

Design, Development, and Usability Evaluation of a Role-Specific Augmented Reality Decision Support System for Cardiac Arrest Resuscitation

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¹ University of Calgary Calgary CA

² Geneva University Hospitals Geneva CH

³ University of Geneva Geneva CH

⁴ Geneva University Hospitals Geneva CH

⁵ University Hospitals of Geneva Geneva CH

Corresponding Author:

Kangsoo Kim

University of Calgary
2500 University Dr NW
Calgary
CA

Abstract

Background: Cardiopulmonary arrest is a critical medical emergency that requires adherence to specific clinical guidelines to ensure optimal outcomes. Deviations from these guidelines, often due to task complexity, can negatively impact patient outcomes. Augmented reality (AR) has the potential for supporting resuscitation teams by providing real-time, role-specific decision support to improve adherence to clinical guidelines.

Objective: This study aims to design, develop and evaluate a role-specific AR decision support system tailored for resuscitation team leaders and medication nurses. Our primary objective is to assess usability, user experience, and technology acceptance, determining the system's feasibility in a simulated clinical setting.

Methods: We designed and refined the AR system using a 4-step iterative prototyping development approach, integrating feedback from domain experts. The system was tested in a simulated clinical environment with 10 experienced emergency healthcare professionals (5 physician team leaders and 5 medication nurses). Post-simulation surveys assessed usability, user experience, and technology acceptance.

Results: The results revealed high usability, user experience, and technology acceptance for the role-specific AR decision support system, with favorable ratings from healthcare professionals. The team leader and medication nurse roles both received "above average" scores in usability, with the medication nurse role rated "excellent." User experience metrics showed positive outcomes in attractiveness, pragmatic quality, and hedonic quality, indicating that users found the system both functional and engaging. High scores in perceived usefulness and ease of use suggest strong acceptance, underscoring the system's potential to improve clinical protocol adherence during cardiopulmonary arrest.

Conclusions: The role-specific AR decision support system for resuscitation teams demonstrates strong feasibility and operational acceptance, suggesting its potential to improve adherence to guidelines during cardiopulmonary arrest.

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Original Manuscript

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¹ Electrical and Software Engineering, Schulich School of Engineering, University of Calgary, Canada

² KidSIM Simulation Program, Alberta Children's Hospital, University of Calgary, Calgary, Alberta, Canada

³ Department of Pediatrics and Emergency Medicine, Cumming School of Medicine, University of Calgary, Canada

⁴ Department of Pediatric Emergency Medicine, Geneva Children's Hospital, Geneva University Hospitals, Geneva, Switzerland

⁵ Faculty of Medicine, University of Geneva, Geneva, Switzerland

⁶ TECFA, Faculty of Psychology and Educational Sciences, University of Geneva, Geneva, Switzerland

⁷ Division of Computer Sciences, Geneva University Hospitals, Geneva, Switzerland

Corresponding Author:

Kangsoo Kim, Ph.D.,
Electrical and Software Engineering,
Schulich School of Engineering,
University of Calgary
2500 University Dr NW
Calgary, AB T2N 1N4
Canada

Phone: +1 (403) 220-5644

Email: kangsoo.kim@ucalgary.ca

Abstract

Background: Cardiac arrest is a critical medical emergency that requires strict adherence to clinical guidelines for optimal outcomes. Deviations from these guidelines, often due to task complexity, can adversely affect patient outcomes. Augmented reality (AR) has the potential for supporting resuscitation teams by providing real-time, role-specific decision support to improve adherence to clinical guidelines.

Objective: This study aimed to design, develop, and evaluate a role-specific AR decision support system tailored for resuscitation team leaders and medication nurses. The primary objective was to assess its usability, user experience, and technology acceptance, determining the system's feasibility in a simulated clinical setting.

Methods: We developed and refined the AR system using a four-stage iterative prototyping approach, integrating feedback from domain experts throughout the process. The system was evaluated in a simulated clinical environment with 10 experienced emergency healthcare professionals (5 physician team leaders and 5 medication nurses). Usability, user experience, and technology acceptance were assessed using post-simulation surveys.

Results: The role-specific AR decision support system demonstrated high usability, positive user experience, and strong technology acceptance among healthcare professionals. Both the team leader and medication nurse roles rated “above average” (> 68 out of 100), with the medication nurse role rating it as “excellent” (> 80.2 out of 100). User experience metrics showed positive results in attractiveness, pragmatic quality, and hedonic quality, indicating that users found the system both functional and engaging. High perceived usefulness and ease-of-use scores further reinforced strong acceptance, underscoring the system’s potential to improve clinical protocol adherence during cardiac arrest.

Conclusions: The role-specific AR decision support system for resuscitation teams demonstrated strong feasibility and operational acceptance, indicating its potential for further exploration in enhancing adherence to clinical guidelines during cardiac arrest management.

Keywords: Cardiopulmonary Resuscitation; Augmented Reality; Simulation Training; Wearable Electronic Devices; Digital Health; User-Computer Interface; Decision Support Systems, Clinical; Guideline Adherence; Technology Acceptance; User-Centered Design

Introduction

Cardiopulmonary resuscitation (CPR) is administered to thousands of patients experiencing cardiac arrests (CA) each year in North America.¹ Guideline-compliant basic life support (BLS) and advanced life support (ALS) guidelines significantly improve patient outcomes following CA.^{2,3} However, healthcare providers often face challenges in consistently adhering to these guidelines during in-hospital CA. Deviations, such as delays in epinephrine administration, defibrillation, and medication dosing errors, are commonly linked to poor patient outcomes.⁴ These deviations are often attributed to the high cognitive demands and mental workload experienced by resuscitation team members.^{5,6}

Cognitive aids, designed to assist in decision-making and information recall, have demonstrated improved adherence to resuscitation guidelines during simulated cardiopulmonary arrest events.⁷⁻¹² By reducing errors and improve the timing of key interventions, cognitive aids can enhance clinical performance.¹¹ However, traditional cognitive aids sometimes introduce delays in initiating CPR or administering drugs due to their poor design or excessive complexity, highlighting the need for more efficient, role-specific decision support solutions. Augmented Reality (AR)—a technology that seamlessly blends digital content with the physical environment—can support anticipatory behaviors in CA by delivering real-time, role-specific prompts and upcoming tasks directly within the user's field of vision through a head-mounted display.¹³ This immersive approach may enhance situational awareness, enabling resuscitation team members to anticipate critical steps, minimize errors, and ensure timely execution of life-saving interventions.

