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DESIGN OF A MOBILE WEB-BASED DASHBOARD TO IMPROVE WORK PRACTICES OF CRNA BOARD RUNNERS

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DESIGN OF A MOBILE WEB-BASED DASHBOARD TO IMPROVE WORK PRACTICES OF CRNA BOARD RUNNERS

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ABSTRACT

Traditional artifacts such as whiteboards serve as key tools in helping healthcare professionals keep track of frequently changing information and managing their work schedule. The simplicity of these tools has made them easy to adopt into the work culture and since these artifacts are not usually electronic, they need no external technical support or maintenance. However, these artifacts present unique challenges to their users, the primary one being lack of mobility offered. The whiteboards are usually stationary and the users will have to assemble near them to update or gather information. In a hospital, this adds significant overhead to the workflow efficiency since users will have to spend time walking from their changing locations to the whiteboards. In addition, the fact that these artifacts are not electronic means that they cannot be connected to the information technology (IT) system, meaning the information present on them are not updated in real-time.

In this research, such challenges faced by certified and registered nurse anesthetists (CRNA) board runners of a large regional hospital in the south eastern United States were studied. To help address the challenges faced by the board runners in their task execution, a new web app designed for the Google Nexus 7 tablet was introduced as a potential replacement for the whiteboard. Ten board runners participated in this study to evaluate the new web app in comparison with the whiteboard in a simulated work environment. The participants were given 10 different tasks to perform with both the web app and the whiteboard. Measures such as task performance (time and errors), situational awareness (SA), needs ratings, system usability and perceived workload were collected and analyzed. Once the web app and the whiteboard were evaluated, a preference ranking for the type of device was also collected from all the participants.

Time taken for overall task execution was longer for the whiteboard and the errors committed did not differ significantly among the two devices. SA was found to be similar across the devices and there were no significant differences. All 6 primary needs collected and the overall system usability were rated significantly higher for the web app. The workload indices of mental demand, physical demand, temporal demand, effort and frustration had significantly higher ratings for the whiteboard and the performance was rated significantly higher for the web app. All of the 10 participants preferred the web app over the whiteboard.

DEDICATION

This project is dedicated to my wife Hridya, my little boy Arnav, my parents K.V. Sreedhara Variyar and P.V. Sathya Bhama, my parents-in-law A.P Haridas and Jaya Haridas, for being my pillars of support; and to the healthcare professionals for their contributions to humanity.

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CHAPTER ONE

INTRODUCTION

Mobile devices such as smartphones and tablet PCs have transformed how business professionals exchange information and ideas, and stay connected with their colleagues. These devices, with continually evolving features and options such as voice-controlled apps, GPS systems, and responsive web-browsers, are proving to be key assets in improving work-practices in an industrial setting (Boulos, Wheeler, Tavares & Jones, 2011). Their increasing use is attributed primarily to mobility, the ability to have access to real-time information independent of location. For example, SmartGlance, a mobile web dashboard developed and marketed by Invensys is used by professionals on their smartphones and tablets to access on-demand or automated reports of company performance indicators (Wonderware Smartglance, n.d.). Immediate access to this information aids the users in making decisions and communicating with other stakeholders with little delay.

Professionals in the healthcare industry, however, have been slower in integrating mobile devices into their work culture for various reasons (Boulos et al., 2011). The healthcare domain is characterized by highly collaborative, complex workflows. In a hospital, doctors, nurses, certified and registered nurse anesthetists (CRNAs), and anesthesiologists collaborate among and across team members, spread over different units-of-care such as operating rooms (ORs), charge desks, outpatient clinics, post anesthesia care units, and pre-op and post-op areas to gather information and deliver patient-care. The flow of information from one unit to another is often *ad-hoc*, lacking any regular pattern. External variables, for example, unexpected add-on and emergency cases complicate the information flow further. New mobile technologies introduced have often failed to adapt to this complex and dynamic environment, resulting in limited use among medical professionals. In addition, usability issues such as difficulty in entering data and small screen size have also hindered the adoption of mobile devices into the work practice (Wu, Wang & Lin, 2007; Haller, Haller, Courvoisier & Lovis, 2009).

Even though the rate of acceptance of mobile devices has been slow, their use among healthcare professionals has been growing steadily over the last five years. Physicians and anesthesiologists are increasingly using apps on their smartphones to keep track of their schedules, view changes in patient status, and refer to drug dosage data (Boulos et al., 2011). Having such information readily available has given them the freedom to engage with patients away from their offices. Because of these benefits, healthcare professionals are beginning to view mobile devices as tools that can enhance their practice by offering this mobility and functionality in a device that fits into one's pocket (Lu et al., 2003). In fact, a Pricewaterhouse Coopers report on mobile usage among healthcare professionals indicates that 59% of the physicians surveyed see adoption of mobile health applications in their practices in the near future (Pulling it all together: social, mobile, analytics, cloud, 2012).

While the current research suggests that mobile technology has the potential to have a positive impact on healthcare, the extent of this impact needs further research (Caroll & Christakis, 2004; Phillips, Felix, Galli, Patel & Edwards, 2010). To address this need, this research proposes to investigate the effectiveness of a mobile device in improving the work practices of a specific group of healthcare professionals, CRNA board runners in perioperative services. These medical professionals are highly mobile in their daily routine and require access to real-time information. As such they represent an appropriate group to which a new mobile technology might be introduced and evaluated. This research will be conducted at a large regional hospital in the south eastern United States.

The hospital is a 746-bed, Level 1 trauma center, with 30 ORs divided into three groups or cores, B, C and D; 3 gastro-intestinal (GI) rooms; and a separate child specialty center. Among the 40 CRNAs employed there, on average 30 will be present daily to staff these units over three shifts. Of the 30, one is chosen by the team manager, based on experience, to function as the board runner during the busiest 7 a.m. to 3 p.m. shift. He/she is responsible for assigning the team members to different units as needed and relieving them for breaks at mid-morning, lunch and mid-afternoon. These two tasks involve important challenges. The board runners have to keep track of a multitude of evolving parameters such as the statuses of the team members, the ORs, the GI rooms, the add-on cases, the unexpected delays, the emergency cases, and the break information of the team members. All these variables affect the CRNA assignment, and proper staffing at the right times is crucial in delivering care.

Handling this amount of information can be challenging for the board runner, a situation compounded by the fact that this information is spread across locations and artifacts. For the real-time status information, the board runner relies on four large electronic display boards located at the entrance of the OR floor. These boards, part of the Information Technology (IT) infrastructure at the hospital maintained by IBSS Inc headquartered in Columbia, SC, through its proprietary software system SynTrack OR-Max™ (OR-Max, n.d.), display status information on the staff scheduled for a room, the patients, and the type and expected duration of scheduled procedures. From these data, the board runners focus on the changing status of their team members and the units.

Any updates in this status are captured on a whiteboard just below the electronic boards. This whiteboard is divided into three sections, each serving its own purpose. On the left is an array of small rectangular magnetic tags, each marked with the name and shift time of a CRNA. The middle is subdivided into three columns, each representing one of the OR cores. Each column contains 10 cells representing the ORs in that core. The upper right corner is used to hold the tags for GI and child specialty center and the lower right is designated to hold the magnetic tags of those CRNAs currently free, that is, not assigned to any unit and, thus available as needed. To capture a change, for example, if a CRNA needs to be assigned to an OR, the board runner moves the magnetic tag of this team member from the left of the white board to the appropriate cell in the middle, representing assignment to the OR. This assignment is at the discretion of the board runner and is done after evaluating if the CRNA's shift time and expertise fit the assignment.

In addition to the electronic boards and the whiteboard, two other whiteboards are placed in the CRNA break room; one is dedicated to mid-morning and lunch, and the other to mid-afternoon break. The challenge in using these boards is that each can have as many as 30 names for just one break. Because the break information is not available from the electronic boards, these whiteboards help the board runner to be aware of the current break situation of the team members and to make decisions on assignments in light of the break schedule.

Monitoring the electronic boards, updating the whiteboards and keeping track of names on the break room boards is quite demanding. This situation is further complicated by the board runners' need to be mobile to execute their task of giving breaks. At 8:30 a.m., 11:30 a.m., and 2:00 p.m., the CRNAs listed on the break boards are called through a voice-controlled device (Vocera) to check if they need a break. If the response is affirmative, the board runner walks from the break room to each of the units and relieves them, one at a time. Being tied to the whiteboard and electronic boards for information updates, and covering 30 ORs, three GIs and the child specialty center at three different times involves a lot of walking. In fact, during one of the preliminary observations for this research, one board runner commented, "I walk an average of 4 miles a day when I run the board."

To help the board runners more efficiently and effectively accomplish their tasks, this research proposes to develop a web-based dashboard on a mobile device to potentially replace the three whiteboards, an idea receiving support from the board runners and their managers. The decision to use a web-based dashboard rather than a native application was made based on the following considerations:

- It can be more easily integrated with the existing web-based IT system (OR-Max).
- It eliminates the need to install the solution on individual devices.
- Its interface can be designed to be platform-independent, allowing its use on multiple devices.

The mobile device used in this study will be the Google Nexus 7 tablet PC. The research will be conducted in the following phases:

1. Follow a user-centered product design methodology (Ulrich & Eppinger, 2012) to design the dashboard interface.
2. Conduct a controlled behavioral study to evaluate the effectiveness of the dashboard in comparison to the existing whiteboards.

These phases are described in more detail in the methodology section.

CHAPTER TWO

LITERATURE REVIEW

Existing research suggests that the successful introduction of mobile technology to medical professionals is dependent on the characteristics and use of the physical artifacts that it intends to augment (Nemeth, O'Connor, Klock & Cook, 2006). These artifacts, for example paper charts and whiteboards, have been found to play a key role in collaborative work in this field because of their cognitive properties (Norman, 1990; Hutchins, 1995). These properties, according to Zhang (1997), include serving as memory aids, both short-term and long-term, to reduce memory load; providing ready-to-use information so that there is little effort in interpreting the information; simplifying a task by generating efficient action sequences; making invisible and transient information visible; and maximizing accuracy by facilitating decision making.

More specifically, in a work-environment people use these properties to execute a wide variety of tasks efficiently by representing their internal information on the external artifacts (Zhang & Patel, 2006). Researchers (Hutchins, 1995; Zhang, 1997) term such distribution of knowledge across internal and external representations as "distributed cognition." Since information is spread across these components, the relationship between them characterizes the collaborative actions of the people in the work-environment. Such an environment is referred to as a distributed cognitive system (DCS) (Zhang & Patel, 2006).

Hutchins (1995) uses the analysis of an airline cockpit system to illustrate the collaborative use of the cognitive properties of artifacts. To make an appropriate adjustment in the speed of an aircraft during take-off and landing, the co-pilot checks the weight of the aircraft, one of the parameters indicated on the fuel quantity indicator (FQI). He then checks this value on the appropriate speed card indicating the permissible speed for the weight. He reads this value aloud to the pilot before placing the artifact in a visible location for easy referral for both of them. The pilot orally confirms the value he heard and adjusts the speed of the aircraft.

In this system, the interwoven relationship between the internal mental model of the pilots and their external representations exemplifies a DCS. The weight indicated on the FQI, which is short-lived, is captured by the co-pilot's memory and represented on an artifact, the appropriate speed card. The card acting as a memory aid thus helps retain the transient information (weight) and emphasizes the information as it is placed in a location visible to both the pilots, thereby avoiding the need to memorize the spoken words (also transient information) of the co-pilot. In addition, the card exemplifies Zhang's other cognitive properties of providing ready-to-use information, facilitating decision-making and improving efficiency, making it an intrinsic component of the collaboration in the cockpit system.

Similarly, the cognitive properties of artifacts used in healthcare have been investigated to understand their role in collaborative work. Bardram's (1997) observations of a planning board used by the staff of a radiology department in a cancer center revealed that the board offered functionalities to the staff that made their task execution easier. It gave an overview of examinations to be performed over a 13-week time frame, helping the staff to improve administering treatments to patients whose schedules spanned more than 10 weeks, thus acting as a memory aid. Further, the board was highly conspicuous to all team members, which made transient information such as evolving statuses visible to all staff, helping them visualize the workloads and making the adjustments needed in the case of conflicts. The study concludes suggesting that technology introduced to support the staff should consider retaining these properties.

More recently, a study conducted by Lasome and Xiao (2001) investigated the properties of a whiteboard used by nurses in a Level-1 trauma center OR that need to be reflected in computer displays. The study found that the flexibility of the board with its easy-to-use magnetic tags helped the staff store and update statuses, visualize workload, and communicate with other team members. The researchers suggest that computer displays should accommodate these features to fulfill the need of shared awareness to ensure their successful use. They also argue that the successful adoption of computer displays is further dependent on their flexibility to change according to users' needs over time.

A related study by Xiao, Lasome, Moss, Mackenzie and Faraj (2001) analyzed the advantages and disadvantages of a whiteboard in an OR and how technology can help address the limitations while retaining the benefits. According to the researchers, the simplicity of the board allowed for representing the staff assignments or schedule changes with very little effort. Further, the team members gathered and updated their statuses directly in front of the board, improving interpersonal communication and collaboration. The researchers advise that for the successful implementation of computer displays, these features offered by the whiteboard should be maintained, including the collaboration mediated by its stationary characteristic.

However, the fact that the board was stationary, the researchers point out, was also a disadvantage. Events in the OR change rapidly, and the staff may be unable to access the board quickly to obtain updated information. If technology can relieve the staff from this constraint by affording mobility, it can facilitate timely coordination. Also, if new technology can be integrated into the existing IT system, the staff could manage data entry through this technology and eliminate the need to also maintain the whiteboard.

These studies direct the attention of the research community toward the possibility of introducing technology to medical professionals that is mobile, affording the flexibility of accessing real-time information and providing visibility of status to the stakeholders regardless of their location. Though the studies present the implications of the stationary computer displays, there is limited research on how these findings could be extended to small mobile devices. However, since the early 2000s, the increasing availability of mobile devices such as personal digital assistants (PDAs) has prompted researchers to explore the use and impact of mobile devices among healthcare professionals.

One such study, conducted by Aziz et al. (2005), compared the use of PDAs with pagers in facilitating communication among physicians, focusing on the response times to random calls initiated by the research team. The study found that for the PDAs, both the average response times and the failure to respond were lower than for the pager, because the former allowed for the direct immediate communication important in critical situations, while the pager required the physicians to locate a phone to respond.

The effect of mobile handhelds was further explored by Adams et al. (2006) in their study investigating response times of cardiologists in performing the procedure of percutaneous coronary intervention. At a 756-bed hospital, they observed how these times were affected when patient data were transmitted directly to a wireless handheld device compared to when the data was carried by the nurses in person. The results revealed that the median time was reduced to 50 minutes from 101 minutes ($p < 0.0001$) when employing wireless data transmission. The researchers suggest that this is "significantly shorter" and can help healthcare professionals save time and adhere to quality standards while delivering timely patient care. They attribute this to the mobility and wireless capability offered by the handhelds.

Though mobile devices have been found to have a positive impact on the healthcare workflow, researchers suggest that their adoption depends on several factors. Holzinger and Errath (2007) found that the usability of the device depends on the ease with which the interface can be used. After studying the use of a web-interface designed for clinicians, the researchers suggested that the key strokes needed to accomplish a task should be as few as possible. Further, the interface should keep horizontal scrolling to a minimum and present only the necessary information upfront with details being presented on demand. These features are important in a dynamic and fast-paced environment like healthcare.

The researchers also discuss guidelines related to errors, including: providing a back button on the interface for reversibility, requiring confirmation if the requested action causes a change and displaying meaningful error messages. To avoid errors, they suggest the following guidelines:

- Avoid unnecessary text entry
- Provide default values wherever possible
- Enable users to exit the application quickly without losing any information
- Provide functionalities that are easy to use and navigate and prevent unintended consequences.

In a similar study, Alnanih, Radhakrishnan and Ormandjieva (2011) suggested further guidelines for designing user interfaces for mobile devices in healthcare. One important feature is for the interface to be “context-aware,” so that it can change depending on the users’ environment, thus facilitating data entry and information access. For example, if the interface can adjust automatically to user preferences based on their login credentials or time of use, it can avoid the necessity of the additional step of adjusting the display manually before using it. Such intelligent displays help ensure user satisfaction in terms of ease-of-use.

Even though these studies have analyzed the use of mobile devices, there is limited research addressing their feasibility as replacements for artifacts such as whiteboards. Further, there is limited literature available on the impact of new generation mobile devices such as smartphones and tablet PCs in healthcare, perhaps because powerful mobile technology has become available only in the last few years. To address this situation, this research investigates how the functionalities of a whiteboard can be adapted in a mobile device to aid in collaborative work for CRNAs.

CHAPTER THREE

DESIGN OF MOBILE INTERFACE

To provide the functionalities of a whiteboard on a mobile device, this research focuses on designing a web-based interface for a Google Nexus 7 Tablet by adapting the User-Centered Design methodology developed by Ulrich and Eppinger (2012). The methodology will include the following four steps:

1. Identification of user needs
2. Identification of metrics
3. Concept generation, detailed design, formative testing and iterative refinement
4. Summative concept testing

Steps 1, 2 and 3 will be termed as Phase 1 of this research and Step 4 will be conducted in Phase 2.

Step 1. Identification of User Needs

Observations were conducted at the hospital to determine the needs of the board runners. IRB approval for this phase was obtained by the research team (see Appendix 1). The CRNA manager recommended the participants to be shadowed. Six board runners and 3 CRNAs were shadowed over a period of 6 days, Monday through Saturday, to understand how board runners interact with the whiteboard and their peers. The morning shift, 7 a.m. to 3 p.m., was chosen for these observations because it is usually the busiest time with the level of surgical activities that require the use of a board runner. During this time, the research team also spent two morning shifts in the ORs to observe the interaction of the board runners with the CRNAs.

While shadowing, the research team took notes of their observations, and any questions or clarifications needed were directed to the board runners when they were free to respond. In addition to the observations, the CRNA nurse manager and the Director of Perfusion and Anesthesia Services were interviewed to understand their managerial goals and constraints.

Data gathered from the observations and interviews were interpreted, analyzed and phrased as the need statements shown in Table 3.1. For example, it was observed that the board runner tilted magnetic tags on the board at an angle to indicate when CRNAs were nearing the end of their shift. This observation was translated into Need Statement 5 as “the system displays which CRNAs are nearing end of shift.”

The resulting 40 need statements represent the potential features to be implemented in the proposed mobile interface. Using an affinity diagram, these needs were subsequently grouped into the 6 primary needs and 40 secondary needs seen in Table 3.1.

Table 3.1: Hierarchical list of needs from observations

	Staff information displayed on the interface
1	The system displays a real-time list of available CRNAs.
2	The system displays which CRNAs need breaks during break times (typically 8.30 a.m., 11.00 a.m. and 1.30 p.m.).
3	The system displays which CRNAs do not need breaks during break times (typically 8.30 a.m., 11.00 a.m. and 1.30 p.m.).
4	The system displays whether a CRNA who needs a break has been relieved

	by an available CRNA.
5	The system displays which CRNAs are nearing end-of-shift.
6	The system displays the shift times of the CRNAs scheduled for the day.
7	The system displays the shift end-time of the CRNAs scheduled for the day.
8	The system explains the meaning of any color codes for CRNA names (for example, regarding break information and status).
9	The system displays the current location of each anesthesiologist.
10	The system displays the anesthesiologist assigned to each OR.
11	The system displays names of students/residents assisting CRNAs in each OR.
	CRNA information entered on the interface
12	The system allows the board runner to update shift times of CRNAs in OR-Max.
13	The system allows the board runner to assign CRNAs to rooms for the next day as well as on the same day based on their schedule and availability (more than one CRNA may be assigned to some rooms).
14	The system allows the board runner to maintain an updatable list of the availability of the CRNAs (Available, Not available, On call).
	Procedure and room status displayed on the interface
15	The system displays the status of GI rooms around 2.00 p.m.
16	The system displays information from the charge desk about case delays and add-on cases.
17	The system displays the status of a procedure in progress.
18	The system displays the type of procedure in progress in each OR.
	Enabling status communication with the team
19	The system enables the board runner to update the charge desk whether a CRNA is available to handle an add-on case.
20	The system enables the board runner to update the charge desk when a CRNA is available to handle an add-on case.
21	The system enables the board runner to determine the status of ORs that are 'On Hold' due to unavailability of CRNAs for staffing.
22	The system enables the board runner to communicate the status of ORs that are 'On Hold' due to unavailability of CRNAs for staffing.
23	The system allows the board runner to determine the status of ORs that are in the 'Get ready' process.
24	The system allows the board runner to communicate the status of ORs that are in the 'Get ready' process.
25	The system helps the board runner to communicate with CRNAs about their current case.
26	The system helps the board runner to communicate with CRNAs about their next case.
27	The system helps the board runner to communicate with CRNAs to coordinate preparation for an upcoming case.

	Ease of use
28	The device fits securely in a scrub's pocket.
29	The system minimizes the use of Vocera.
30	The system minimizes the use of personal phones.
31	The system does not overwhelm the board runner with information.
32	The system's interface is easy to use.
33	The system is easy to keep track of.
	User satisfaction
34	The system reduces the need for the board runner to walk from location to location.
35	The system eases the task of managing breaks for the CRNAs.
36	The system eases the task of assigning CRNAs to ORs.
37	The system eases the task of relieving CRNAs when they approach the end of their shift.
38	The system enables CRNAs to arrange for someone in the team to give them a break without the help of the board runner.
39	The system enables better communication between the board runner and the CRNAs.
40	The system eliminates the need to have and use a white board.

These 40 need statements were given to the CRNAs in the survey format seen in Appendix 2. On the left, the users rated each on a scale of 1-5, with 1 being the least important and 5 being the most. On the right, they checked if they thought the need was unique, exciting or unexpected.

The CRNA manager was informed of the survey three days in advance through email, in turn communicating this information to the CRNAs. On the scheduled day, the surveys were printed and placed in the break room for the participants to complete during their free time. A member of the research team was present in the break room for the day to clarify any questions. A total of 17 CRNAs, 6 of them with experience as board runners, completed the survey. In addition, the CRNA manager and the Director of

Anesthesia and Perfusion Services were surveyed to obtain the ratings from the clients' perspective.

