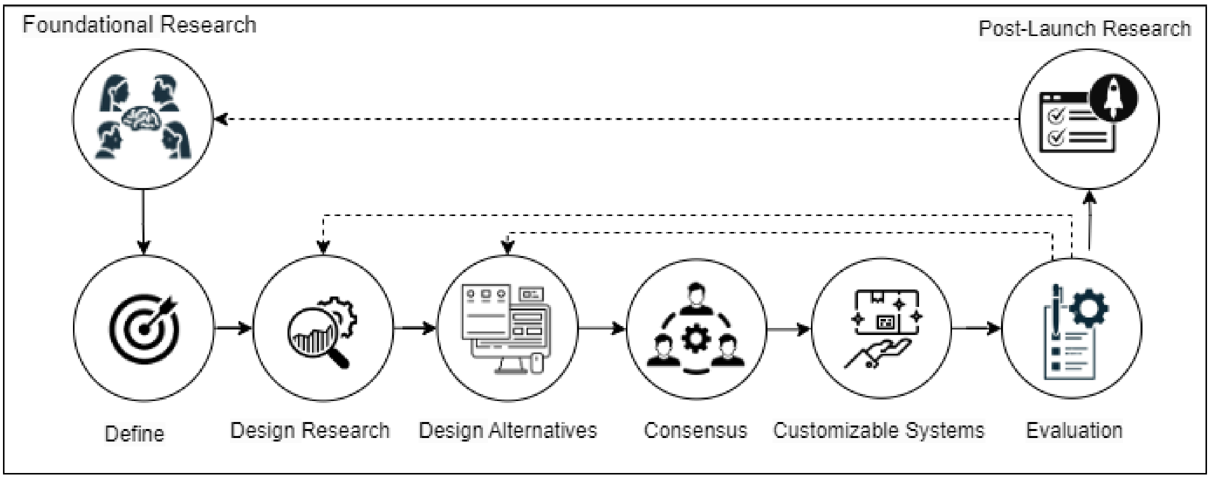

Figure 1: Illustration of the adopted design approach for developing a customizable or critical healthcare system using participatory design guidelines

the user's empowerment reluctantly increase the system's relevancy, innovativeness, and adoption. Human-centered design approaches that involve the user as a co-creator increase efficiency and satisfaction while decreasing the rate of medical errors [5]. This is because treating a serious and unstable patient with poor functional and performing healthcare devices may be dangerous and harmful to the patient [5]. Besides the bad performance and inadequate functionality, the poor usability of the ventilator interface design was discussed as the leading cause of human or use-related errors [5], implying that the precise arrangement of functional features and controls when using interactive screens is paramount to ensure usability and simplicity and to reduce the design complexity. Well-mature tools and designing techniques are important in the development of effective interfaces [17]. However, errors occurred due to incomplete and inappropriate interface design that failed to fulfill the users' needs. Jiang et al. [18] studied the influence of ventilator design on user recognition and overall task efficiency. They argue that choosing the relevant design and ergonomic aspects and studying operator experiences and competency is crucial to avoid errors while operating the ventilators [16]. Moreover, humans cognitive capacity or processing memory is quite limited, so processing the excessive information on the screen also requires extensive cognitive load, which may lead to usability-related errors [5]. Therefore, a well-designed interface, interaction, and hardware quality significantly and positively influence the user perception of critical healthcare devices [15]. Likewise, Liu et al. [14] also identified the effect of information organization on the perceived usability (subjective perception) of the ventilator interface. Due to critical input from physicians, manufacturers should improve the interface design of ventilators to make them error-free and user-friendly [19]. Besides appropriate design strategies and choosing a relevant methodology, it also requires exploring the participation roles (e.g., patients, clinicians, doctors, & medical staff), caregivers, operating environment (e.g., temperature, light, noise, workload, & critical), device types, expectations, process complexity, user demographics, and usage urgency (e.g., convenience, safety, & efficiency) [9].

3. Research Methodology and Experimental Design

The prime objective of the study was to ensure simplicity in the interface design of critical healthcare devices by minimizing the complexity. It requires the selection of appropriate design and assessment approaches to improve the user experience. An experimental prototype was built for the current study (See Figure 2). The prototype was similar to the HAMILTON - C6 ventilator (smart and intelligent ventilators for ICU) [20] and considered a reliable and efficient ventilator in the technological studies [16, 15]. The interface design of the employed ventilator was altered with a little bit of design variations by involving the users as co-creators or designers. The PD empowers the user/ stakeholders (doctor,