This paper presents the design, development, and evaluation of an AR-based decision support system tailored to the resuscitation team leader (i.e. physician) and medication nurse roles during CA. This research addresses three key questions:

- [1] What constitutes an effective design and layout for an AR system to support the resuscitation team leader and medication nurse?
- [2] How do clinicians perceive the usability and user experience of a role-specific AR system as a decision support tool?
- [3] How acceptable is the developed AR system for clinical practice?

Methods

This study received approval from the Conjoint Health Research Ethics Board (CHREB) at the University of Calgary (REB23-1007).

Iterative Prototyping Approach for System Design

The design of the AR decision support system employed a four-stage iterative prototyping development approach, integrating feedback from domain experts (i.e., end-user healthcare providers) to refine the interface progressively. This included gathering expert insights to align the system's functionality and layout with the needs of resuscitation team roles. The four stages were as follows:

- **Defining System Requirements:** This stage comprised of a literature review, sequential team meetings, and group discussion to establish foundational requirements for the AR system. Input gathered from an interprofessional team—including clinical resuscitation experts (e.g. emergency physicians, critical care physicians, pediatricians, and emergency and critical care nurses) and software engineers from the KidSIM Simulation Program at Alberta Children's Hospital, the Department of Electrical and Software Engineering at the University of Calgary, Canada, and

Geneva University Hospitals (HUG), Switzerland—helped identify essential content elements for the AR displays.

- **Mock-ups and Static Prototypes:** Initial designs and static prototypes were created to visualize the layout, role-specific information, and general functionality. Static prototypes were first tested internally, allowing the team to refine layout choices based on readability, functionality, and clarity.
- **Dynamic Prototypes:** This phase marked the transition from static to dynamic prototypes, introducing interactive elements. Dynamic prototypes, involving a fully functional wearable system with AR displays, were tested with each participant using verbal walk-throughs of an 8-minute simulated in-hospital CA case (i.e., ventricular fibrillation progressing to pulseless electrical activity). Participants wore the HoloLens 2 (Microsoft Corporation, Redmond, WA, USA) device, were verbally presented with a clinical CA case verbally, and asked to verbalize their decisions. Verbal feedback was collected from each participant after the case and used to refine the system, including optimizing font sizes, enhancing color contrast for improved readability, and adjusting user interface (UI) layout elements to minimize visual obstructions. Additional features, such as the integration of cardiac information for medical professionals and role-specific timers (e.g., epinephrine and CPR timers), were implemented to reduce cognitive load and ensure accurate, timely task performance.

Domain experts evaluated design aspects, such as layout preferences, timer functionality, and medication management features. For instance, end-users recommended that timers should flash when 10 seconds remain, turning red and flashing in the final seconds to signal urgency. These recommendations were incorporated, alongside other improvements like reducing the height of UI elements, repositioning drug information, and adding flashing functions to enhance user interaction and visibility. Team leaders also suggested adjustments to the placement of fixed items, such as CPR algorithms and the list of reversible causes (i.e. ‘Hs and Ts’), to improve accessibility during resuscitation efforts. Through the iterative design and development process, progressive enhancements were made to both the team leader and medication nurse displays. These included adopting a fixed layout with flashing alerts, optimized text sizes, and clear instructional prompts, ensuring the system met the practical needs of healthcare providers.

- **Full System Evaluation:** The system underwent pilot testing in a full-scale simulated CA scenario. Details of the system evaluation and CA scenario are outlined below.

System Architecture and Components

The AR decision-support system was built using a server-client architecture that enables seamless real-time synchronization between a web-based control system and the AR interfaces for both the team leader and medication nurse (Figure 1). This architecture supports role-specific information delivery, ensuring each team member accesses only the information relevant to their respective role.

- **Web-Based Control System (Server):** A Web-based control system was developed to manage and synchronize data flow to both AR devices. While future iterations of the system will integrate data from additional clinical sources (e.g., charting nurse tablet app), this study employed a centralized web application operated by an experimenter overseeing the CA simulation. The experimenter adjusted the CA algorithm’s steps, reset timers, and managed drug administration notifications, with adjustments made on the server instantly synchronized to the AR interfaces, ensuring real-time updates for both the team leader and medication nurse without delay.
- **AR Interfaces for Team Leader and Medication Nurse (Client):** The client side includes two role-specific AR interfaces running on the HoloLens 2 devices, one for the team leader and another for the med nurse. The dynamic displays were designed with user feedback in mind, integrating adjustments that emerged during testing.
 - **Team Leader Display:** Features real-time CPR and medication timers, visual alerts for task progression, and a display of current and upcoming protocol steps (Figure 2). The

display uses a fixed, high horizontal layout positioned above the patient's body, incorporating CPR and epinephrine timers that flash orange with 10 seconds remaining, then switch to red for the final 10 seconds. The medication menu includes weight-based information in the upper corners, with a fixed downward angle for ease of visibility. Flashing icons for notifications ensure visibility for timer expirations and medication administration, displaying the name and dosage for 10 seconds. The cardiac rhythm label was added to the top of the display to keep critical information visible.

- o **Medication Nurse Display:** Provides step-by-step guidance on drug dosage, preparation, and administration timing via the epinephrine timer (Figure 3). The display includes a high horizontal layout with real-time cues. The timer follows the same flashing sequence as the leader's display to signal time-sensitive administration of epinephrine. Additionally, the medication menu includes a counter indicating medications drawn up and ready for use, located outside the table. Weight information is available in the upper corner. Font sizes for column headers and text were increased for readability, and a counter outside the medication table provides clear visibility. Notifications and timers match those on the team leader display to maintain consistency and usability across both roles.