Table 3.2 shown below lists the needs and their mean ratings of both the users and the clients. As seen in the table, there are no practical significant differences between the ratings for the needs across these two groups. The mean ratings of the needs determined their priority for implementation in the proposed solution. The research team set a threshold user rating of 4.0 for a need to be considered critical, with 25 such needs being identified. All 6 primary needs were encompassed by these, with none being identified as unique by the users.

Table 3.2: Mean rating of needs

Sl. no	Need statement	User Rating	Client Rating
1	The system displays real-time list of available CRNAs.	4.65	4.50
2	The system is easy to keep track of.	4.59	4.50
3	The system displays the shift times of the CRNAs scheduled for the day.	4.47	4.00
4	The system's interface is easy to use.	4.47	4.50
5	The system eases the task of relieving CRNAs when they approach the end of their shift.	4.47	4.00
6	The system enables better communication between the board runner and the CRNAs.	4.41	4.00
7	The system displays the shift end-time of the CRNAs scheduled for the day.	4.35	4.00
8	The system displays which CRNAs need breaks during break times (typically 8.30 a.m., 11.00 a.m. and 1.30 p.m.).	4.29	4.00
9	The system eases the task of assigning CRNAs to ORs.	4.29	4.00
10	The system eases the task of managing breaks for the CRNAs.	4.24	4.00
11	The system displays information from the charge desk about case delays and add-on cases.	4.19	4.50

12	The system displays which CRNAs are nearing end-of-shift.	4.18	4.50
13	The system allows the board runner to maintain an updatable list of the availability of the CRNAs (Available, Not available, On call).	4.18	4.00
14	The system displays the status of a procedure in progress.	4.18	4.50
15	The system does not overwhelm the board runner with information.	4.18	4.50
16	The system helps the board runner to communicate with CRNAs to coordinate preparation for an upcoming case.	4.13	4.50
17	The system displays the type of procedure in progress in each OR.	4.12	4.50
18	The system helps the board runner to communicate with CRNAs about their next case.	4.12	4.50
19	The system displays the status of GI rooms around 2.00 p.m.	4.06	4.50
20	The system reduces the need for the board runner to walk around.	4.06	4.50
21	The system enables CRNAs to arrange for someone to give them a break without the help of the board runner.	4.06	4.00
22	The system displays whether a CRNA who needs a break has been relieved by an available CRNA.	4.00	4.00
23	The system helps the board runner to communicate with CRNAs about their current case.	4.00	4.00
24	The system allows the board runner to assign CRNAs to rooms for the next day as well as on the same day based on their schedule and availability (more than one CRNA may be assigned to some rooms).	4.00	4.50
25	The device fits securely in a scrubs' pocket.	4.00	4.50
26	The system displays the anesthesiologist assigned to each OR.	3.88	4.00
27	The system minimizes the use of Vocera.	3.82	4.00
28	The system enables the board runner to update the charge desk as to whether a CRNA becomes available to handle an add-on case.	3.76	3.00
29	The system enables the board runner to update the charge desk when a CRNA is available to handle an add-on case.	3.76	3.00
30	The system allows the board runner to determine the status of ORs that are in the 'Get ready' process.	3.76	4.00

31	The system allows the board runner to communicate the status of ORs that are in the 'Get ready' process.	3.71	3.00
32	The system eliminates the need to have and use a white board.	3.71	4.00
33	The system allows the board runner to update shift times of CRNAs in OR Max.	3.65	3.50
34	The system minimizes the use of personal phones.	3.65	4.00
35	The system explains the meaning of any color codes for CRNA names (for example, regarding break information and status).	3.59	4.00
36	The system enables the board runner to determine the status of ORs that are 'On Hold' due to unavailability of CRNAs for staffing.	3.59	4.00
37	The system displays which CRNAs do not need breaks during break times (typically 8.30 a.m., 11.00 a.m. and 1.30 p.m.).	3.53	4.00
38	The system enables the board runner to communicate the status of ORs that are 'On Hold' due to unavailability of CRNAs for staffing.	3.53	4.00
39	The system displays names of students/residents assisting CRNAs in each OR.	3.41	4.00
40	The system displays the current location of each anesthesiologist.	3.12	3.50

Step 2. Identification of Metrics

Based on the 25 most important need statements obtained in Step 1, the subjective and objective metrics describing the output of the system were identified. These metrics were distributed to the users in a questionnaire format for data collection and statistical analysis in Phase 2. A system usability scale (SUS) (seen in Appendix 4), the NASA Task Load Index (NASA-TLX) (seen in Appendix 5), and a Likert scale (seen in Appendix 6) were also used in Phase 2 to measure satisfaction of some needs. Table 3.3 shows the needs, the metrics and the associated tasks.

Table 3.3: Metrics and tasks identification

Need #	Need	Rating	Metric	Measurement	Task
1	The system displays a real-time list of available CRNAs.	4.65	Time taken to find the number of available CRNAs. Number of errors committed.	Seconds #	Find the number of available CRNAs.
			User rating of system's ability to display a real-time list of available CRNAs.	Subjective measure : 1-5 scale	
2	The system is easy to keep track of.	4.59	User rating of system's track-ability.	Subjective measure : 1-5 scale	
3	The system's interface is easy to use.	4.47	Ease of use	SUS-3: I thought the system was easy to use.	
4	The system displays the shift times of the CRNAs scheduled for the day.	4.47	Time taken to find the shift times of four available CRNAs. Number of errors committed.	Seconds #	Find the shift times of CRNAs A, B, C and D.
			User rating of the system's ability to display the shift times of CRNAs.	Subjective measure : 1-5 scale	
5	The system eases the task of relieving CRNAs when they	4.47	Mental demand Physical demand	NASA TLX	1. Find the names of

	approach the end of their shift.		Time taken to find the names of CRNAs nearing their end of shift Time taken to assign two available CRNAs to cover for two CRNAs nearing the end of their shift. Number of errors committed.	Seconds Seconds #	CRNAs nearing their end-of-shift. 2. Assign CRNAs A and B to two ORs 12 and 26.
6	The system enables better communication between the board runner and the CRNAs.	4.41	User rating of system's effectiveness in enabling communication between the board runner and the CRNAs.	Subjective measure : 1-5 scale	
7	The system displays which CRNAs need breaks during break times (typically 8.30 a.m., 11.00 a.m. and 1.30 p.m.).	4.35	User rating of the system's effectiveness in displaying break requests of CRNAs.	Subjective measure : 1-5 scale	Find the names of CRNAs who need a break.
			Time taken to find the number of CRNAs who need a break. Number of errors committed.	Seconds #	
8	The system displays the shift end-times of the CRNAs scheduled for the day.	4.29	User rating of system's effectiveness in displaying shift times of CRNAs.	Subjective measure : 1-5 scale	Find the shift times of CRNAs A, B, C and D.
9	The system eases the task of assigning CRNAs to ORs.	4.29	Time taken to complete the assignment task.	Seconds #	Assign CRNAs A and B to two ORs 12 and 26.

			Number of errors committed.		
			Mental demand	NASA TLX	
10	The system displays information from the charge desk about case delays and add-on cases.	4.24	User rating of system’s effectiveness in displaying information from the charge desk about case delays and add-on cases.	Subjective measure : 1-5 scale	
11	The system displays which CRNAs are nearing end-of-shift.	4.19	User rating of system's effectiveness in displaying end-of-shift status.	Subjective measure : 1-5 scale	Find the names of CRNAs nearing their end-of-shift.
			Time taken to find the number of CRNAs whose shifts end in 30 minutes.	Seconds	
			Number of errors committed.	#	
12	The system displays the status of a procedure in progress.	4.18	User rating of system's effectiveness in displaying the status of procedures in progress.	Subjective measure : 1-5 scale	
13	The system does not overwhelm the board runner with information.	4.18	Mental demand	NASA TLX	

14	The system eases the task of managing breaks for the CRNAs.	4.18	Mental demand Physical demand	NASA TLX	1. Find the names of CRNAs who need a break. 2. Change the status of a CRNA in OR 32 to "On Break" 3. Find the names of CRNAs on break. 4. Find location of CRNAs D, E, F, G
			Time taken to execute the tasks. Number of errors committed.	Seconds #	
15	The system helps the board runner to communicate with CRNAs to coordinate preparation for an upcoming case.	4.18	User rating of system's effectiveness in helping the board runner to communicate with CRNAs to coordinate preparation for an upcoming case.	Subjective measure : 1-5 scale	
16	The system allows the board runner to maintain an updatable list of the availability of the CRNAs (Available, Not available, On call).	4.13	User rating of system's effectiveness in maintaining an updatable list of the availability of the CRNAs.	Subjective measure : 1-5 scale	

17	The system displays the type of procedure in progress in each OR.	4.12	User rating of system's effectiveness in displaying procedure types.	Subjective measure : 1-5 scale	Find the names of the procedures in OR 11 and OR 12 and 32.
18	The system helps the board runner to communicate with CRNAs about their next case.	4.12	User rating of system's effectiveness in helping the board runner to communicate with CRNAs about their next case.	Subjective measure : 1-5 scale	
19	The system displays the status of GI rooms around 2.00 p.m.	4.06	User rating of system's effectiveness in displaying the status of GI rooms around 2.00 p.m.	Subjective measure : 1-5 scale	
20	The system reduces the need for the board runner to walk from location to location.	4.06	User rating of system's effectiveness in reducing the need for the board runner to walk from location to location.	Subjective measure : 1-5 scale	
			Physical demand	NASA TLX	
21	The system enables CRNAs to arrange for someone in the team to give them a break without the help of the board runner.	4.06	User rating of system's effectiveness in enabling CRNAs to arrange for someone in the team to give them a break without the help of the board runner.	Subjective measure : 1-5 scale	
22	The system displays whether a CRNA who needs a break has been relieved by an available CRNA.	4.06	User rating of system's effectiveness in displaying break status.	Subjective measure : 1-5 scale	

23	The system allows the board runner to assign CRNAs to rooms for the next day as well as on the same day based on their schedule and availability (more than one CRNA may be assigned to some rooms).	4.00	User rating of system's effectiveness for making CRNA assignments.	Subjective measure : 1-5 scale	
24	The device fits securely in a scrubs' pocket.	4.00	User rating of system's ability to fit in a scrubs' pocket.	Subjective measure : 1-5 scale	
25	The system helps the board runner to communicate with CRNAs about their current case.	4.00	User rating of system's effectiveness in helping the board runner to communicate with CRNAs about their current case.	Subjective measure : 1-5 scale	

Step 3. Concept generation, Detailed design, Formative testing and Iterative refinement

Based on the needs and metrics identified, two concepts were generated: a single-screen interface and a 3-screen interface. These were then prototyped in Axure and are explained below.

Concept 1: Single-screen Interface

This concept, shown in Figure 3.1 below, provides the board runner with four functionalities: assign, change status, relieve and overview, in a single screen. This screen is divided into three sections. On the left is a list of CRNAs sorted and color-coded based on their status for the day. For example, blue is “available,” gray is “unavailable,” brown is “on break.” Shift times of the CRNAs are also listed below their names. On the right, a list of the cores, B, C, D, GI, is provided. Based on the selection in this list, ORs in a particular core are populated in the middle with their respective CRNAs and procedures. Below the OR number and CRNA name, the procedure name, scheduled start time and actual start time (shown in red) of the procedure are displayed. The current status of the procedure is displayed next to the actual start time.

These lists are generated from the OR-Max database in real-time. A relieve button is provided below the core list. The overall configuration of the lists provides an overview of current statuses of the ORs and the CRNAs to the board runner. The functionalities of assign, change status and relieve are explained below.

Assign and change status

To assign a CRNA to an OR, the board runner drags and drops the name from the left to the middle. For example, in Figure 3.1, the board runner has assigned CRNAs Rick, Kris Zach and Phil to ORs 11, 12, 14 and 15 respectively in the B core. The assigned CRNAs are coded in blue to indicate they are "active" in the ORs. This screen also allows the board runner to change the status of CRNAs. Double tapping on the name of the CRNA, e.g., John, on the left list opens a pop-up window with a list of options as shown in Figure 3.2. Selecting the appropriate option causes the CRNA name to change color. For example, if "Not in" is selected, the color changes to gray. Figure 3.3 shows an example where the status of a CRNA named John has been changed to "Not in." Similarly, double tapping a CRNA whose status is "not in," i.e., gray, gives the only option of changing the status to "available."

Relieve

When a CRNA requests a break or approaches end of shift, the board runner is notified by highlighting the name of the CRNA in the middle list in red. To relieve this CRNA, the board runner taps on the name of the CRNA highlighted in red in the middle list and then taps on the relieve button, changing the color of the CRNA to brown and transferring it to the list on the left. Then, the board runner can drag an available CRNA from the list on the left to the OR that was just relieved. This helps the board runner to be aware of which CRNA is covering the OR during a break. The final state of the relieve operation is represented in Figure 3.4. Here, Kris, who requested for a break in OR 12, is now being covered by Pete. Once a break is completed, the CRNA giving the break (Pete), is assigned back to the available list and the name of the CRNA whose break is completed (Kris), is reassigned to the original OR. This reassignment changes the color of CRNA (Kris), from brown to blue, indicating "active" and the status returns to the original state seen in Figure 3.3.

Figure 3.1: Single-Screen interface

Figure 3.2: Single-screen interface – Options to change status

Figure 3.3: Single-screen interface – status changed to “Not in”

Figure 3.4: Single-screen interface Relieve operation

Concept 2: 3-screen Interface

This concept shares similarities with the single-screen interface in terms of screen elements and their organization. For example, the three lists for CRNA, ORs and cores are replicated in this concept as well. The major difference is that the functionalities of assign and change status, relieve, and overview are implemented separately in three screens. To navigate from one screen to the other, buttons are provided on top of each screen. The functionalities of the screens are explained below.

Assign screen

Similar to the single-screen interface, this screen also has three columns as shown in Figure 3.5 below. To assign a CRNA to an OR, the board runner drags and drops the name from the list on the left to the OR listed in the middle. Also, the functionality of changing status of CRNAs is provided in this screen and is implemented as explained in the single-screen interface.

Figure 3.5: 3-Screen interface – Assign screen

Relieve screen

The relieve screen as seen in Figure 3.6 below is similar to the assign screen except that the middle column lists the CRNAs along with their shift times and the OR number they are assigned to, both generated from OR max. Similar to the single-screen interface, when a CRNA requests a break or approaches end of shift, the name on the middle list changes color to red. The board runner can double tap on the name to open a pop-up window with options as shown in Figure 3.7. If "On break" is chosen, the color of the CRNA name changes to brown. The board runner can then drag an available CRNA and drop on top of this name. If "End of Shift" is chosen, the CRNA drops off from the middle list and is transferred to the left with color gray. An example is shown in Figure 3.8 where Zach in OR 11 has been relieved for a break and John is covering for this CRNA.