Figure 2: Developed experimental prototype of the selected ventilator

Table 1
System Usability Scale

No.	Survey Items	Mean	SD
1	The interface design use appropriate colors, animation, images, and layout.	4.82	1.765
2	The system switches from one screen to the next smoothly.	4.81	1.752
3	I found the various functions in this system were well integrated.	4.87	1.842
4	Is the system consistent?	4.80	1.893
5	The system uses controls that are immediately obvious.	4.91	1.790
6	It was easy to learn to use the system.	3.99	2.215
7	I found that the system is simple. (Dependent variable)	4.92	1.721

medical staff, and caregivers) to participate actively so the designers can understand their actual needs during the design process. An experiment was conducted to evaluate the perceived usability of experimental ventilators in the intensive care units of hospitals. Usability is a quality factor that precisely describes the users' experiences with technologies and software systems with respect to their needs, expectations, values, abilities, and context of use [21, 22]. The experimental prototype was deployed online using web-based services. A 19-inch touchscreen system (16 GM RAM with NVIDIA graphic card) was used for experimentation and data collection, whereas the originally targeted ventilator was 17 inches. Written instructions and guidelines for the chosen task were provided to the participants before the experiment. The tasks include starting ventilation, changing the setting, and changing the model only. In 13 months, 167 people participated in the experimentation with complete feedback. Several reliable system usability assessment tools (e.g., system usability scale) are available in the literature to evaluate perceived usability. The survey tools employed in this study include ten survey items using a Likert-scaled incurring rating from "strongly disagree, disagree, neutral agree, and strongly agree". It specifies the degree to which users perceived the technology as complex, easy to use, cumbersome, consistent, integrated functions, supportive, requires significant learning, and confident or other experiences (see Table 1). The measurement items to gather the user perception for the experimental prototype were adopted from the literature [23, 24, 25, 26, 27, 28, 29, 30]. The used items were modified to achieve the required assessment goals by gathering the participants' experience and true perception of the developed prototype.

Table 2
Correlations: Pearson Correlation

	7.	1.	2.	3.	4.	5.	6.
7.	-	.563	.600	.678	.742	.706	.444
1.	.563.	-.	.551.	.528	.554	.542	.332
2.	.600	.551	-.	.611	.558.	.584	.341
3.	.678	.528	.611	-	.747	.649	.401
4.	.742	.554	.558	.747	-	.659	.431
5.	.706	.542	.584	.649	.659	-	.397
6.	.444	.332	.341	.401	.431	.397	-

Table 3
Model Summary

R Square	Adjusted R Square	Std. Error of the Estimate	F Chan	Significance. F Change
.666	.662	1.000	211.921	.000

Table 4
Model Summary: Structured Model

Model	B	Std. Error	Beta	t	Significance
Constant	.505	.137	Beta	3.696	.000
1. Interface Design → Simplicity (less complex)	.081	.029	.083	2.773	.006
2. Smooth Transitions → Simplicity (less complex)	.114	.031	.116	3.680	.000
3. Functional Integrity → Simplicity (less complex)	.092	.035	.098	2.605	.009
4. Consistency → Simplicity (less complex)	.312	.034	.343	9.081	.000
5. Control Obviousness → Simplicity (less complex)	.260	.033	.271	7.989	.000
6. Easy to Lean → Simplicity (less complex)	.064	.020	.082	3.161	.002

4. Results and Discussion

Linear regression (LR) was used to explore the significance of usability and design aspects that are important to minimize the complexity of interface design. The SPSS software was used to perform the LR. LR is a statistical approach to assess the strength of the relationship or association between independent and dependent variables [31]. It intends to model the relationship between the variables by appropriate fitting a linear equation (linear expression) to the observed (experimental) data [31]. This method is extensively used for forecasting and prediction in technological studies [31]. The computed results revealed that the adopted methodologies show significant outcomes (see Tables 2, 3, 4). The design strategies used to develop the interface design and organize the features improve the user interaction with the developed prototype of the employed ventilator. In continuation, several other studies [16, 15] also emphasized the need to improve the user experiences and initial perception of ventilators by minimizing the design and process complexities. The results also provided sufficient grounds for the employed design approaches and development methodologies (PD). It was observed that the developed user interface for the selected ventilator improves user perception by ensuring simplicity in design, process, and information organization. In a study, Lee et al. [1] also observed simplicity as the principal component of perceived usability, significantly improving users' initial perceptions and positive experiences with technologies. Simplicity is a crucial component of a highly usable interface. A simple and well-structured interface design to support task performance, layout, hierarchical organization, animations, and visual elements improves the user perception of usability and learning to use. The easy-to-learn and easy-to-use supports the users in task performance and prevents them from input errors. Moreover, safe input values, instantaneous information, and quick settings to control the ventilator provide the ideal usability experience. Likewise, simplicity means a layout that includes a framework having well-structured processes and information, interface organization, proper arrangement functionality and features to ensure smooth workflow [1, 32, 33].

5. Conclusion

Simplicity reduces complexity as complex user interface design (touch screen and physical e.g., LEDs, knobs, and touch buttons) of critical healthcare devices may lead to use-related errors. Involving users as co-craters to design simple user interfaces for critical healthcare systems helps reduce user-related errors and, ultimately, lowers the risk to life. The participation of co-creators is also effective in reducing the design and process complexity while developing the experimental prototype, which may help reduce cognitive load. Likewise, Katre et al. [19] argue that due to critical input from physicians, manufacturers should improve the interface design of ventilators to make them error-free and user-friendly. A usability evaluation was conducted to assess the users' perceptions and real experiences with the experimental prototype in actual settings. The test and questionnaire concerning the experimental prototype revealed a strong association between design aspects and the simplicity of the system. This implies that a well-integrated, and organized design presenting only essential information, and supporting the user in performing the relevant tasks and operations is very important to deal with the patient in critical situations to foster the safety and reliability of critical healthcare devices.

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