The server-client architecture, role-specific display features, and real-time synchronization capabilities offer a cohesive, user-centered tool for supporting resuscitation team roles. This system is designed to provide seamless, context-sensitive guidance, with the flexibility to adapt based on ongoing user feedback, ultimately enhancing the effectiveness and efficiency of the resuscitation team.

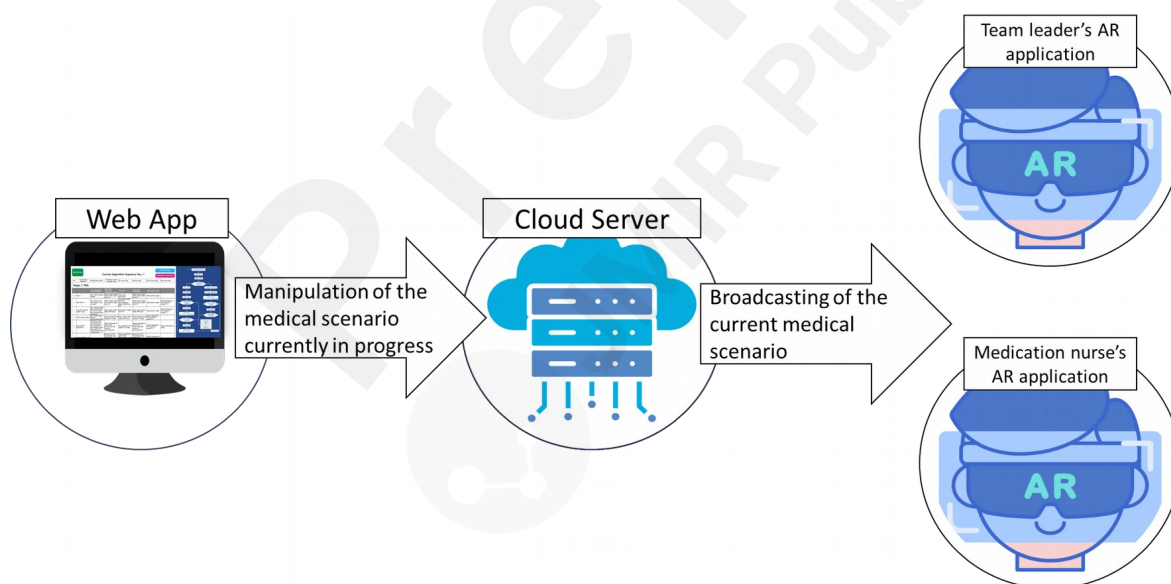


Figure 1. Overview of the AR system architecture illustrating the web-based control system, cloud server, and role-specific AR interfaces for the team leader and medication nurse.



Figure 2. Team leader display showcasing real-time CPR and medication timers, visual alerts for task progression, and stepwise guidance for current and upcoming guideline tasks during a simulated CA scenario.



Figure 3. Medication nurse display showing step-by-step guidance on drug dosages, preparations, and administration timing, with a real-time epinephrine timer for ensuring timely interventions.

Participants and Sample Size

Inclusion criteria for participants were defined as: pediatric emergency physicians or pediatric emergency nurses with over 5 years of clinical practice experience, BLS certification, and Pediatric Advanced Life Support (PALS) certification. There were no specific exclusion criteria. We sought to recruit a convenience sample of five physicians and five nurses from the Emergency Department at Alberta Children's Hospital for this study.

Procedure: Full System Evaluation with Simulated Cardiac Arrest Scenario

To evaluate the AR system, we conducted a simulated in-hospital pediatric CA scenario. The simulation took place at the KidSIM Simulation Center at Alberta Children's Hospital. Two participants (one physician team leader and one medication nurse) were paired with three research actors to form a resuscitation team. Research actors were trained to play the standardized roles of airway provider, and CPR provider / bedside clinician. The two participants wore HoloLens 2 devices, which were assigned to their respective clinical roles, creating an authentic team-based clinical resuscitation environment for focused evaluation of the AR system's impact on their performance and user experience.

The simulated scenario featured a 5-year-old male presenting with pulseless ventricular tachycardia (pVT), progressing through ventricular fibrillation (VF) and pulseless electrical activity (PEA), before achieving return of spontaneous circulation (ROSC) at the 18-minute mark.

- **Simulation Phases and Role Assignments:** Participants, acting as team leader or medication nurse, were guided by visual prompts on their respective AR displays. The team leader guided overall clinical management, including airway management, CPR, defibrillation, and ordering medication. The medication nurse handled intravenous medication preparation and administration, following role-specific cues on the AR interface.
- **Scenario Stages and Expected Management by Participants:**
 - **pVT (0-6 minutes):** The team leader initiated CPR, established IV/IO access, managed defibrillation, ordered medications, and secured a definitive airway. The medication nurse prepared and administered epinephrine and other emergency drugs as needed.
 - **VF (6-12 minutes):** AR prompts guided defibrillation, continued CPR, and timely drug administration.
 - **PEA (12-18 minutes):** Both participants received specific visual prompts for resuming CPR, administering medications, and considering reversible causes of CA.
 - **ROSC:** The scenario concluded upon achieving ROSC, marking the end of the simulated resuscitation event.

Following the simulation, participants completed a survey¹⁴ evaluating perceived usability, user experience, and technology acceptance of the AR display they used. After survey completion, participants also provided verbal feedback on their experience. The total study duration was approximately 30–40 minutes, including setup and survey completion.

Measures

To provide a comprehensive assessment of the AR support system's usability, user experience, and acceptance, we used three well-established instruments. These measures provided a comprehensive evaluation of the system's feasibility for real-world use in CPR training and clinical operations. Each measure is described in detail below.

Usability

The System Usability Scale (SUS) is a widely used tool for measuring usability. It consists of 10 questions that assess users' perceptions of system ease of use and overall usability.¹⁵ Each question is rated on a 5-point Likert scale, from "Strongly Disagree" (1) to "Strongly Agree" (5), capturing both effectiveness and efficiency. SUS scores are calculated by first adjusting responses: for odd-numbered items, 1 is subtracted from the user's rating, and for even-numbered items, the rating is subtracted from 5. The adjusted scores for each question are summed, and the total is multiplied by 2.5 to convert the raw score to a range of 0 to 100. Scores above 68 are considered "above average,"

while scores exceeding 80.3 indicate “excellent” usability.¹⁵ These benchmarks provide a practical reference for interpreting system usability levels. A more detailed interpretation with larger dataset is provided in Multimedia Appendix 1Error! No bookmark name given..