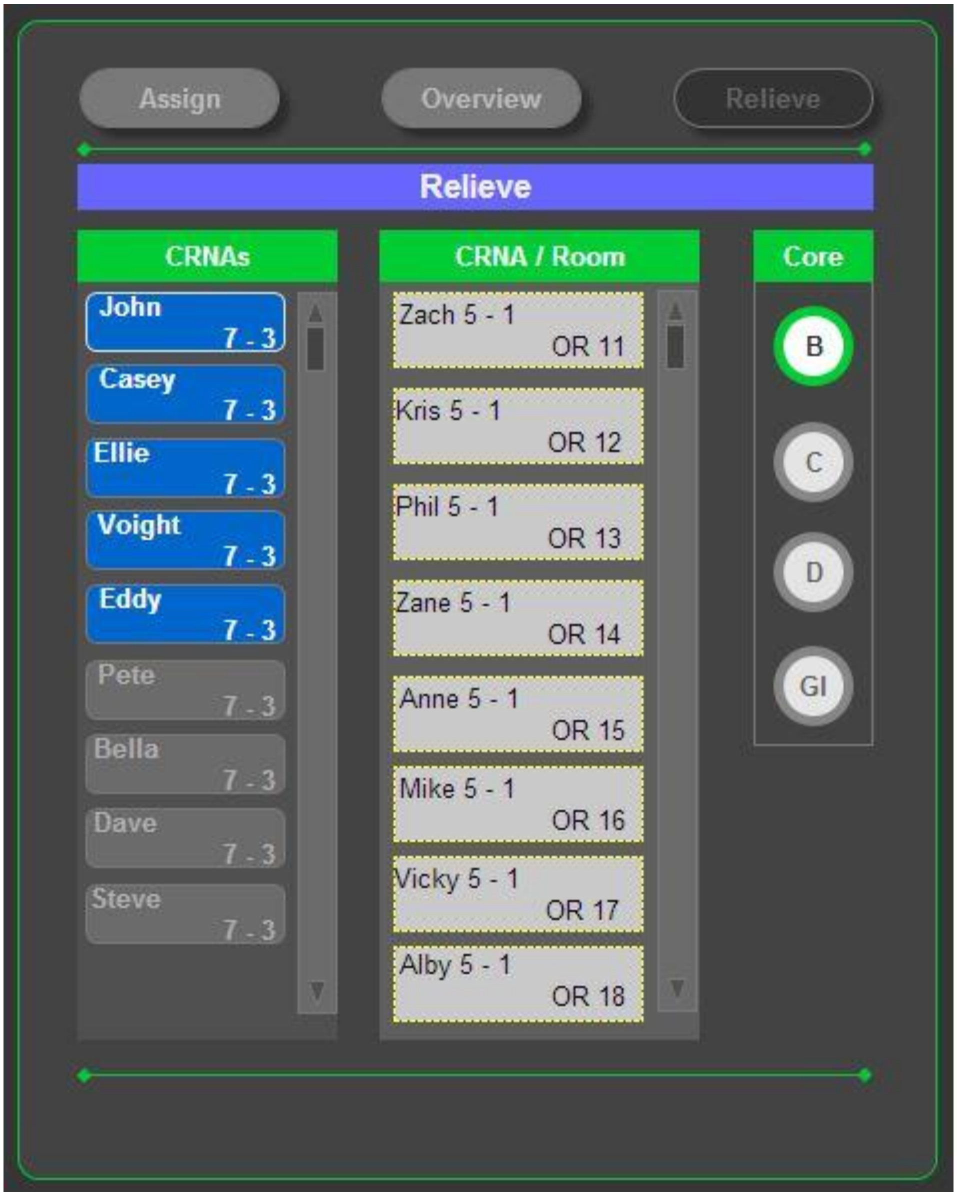

Figure 3.6: 3-Screen interface – Relieve screen

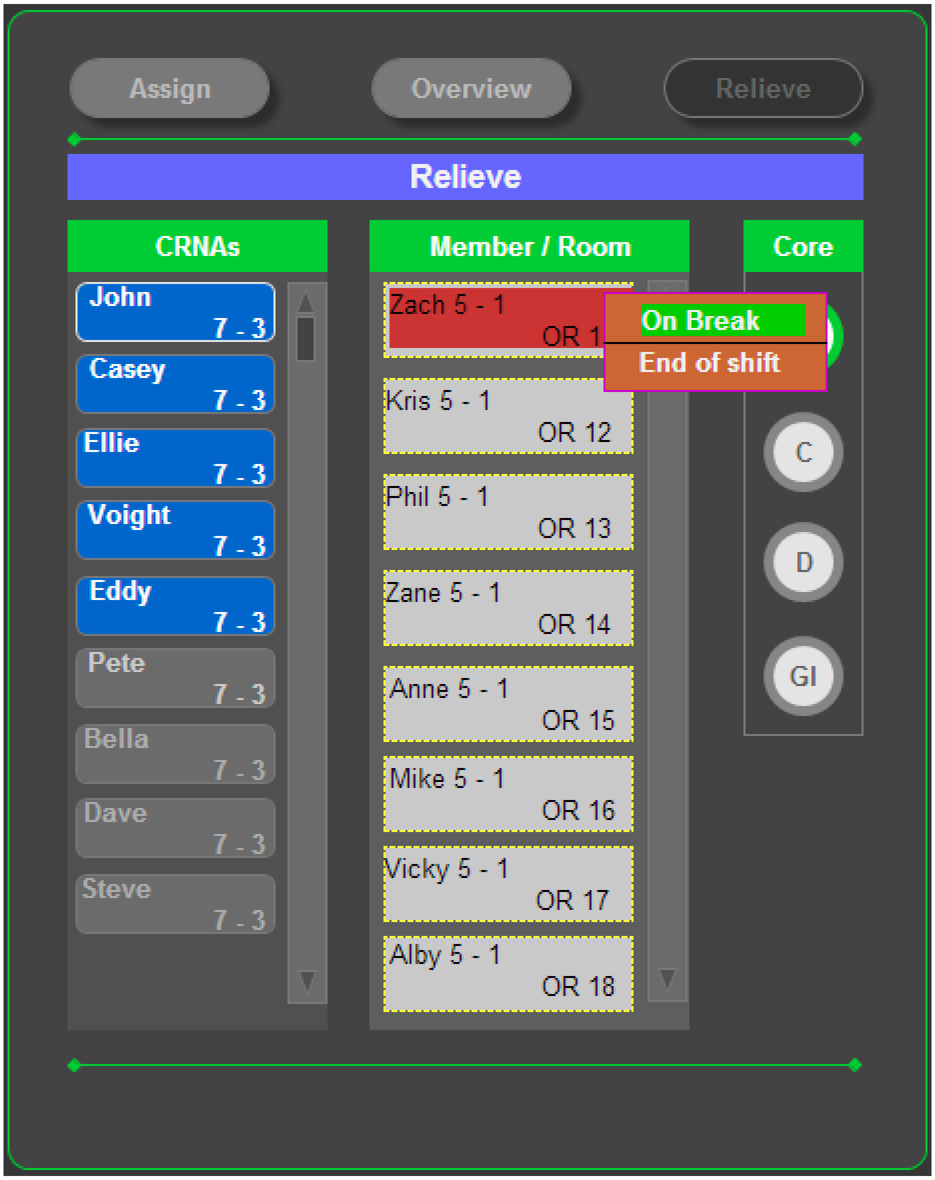

Figure 3.7: 3-screen interface – Relieve operation

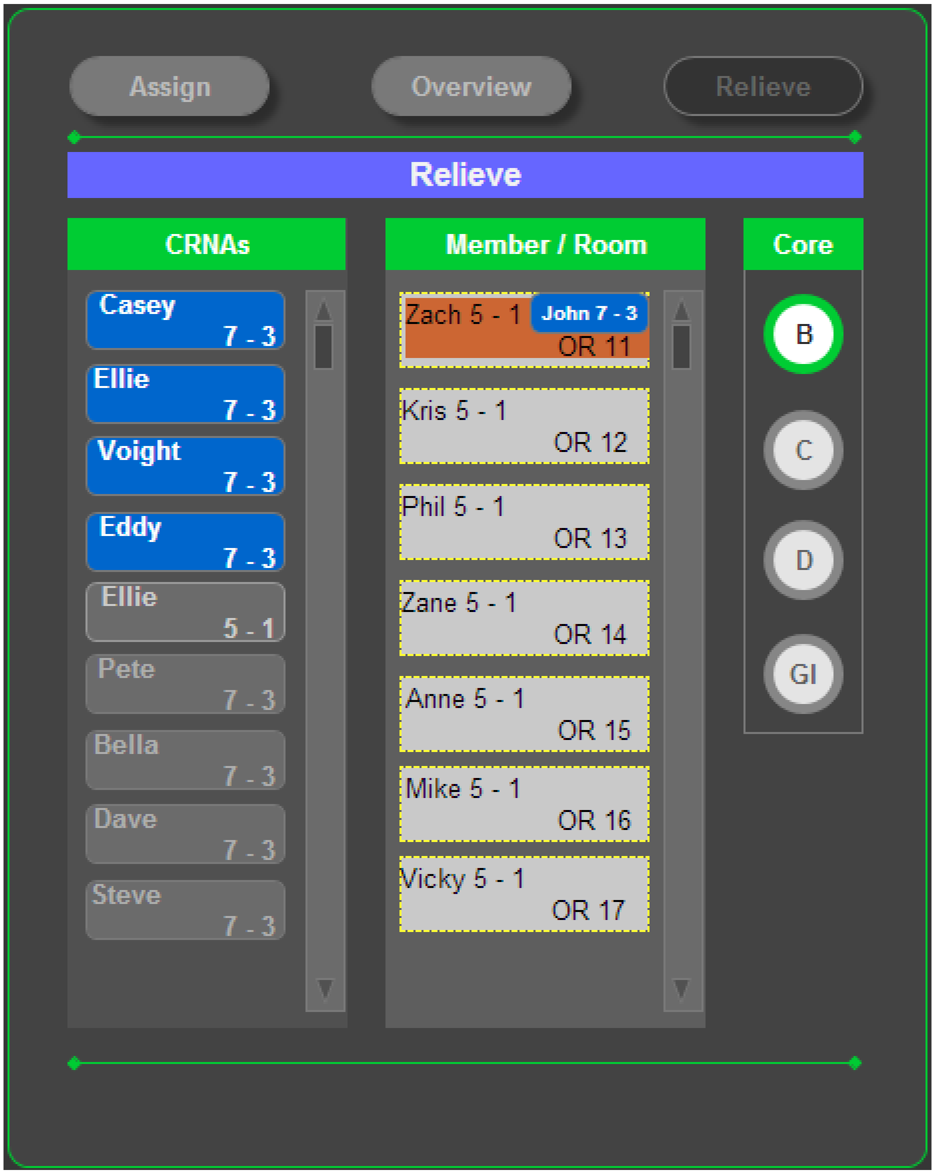

Figure 3.8: 3-Screen interface – Final state of relieve operation

Overview screen

This screen allows the board runner to get a quick status update on the ORs and the CRNAs. The overview screen includes the two lists shown in Figure 3.9 below. The left one lists CRNAs along with their shift times, the ORs they are assigned to, the surgery scheduled, the surgeon assigned, procedure, scheduled and actual times of procedure and status of the procedure. The second, similar to the previous two screens lists the cores. As there are only two lists, the left list is wider than the ones seen in the Assign and Relieve screens. This allows more detail, especially procedure names, statuses, scheduled and actual start times, and surgeons to be included, and aids the board runner before an assign or a relieve operation is performed.

In addition, if the board runner is on a screen other than Relieve, a notification icon will appear on the Relieve button located on the top to draw attention of the board runner to a break request or when a CRNA approaches end of shift. This can be seen in Figure 3.9.

Figure 3.9: 3-Screen interface – Overview screen

Both prototypes were presented to the board runners, the CRNA manager and the Director of Anesthesia and Perfusion Services for evaluation. This evaluation process was conducted in three stages. In stage 1, the users were asked to select the preferred prototype based on its features and functionalities. Upon evaluating the prototypes, the users selected the single-screen as their preferred choice as it included all the information and features they needed. Since all the functionalities were presented on a single screen, the users commented that it was “easier and faster” to use than the 3-screen prototype.

In stage 2, the single-screen prototype was refined based on the feedback gathered from the users through user-testing sessions. The ‘Relieve’ button was removed since color coding was being used to indicate break status. When the board runner drags and drops an available CRNA to provide a break, the color of the CRNA who requested the break changes from red to brown, indicating “On break”. Once the break ends, the covering CRNA can be dragged back to the available list which turns the color from brown to blue, indicating “Active”. This change in the relieve operation was perceived by the board runners as easier compared to the original version.

Further, the list of cores was moved to the top of the screen from the right to increase the width of the OR list. This change allowed increasing the length of the name of the procedure scheduled in the ORs and increasing the width of movable elements containing CRNA names. In addition, the background color of the parent container was changed to white since some users had difficulty reading the text when information was presented on a dark background. The background colors of other UI elements such as the header, the core list, the OR list and the CRNA list were also changed to ensure better contrast and readability. These changes are shown in Figure 3.10 below.

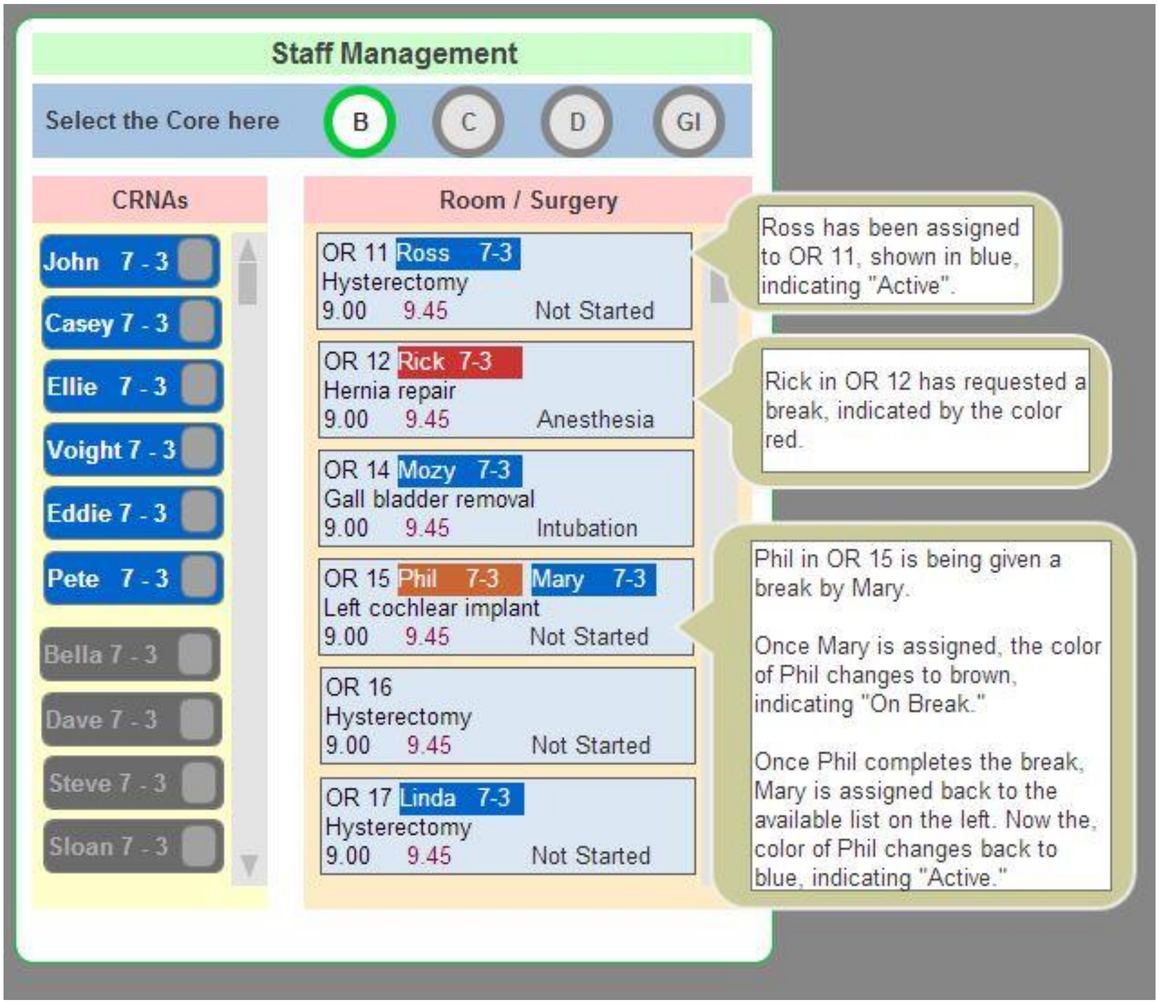

Figure 3.10: Refined single-screen prototype

Finally, a new rectangular block which can be tapped was included inside the movable elements present in the available list to change the status of CRNAs. On tapping this block, a pop-up window will be opened with the options of “Available” and “Not in,” similar to the one explained in the original version of the prototype. This change was made since the option of double tap is not available on mobile devices. Figure 3.11 given below shows how change of status is achieved.

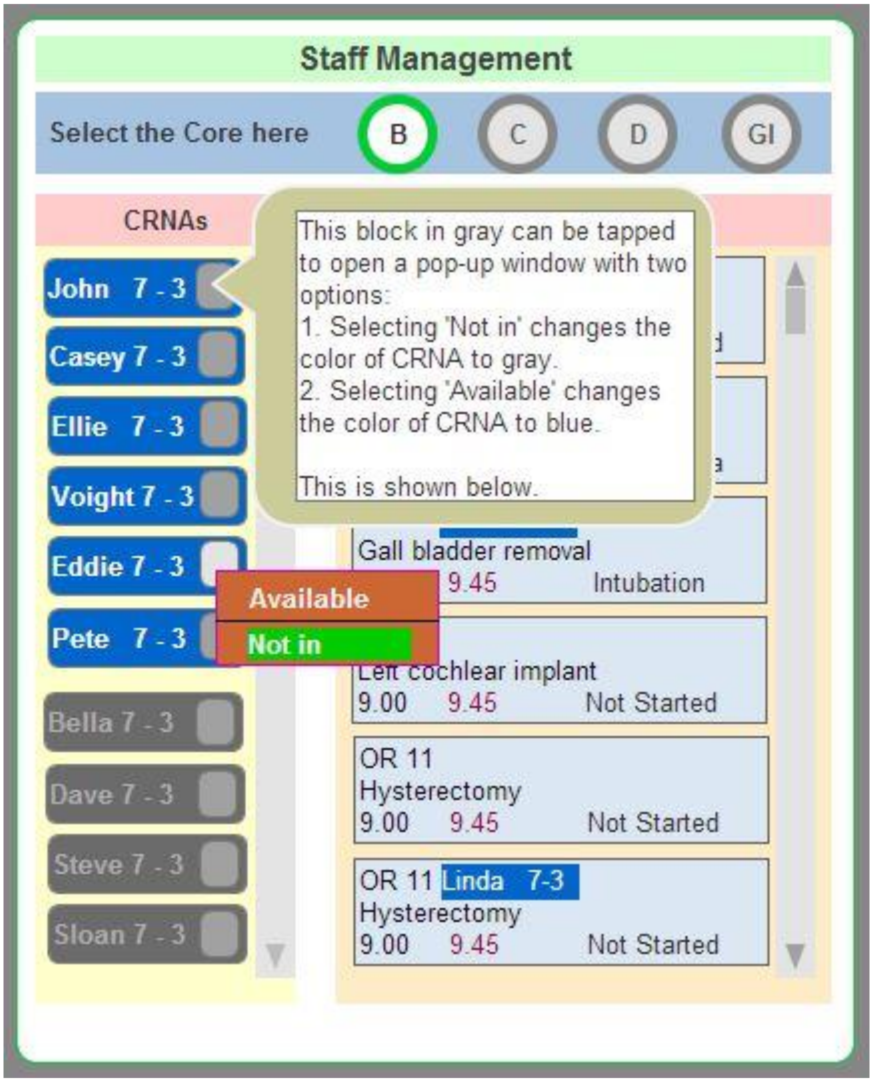

Figure 3.11: Change of status in the new single-screen prototype.

In stage 3, the feedback gathered from stage 2 was included in the design and the frontend of the mobile web application (web app) was developed using HTML, CSS and JQuery. JSON was used as the layer between the frontend and the backend to save the changes made in the user interface (UI). The research team also proposed the idea of including OR Max screens on the mobile device, generated on an additional tab in the browser, to potentially enhance situational awareness (SA). The users, however, when presented with these screens had difficulty reading the text and preferred not to use them.

CHAPTER FOUR

HYPOTHESES

The following hypotheses are proposed:

1. Task performance will be higher using the web app.

    1a) The web app displays the real-time status of CRNAs and ORs, and makes this information available wherever the board runner is located. It is thus hypothesized that the time taken for task execution will be longer with the current whiteboard.

    1b) The new interface includes intuitive and easy-to-use features. It is thus hypothesized that the number of errors committed during task execution will be greater with the current whiteboard.

2. Situational Awareness (SA) will be higher with the web app.

    The web app is designed to display the required information regarding team schedule and assignments by automatically updating from OR-Max. The information architecture, including color coding, is designed to facilitate overall perception of the current task environment. It is thus hypothesized that the mobile web application will improve SA.

3. Ratings for needs identified as subjective in Table 3.3 will be higher for the web app.

    The web app has been designed to include features that are not available in the whiteboard to satisfy the most important needs. It is thus hypothesized that ratings of needs satisfaction will be lower for the whiteboard.

4. Workload perceived by the users will be lower for the web app.

    The web app displays relevant information to the board runner in a concise format, thereby helping to prevent information overload. Since information that currently has to be gathered from different sources is integrated in the mobile application, it is hypothesized that the workload will be higher for the whiteboard.

5. Usability scores will be higher for the web app.

    The new interface will be designed in accordance with Norman's (2013) design principles, providing visibility, feedback, constraints, natural mappings, consistency and signifiers. It is thus hypothesized that usability will be higher for the mobile device.

6. The web app will be preferred over the whiteboard.

    As a result of hypotheses 1, 2, 3, 4 and 5, it is hypothesized that the overall preference will be for the mobile application.

CHAPTER FIVE

RESEARCH DESIGN

Step 4. Summative Concept Testing

IRB approval for this phase was obtained by the research team (seen in Appendix 8). In this phase, the web app implemented on the mobile device was tested in a simulated work environment with 10 CRNA board runners. The simulated environment was equipped with a whiteboard, OR-Max display screens (simulated with laptop computers) and a break room board. To simulate the real-world configuration, the whiteboard and the display screens were located close to each other; however, the break room board was positioned at a farther distance from the screens such that the information present on it was not visible to the participants when using the whiteboard.

The participants for the study were recruited by asking the CRNA manager and the Director of Anesthesia and Perfusion Services for their recommendations. The researcher also met with the participants to determine their interest in using mobile applications at the workplace and in participating in this study. The participants who volunteered for this study provided demographic information including age, years of experience as a board runner and familiarity in using mobile devices, rated on a 1 – 7 scale (seen in Appendix 3). The average age of the participants was 37, average years of experience as a board runner was 5.1 years and familiarity in using mobile devices had an average of 6.5 (median = 7).

Experimental Design

The study used a within-subjects design, with one factor, device type, being tested at two levels: the whiteboard and the web app. Each participant was tested at both the levels. Before the evaluation, the web app was given to each of the 10 participants to allow them to practice using the device. For the evaluation, the participants were given the tasks identified in Table 3.3 to perform using both devices. The tasks are summarized below in Table 5.1:

Table 5.1 Task Summary

#	**Task**
1	Find the number of available CRNAs.
2	Assign CRNAs A and B to ORs 12 and 26.
3	Find the names of the CRNAs nearing their end-of-shift.
4	Change the status of a CRNA in OR 32 to "On Break"
5	Assign two available CRNAs to cover for two CRNAs nearing the ends of their shifts.
6	Find the names of the CRNAs on break.
7	Find the shift times of CRNAs A, B, C and D.
8	Find the locations of CRNAs E, F, G, H.
9	Find the names of the procedures scheduled in OR 11, OR 12 and OR 32.
10	Find the names of the CRNAs who need a break.

During the execution of the tasks on both interfaces, a distraction task was employed every 20 seconds. In this task, a software application on another mobile device called out a random name of a member of the participant’s team. On hearing the name, the participants updated a count of the number of names heard on a sheet of paper. This task was included to simulate real-world distractions faced by the board runners such as phone calls and messages.

To minimize order effects, half of the participants were tested on the whiteboard before being evaluated on the web app. This order was reversed for the other half. The study was conducted over a period of 3 weeks. During Week 1, the participants practiced with the web app for 15 minutes to familiarize themselves with its features. The research team guided the users on the available options and clarified any questions that they had. During Week 2, the participants were asked to perform the tasks on the devices, two participants per day. One participant executed the tasks on the whiteboard while the other participant executed the tasks using just the tablet. This process was repeated during Week 3 but with the device assignments reversed. The experimental design is shown below in Table 5.2 with 0 representing the whiteboard and 1 the mobile interface. The ten participants have been identified as A through J for illustration.

Table 5.2 Counterbalanced assignment order for interface evaluation

	Day	**Participant**	**Type of Interface**
Week 2 Evaluation of Interfaces	**1**	A	1
		B	0
	2	C	1
		D	0
	3	E	1
		F	0
	4	G	1
		H	0
	5	I	1

		J	0
Week 3 **Evaluation of Interfaces**	**1**	A	0
		B	1
	2	C	0
		D	1
	3	E	0
		F	1
	4	G	0
		H	1
	5	I	0
		J	1

Independent Variable

The independent variable for this research was the device type, evaluated at two levels:

1. The current whiteboard
2. The mobile web app on a Google Nexus 7 Tablet

Dependent Variables

Both objective and subjective dependent variables were used in this study. The objective measures were

1. Time taken to perform the tasks correctly, recorded using a timer.
2. Number of errors committed during task execution.

3. Number of errors made during a situational awareness (SA) assessment. This was measured using a SA questionnaire, having queries regarding the current situation, shown in Appendix 8. The names of CRNAs are listed as A through J for illustration in Appendix 8.

The subjective measures for this study were

4. The ratings for needs listed as subjective measures, identified in Table 3.3, collected using a 7-point Likert scale (seen in Appendix 6).
5. The workload perceived by the users, measured using the NASA-Task Load Index (NASA-TLX) (Hart, S.G., and Staveland, L.E., 1988), shown in Appendix 5. The scores, rated by users on scales measuring mental demand, physical demand, temporal demand, performance, effort and frustration, were used to determine the overall perceived workload.
6. The usability perceived by the participants while performing the 10 tasks. The SUS questionnaire (Brooke, 1996) was used for this measurement (seen in Appendix 4).
7. A preference ranking for the type of device was collected from the participants using a questionnaire (seen in Appendix 7) once they completed their tasks on both of the devices.

Procedure

At the beginning of Week 1, before the new interface was introduced to the users, the 10 participants were greeted by the research team and briefed on the study and the use of the new device. Following the introduction, the participants were asked to read and sign a consent form. During this meeting, the participants were divided into two groups of five each.

Then during the week, one participant from each group was given the web app to practice on a single day for around 15 minutes. Hence, over 5 days, all 10 participants had this opportunity. The research team guided them through the navigational features of the new device. During Week 2, participants in Group 1 and Group 2 completed the tasks on the whiteboard and the tablet respectively. On each day of the week, two participants, one from each group, completed the evaluation. The participants were then administered the SA questionnaire after blanking the displays. Finally, the participants completed the SUS, NASA –TLX and Likert questionnaires. Each participant required approximately 15 minutes to complete the tasks on the devices and the questionnaires. This process was repeated during Week 3 with the devices that the participants did not evaluate during Week 2.

During the execution of tasks on both of the devices, a distraction task was employed every 20 seconds. In this task, a software application on another mobile device called out a random name of a member of the participant’s team. On hearing the name, the participants updated a count of the number of names heard on a sheet of paper. For example, on hearing the first name, they marked “|” on the paper, on hearing the second name, they updated the count as “| |”, for the third, they updated it as “| | |”, and so on, increasing the count as and when they heard a name. This task was used to simulate distractions faced by the board runners while carrying out their daily job activities, such as phone calls and messages.

Once the tasks were completed, the displays were blanked and the participants completed the SA questionnaire. The subjective Likert questionnaire, the SUS and the NASA-TLX questionnaires were also given to the users once they completed the tasks on each device. Finally, a preference ranking questionnaire was completed by the participants after they had evaluated both of the devices.

Statistical Analysis

The data collected was analyzed for normality and treated accordingly for any deviation. IBM- SPSS 21 was used to conduct a repeated measures ANOVA to determine the presence of statistically significant differences for the dependent variables across the two levels of the independent variable.

Power Analysis

G*Power software (Faul, Erdfelder, Buchner, & Lang, 2009) was used to conduct a power analysis to calculate the sample size required to produce significance between the independent variables. For a power of 0.8, an effect size of 0.16 ($r^2 = 0.16$, Cohen’s d = 0.88) was estimated and the least number of samples required to obtain a significant difference was 10.