User Experience

The User Experience Questionnaire (UEQ) evaluates multiple dimensions of user experience, including *attractiveness*, *pragmatic quality*, and *hedonic quality*.¹⁶ The UEQ consists of 26 items rated on a 7-point semantic differential scale, ranging from -3 (most negative) to +3 (most positive). Each item evaluates different attributes of the experience, contributing to an overall understanding of user satisfaction and engagement with the system.

- **Attractiveness:** Represents the overall appeal of the system, combining both pragmatic and hedonic aspects. High scores indicate a favorable general impression.
- **Pragmatic Quality:** Assesses the system’s usability and functionality, focusing on task accomplishment through three dimensions: (a) Perspicuity: ease of understanding and familiarization; (b) Efficiency: speed and effectiveness in task completion; and (c) Dependability: user’s perception of control and reliability.
- **Hedonic Quality:** Captures the emotional and experiential dimensions of user interaction, covering: (a) Stimulation: how exciting and motivating the system is; (b) Novelty: perceived originality and creativity of the system.

Scores for each dimension reflect the system’s performance on each aspect, with values above 0.8 indicating a positive experience and values exceeding 1.5 indicate an above-average experience. Detailed evaluation criteria are outlined in Multimedia Appendix 2Error! No bookmark name given., supported by a benchmark dataset. By distinguishing between pragmatic and hedonic qualities, the UEQ provides a comprehensive view of both the system’s practical utility and the overall satisfaction and enjoyment it offers users. The combination of pragmatic and hedonic insights allows the UEQ to capture both the functionality and emotional impact of the AR system, offering a nuanced understanding of user experience. This dual approach is particularly valuable for evaluating technologies like AR, where both task efficiency and user engagement are critical to system acceptance and effectiveness.

Technology Acceptance

The Technology Acceptance Model (TAM) assesses user acceptance of new technologies based on the relationship between two main dimensions: (a) Perceived Usefulness (PU), which measures the extent to which users believe that using a given technology enhances their job performance, and (b) Perceived Ease of Use (PEU), which evaluates the extent to which users believe that using a technology will result in less effort to perform their tasks, focusing on its intuitiveness and the learning curve involved.¹⁷ For this study, TAM was adapted to include 12 items across two primary dimensions, each rated on a 7-point Likert scale, from “Strongly Disagree” (1) to “Strongly Agree” (7). Scores are averaged for each dimension, with scores above 5 generally indicating a positive user perception and a strong likelihood of adoption.¹⁸ High scores across both dimensions suggest that users view the system as both beneficial and user-friendly—key factors for ensuring sustained use. The dual focus on perceived usefulness and ease of use makes TAM a valuable tool for assessing the likelihood of real-world adoption of technologies like AR.

Results

Participants

We recruited 10 participants: five physicians and five nurses. Participants attended usability testing sessions in physician-nurse pairs. All participants had completed BLS and PALS training, qualifying to assess the AR system's usability and functionality. Table 1 provides an overview of the participants' demographic characteristics.

Table 1. Participant demographics

	Team Leader	Medication Nurse
Gender (M: male, F: female)	M: 3, F: 2	M: 1, F: 4
Age (years mean $\pm$ SD)	41.20 $\pm$ 5.36	44.80 $\pm$ 2.95
Duration in Practice (years mean $\pm$ SD)	10.50 $\pm$ 5.24	20.75 $\pm$ 4.35
How many times have you had to care for a child in cardiac arrest during a <u>real, live event</u> in the past 2 years? (times mean $\pm$ SD)	1.50 $\pm$ 1.73	2.20 $\pm$ 0.84
How many times have you had to care for a child in cardiac arrest during a <u>simulated event</u> in the past 2 years? (times mean $\pm$ SD)	4.00 $\pm$ 0.00	3.67 $\pm$ 1.53
Have you ever used any type of Augmented Reality device for <u>professional use</u>?	1 participant with prior experience (>10 times)	No prior experience
Have you ever used any type of Augmented Reality device for <u>recreational use</u> (e.g., gaming)?	3 participants (>10 times)	1 participant (1–4 times)

Usability

The AR system achieved favorable usability, indicating an intuitive and efficient interface for both the team leader and medication nurse roles. The SUS revealed that the team leader role scored a mean of 75.50 (SD 9.25, SE 4.14, 95% CI [64.00, 87.00]), corresponding to a “B” grade (74.10–77.10) in the SUS grading scale, categorized as “Acceptable” (Multimedia Appendix 1). This score suggests that team leaders found the system functional and user-friendly. The medication nurse role achieved an even higher mean score of 82.00 (SD 11.20, SE 5.02, 95% CI [68.00, 96.00]), earning an “A” grade (80.80–84.00), which falls within the “Excellent” usability range (Figure 4). These results indicate a strong user experience, particularly in supporting medication preparation and administration tasks.