CHAPTER SIX

RESULTS

All 10 participants completed both sessions of the study. During the sessions, the dependent measures of task performance (time and number of errors), SA, needs ratings, NASA TLX workload assessment and SUS ratings were collected. In addition, the participants ranked their preferences for the type of device at the completion of the last session. The data collected were analyzed for normality, the results indicating that all dependent measures were normal. In the NASA TLX, the performance index was reverse coded since it was worded differently from the other indices. Reverse coding was also done to questions 2, 4, 6, 8 and 10 of the SUS since they were negatively worded. These measures were then analyzed for significant differences using a repeated measures ANOVA with a 95% confidence interval.

Objective Measures

In both the sessions, the objective measures included:

- Time taken for task completion, measured in seconds.
- Number of errors committed during task execution.
- Number of errors made on the SA assessment.

The first two were measured while the tasks were being performed and the last was measured upon completion of the tasks.

Statistical analysis of the task execution time revealed a significant difference between the whiteboard (M = 134.823, SD = 5.97785) and the web app (M = 87.264, SD = 3.08344), $F(1,9) = 561.08$, $p <= 0.05$. The descriptive statistics and ANOVA results for task time are shown in Tables 6.1 and 6.2, respectively. The mean task completion times for the two devices are displayed in Figure 6.1.

Table 6.1: One-way ANOVA descriptive statistics for task time in seconds

		N	Mean	Std. Deviation	Std. Error	95% CI Lower Bound	95% CI Upper Bound	Minimum	Maximum
Task Time	Whiteboard	10	134.823	5.978	1.890	130.547	139.099	125.680	144.170
	Web App	10	87.264	3.083	0.975	85.058	89.470	80.620	91.030

Table 6.2: One-way ANOVA results for task time in seconds

		Type III Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Task Time	Device	11309.292	1	11309.292	561.081	.0000001	.984
	Error	181.406	9	20.156			

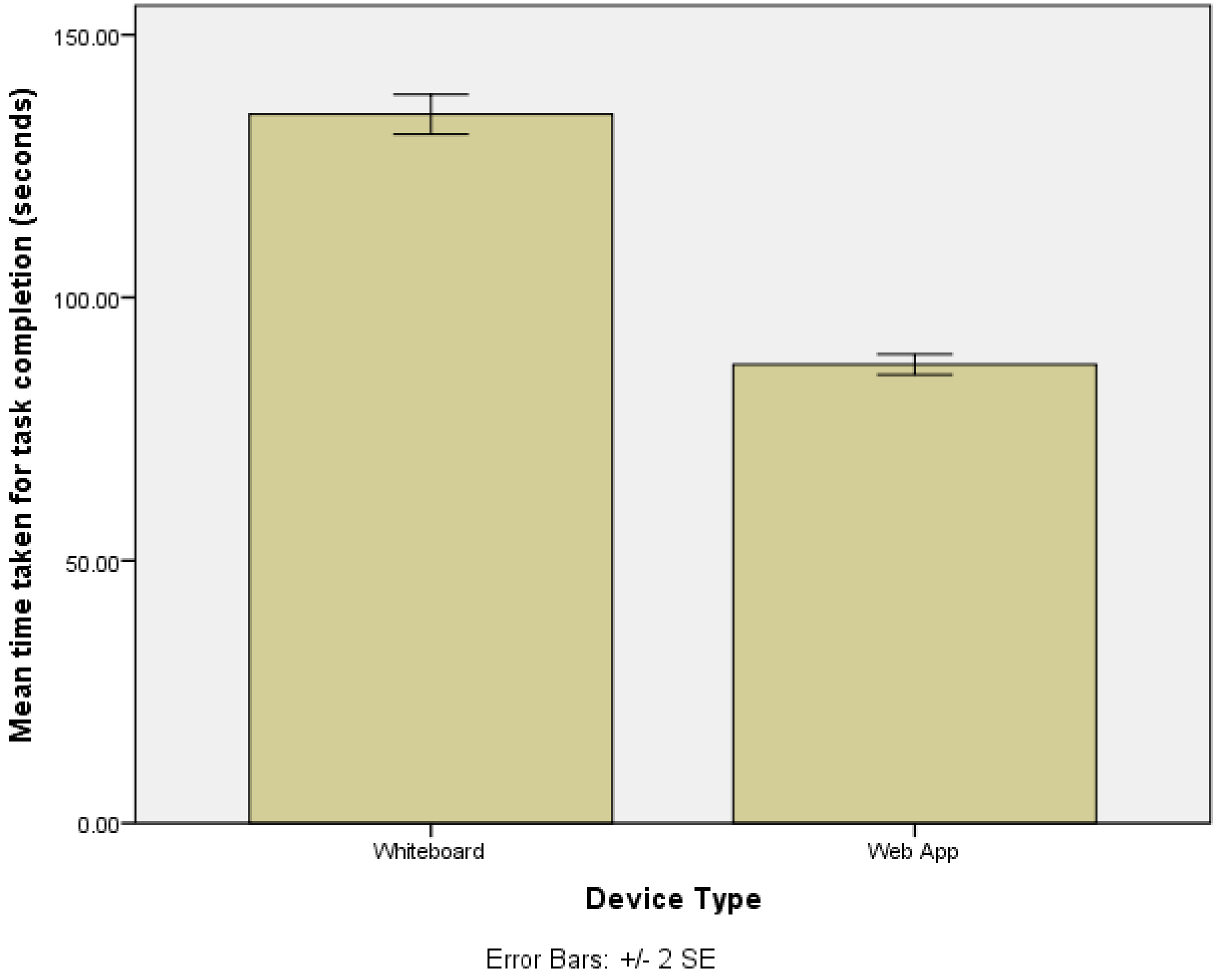

Figure 6.1: Mean time taken for task completion in seconds

The difference in the number of task execution errors between the whiteboard (Median = 0.5, Mean = 0.6, SD = 0.699) and the web-app (Median = 1, Mean = 0.7, SD = 0.675), F(1,9) = 0.130, p = 0.726, was not significant. The descriptive statistics and ANOVA results for the number of task execution errors are shown in Tables 6.3 and 6.4, respectively. Figure 6.2 displays the mean number of task execution errors for the two devices.

Table 6.3: One-way ANOVA descriptive statistics for number of task execution errors

						95% CI			
Device	N	Mean	Median	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Minimum	Maximum
Whiteboard	10	0.600	0.500	0.699	0.221	0.100	1.100	0.000	2.000
Web App	10	0.700	1.000	0.675	0.213	0.217	1.183	0.000	2.000

Table 6.4: One-way ANOVA results for number of task execution errors

		Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Task Error	Device	.050	1	.050	.130	.726	.014
	Error	3.450	9	.383			

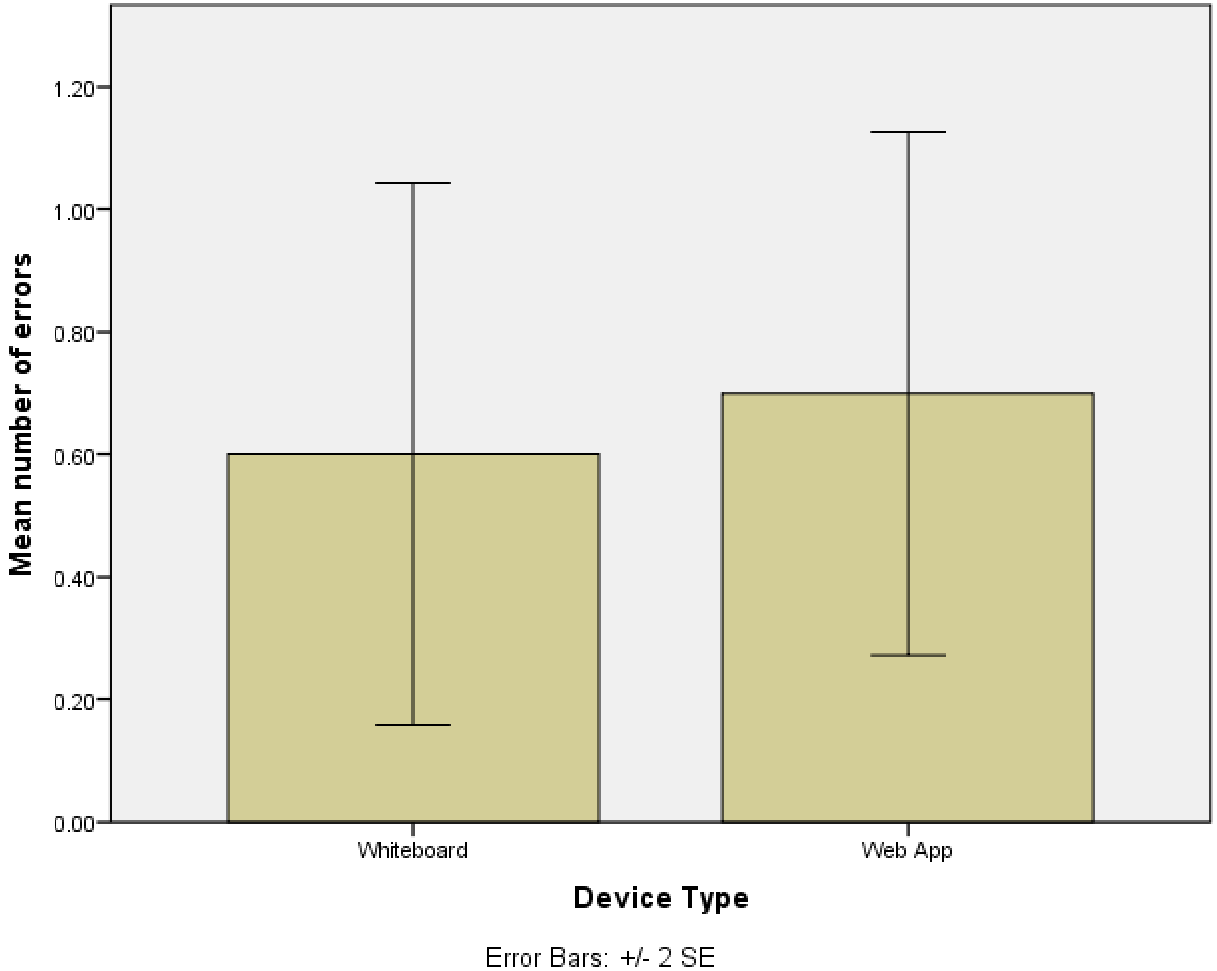

Figure 6.2: Mean number of errors for task execution

Analysis of the number of situational awareness assessment errors showed no significant difference between the whiteboard (Median = 6, Mean = 5.9, SD = 0.738) and the web app (Median = 5.5, Mean = 5.5, SD = 0.527), $F(1,9) = 2.25$, $p=0.168$. The descriptive statistics and ANOVA results for the number of situational awareness task errors are shown in Tables 6.5 and 6.6, respectively. The mean numbers of situational awareness task errors are depicted in Figure 6.3.

Table 6.5: One-way ANOVA descriptive statistics for situational awareness task errors

Device	N	Mean	Median	Std. Deviation	Std. Error	95% CI Lower Bound	95% CI Upper Bound	Minimum	Maximum
Whiteboard	10	5.900	6.000	0.738	0.233	5.372	6.428	5.000	7.000
Web App	10	5.500	5.500	0.527	0.167	5.123	5.877	5.000	6.000

Table 6.6: One-way ANOVA results for situational awareness task errors

		Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
SA Error	Device	.800	1	.800	2.250	.168	.200
	Error	3.200	9	.356			

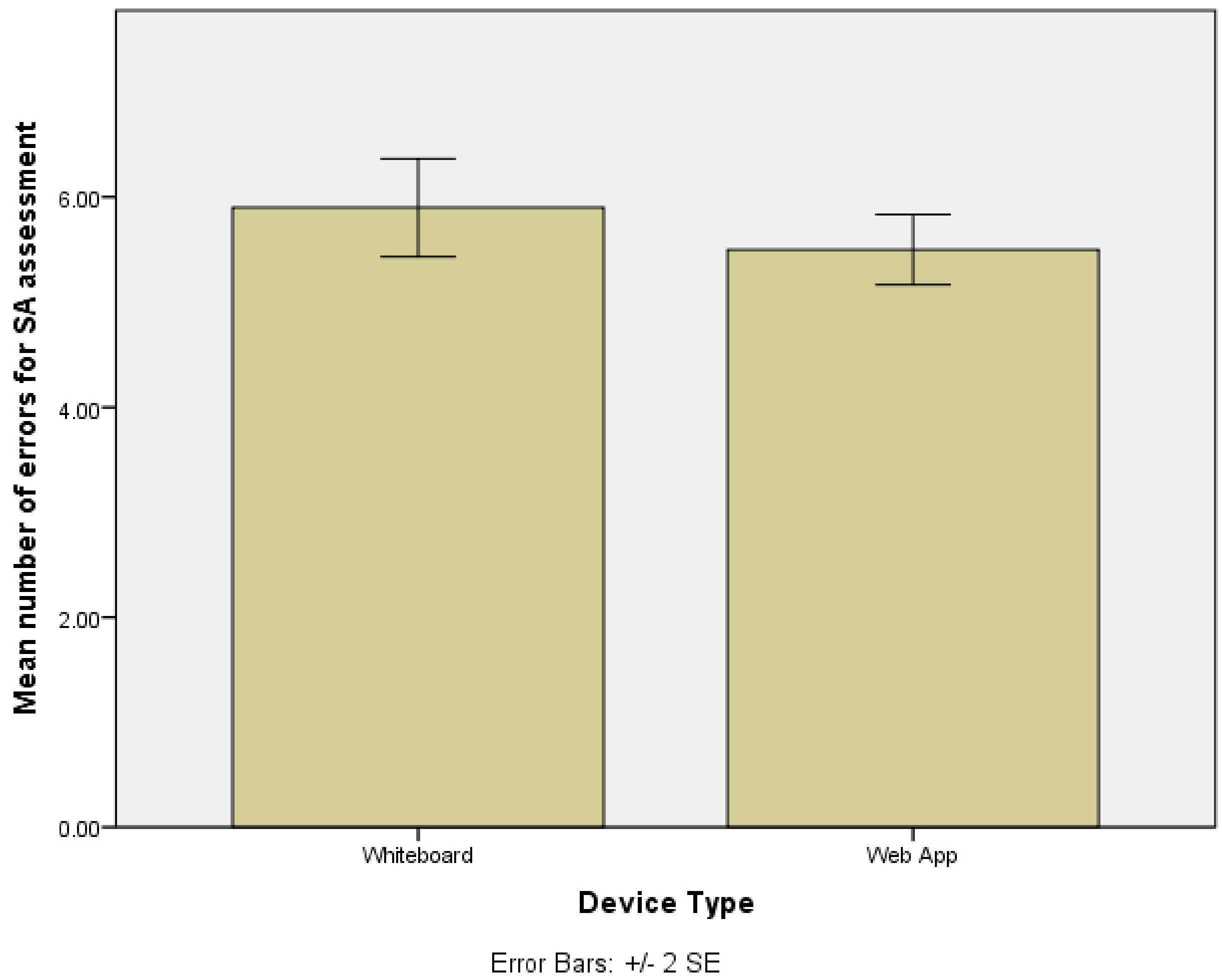

Figure 6.3: Mean number of errors made in the situational awareness assessment

Subjective measures

The subjective measures of the experiment included

- Needs satisfaction ratings.
- Workload assessment.
- System usability.
- Preference ranking for the device type.

To analyze the 20 needs rated on a 1 – 7 scale, they were categorized into 6 groups (the primary needs originally identified) based on the hierarchical list in Table 3.1. A repeated measures ANOVA was conducted on each of these 6 groups, the results indicating that all the groups had statistically significant differences between the devices. The descriptive statistics and ANOVA results are shown in Tables 6.7 and 6.8, respectively.

Table 6.7: One-way ANOVA descriptive statistics for the primary needs

Primary Need	Device	N	Mean	Median	SD	Std. Error	95% CI Lower Bound	95% CI Upper Bound	Min	Max
Staff information displayed on the interface	Whiteboard	10	4.25	4.25	1.07	0.34	3.49	5.01	2.67	5.83
	Web App	10	6.65	6.67	0.32	0.10	6.42	6.88	6.17	7.00
CRNA information entered on the interface	Whiteboard	10	4.30	4.25	1.36	0.43	3.33	5.27	2.50	7.00
	Web App	10	6.50	6.75	0.67	0.21	6.02	6.98	5.00	7.00
Procedure and room status displayed on the interface	Whiteboard	10	3.63	3.75	0.88	0.28	3.00	4.25	2.25	4.75
	Web App	10	6.15	6.25	0.54	0.17	5.76	6.54	5.25	7.00
Enabling status communication with the team	Whiteboard	10	3.53	3.17	1.24	0.39	2.65	4.42	1.67	5.33
	Web App	10	6.37	6.33	0.66	0.21	5.90	6.84	5.00	7.00
Ease of use	Whiteboard	10	2.30	2.00	0.86	0.27	1.69	2.91	1.50	4.00
	Web App	10	5.70	6.00	0.86	0.27	5.09	6.31	4.00	6.50
User satisfaction	Whiteboard	10	2.97	3.00	1.02	0.32	2.23	3.70	1.33	4.67
	Web App	10	6.47	6.50	0.48	0.15	6.13	6.81	5.67	7.00

Table 6.8: One-way ANOVA results for 6 the primary needs

Primary Need	Source	Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Staff information displayed on the interface	Device	1036.80	1	1036.80	46.38	.00008	.837
	Error	201.20	9	22.36			
CRNA information entered on the interface	Device	96.80	1	96.80	14.97	.004	.625
	Error	58.20	9	6.47			
Procedure and room status displayed on the interface	Device	510.05	1	510.05	77.22	.00001	.896
	Error	59.45	9	6.61			
Enabling status communication with the team	Device	361.25	1	361.25	46.95	.00007	.839
	Error	69.25	9	7.69			
Ease of use	Device	231.20	1	231.20	87.43	.00001	.907
	Error	23.80	9	2.64			
User satisfaction	Device	551.25	1	551.25	88.20	.00001	.907
	Error	56.25	9	6.25			

Analysis of the first primary need, Staff information displayed on the interface, showed a significant difference between the whiteboard (Mean = 4.25, Median = 4.25, SD = 1.07) and the web app (Mean = 6.65, Median = 6.67, SD = 0.32), $F(1,9) = 46.38$, $p<=0.05$. Figure 6.4 shows the mean ratings for the primary need "Staff information displayed on the interface" for both of the devices.

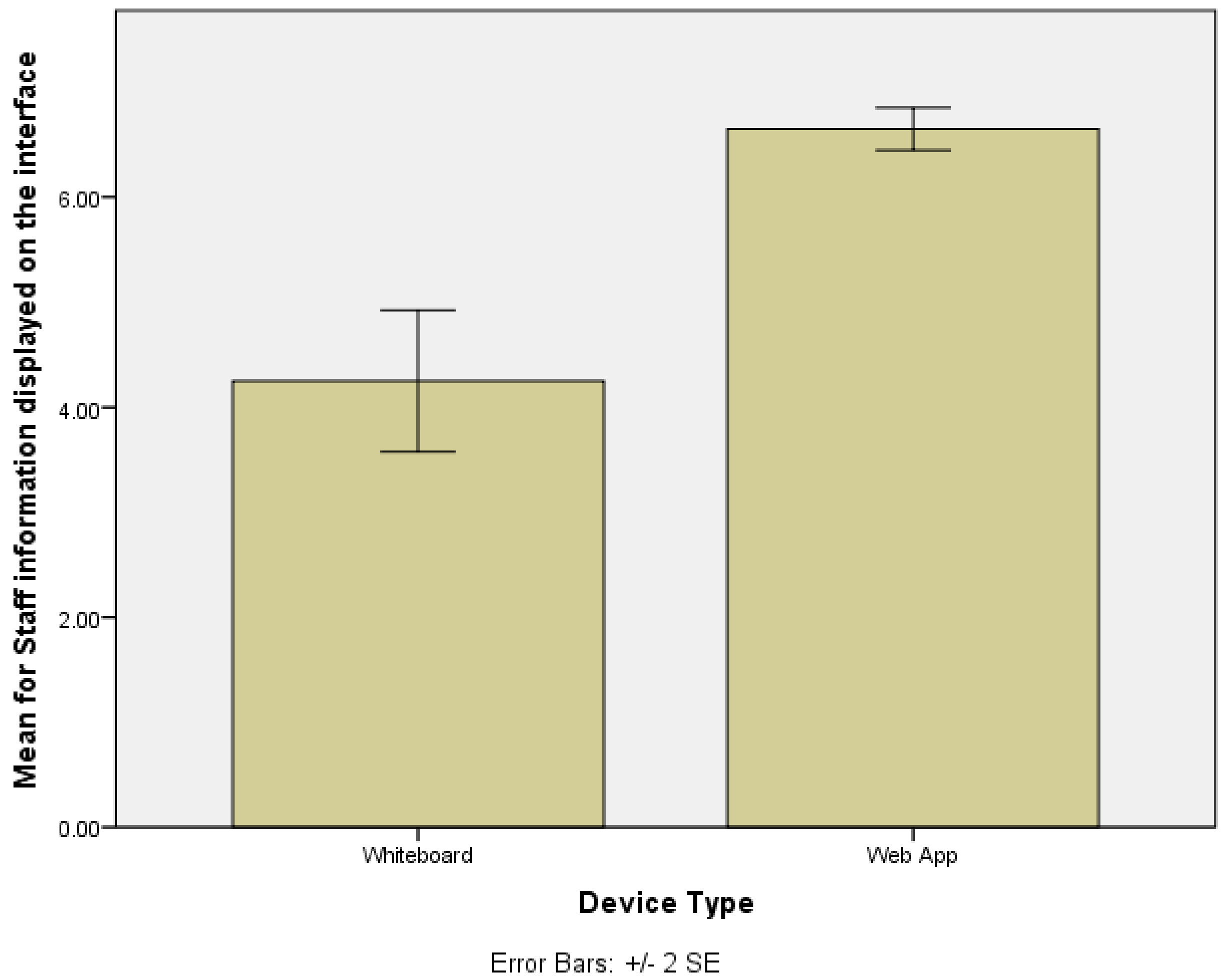

Figure 6.4: Mean ratings for the primary need “Staff information displayed on the interface”

Analysis of the second primary need, CRNA information entered on the interface, showed a significant difference between the whiteboard (Mean = 4.3, Median = 4.25, SD = 1.36) and the web app (Mean = 6.5, Median = 6.75, SD = 0.67), $F(1,9) = 14.97$, $p \le 0.05$. Figure 6.5 shows the mean ratings for the primary need "CRNA information entered on the interface" for both of the devices.

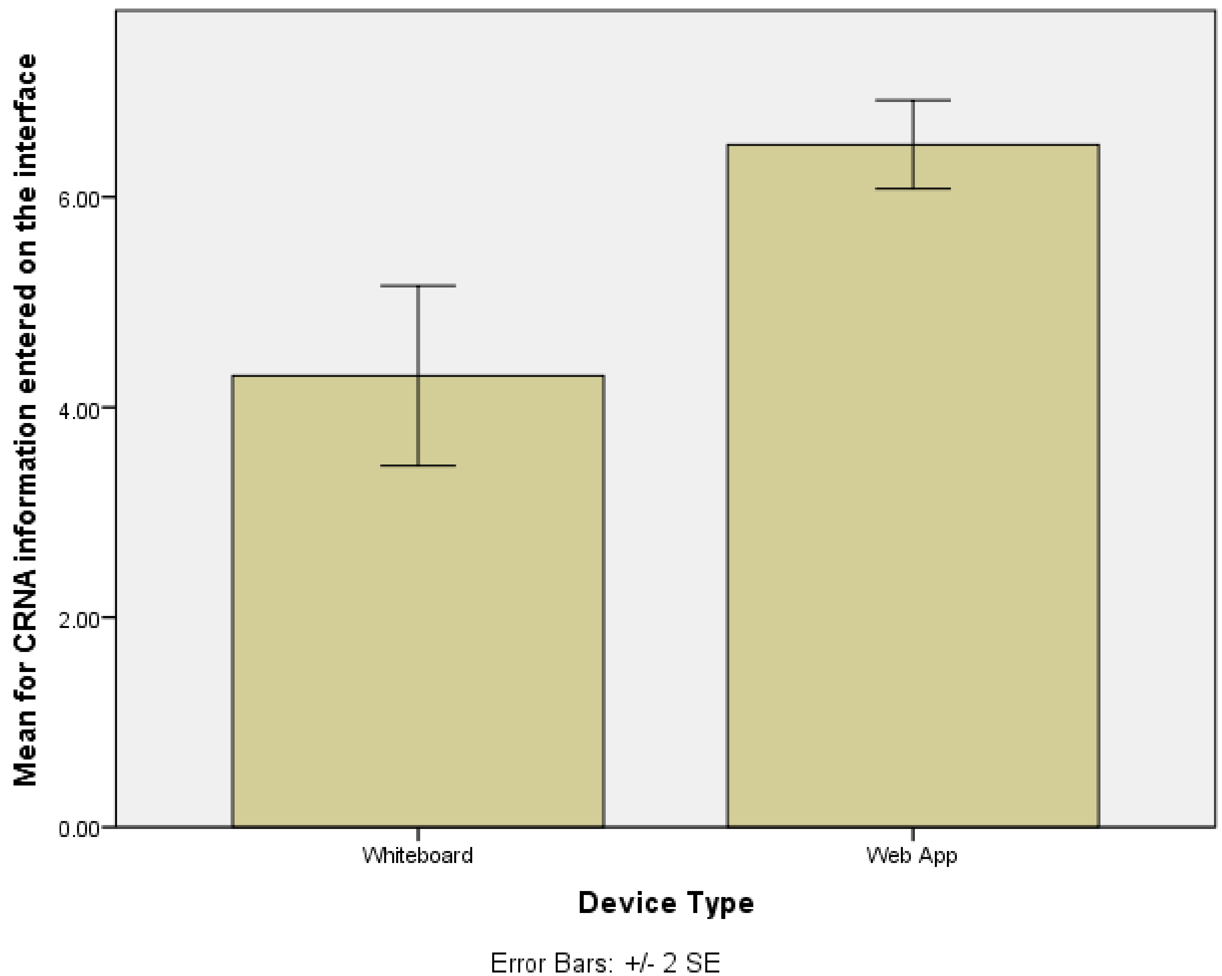

Figure 6.5: Mean ratings for the primary need “CRNA information entered on the interface”

Analysis of the third primary need, Procedure and room status displayed on the interface, showed a significant difference between the whiteboard (Mean = 3.62, Median = 3.75, SD = 0.87) and the web app (Mean = 6.15, Median = 6.25, SD = 0.54), $F(1,9) = 77.22$, $p <= 0.05$. Figure 6.6 shows the mean ratings for the need “Procedure and room status displayed on the interface” for both of the devices.

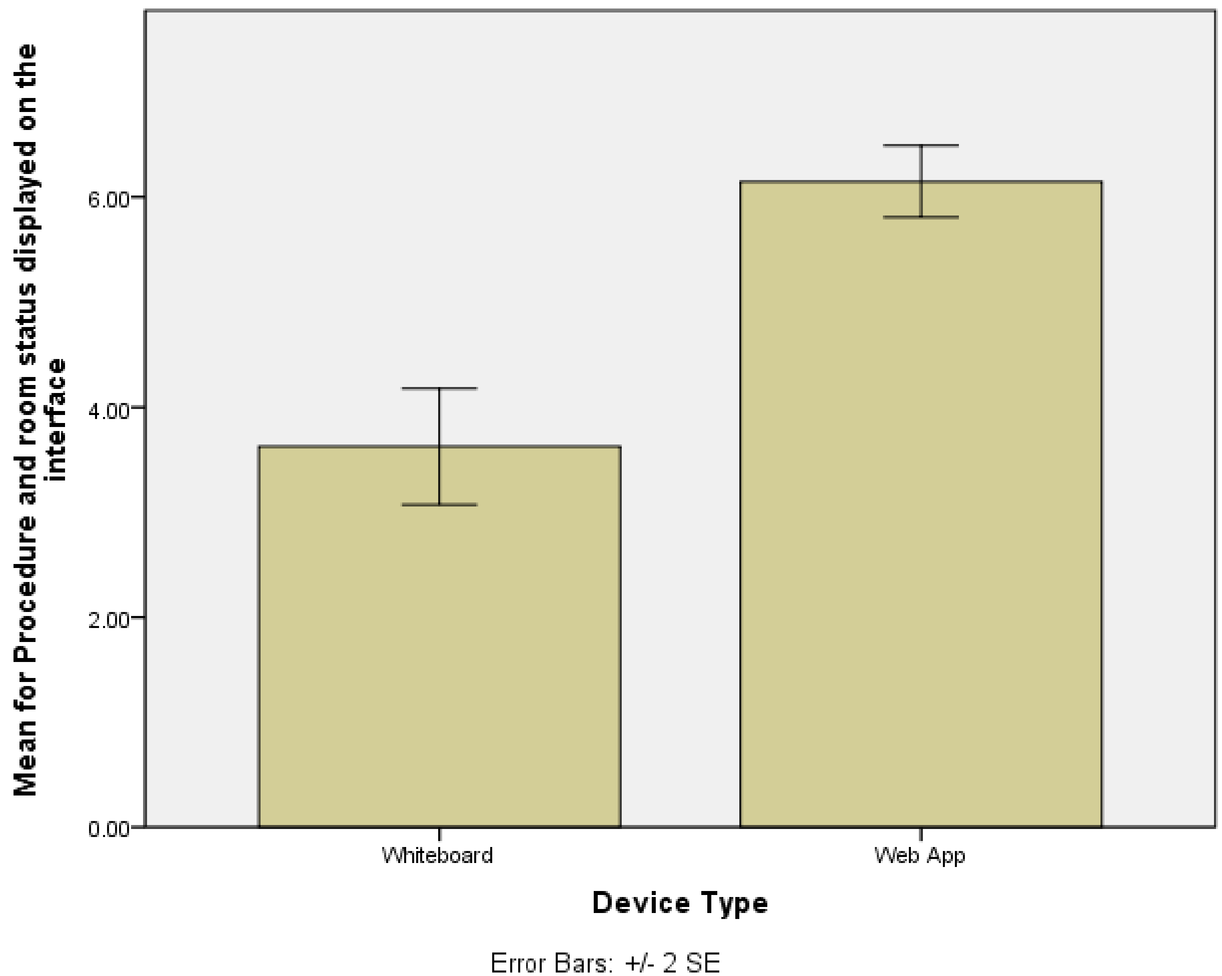

Figure 6.6: Mean ratings for the primary need “Procedure and room status displayed on the interface”

Analysis of the fourth primary need, Enabling status communication with the team, showed a significant difference between the whiteboard (Mean = 3.53, Median = 3.17, SD = 1.24) and the web app (Mean = 6.37, Median = 6.33, SD = 0.66), $F(1,9) = 46.95$, $p \le 0.05$. Figure 6.7 shows the mean ratings for the need "Enabling status communication with the team" for both of the devices.

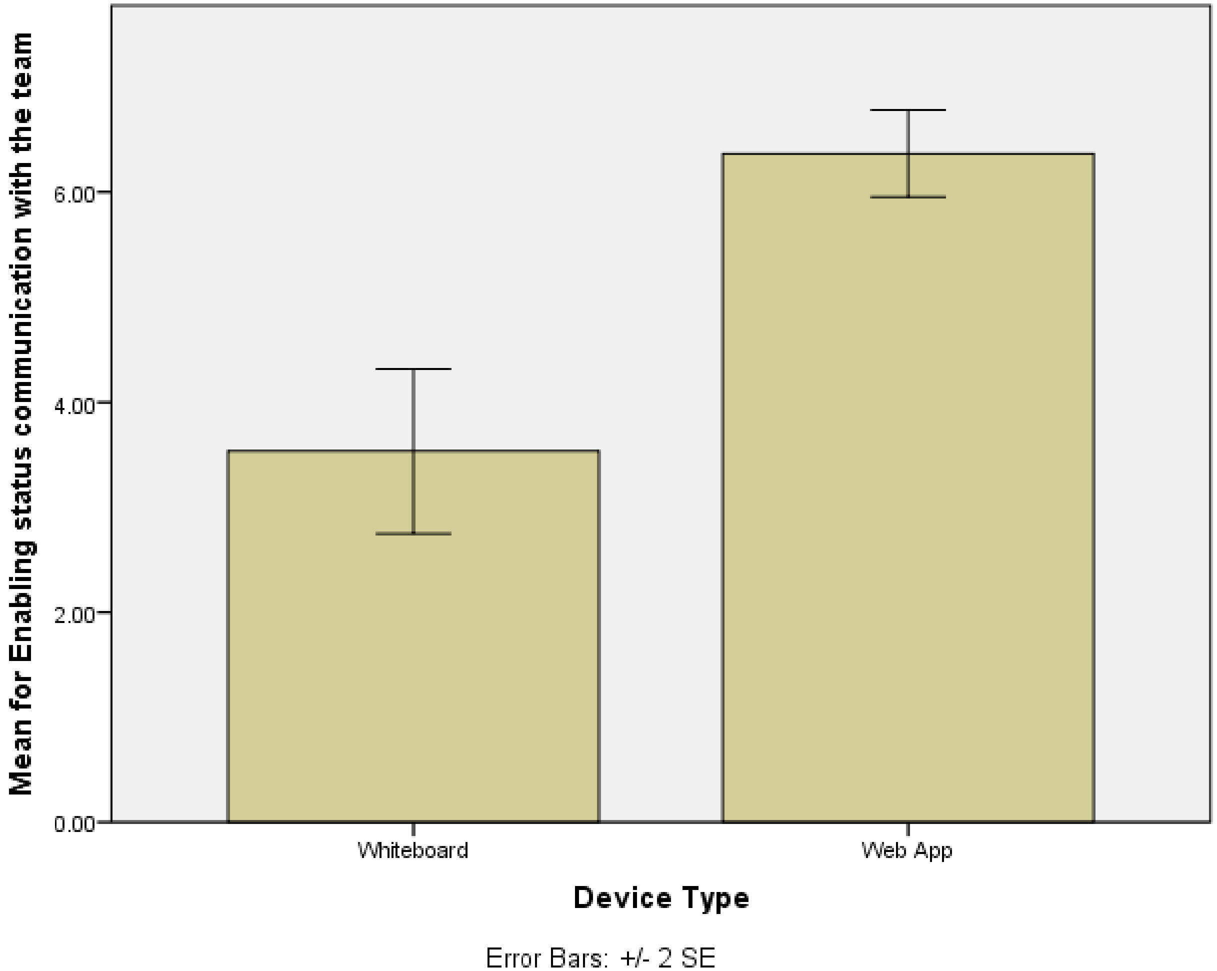

Figure 6.7: Mean ratings for the primary need “Enabling status communication with the team”

Analysis of the fifth primary need, Ease of use, showed a significant difference between the whiteboard (Mean = 2.3, Median = 2, SD = 0.86) and the web app (Mean = 5.7, Median = 6, SD = 0.86), $F(1,9) = 87.43$, $p <= 0.05$. Figure 6.8 shows the mean ratings for the need "Ease of use" for both of the devices.

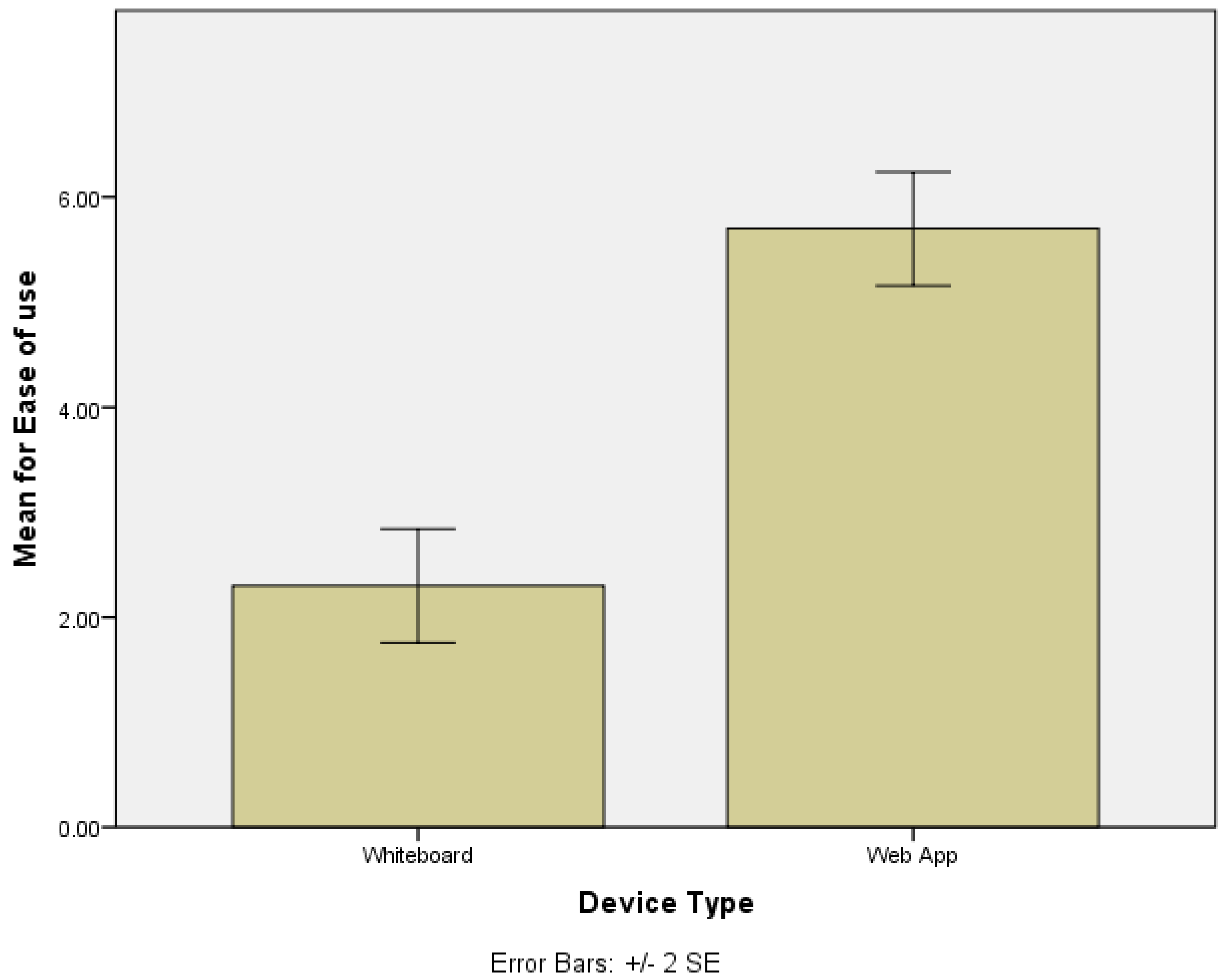

Figure 6.8: Mean ratings for the primary need “Ease of use”

Analysis of the sixth primary need, User Satisfaction, showed a significant difference between the whiteboard (Mean = 2.97, Median = 3, SD = 1.02) and the web app (Mean = 6.47, Median = 6.5, SD = 0.48), $F(1,9) = 88.20$, $p <= 0.05$. Figure 6.9 below shows the mean ratings for the need "User Satisfaction" and Figure 6.10 summarizes the mean ratings for the 6 primary needs for both of the devices.

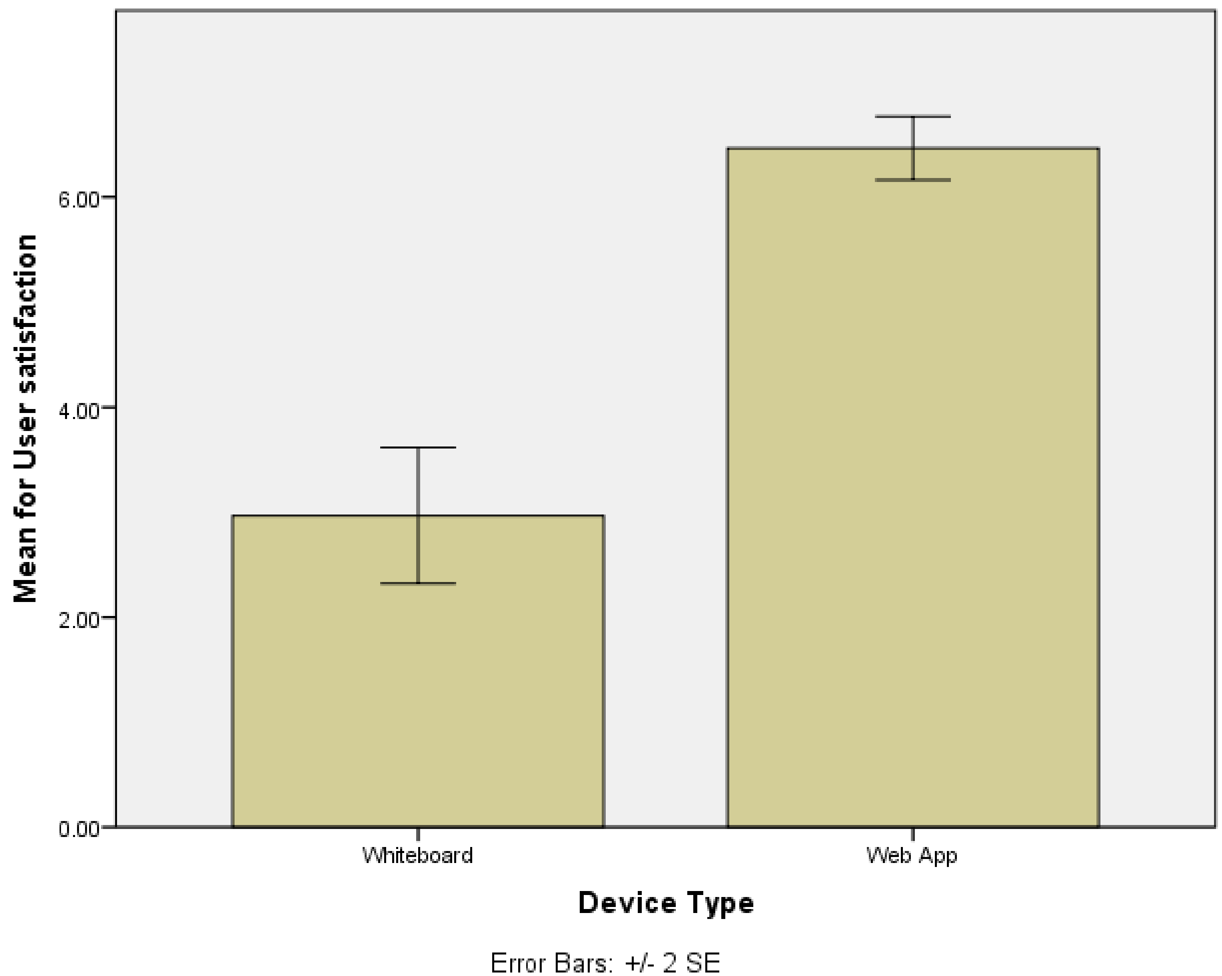

Figure 6.9: Mean ratings for the primary need “User Satisfaction”

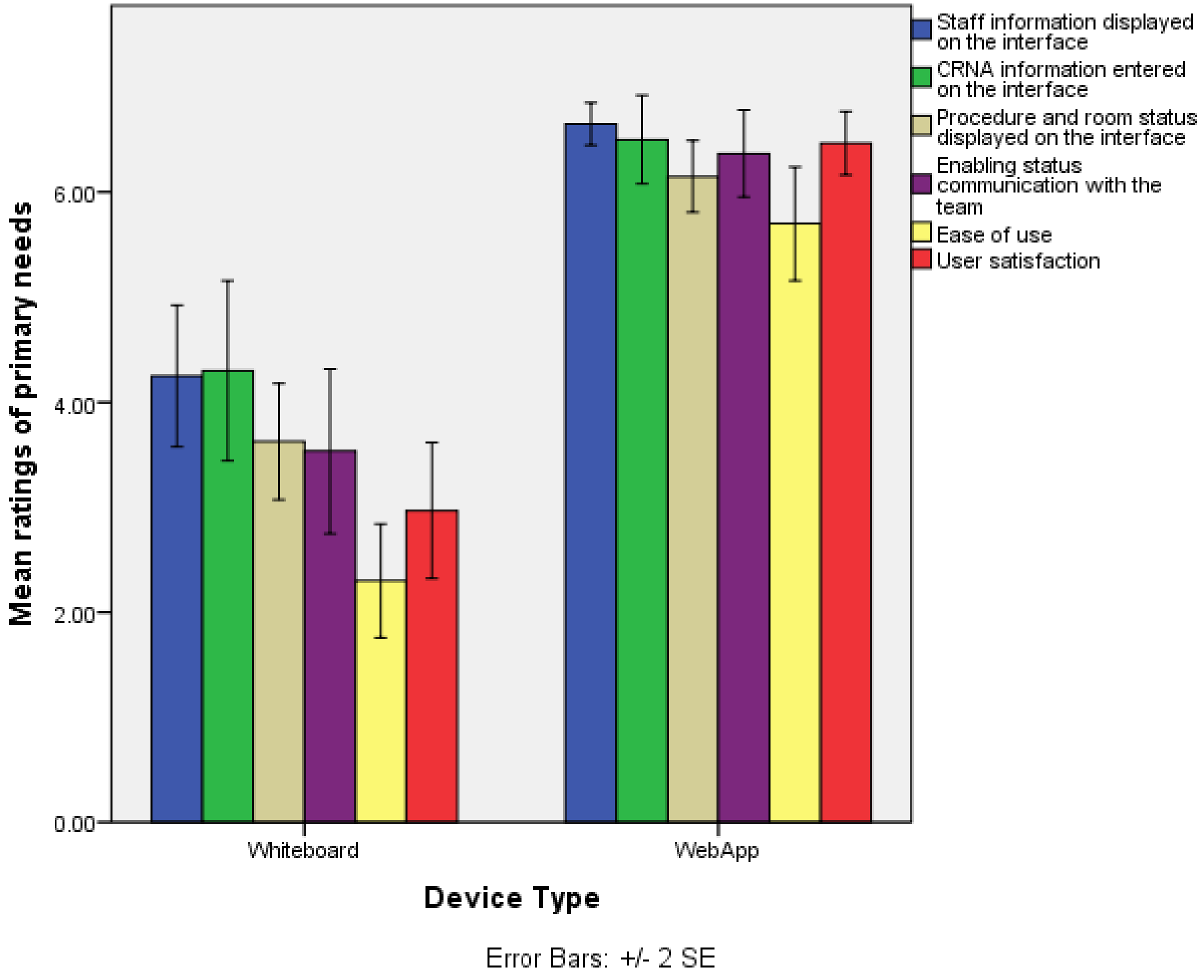

Figure 6.10: Summary of mean ratings for the 6 primary needs

Each NASA TLX index -- Mental demand, Physical demand, Temporal demand, Performance, Effort and Frustration -- rated on a scale of 1 – 7 was analyzed separately, the results indicating that each was statistically significant across the devices. The descriptive statistics and results from a repeated measures ANOVA for the NASA TLX measures are shown in Tables 6.9 and 6.10, respectively.