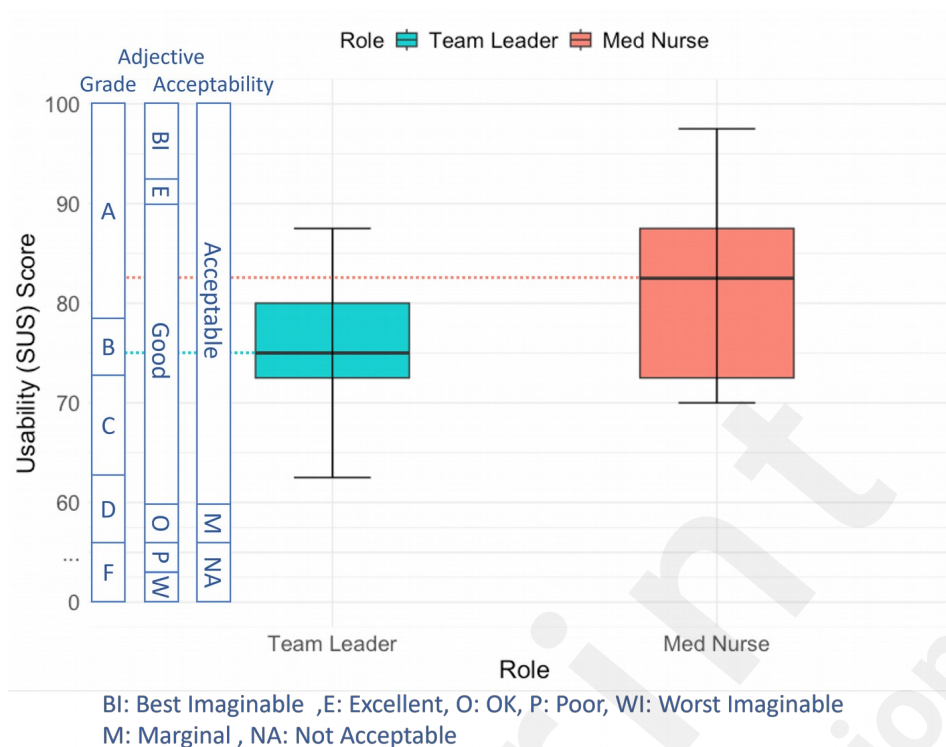


Figure 4. Box plot displaying System Usability Scale (SUS) scores for the team leader and medication nurse roles in the AR support system. The medication nurse role achieved higher usability scores, reflecting an “Excellent” grade compared to the “Good” usability rating for the team leader role.

User Experience

High-Level Results: Attractiveness, Pragmatic Quality, and Hedonic Quality

Figure 5 illustrates the high-level results for the UEQ dimensions.

- **Attractiveness:** The team leader role scored a mean of 1.87 (SD 1.14, SE 0.51, 95% CI [0.45, 3.28]), while the medication nurse role scored higher, with a mean of 2.43 (SD 0.52, SE 0.23, 95% CI [1.79, 3.08]). Both scores surpass the above-average benchmark, indicating a favorable overall impression of the system’s appeal.
- **Pragmatic Quality:** Reflecting the system's usability and task-support effectiveness, the team leader role achieved a mean score of 1.88 (SD 0.87, SE 0.39, 95% CI [0.80, 2.97]), while the medication nurse role had a mean score of 1.80 (SD 0.69, SE 0.31, 95% CI [0.94, 2.66]). These scores indicate that both roles found the system efficient for task completion with minimal effort.
- **Hedonic Quality:** The team leader role scored a mean of 2.40 (SD 0.89, SE 0.40, 95% CI [1.30, 3.50]), while the medication nurse role scored 2.28 (SD 0.69, SE 0.31, 95% CI [1.42, 3.13]). These high scores highlight that the users found the system engaging and stimulating, contributing to a positive user experience.

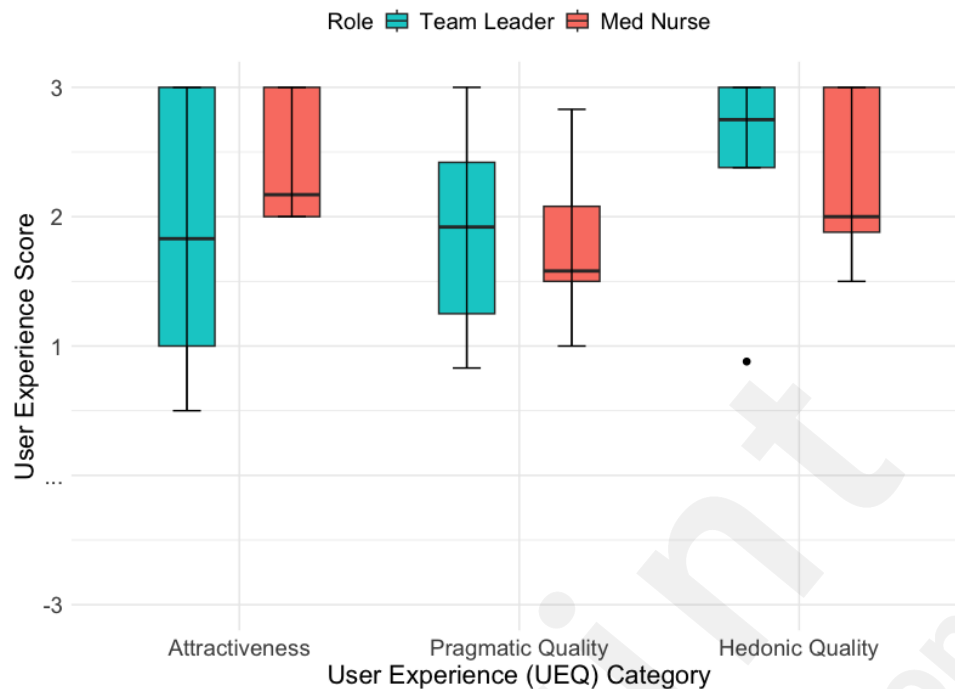


Figure 5. Box plot displaying high-level User Experience (UEQ) scores, including attractiveness, pragmatic quality, and hedonic quality for team leader and medication nurse roles in the AR system.

Pragmatic Quality Sub-Dimensions

The analysis of pragmatic quality sub-dimensions (Figure 6) revealed comparable results for both roles, emphasizing the system's intuitiveness, efficiency, and reliability.

- **Perspicuity:** both the team leader and medication nurse roles reported a mean score of 1.80. The team leader's result (SD 1.14, SE 0.51, 95% CI [0.39, 3.21]) and the medication nurse's results (SD 0.76, SE 0.34, 95% CI [0.86, 2.74]) indicate that users found the system easy to learn and navigate.
- **Efficiency:** For task completion speed and support, both roles achieved high mean scores of 2.15. The team leader's score (SD 0.68, SE 0.30, 95% CI [1.31, 2.99]) and the medication nurse's score (SD 0.38, SE 0.17, 95% CI [1.68, 2.62]) suggest that the system facilitated smooth and effective task performance.
- **Dependability:** The team leader role achieved a mean score of 1.70 (SD 1.02, SE 0.46, 95% CI [0.43, 2.97]), while the medication nurse role scored slightly lower at 1.45 (SD 1.30, SE 0.58, 95% CI [-0.17, 3.07]). These scores indicate that users felt a good level of control and reliability, with some variability observed.

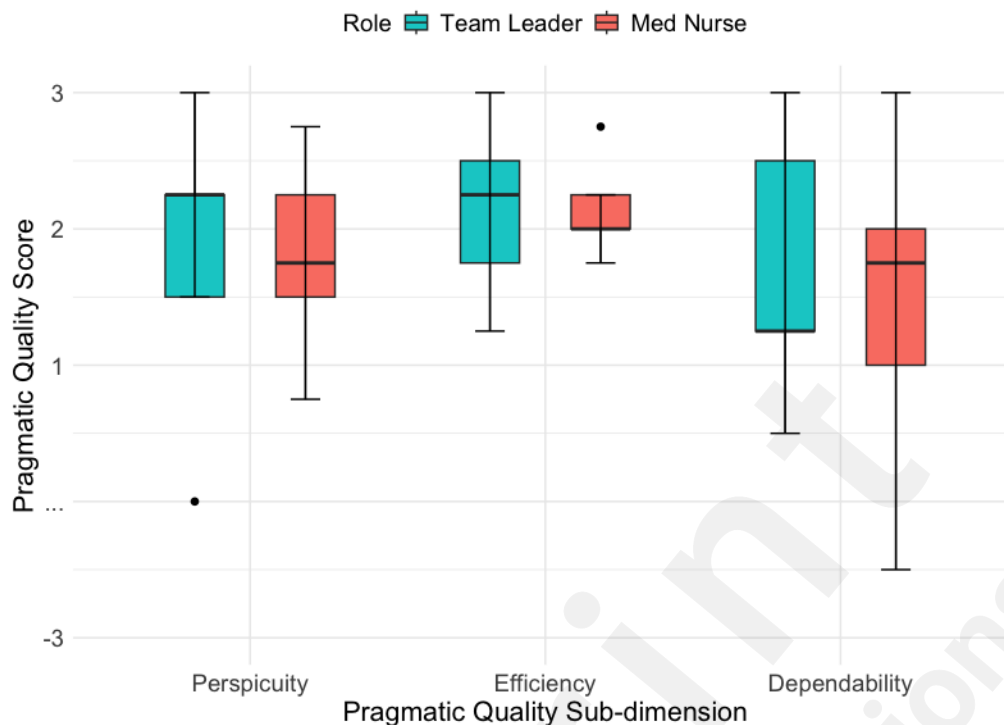


Figure 6. Box plot displaying pragmatic quality sub-dimensions (perspicuity, efficiency, dependability) for team leader and medication nurse roles, reflecting usability-focused aspects of the AR system.

Hedonic Quality Sub-Dimensions

The analysis of Hedonic Quality sub-dimensions (Figure 7) focused on simulation and Novelty, capturing the emotional and experiential aspects of user interaction with the AR system.

- **Stimulation:** The team leader role achieved a mean score of 2.25 (SD 0.94, SE 0.42, 95% CI [1.09, 3.41]), while the medication nurse role scored similarly at 2.20 (SD 0.84, SE 0.37, 95% CI [1.16, 3.24]). These scores suggest that the system is engaging and helps sustain users' interest, motivating them throughout its use.
- **Novelty:** This sub-dimension assesses the system's originality and innovative aspects. The team leader role scored a mean of 2.55 (SD 0.87, SE 0.39, 95% CI [1.47, 3.63]), while the medication nurse role scored 2.35 (SD 0.86, SE 0.38, 95% CI [1.28, 3.42]). These results indicate that users perceived the AR system as innovative, contributing to a unique and satisfying experience.

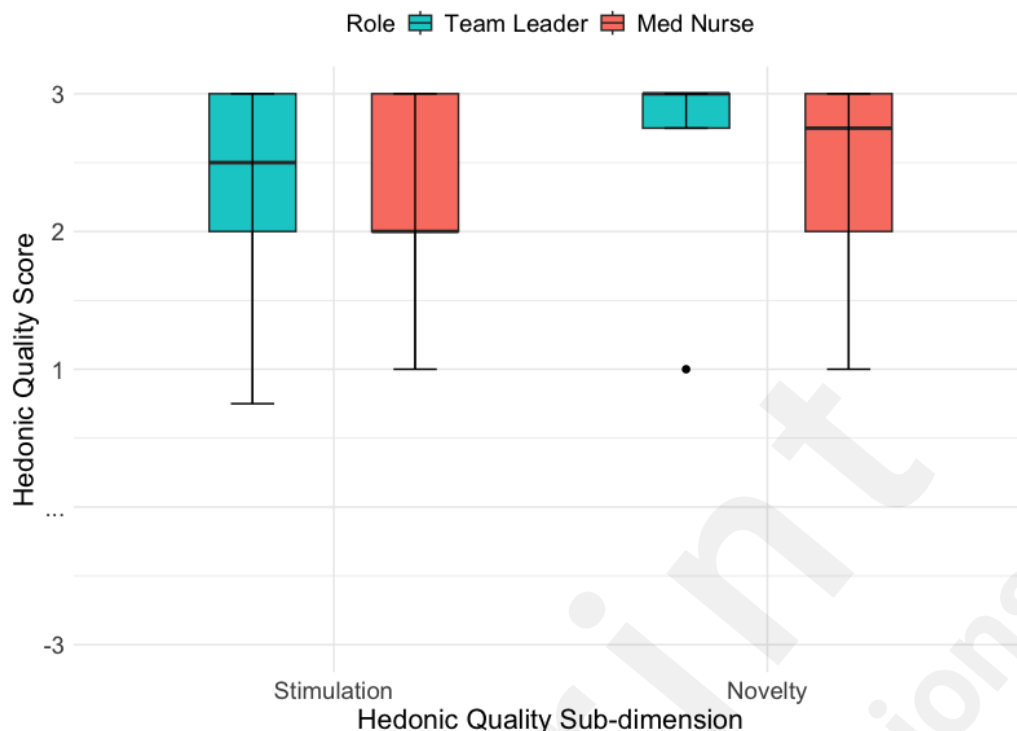


Figure 7. Box plot displaying hedonic quality sub-dimensions (stimulation and novelty) for team leader and medication nurse roles, representing the emotional and experiential user engagement with the AR system.