Table 6.9: One-way ANOVA descriptive statistics for NASA TLX indices

NASA TLX Index	Device	N	Mean	Median	SD	Std. Error	95% CI Lower Bound	95% CI Upper Bound	Min	Max
Mental Demand	Whiteboard	10	3.20	3.00	1.32	0.42	2.26	4.14	1.00	5.00
	Web App	10	1.40	1.00	0.52	0.16	1.03	1.77	1.00	2.00
Physical Demand	Whiteboard	10	2.90	3.00	1.20	0.38	2.04	3.76	1.00	5.00
	Web App	10	1.20	1.00	0.42	0.13	0.90	1.50	1.00	2.00
Temporal Demand	Whiteboard	10	3.50	4.00	1.51	0.48	2.42	4.58	1.00	6.00
	Web App	10	1.40	1.00	0.52	0.16	1.03	1.77	1.00	2.00
Performance	Whiteboard	10	2.90	2.50	1.52	0.48	1.81	3.99	1.00	6.00
	Web App	10	1.50	1.50	0.53	0.17	1.12	1.88	1.00	2.00
Effort	Whiteboard	10	3.10	3.00	1.20	0.38	2.24	3.96	1.00	5.00
	Web App	10	1.40	1.00	0.52	0.16	1.03	1.77	1.00	2.00
Frustration	Whiteboard	10	2.90	2.50	1.37	0.43	1.92	3.88	1.00	5.00
	Web App	10	1.20	1.00	0.42	0.13	0.90	1.50	1.00	2.00

Table 6.10: One-way ANOVA results for NASA TLX Indices

NASA TLX Index	Source	Sum of Squares	df	Mean Square	F	Sig.	Eta Squared
Mental Demand	Device	16.20	1.00	16.20	18.69	0.002	0.68
	Error	7.80	9.00	0.87			
Physical Demand	Device	14.45	1.00	14.45	18.45	0.002	0.67
	Error	7.05	9.00	0.78			
Temporal Demand	Device	22.05	1.00	22.05	23.49	0.001	0.72
	Error	8.45	9.00	0.94			
Performance	Device	9.80	1.00	9.80	8.65	0.016	0.49
	Error	10.20	9.00	1.13			
Effort	Device	14.45	1.00	14.45	21.50	0.001	0.70
	Error	6.05	9.00	0.67			
Frustration	Device	14.45	1.00	14.45	16.16	0.003	0.64
	Error	8.05	9.00	0.89			

Mental demand showed a significant difference between the whiteboard (Mean = 3.2, Median = 3, SD = 1.32) and the web app (Mean = 1.4, Median = 1, SD = 0.52), $F(1,9) = 18.69$, $p<=0.05$. Figure 6.11 shows the mean ratings for mental demand for both of the devices.

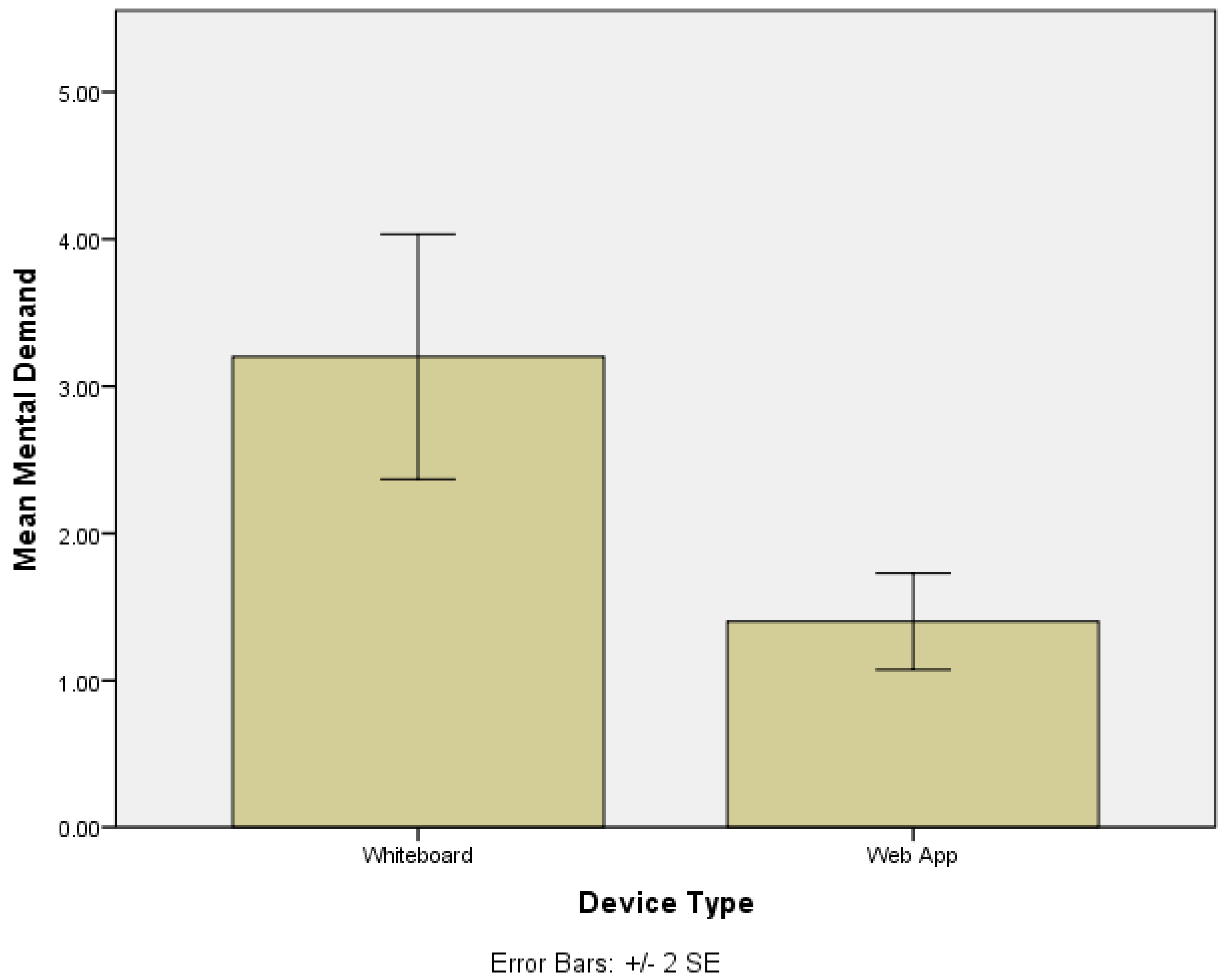

Figure 6.11: Mean ratings for Mental Demand

Physical demand showed a significant difference between the whiteboard (Mean = 2.9, Median = 3, SD = 1.20) and the web app (Mean = 1.2, Median = 1, SD = 0.42), $F(1,9) = 18.45$, $p <= 0.05$. Figure 6.12 below shows the mean ratings for physical demand for both of the devices.

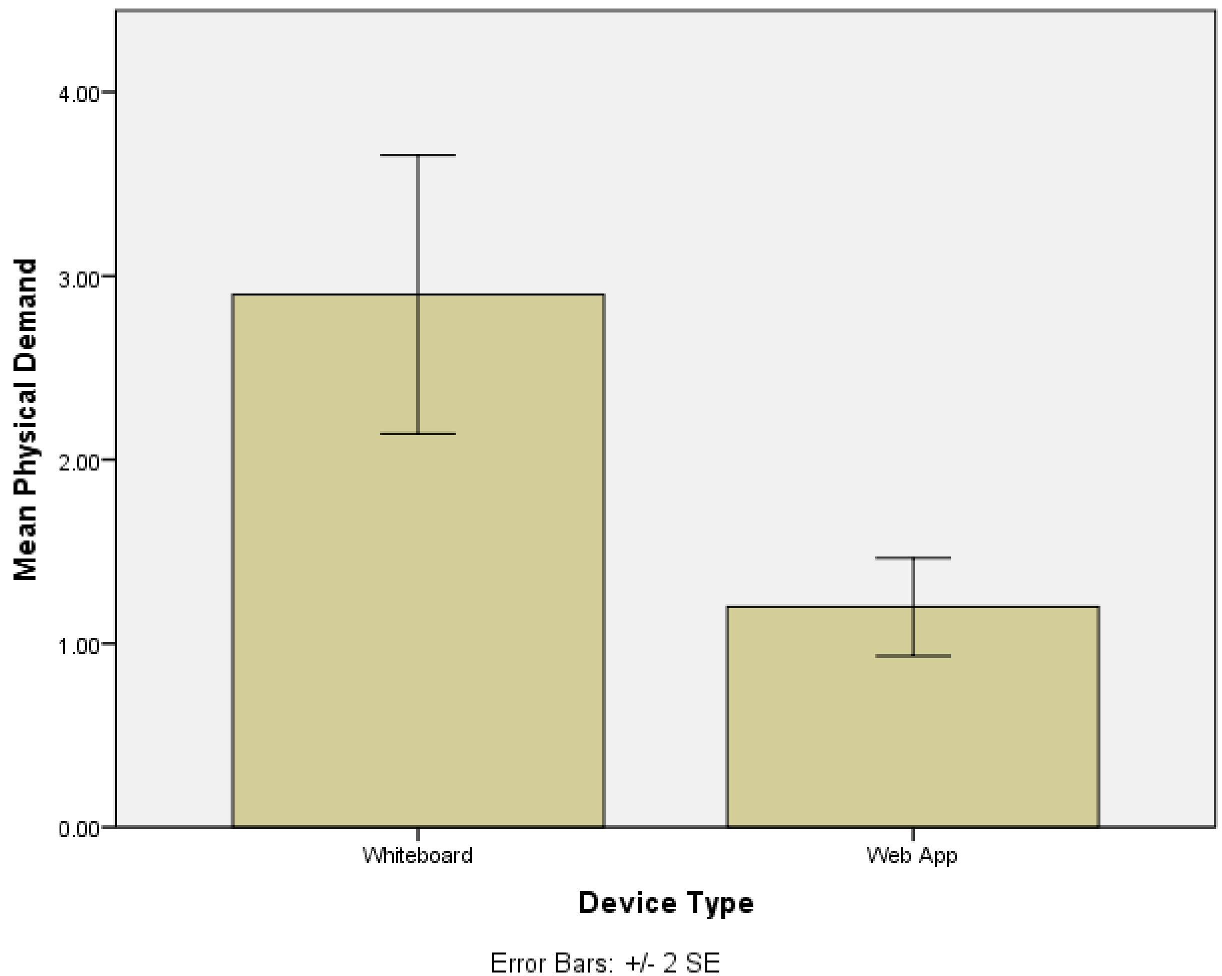

Figure 6.12: Mean ratings for Physical Demand

Temporal demand showed a significant difference between the whiteboard (Mean = 3.5, Median = 4, SD = 1.51) and the web app (Mean = 1.4, Median = 1, SD = 0.52), $F(1,9) = 23.49$, $p <= 0.05$. Figure 6.13 below shows the mean ratings for temporal demand for both of the devices.

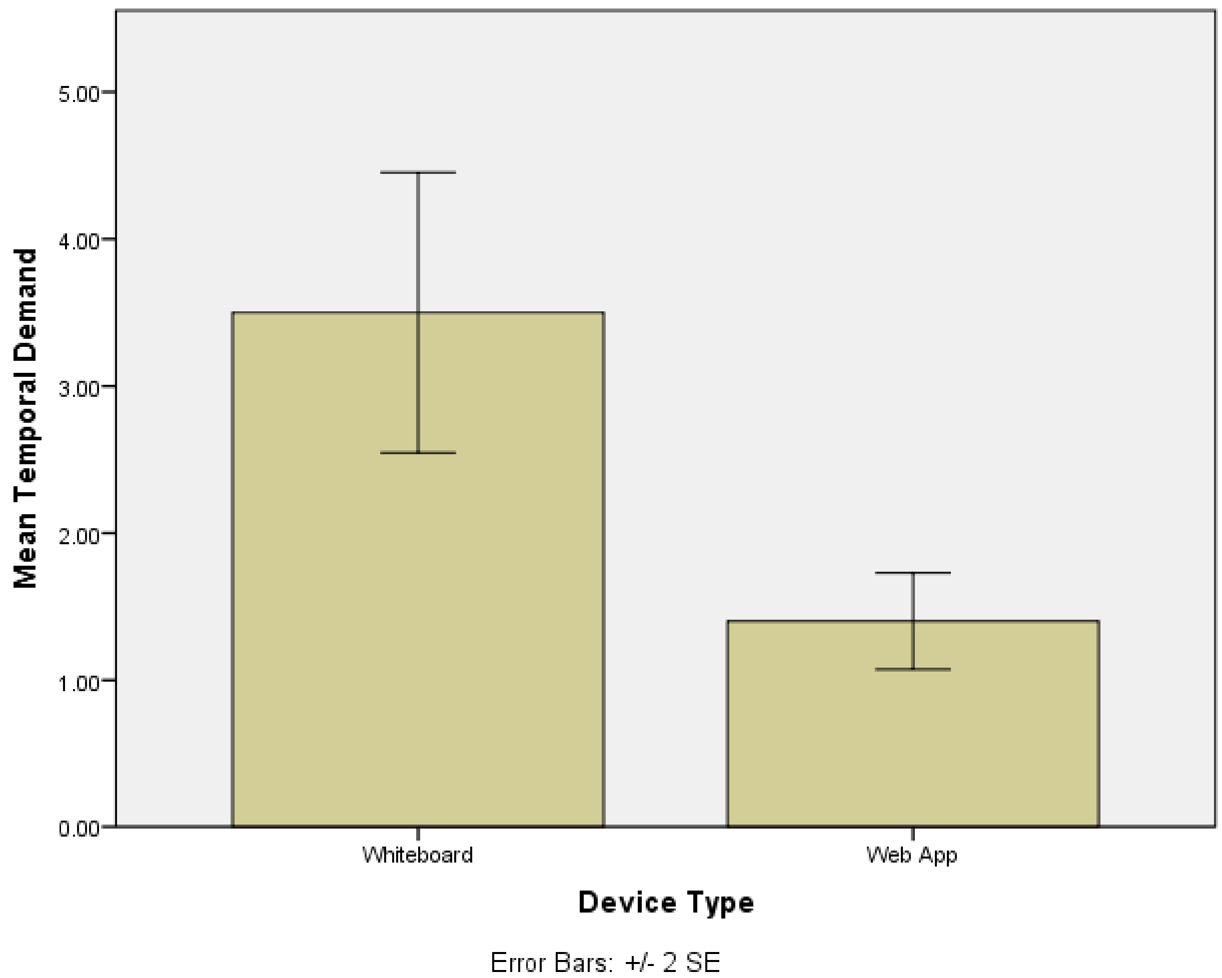

Figure 6.13: Mean ratings for Temporal Demand

Performance (reverse coded) showed a significant difference between the whiteboard (Mean = 2.9, Median = 2.5, SD = 1.52) and the web app (Mean = 1.5, Median = 1.5, SD = 0.53), $F(1,9) = 8.65$, $p <= 0.05$. Since the values are reverse coded, the anchors on the 7-point scale should read as High for the value of 1 and Low for the value of 7. Thus, low mean values indicate that the participants perceived that they were able to achieve their goals better. Figure 6.14 below shows the mean ratings for performance for both of the devices.

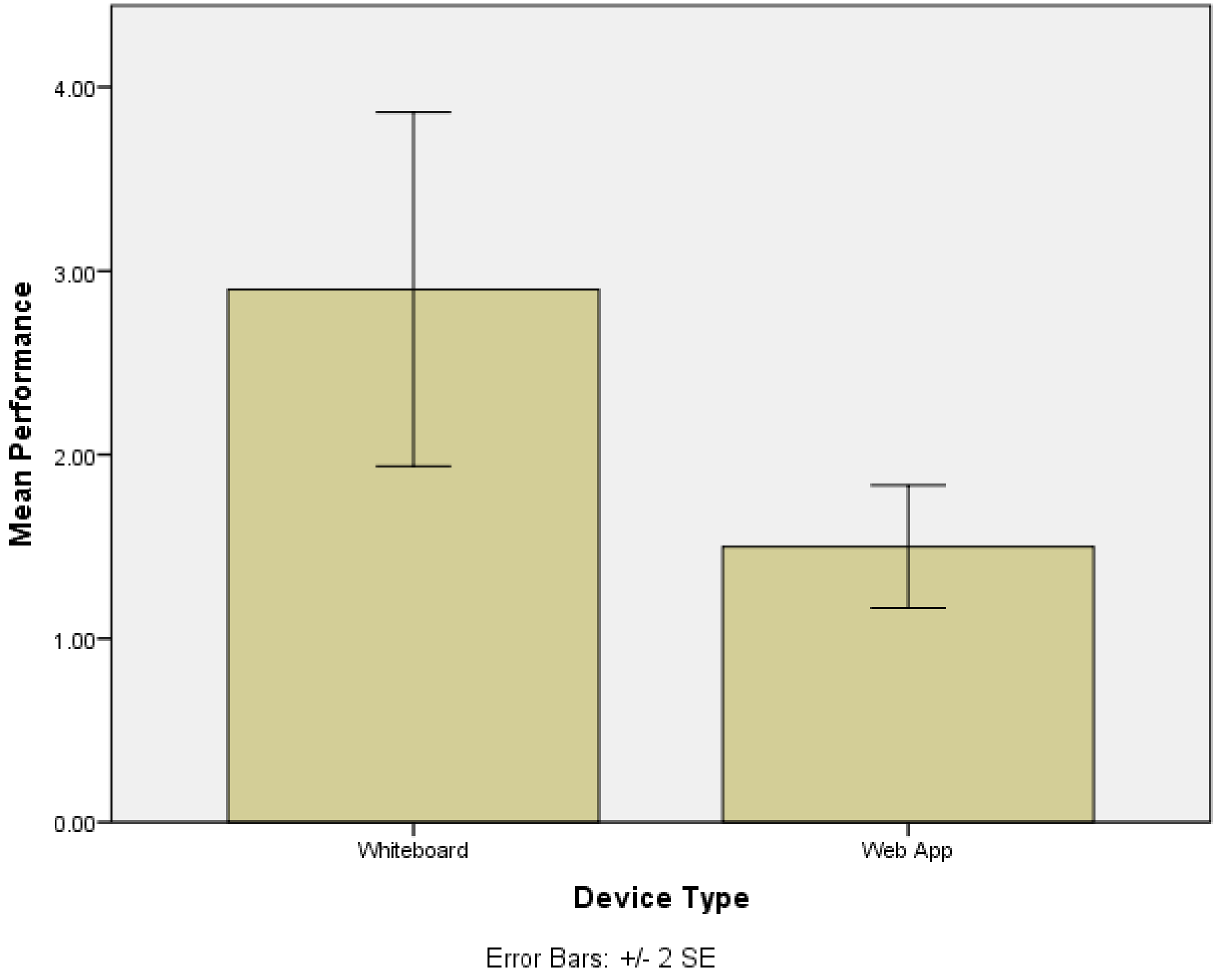

Figure 6.14: Mean ratings for Performance

Effort showed a significant difference between the whiteboard (Mean = 3.1, Median = 3, SD = 1.20) and the web app (Mean = 1.4, Median = 1, SD = 0.52), $F(1,9) = 21.50$, $p <= 0.05$. Figure 6.15 below shows the mean ratings for effort for both of the devices.

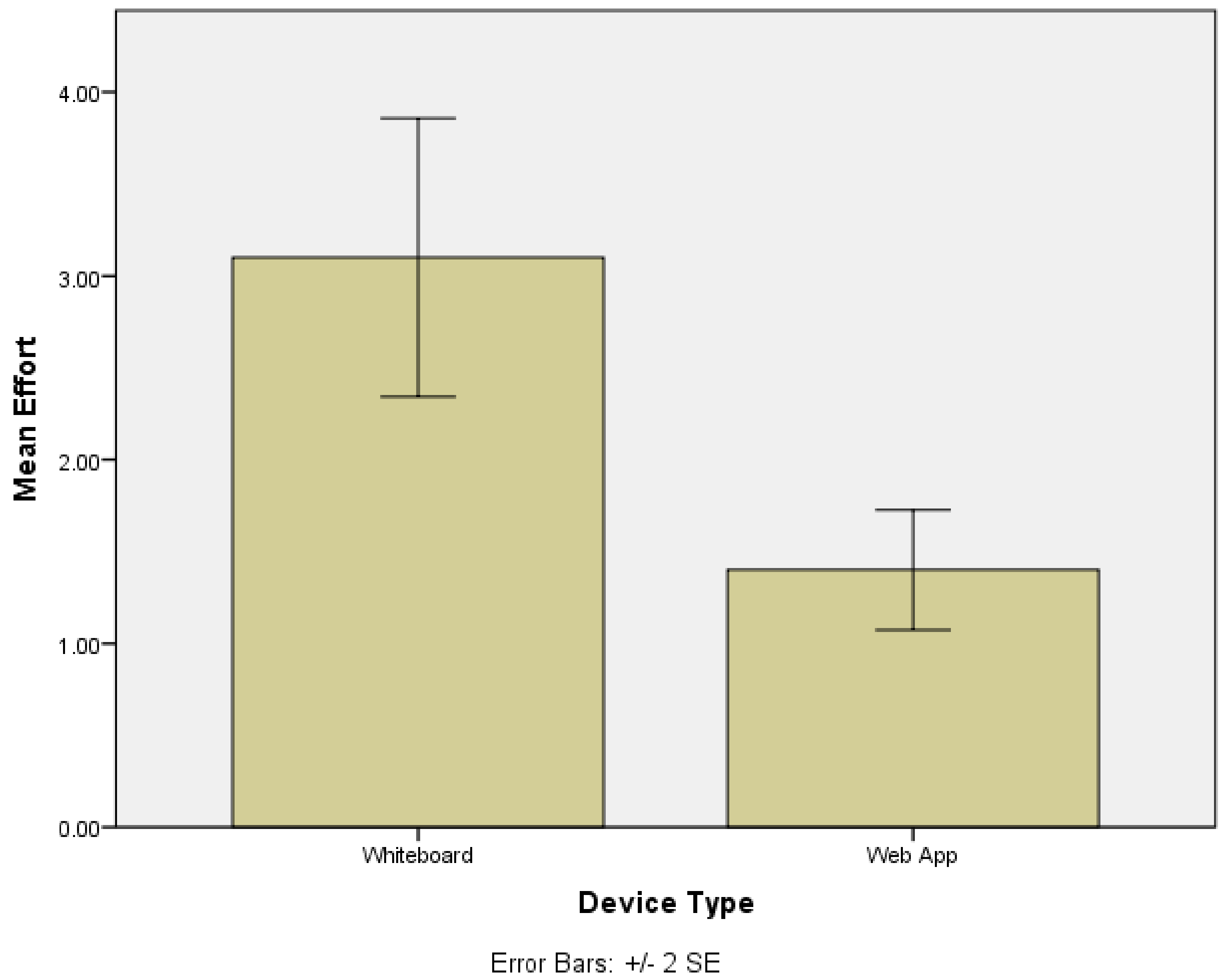

Figure 6.15: Mean ratings for Effort

Frustration showed a significant difference between the whiteboard (Mean = 2.9, Median = 2.5, SD = 1.37) and the web app (Mean = 1.2, Median = 1, SD = 0.42), $F(1,9) = 16.16$, $p <= 0.05$. Figure 6.16 below shows the mean ratings for frustration and Figure 6.17 shows the summary of mean ratings for all the indices in the NASA TLX for both of the devices.

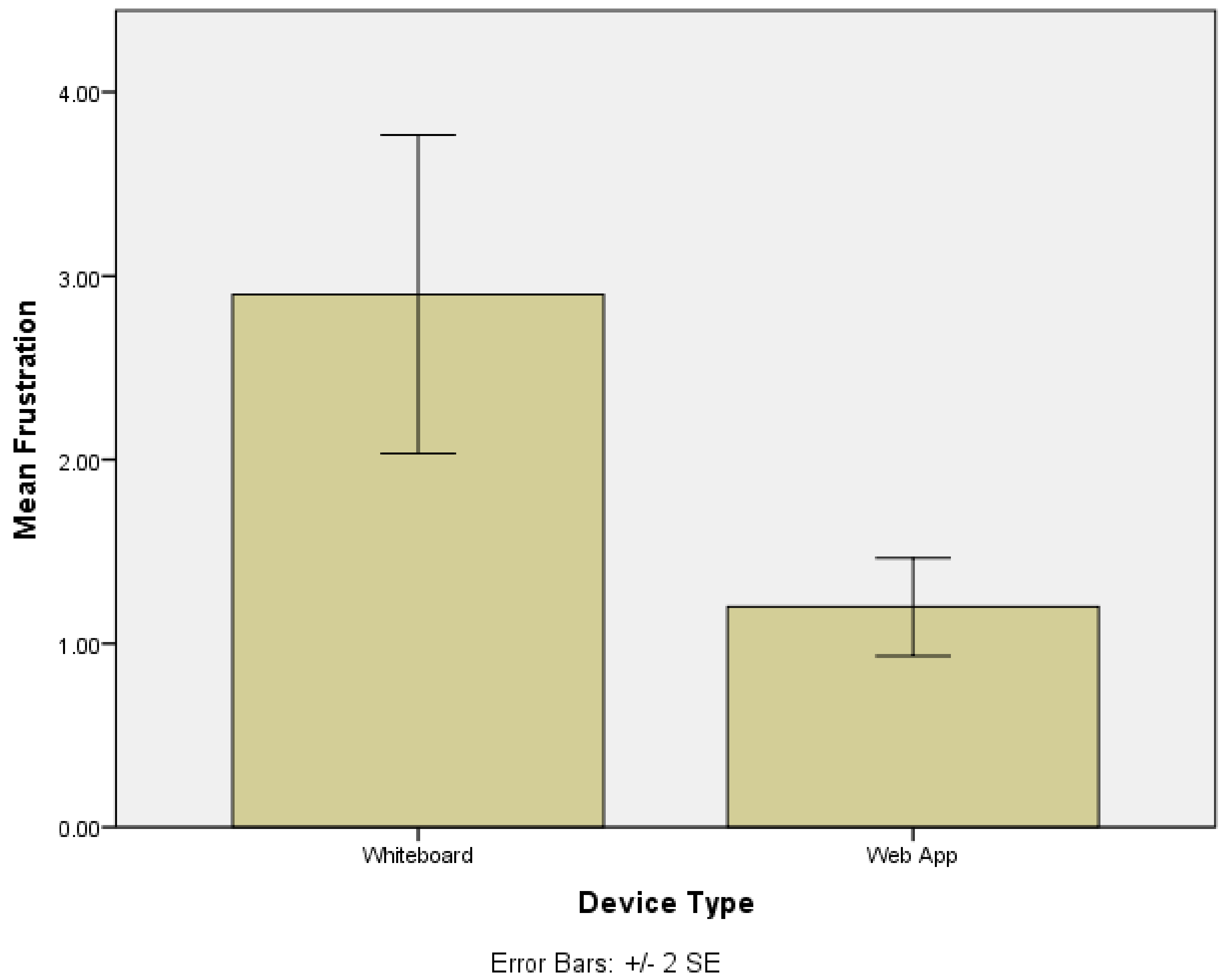

Figure 6.16: Mean ratings for Frustration

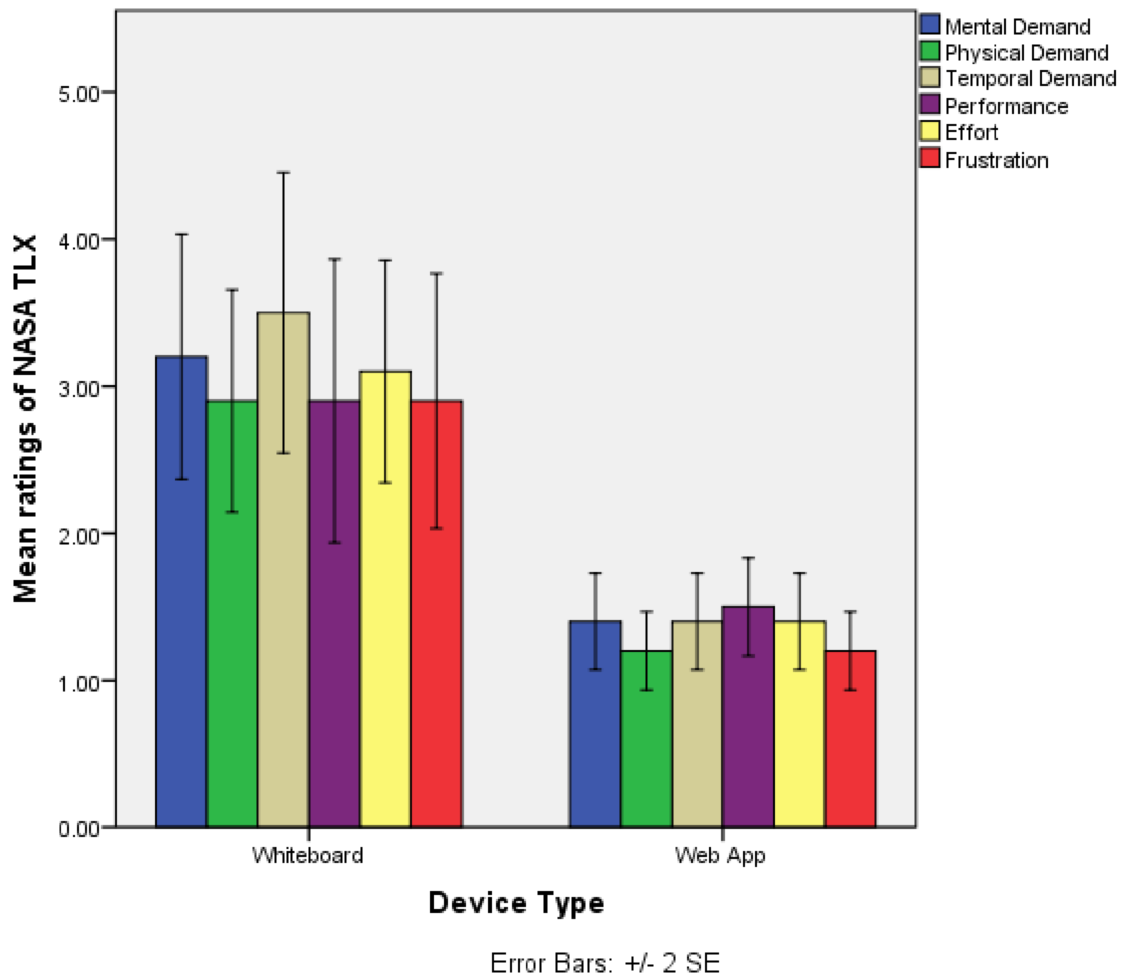

Figure 6.17: Summary of mean ratings for NASA TLX

To analyze system usability, the SUS rating on a 1 – 7 scale was analyzed using a repeated measures ANOVA. There was a significant difference in means between the whiteboard (M = 42, SD = 4.137) and web app (M = 63.4, SD = 3.373), F(1,9) = 10.82, p = 0.002. The descriptive statistics and results from the ANOVA for the SUS measures are shown in Tables 6.11 and 6.12 respectively. The mean SUS ratings for the devices are depicted in Figure 6.18.

Table 6.11: One-way ANOVA descriptive statistics for SUS ratings

Device	N	Mean	Median	Std. Deviation	Std. Error	95% CI Lower Bound	95% CI Upper Bound	Min	Max
Whiteboard	10	42.00	41.50	4.14	1.31	39.04	44.96	37.00	51.00
Web App	10	63.40	62.00	3.37	1.07	60.99	65.81	60.00	70.00

Table 6.12: One-way ANOVA results for SUS ratings

		Sum of Squares	Df	Mean Square	F	Sig.	Eta Squared
SUS	Device	2289.800	1	2289.800	126.276	.000001	.933
	Error	163.200	9	18.133			

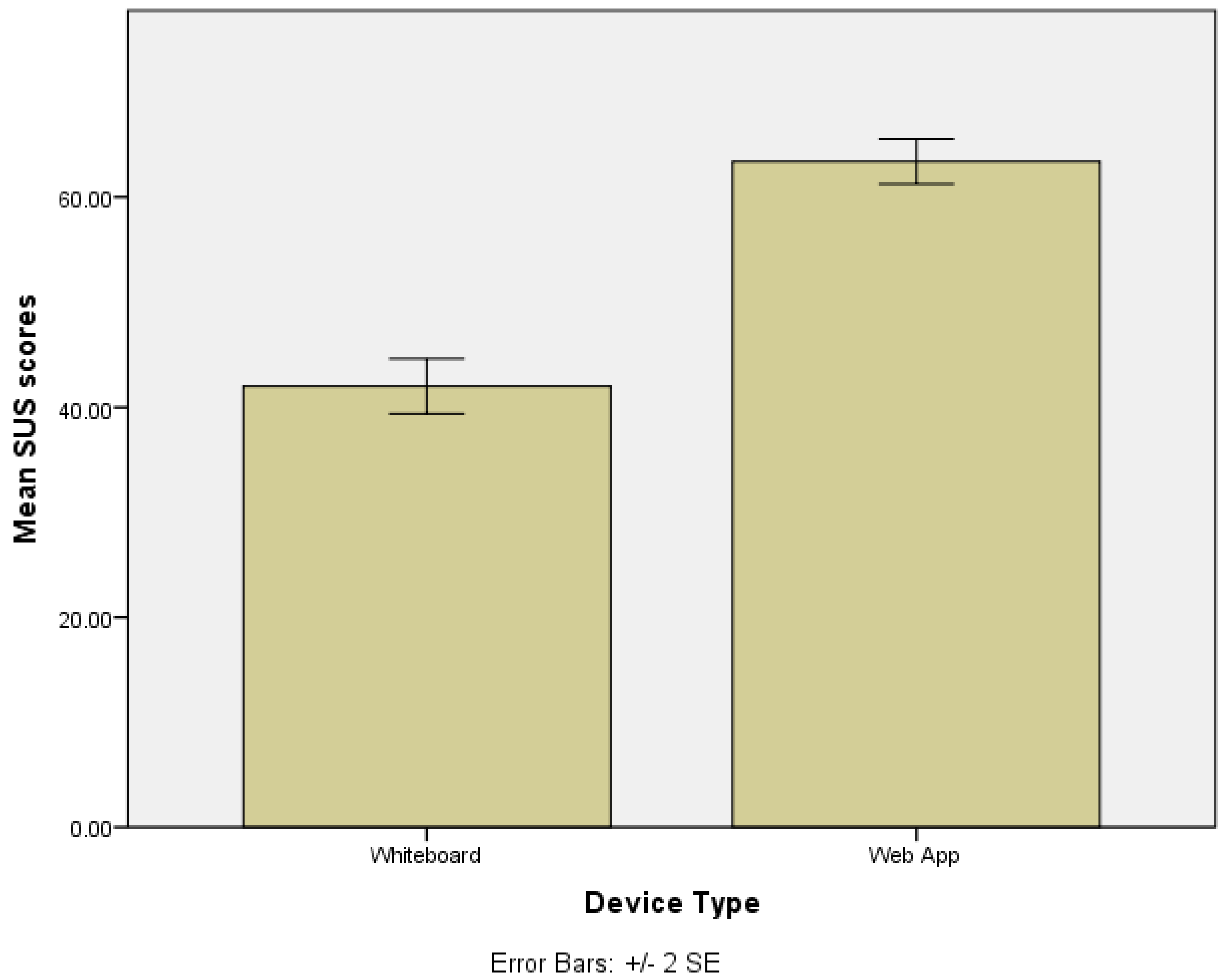

Figure 6.18: Mean SUS ratings

Finally, upon completion of both the sessions of the experiment all ten of the participants indicated that they preferred the mobile web app to the whiteboard.

Post-Experiment Power Analysis

All of the dependent measures exceeded the initially estimated effect size (r^2) of 0.16 except for the task execution and SA error counts. Hence, the sample size (N = 10) chosen for this study meets the power requirements for all of the dependent measures which were found to be significant.

CHAPTER SIX

DISCUSSION AND CONCLUSIONS

Statistical analysis of the data supported 5 of the 6 proposed hypotheses, finding significant differences between the devices for all dependent measures except for the numbers of task execution and situational awareness assessment errors. These results suggest that the mobile web app is a potential replacement for the whiteboard. These findings are discussed using comments from the participants and the personal observations of the researcher.

Objective Measures

Task Execution Time

The shorter task execution time recorded for the mobile web app supports Hypothesis 1a. When the whiteboard was used to perform the tasks to determine which CRNAs are on a break and who need breaks (Tasks 6 and 10 identified in Table 5.3), the participants had to walk from its location to the break board. This additional walking increased the time for the whiteboard for these two tasks by more than 100%. In addition, to find the procedures in the ORs (Task 9), the participants took 15% more time with the whiteboard to find this information. In the whiteboard condition, all of the OR Max screens had to be searched to find this information. In the web app condition, this information could be found directly on the mobile device by selecting each of the four cores for display. These results are also supported by the higher physical demand and mental demand ratings in the NASA TLX workload assessment for the whiteboard.

Task Execution Error Rate

The difference in numbers of errors committed on the devices was not significant. Thus, Hypothesis 1b is not supported. This result could be due to the fact that the tasks given to the participants were familiar to them, meaning they had no difficulty in correctly executing them despite having a distraction task every 20 seconds. The low mean numbers of errors of 0.6 (Median = 0.5) and 0.7 (Median = 1) for the whiteboard and the web app, respectively, indicate that the participants did not make many mistakes executing the tasks.

Situational Awareness Error Rate

The numbers of errors made during the SA assessment were not significantly different for the two devices; hence Hypothesis 2 is not supported. Of the five SA questions, for the question pertaining to the break status of the team (Question 2 in Appendix 8) participants committed twice as many errors in the whiteboard condition than in the web app condition. One potential reason could be that the web app used color coding to indicate the statuses of team members. During the study, participants commented that this color coding helped them to be aware of the break statuses in particular, something that could not be accomplished with the whiteboard and the OR Max screens. The numbers of errors were similar for the two devices for the other four questions. This could be because the participants had less than 15 minutes to evaluate the devices and it may not have been possible for them to gather and remember the information present on the devices, and thus achieve high levels of situational awareness in such a short period of use.

Subjective Measures

Needs Ratings

All six of the primary needs into which the 20 secondary needs were categorized achieved significantly higher ratings for the web app, supporting Hypothesis 3. The needs were rated on a 1 – 7 scale where a rating of 1 indicated that the participants strongly disagreed with the ability of the system to satisfy a need and a rating of 7 indicated strong agreement. The participants strongly agreed (mean rating >=6) that the web app was able to satisfy 17 of the 20 needs. Four participants disagreed with Need 22 (The device fits securely in a scrubs pocket, mean = 4.9) for the web app as they thought its size was not appropriate for their pockets. This is also the need that received the lowest rating (mean = 1.1) for the whiteboard.

These results indicate that the participants perceived the web app to be a better interface than the whiteboard for fulfilling their most important needs. Some of the features that may have contributed to this perception could be the inherent portability of the app; its intuitive, simple interface; and the availability of status updates on all of the team members in real time.

NASA TLX and SUS

The indices in the NASA TLX -- mental demand, physical demand, temporal demand, performance, effort and frustration -- were all rated significantly better for the web app, supporting Hypothesis 4. The tasks that required the participants to search for information on the OR Max boards and the break boards (Tasks 6, 8 and 10) may have required more mental and physical demand when using the whiteboard, which also increased the total time taken for task execution.

The distributed nature of information on the break board, whiteboard and OR Max screens required participants to memorize information and quickly execute the tasks before forgetting it. This may have contributed to an increased perception of temporal demand. The memorization and walking involved in the execution of these tasks required more mental and physical demand and may also have contributed to the increased perception of effort and frustration. Further, during the execution of these tasks, the participants commented that using the whiteboard was “too hard” and the mobile device was “obviously way better.”

The overall usability ratings of the whiteboard and the web app collected using the SUS were found to be significantly higher for the web app, supporting Hypothesis 5, indicating that the web app is easier for the board runners to use than the whiteboard.

Preference Ranking

On the preference ranking questionnaire, 100% of the participants preferred the web app to the whiteboard, supporting Hypothesis 6. This finding is also supported by the statistical results obtained for the measures of time taken, needs ratings, NASA TLX and the SUS.

Conclusions

Analysis of these results suggests that there are opportunities for improving the work practices of board runners. The use of traditional artifacts such as whiteboards introduces many limitations and adds overhead to the overall task performance of the board runners. The new web app technology introduced in this study was found to reduce this overhead by leveraging a few functionalities of the existing IT system and representing the functionality of the existing whiteboards with features such as an easy-to-use drag and drop user-interface in a mobile platform. Statistical analyses of dependent measures and comments from the participants support the prospect that the users would be willing to adopt mobile technologies if they are designed and implemented through a user-centered approach like the one used here.

To implement the web app designed for this study at the hospital, it would be appropriate to integrate the frontend UI with the IT database and evaluate the performance more rigorously using longer task sessions, measuring SA during task execution (Endsley, 1995), providing more distractions, looking for variations induced as a result of the Hawthorne effect (McCarney et al., 2007), and possibly through a real-world study with more users. Such studies would help to determine how well the CRNAs share information with their team members in real-time and would be crucial in evaluating the performance of the product and addressing some of the limitations of this research.