Technology Acceptance

The TAM scores were evaluated across PU and PEU. Combined scores were also calculated to provide an overall measure of acceptance for each role (Figure 8).

- **Combined Acceptance:** The team leader role scored a mean of 5.92 (SD 0.46, SE 0.21, 95% CI [5.35, 6.49]), while the medication nurse role achieved a slightly higher score of 6.02 (SD 0.56, SE 0.25, 95% CI [5.32, 6.71]). These high scores indicate strong overall acceptance of the AR system, suggesting that users found it valuable and suitable for regular use.
- **PU:** The team leader role achieved a mean score of 5.87 (SD 0.74, SE 0.33, 95% CI [4.95, 6.78]), while the medication nurse role scored slightly higher at 5.96 (SD 0.74, SE 0.33, 95% CI [5.05, 6.88]). These results indicate that both roles recognized the system as beneficial tool for supporting clinical tasks and improving efficiency.
- **PEU:** The team leader role scored a mean of 6.06 (SD 0.56, SE 0.25, 95% CI [5.37, 6.76]), while the medication nurse role scored similarly at 5.97 (SD 0.60, SE 0.27, 95% CI [5.22, 6.72]). These high scores indicate that users found the system easy to learn and operate, requiring minimal cognitive effort for effective use.

Together, these results underscore the AR system's high level of acceptance among both roles, with users perceiving it as a valuable, easy-to-use tool for improving performance during clinical resuscitation scenarios.

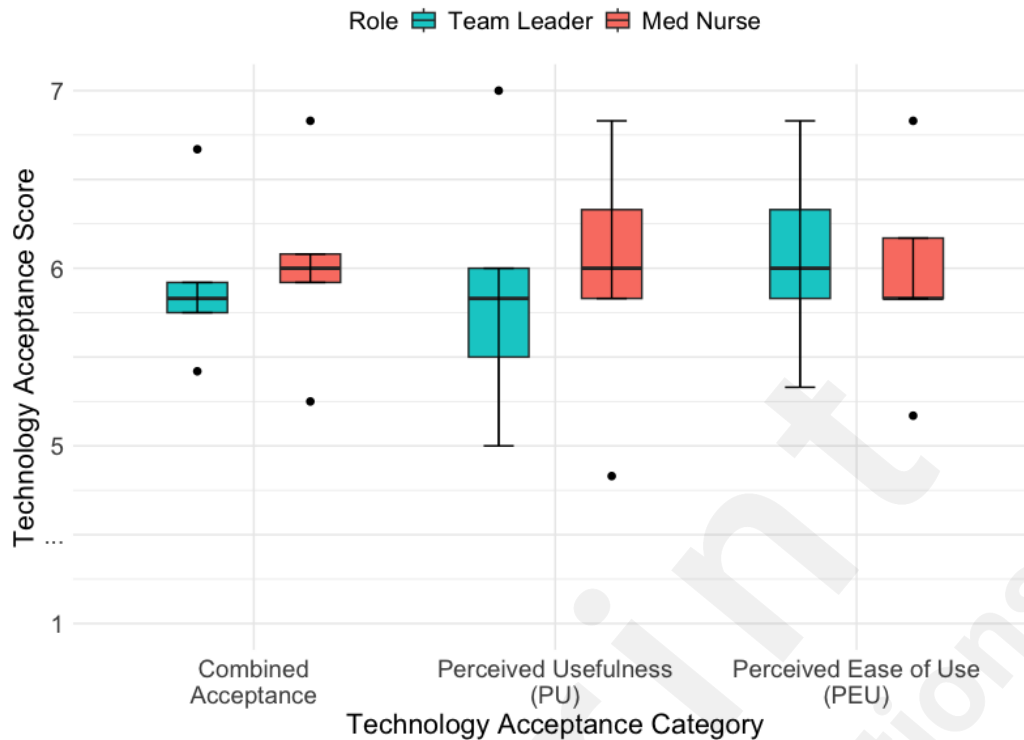


Figure 8. Box plot displaying technology acceptance scores for team leader and medication nurse roles.

Discussion

Our contributions are threefold: (1) the design and development of a AR system tailored to resuscitation team members, incorporating feedback from domain experts to refine its interface and functionality; (2) the establishment of a controlled testbed simulating a CPR scenario, allowing for controlled evaluation of the system's performance and impact in a realistic clinical environment; and (3) the evaluation of the AR system's potential and effectiveness through a user study involving 10 experienced emergency care providers, focusing on its usability, user experience, and technology acceptance in practice. These contributions provide a foundation for AR-based decision support systems in medical resuscitation, offering insights into both system design and practical implementation.

Main Findings and Implications

The evaluation revealed several key findings with significant implications for the adoption and future development of the AR system for resuscitation teams. Overall, the AR system achieved high scores in usability, user experience, and technology acceptance, indicating that it is well-suited to support resuscitation team roles. The role-specific displays effectively minimized the need for external aids, enabling users to remain focused on the scenario and perform their tasks seamlessly and without unnecessary delay.

High Ease of Use and Learning

The AR system demonstrated a high level of ease of use, as indicated by high usability scores and strong performance in the PEU dimension of the TAM. This shows its potential to effectively support critical tasks in CA cases. Participants found the interface intuitive, reporting minimal learning

curves, which suggest that users can become proficient quickly without extensive training. This ease of use not only enhances user satisfaction but also lowers barriers to adoption, as users are more likely to embrace technology that requires minimal effort to learn¹⁷. Additionally, previous research indicates that high usability is associated with reduced cognitive load and improved task performance¹⁹—both essential in emergent clinical care contexts like CPR operations. These findings confirm that the AR system's user-centered design and interface effectively support resuscitation team members, enabling them to focus on their tasks without relying on external aids.

High Usefulness and Effectiveness

The system was developed through an iterative process to enhance content relevance, timeliness, and information presentation, aiming to maximize usefulness and effectiveness. The results showed high scores in the pragmatic quality dimension of the UEQ and the PU dimension of TAM, indicating that the system meets users' practical needs. Participants perceived it as significantly improving their task performance and efficiency, demonstrating its potential to enhance real-world productivity. This high level of effectiveness is critical for fostering user retention and continued engagement, as users are more inclined to integrate a system that adds value to their work processes.²⁰ In particular, the role-specific information provided by the AR system—enabling both team leaders and medication nurses adhere to CPR guidelines—ensures timely task execution and guideline compliance.

High Novelty and Enjoyability

The AR system also scored highly in the hedonic quality dimension of the UEQ, reflecting its engaging and novel features. Participants reported that the system sustained their interest and motivation during task execution, contributing to an overall enjoyable user experience. This element of enjoyment plays an important role in fostering greater retention and motivation among CPR practitioners in both operational and training environments.²⁰ The high novelty scores further suggest that the system's innovative presentation of information enhances user satisfaction and could promote the broader adoption of AR tools in healthcare settings.

Effective AR-based Role-Specific Design for Resuscitation Teams

The AR system received high scores across usability, user experience, and technology acceptance, suggesting it is both effective and user-friendly. These results highlight its potential as a valuable tool in resuscitation scenarios, fulfilling key aspects of technology acceptance and improving CPR operations. While AR offers a broader spectrum by merging physical and virtual environments to create immersive experiences, AR has demonstrated significant promise in healthcare for providing intuitive and context-aware decision support by overlaying critical information directly onto the physical environment.^{21,22} Prior studies have shown that AR can reduce cognitive load and improve task performance by presenting spatially registered information, enabling users to interpret and act on visual prompts more effectively.^{21,23} Additionally, AR systems have been proven to improve user engagement and task efficiency by aligning visual cues with real-world objects and actions, creating seamless integration of digital and physical information.^{21,23}

Our study highlights the critical importance of tailoring AR interfaces to the distinct roles within resuscitation teams. By integrating iterative feedback from domain experts, the design process focused on role-specific displays that prioritize clarity, timeliness, and relevance of information. Key features, such as flashing timers, strategically positioned visual cues, and optimized layouts, were effectively designed and implemented to match each specific role in the resuscitation scenario. These design choices supported adherence to CA guidelines and facilitated smooth coordination between team members, ultimately improving task performance and reducing cognitive load. The findings underscore the value of user-centered design in creating AR systems that align with the operational needs of healthcare professionals, ensuring usability and effectiveness in high-stakes clinical

environments.

Limitations and Future Work

While the AR system demonstrated high usability, user experience, and technology acceptance, several limitations need to be addressed in future work. Firstly, the study's simulated pediatric cardiac arrest scenario, while useful for evaluation, may not capture the full range of real-world situations that resuscitation teams might encounter. Expanding the system's evaluation to include a broader range of scenarios could improve its generalizability across diverse clinical environments. Second, the small sample size may restrict the robustness of the results, as it may not fully represent the broader population of CPR-trained professionals. Finally, the lack of objective performance metrics in this initial evaluation restricts the ability to measure the system's direct impact on task efficiency and team coordination.

To address these limitations, future research will involve testing the AR system in various CPR simulation scenarios to assess its adaptability and reliability before clinical implementation. Plans include conducting an international multi-site study with a larger, more diverse participant pool to gain broader insights. This study will also involve incorporating the AR tool into an expanded CPR support system, including additional tools such as a widescreen display for team information visualization, a tablet-based progress monitoring tool providing real-time clinical data, and advanced control interfaces. To gain deeper insights into user performance and behavior, follow-up studies will incorporate objective performance metrics, such as task completion time, gaze tracking, and speech analysis. These metrics will be instrumental in evaluating the system's effectiveness in real-world, high-stakes environments, with the ultimate goal of refining and enhancing its role-specific support functionalities for future clinical use.

Conclusions

This study demonstrates the feasibility and effectiveness of a role-specific AR support system designed for resuscitation teams, particularly for team leaders and medication nurses. The system received high usability, user experience, and acceptance ratings from CPR-trained professionals, suggesting significant potential for both clinical and training applications. By delivering structured, real-time, and role-specific guidance, the AR support system possibly enhances CPR task performance and adherence to critical guidelines—both of which are essential in high-stakes resuscitation scenarios. The system's intuitive design minimizes cognitive load, enabling healthcare providers to focus on their tasks without relying on external aids. These findings support the system's applicability in improving the efficiency, accuracy, and effectiveness of CPR operations, emphasizing its value as an assistive tool in emergency care settings.

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carried out by RK, HN, and KK. Manuscript writing was undertaken by RK, AC, HN, and KK, with YL, JD, DD, JNS, SM, ADM, AR, SO, and FE providing critical review and editing. All authors have reviewed and approved the final version of the manuscript, and take responsibility for the integrity and accuracy of the research. The corresponding author affirms that the manuscript is an honest, accurate, and transparent account of the study and confirms that any deviations from the original study plan have been documented. Consent for publication was obtained from the participants.

Conflicts of Interest

None declared.

Abbreviations

ALS: advanced life support
AR: augmented reality
BLS: basic life support
CA: cardiac arrests
CPR: cardiopulmonary resuscitation
IV/IO: intravenous/intraosseous
PALS: pediatric advanced life support
PEA: pulseless electrical activity
PEU: perceived ease of use
PU: perceived usefulness
pVT: pulseless ventricular tachycardia
ROSC: return of spontaneous circulation
SUS: system usability scale
TAM: technology acceptance model
UEQ: user experience questionnaire
UI: user interface
VF: ventricular fibrillation

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Supplementary Files

Multimedia Appendixes

Table S1. Grading scale for SUS scores with corresponding percentile ranges, usability adjectives, and acceptability levels (<https://measuringu.com/interpret-sus-score/>).

URL: <http://asset.jmir.pub/assets/f49515dcb08709af8e8cfc0b269df0e3.xlsx>

Table S2. Interpretation criteria for UEQ scores across different scales (<https://www.ueq-online.org/>).

URL: <http://asset.jmir.pub/assets/6654b80ab4ab9c66415f8f2bf8b30b6d.xlsx>