Since the web app was developed exclusively for the CRNA board runners, the number of participants available for this study was limited. Even though the sample size met the power requirements, some of the dependent measures, for example workload perceived and preference ranking for the device, may have been over-estimated as a result of having a low sample size (e.g., Lee, Siow Ming, et al., 2008; Lee, S., et al, 2008). Further, since the whiteboard in the actual setting is conspicuous to other hospital employees such as nurses and administrative staff, it would be appropriate to study if there are any dependencies between their work practices and the whiteboard before implementing the web app as a complete replacement.

Future research could extend the dissemination of mobile technologies to a variety of user groups. Other potential user groups who may benefit from such a technology could be the nurses, anesthesiologists and other healthcare providers working as a team and currently using traditional artifacts such as whiteboards to accomplish communication, coordination and collaboration. Portable and easy-to-use technology that can help these users be aware of team member status and to update them of changes in real-time could be beneficial in addressing the limitations they encounter when using these traditional artifacts.

APPENDICES

Appendix 1

Informed Consent to Participate in Interviews and Observations

IRB File #Pro00020783

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

Creating learning systems with mobile technology to improve coordination in perioperative services

Study to be Conducted at: *Greenville Memorial Hospital*
701 Grove Road
Greenville, SC 29605-5601

Sponsor Name: *National Science Foundation*

Principal Investigator: *Kevin M. Taaffe, (864) 656-0291*

INTRODUCTION

You are being asked to participate in a research study. The Institutional Review Board of the Greenville Hospital System has reviewed this study for the protection of the rights of human participants in research studies, in accordance with federal and state regulations. However, before you choose to be a research participant, it is important that you read the following information and ask as many questions as necessary to be sure that you understand what your participation will involve. Your signature on this consent form will acknowledge that you received all of the following information and explanations verbally and have been given an opportunity to discuss your questions and concerns with the principal investigator or a co-investigator.

PURPOSE

You are being asked to participate in this study because of your knowledge of perioperative services.

The purpose of this study is to better understand how the different services provided in the perioperative setting are coordinated, to identify barriers that may make it difficult to achieve effective coordination of these services, and to consider how technology might be used to overcome these barriers. We anticipate that approximately 10 individuals may participate in this initial investigation at Greenville Memorial Hospital. We hope to be able to spend about an hour or so discussing these issues with you in our initial meeting and, if possible, we expect that we would benefit from scheduling follow-up meetings with you at later dates to enhance our understanding of the issues.

PROCEDURES
After obtaining your informed consent to participate in this study, members of the project team (Drs. Kevin Taaffe, Larry Fredendall, and Joel Greenstein from Clemson University and Drs. Nathan Huynh and Jose Vidal from the University of South Carolina) will meet with you individually or in groups with other GHS administrators, managers, and staff to discuss the problems of coordinating perioperative services. We may agree that it would be helpful for you to physically walk us through your work environments as we carry out these discussions. We will take written notes of these discussions as they take place.

POSSIBLE RISKS
There are no known risks related to participation in this study.

We do not plan to ask any questions that are personal in nature. You do not have to answer any questions that you do not wish to answer. It is possible that you may say something you regret having said. Should you say something that you would prefer we not attribute to you or that we not record at all, we will strike any notes that you indicate you would like us to remove.

POSSIBLE BENEFITS
It is not possible to know whether or not you may benefit from participating in this study. You understand that the information gained from this study may be used scientifically and may be helpful to others.

This research is focused on the development of technologies and work processes that will enhance coordination among hospital staff within and across perioperative departments.

COST TO YOU FOR PARTICIPATING IN THIS STUDY
There are no monetary costs associated with participation in this study.

PAYMENT FOR PARTICIPATION

To You: You will not be paid to participate in this study.

To Investigators: The investigators will not be paid above their regular salaries for conducting this study.

To Institution: Clemson University and the University of South Carolina are being paid by the National Science Foundation for administrative costs associated with conducting this study.

COMPENSATION FOR INJURY AS A RESULT OF STUDY PARTICIPATION
Injuries sometimes happen in research even when no one is at fault. The study sponsor, the Greenville Hospital System, or the investigators as part of this study have no plans to pay you or

give you other compensation for an injury, should one occur. However, you are not giving up any of your legal rights by signing this form.

If you think you have been injured or have experienced a medical problem as a result of taking part in this research study, tell the person in charge of this study as soon as possible. The researcher's name and phone number are listed in the 'Contact For Questions' section of this consent.

VOLUNTARY PARTICIPATION

Participation in this study is completely voluntary (your choice). You may refuse to participate or withdraw from the study at any time. If you refuse to participate or withdraw from the study, you will not be penalized or lose any benefits. Your decision will not affect your relationship with the hospital.

NEW INFORMATION

During this study, you will be told of any important new information that may affect your willingness to participate in this study.

CONFIDENTIALITY

Your study records are considered confidential (private), but absolute confidentiality cannot be guaranteed. Information may be kept on a computer. All records may be examined and copied by the Institutional Review Board of the Greenville Hospital System, and other regulatory agencies. This study may result in presentations and publications, but steps will be taken to make sure you are not identified by name.

CONTACT FOR QUESTIONS

For more information concerning this study and research-related risks or injuries, or to give comments or express concerns or complaints, you may contact the principal investigator, Dr. Kevin M. Taaffe, (864) 656-0291.

You may also contact a representative of the Institutional Review Board of the Greenville Hospital System for information regarding your rights as a participant involved in a research study or to give comments or express concerns, complaints or offer input. You may obtain the name and number of this person by calling (864) 455-8997.

A survey about your experience with this informed consent process is located at the following website:

http://www.ghs.org/Research-and-Clinical-Trials

Participation in the survey is completely anonymous and voluntary and will not affect your relationship with the Greenville Hospital System. If you would like to have a paper copy of this survey, please tell the principal investigator.

CONSENT TO PARTICIPATE

The study investigators have explained the nature and purpose of this study to me. I have been given the time and place to read and review this consent form and I choose to participate in this study. I have been given the opportunity to ask questions about this study and my questions have been answered to my satisfaction. After I sign this consent form, I understand I will receive a copy of it for my own records. I do not give up any of my legal rights by signing this consent form.

____

Printed Name of Participant

____ ____________ ____________

Signature of Participant Date Time

____ ____________ ____________

Signature of Witness Date Time

INVESTIGATOR STATEMENT

I have carefully explained to the participant the nature and purpose of this study. The participant signing this consent form has (1) been given the time and place to read and review this consent form; (2) been given an opportunity to ask questions regarding the nature, risks and benefits of participation in this research study; and (3) appears to understand the nature and purpose of the study and the demands required of participation. The participant has signed this consent form prior to having any study-related procedures performed.

____ ____________ ____________

Signature of Investigator Date Time

Principal Investigator: Dr. Kevin M. Taaffe, (864) 656-0291

Co-Investigators: Dr. Larry Fredendall, (864) 656-2016
Dr. Joel Greenstein, (864) 656-5649
Dr. Nathan Huynh, (803) 777-8947
Dr. Jose Vidal, (803) 777-0928
Sue Seitz, RN, MSN, CNOR, (864) 455-5561

Appendix 2

Importance Survey of Needs

Date	
Based upon our preliminary observations and interviews, we are proposing the following list of features for the mobile information dashboard intended for the CRNA board runner.	
Please review this list and for each of the features, please indicate on a scale of 1-5 how important each feature is to you. Please use the following scale:	
1 – Feature is undesirable.	
2 – Feature is not important, but I would not mind having it.	
3 – Feature would be nice to have but is not necessary.	
4 – Feature is highly desirable but I would consider a website without the feature.	
5 – Feature is critical. I would not consider a website without this feature.	
In addition, if you find a particular feature unique, unexpected or potentially exciting, please place a "check mark" in the box to the right of the feature description.	
Your participation is voluntary and no personally identifiable information will be collected. Rating the features will take about 5 to 10 minutes of your time.	

# (1-5)	**Dashboard Feature**	**Check box if feature is unique, exciting or unexpected**
	The system displays real-time list of available CRNAs.	
	The system displays which CRNAs need breaks during break times	

	(usually 8.30Am, 11.00Am and 1.30Pm).	
	The system displays which CRNAs do not need breaks during break times (usually 8.30Am, 11.00Am and 1.30Pm).	
	The system displays whether a CRNA who needs a break has been relieved by an available CRNA.	
	The system displays which CRNAs are nearing end-of-shift.	
	The system displays the shift times of the CRNAs scheduled for the day.	
	The system displays the shift end-time of the CRNAs scheduled for the day.	
	The system explains the meaning of color codes for CRNA names (regarding break information and status).	
	The system allows the board runner to update shift times of CRNAs in OR.	
	The system allows the board runner to assign CRNAs to rooms for the next day as well as on the same day based on their schedule and availability (more than one CRNA may be assigned to some rooms).	
	The system allows the board runner to maintain an updatable list of the availability of the CRNAs (Available, Not available, On call).	
	The system displays the status of GI rooms around 2.00Pm.	
	The system displays information from the charge desk about case delays and add-on cases.	
	The system displays the status of a procedure in progress.	
	The system displays the type of procedure in progress in each OR.	
	The system displays the anesthesiologist assigned to each OR.	
	The system displays the current location of each anesthesiologist.	
	The system displays names of students/residents assisting CRNAs in each OR.	
	The system enables the board runner to update the charge desk	

	whether a CRNA is available to handle an add-on case.	
	The system enables the board runner to update the charge desk when a CRNA is available to handle an add-on case.	
	The system enables the board runner to determine the status of ORs that are 'On Hold' due to unavailability of CRNAs for staffing.	
	The system enables the board runner to communicate the status of ORs that are 'On Hold' due to unavailability of CRNAs for staffing.	
	The system allows the board runner to determine the status of ORs that are in the 'Get ready' process.	
	The system allows the board runner to communicate the status of ORs that are in the 'Get ready' process.	
	The device fits securely in a scrubs' pocket.	
	The system minimizes the use of Vocera.	
	The system minimizes the use of personal phones.	
	The system does not overwhelm the board runner with information.	
	The system's interface is easy to use.	
	The system is easy to keep track of.	
	The system reduces the need for the board runner to walk from location to location.	
	The system helps the board runner to communicate with CRNAs about their current case.	
	The system helps the board runner to communicate with CRNAs about their next case.	
	The system helps the board runner to communicate with CRNAs to coordinate preparation for an upcoming case.	
	The system enables the task of managing breaks for the CRNAs.	
	The system eases the task of assigning CRNAs to ORs.	
	The system eases the task of relieving CRNAs when they approach the end of their shift.	

	The system enables CRNAs to arrange for someone in the team to give them a break without the help of the board runner.	
	The system enables better communication between the board runner and the CRNAs.	

Appendix 3

Demographic Information

Please fill your information for the following:

Age:
Years of experience as board runner:

Familiarity with touch screen mobile devices (e.g., smartphones – iPhone, Galaxy):

Not at all			Moderately			Extremely
1	2	3	4	5	6	7

Appendix 4:

System Usability Scale (SUS)

		Strongly disagree			**Neither agree or disagree**			**Strongly agree**
	Feature	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	I think that I would like to use this system frequently							
2	I found the system unnecessarily complex							
3	I thought the system was easy to use							
4	I think that I would need a support of a technical person to be able to use this system							
5	I found the various functions in this system were well integrated							
6	I thought there was too much inconsistency in this system							
7	I would imagine that most people would learn to use this system very quickly							
8	I found the system very cumbersome to use							
9	I felt very confident using the system							
10	I needed to learn a lot of things before I could get going with this system							

Appendix 5

NASA Task Load Index (NASA-TLX)

NASA-TLX Mental Workload Rating Scale

Please place an "X" along each scale at the point that best indicates your experience with the display interface.

		Low			**Medium**			**High**
	Feature	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	**Mental Demand:** How mentally demanding was the task?							
2	**Physical Demand:** How physically demanding was the task?							
3	**Temporal Demand:** How hurried or rushed was the pace of the task?							
4	**Performance:** How successful were you in accomplishing what you were asked to do?							
5	**Effort:** How hard did you have to work to accomplish your level of performance?							
6	**Frustration:** How insecure, discouraged, irritated, stressed, and annoyed were you?							

Appendix 6

7-point Likert Scale for Needs Rating

Based on your interaction with the device, please place and X mark in the appropriate box for each feature of the system.

		Strongly disagree			**Neither agree or disagree**			**Strongly agree**
	Feature	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	The system displays a real-time list of available CRNAs.							
2	The system is easy to keep track of.							
3	The system displays the shift times of the CRNAs scheduled for the day.							
4	The system displays which CRNAs need breaks during break times (typically 8.30 a.m., 11.00 a.m. and 1.30 p.m.).							
5	The system displays the shift end-time of the CRNAs scheduled for the day.							
6	The system enables better communication between the board runner and the CRNAs.							
7	The system displays which CRNAs are nearing end-of-shift.							
8	The system displays the status of a procedure in progress.							
9	The system allows the board runner to maintain an updatable list of the availability of the CRNAs (Available, Not available, On call).							
10	The system displays information from the charge desk about case delays and add-on cases.							
11	The system displays the type of procedure in progress in each							

	OR.							
12	The system reduces the need for the board runner to walk from location to location.							
13	The system displays whether a CRNA who needs a break has been relieved by an available CRNA.							
14	The system allows the board runner to assign CRNAs to rooms for the next day as well as on the same day based on their schedule and availability (more than one CRNA may be assigned to some rooms).							
15	The system helps the board runner to communicate with CRNAs to coordinate preparation for an upcoming case.							
16	The system helps the board runner to communicate with CRNAs about their next case.							
17	The system displays the status of GI rooms around 2.00 p.m.							
18	The system enables CRNAs to arrange for someone in the team to give them a break without the help of the board runner.							
19	The device fits securely in a scrubs pocket.							
20	The system helps the board runner to communicate with CRNAs about their current case.							

Appendix 7

Preference Ranking Questionnaire

Rank the Devices

Rank the device that you prefer the most as # 1 and the device you prefer the least as # 2.

1. Device 1 – Whiteboard interface

Rank # ________

2. Device 2 – Mobile web-based interface

Rank # ________

Appendix 8

Situational Awareness Questionnaire

Based on the information that you saw on the device, please answer the following questions:

1. Recall the location of team members E, F, G and H.
2. How many break requests are pending at this moment?
3. How many CRNAs are free at this moment?
4. Recall the shift times of team members A, B, C and D.
5. How many CRNAs need to be relieved in the next one hour?

Appendix 9:

Informed Consent to Participate in Research Study

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

IRB File # **Pro00034949**

Design of a Mobile Web-based Dashboard to Improve Work Practices of CRNA Board Runners

Study to be Conducted at:	Greenville Memorial Hospital 701 Grove Road Greenville, South Carolina 29605
Sponsor Name:	*National Science Foundation*
Principal Investigator:	*Dr. Gilbert Ritchie, Greenville Memorial Hospital*, *(864) 455-7171*

INTRODUCTION

You are being asked to participate in a research study. The Institutional Review Board of the Greenville Health System has reviewed this study for the protection of the rights of human participants in research studies, in accordance with federal and state regulations. However, before you choose to be a research participant, it is important that you read the following information and ask as many questions as necessary to be sure that you understand what your participation will involve. Your signature on this consent form will acknowledge that you received all of the following information and explanations verbally and have been given an opportunity to discuss your questions and concerns with the principal investigator or a co-investigator.

PURPOSE

You are being asked to participate in this study because you are a CRNA team member and have experience functioning as a board runner. The purpose of this study is to address challenges faced by board runners while using artifacts such as a whiteboards to manage the team members. The use of whiteboards entails two primary challenges: 1. The board runners have to be highly mobile in gathering and disseminating information, while executing their daily tasks, 2. The amount of information that board runners have to keep track of is very high and is constantly changing. A user-centered design methodology will be used in this study to develop an efficient and effective web based application to enable team management thereby helping in reducing the use of whiteboards. As past research has shown that electronic devices have the potential to address challenges faced while using traditional artifacts, this research proposes to design a web application incorporating functionalities of the whiteboards which will be delivered on a mobile device such as Google Nexus 7 tablet PC. We are conducting the evaluation of this new web application in comparison with the whiteboard in a conference room with 10 CRNA board runners at Greenville Memorial Hospital. The researcher is conducting this study as part of thesis requirements of Clemson University.

PROCEDURES

If you agree to participate in this research study, you will be asked to read and sign this informed consent form. This study will be conducted over a time period of three weeks in a simulated environment such as conference rooms. Your participation in this study will consist of 3 sessions, one per week; each session will last approximately 15 minutes.

In session 1, you will be given the mobile web application for practicing and familiarizing with its features. In session 2, you will be asked to perform specific tasks with the application. These tasks will mirror those that you would be doing with the whiteboards to manage your team members. In session 3, you will be asked to do the same tasks using a whiteboard. The OR-Max display screens will be located in another conference room nearby and you may be required to walk to this room to gather information while performing some tasks in this session. During sessions 2 and 3, the time taken to perform the tasks will be recorded by the researcher using a stop-watch. After the completion of sessions 2 and 3, you will be asked to complete the NASA-TLX workload questionnaire, the System Usability Scale questionnaire, Likert Scale questionnaire and the Situational Awareness questionnaire. At the end of the third session, you will be asked to complete an additional survey ranking the mobile application and the whiteboard based on your preference. Your name will not be collected in the surveys and you may choose not to answer any questions that you do not wish to answer.

The data gathered from this study will be recorded in a secure password-enabled computer laptop so that the research team can use the data for analyzing the performance of both the mobile web application and the whiteboard.

POSSIBLE RISKS

There are no known physical risks associated with the simulated web application evaluation. There is a possible risk of loss of confidentiality.

POSSIBLE BENEFITS

There are no direct benefits to you by participating in this study. The research is focused on designing the functionalities of whiteboards used by CRNA board runners on a mobile device to eliminate barriers such as information overload and the need to be highly mobile.

ALTERNATIVE (OTHER) TREATMENTS
You may choose not to participate in the study. The decision is entirely up to you. If you decide not to participate in the study, you will not be penalized or lose any benefits and your decision will not affect your relationship with the Greenville Health System.

COST TO YOU FOR PARTICIPATING IN THIS STUDY
There will be no cost to you for participating in this study.

PAYMENT FOR PARTICIPATION
To You: You will not be paid to participate in this study.

To Investigators: Neither the investigators nor professional staff will receive any special compensation above and beyond their regular salaries for time and effort to perform procedures, tasks, and accurately collect and submit data.

COMPENSATION FOR INJURY AS A RESULT OF STUDY PARTICIPATION
If you get hurt or sick because of your participation in this study, emergency medical treatment is available but will be provided at the usual charge.

Injuries sometimes happen in research even when no one is at fault. The Greenville Health System, or the investigators as part of this study have no plans to pay you or give you other compensation for an injury, should one occur. However, you are not giving up any of your legal rights by signing this form.

If you think you have been injured or have experienced a medical problem as a result of taking part in this research study, tell the person in charge of this study as soon as possible. The researcher's name and phone number are listed in the 'Contact For Questions' section of this consent.

VOLUNTARY PARTICIPATION
Participation in this study is completely voluntary (your choice). You may refuse to participate or withdraw from the study at any time. If you refuse to participate or withdraw from the study, you will not be penalized or lose any benefits. Your decision will not affect your relationship with the Greenville Health System.

NEW INFORMATION
During this study, you will be told of any important new information that may affect your willingness to participate in this study.

CONFIDENTIALITY
Study records with your personal information on them will be kept private as required by law. Except when required by law, you will not be identified by name, social security number, address, telephone number, or any other personal information in study records given outside of Greenville

Health System (GHS). The contact information we recorded will be destroyed after completion of this research. We will not share your answers with anyone outside this study. This study does not involve any medical tests or procedures; no information will be put in your medical record.

Your study records are considered confidential (private), but absolute confidentiality cannot be guaranteed. Information may be kept on a computer. All records may be examined and copied by the Institutional Review Board of the Greenville Health System, and other regulatory agencies. This study may result in presentations and publications, but steps will be taken to make sure you are not identified by name.

CONTACT FOR QUESTIONS

For more information concerning this study and research-related risks or injuries, or to give comments or express concerns or complaints, you may contact the principal investigator, Dr. Joel Greenstein, Associate Professor, Clemson University, at (864) 656-5649.

You may also contact a representative of the Institutional Review Board of the Greenville Health System for information regarding your rights as a participant involved in a research study or to give comments or express concerns, complaints or offer input. You may obtain the name and number of this person by calling (864) 522-2097.

A survey about your experience with this informed consent process is located at the following website:

http://www.ghs.org/Research-and-Clinical-Trials

Participation in the survey is completely anonymous and voluntary and will not affect your relationship with your doctor or the Greenville Health System. If you would like to have a paper copy of this survey, please tell your study doctor.

CONSENT TO PARTICIPATE

The researcher, ____, has explained the nature and purpose of this study to me. I have been given the time and place to read and review this consent form and I choose to participate in this study. I have been given the opportunity to ask questions about this study and my questions have been answered to my satisfaction. I agree that my information may be used and disclosed (released) as described in this consent form. After I sign this consent form, I understand I will receive a copy of it for my own records. I do not give up any of my legal rights by signing this consent form.

____

Printed Name of Participant

Signature of Participant Date Time

Signature of Witness Date Time

INVESTIGATOR STATEMENT

I have carefully explained to the participant the nature and purpose of this study. The participant signing this consent form has (1) been given the time and place to read and review this consent form; (2) been given an opportunity to ask questions regarding the nature, risks and benefits of participation in this research study; and (3) appears to understand the nature and purpose of the study and the demands required of participation. The participant has signed this consent form prior to having any study-related procedures performed.

Signature of Investigator Date Time

Principal Investigator: Dr. Gilbert Ritchie (864) 455-7171

Co-Investigators: Dr. Joel Greenstein (864) 656-5649
Mahesh Sreedharan (864) 353-4862
Sumonthip Chompoodang (386) 747-1707
Venkatramanan Chanchapalli Madhavan (864) 328-7189

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