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## Contents

### Original Papers

Predictive Factors of Augmented Reality–Based Clinical Task Performance Among Novice Users: Cross-Sectional Quantitative Study ( <a href="#">e81236</a> ) Amogh Vellore, Shovan Bhatia, Michael Kann, Nicolás Kass, Regan Shanahan, Jacquelyn Jardini, Jayne Miner, Sohail Daulat, Griffin Hurt, Rishi Basdeo, Nicole Don, Jacob Biehl, Edward Andrews. . . . .	2
Perceived Usability, User Experience, and Technology Acceptance of Role-Specific Augmented Reality Decision Support Tools for Cardiac Arrest Resuscitation: Prospective Observational Pilot Study ( <a href="#">e72013</a> ) Ryan Kang, Adam Cheng, Yiqun Lin, Hyeongil Nam, Jennifer Davidson, Donovan Duncan, Johan Siebert, Sergio Manzano, Alexandre De Masi, Ana Rajic, Sharleen Olanka, Frederic Ehrler, Kangsoo Kim. . . . .	16

# Predictive Factors of Augmented Reality–Based Clinical Task Performance Among Novice Users: Cross-Sectional Quantitative Study

Amogh J Vellore<sup>1</sup>, BS; Shovan Bhatia<sup>1</sup>, BS; Michael R Kann<sup>1,2</sup>, BE; Nicolás M Kass<sup>3</sup>, MD; Regan M Shanahan<sup>1</sup>, BA; Jacquelyn Jardini<sup>1</sup>, BS; Jayne Miner<sup>1</sup>; Sohail R Daulat<sup>1</sup>, BS; Griffin Hurt<sup>4</sup>, BPhil; Rishi Basdeo<sup>5</sup>, MS; Nicole Don<sup>1</sup>, MA; Jacob T Biehl<sup>4</sup>, PhD; Edward G Andrews<sup>1</sup>, MD

<sup>1</sup>Department of Neurological Surgery, University of Pittsburgh Medical Center, 200 Lothrop St, STE B-400, Pittsburgh, PA, United States

<sup>2</sup>Department of Orthopaedic Surgery, University of Pittsburgh Medical Center, Pittsburgh, PA, United States

<sup>3</sup>Department of Plastic Surgery, University of Pittsburgh Medical Center, Pittsburgh, PA, United States

<sup>4</sup>Department of Computer Science, School of Computing and Information, University of Pittsburgh, Pittsburgh, PA, United States

<sup>5</sup>Department of Mechanical Engineering, Carnegie Mellon University, Pittsburgh, PA, United States

## Corresponding Author:

Edward G Andrews, MD

Department of Neurological Surgery, University of Pittsburgh Medical Center, 200 Lothrop St, STE B-400, Pittsburgh, PA, United States

## Abstract

**Background:** Augmented reality (AR) can provide risk-free training for medical trainees, yet little is known about which learner characteristics facilitate adoption or inform training design.

**Objective:** We aimed to identify which learner characteristics predict AR performance in novices. We hypothesized that higher visuospatial ability and greater video game experience would be associated with faster completion times and fewer errors.

**Methods:** In this cross-sectional study, 21 undergraduate, graduate, and medical students (median age 22, IQR 21-24 years) without previous AR experience were recruited between June and December 2024. Participants completed a technology experience survey, the mental rotation task (MRT) for visuospatial ability, a standardized 7-task AR protocol mimicking clinical use on the Microsoft HoloLens 2 (hologram manipulation, orbit tracing, anatomical plane visualization, and hologram-to-object registration), and the National Aeronautics and Space Administration Task Load Index for cognitive load assessment. Outcome measures included completion time, slips (unintentional errors), and tracing quality.

**Results:** All analyses used a significance of  $\alpha=.05$ . MRT scores did not predict baseline performance time (Pearson  $r=0.15$ , 95% CI  $-0.32$  to  $0.55$ ;  $P=.54$ ) or error rates ( $r=0.18$ , 95% CI  $-0.27$  to  $0.57$ ;  $P=.43$ ). Participants with extensive video game experience ( $>5$  hours/week) made fewer slips (unpaired  $t$  test; mean difference  $-2.62$  slips, 95% CI  $-5.19$  to  $-0.04$ ;  $P=.047$ ), without faster completion times (Mann-Whitney test; median difference  $-22$  seconds, 95% CI  $-7.00$  to  $57.00$ ;  $P=.24$ ). Video game experience did not predict baseline performance time (Pearson  $r=-0.35$ , 95% CI  $-0.69$  to  $0.13$ ;  $P=.14$ ). Significant learning effects emerged in unadjusted analyses: completion times decreased on attempts 2 and 3 compared with attempt 1 (mixed-effects analysis: mean difference 28.75 seconds, 95% CI 12.98-44.52;  $P<.001$ ; 28.00 seconds, 95% CI 10.75-45.25;  $P=.002$ , respectively) with fewer slips (Friedman test:  $\chi^2_2=17.8$ ;  $P<.001$ ; Dunn post hoc:  $P=.008$  and  $P<.001$ , respectively). Orbit tracing (Wilcoxon test: median difference  $-5$  seconds;  $P=.004$ ) and virtual landmark placement times improved (Friedman test:  $\chi^2_3=14.6$ ;  $P=.002$ ; Dunn post hoc:  $P=.009$  and  $P=.02$ ), but physical landmark placement did not. Covariate-adjusted models revealed no significant trial-by-covariate interactions.

**Conclusions:** Visuospatial ability does not predict clinically relevant AR performance, while extensive video game experience was associated with fewer errors. Despite previous studies emphasizing inherent learner characteristics in laparoscopy and endoscopy, covariate-adjusted models showed that AR learning curves were not significantly modified by MRT or video game experience. These findings suggest that early AR performance improvements among novice users are primarily driven by learning rather than visuospatial ability, supporting training approaches that emphasize structured practice, although the modest sample size limits detection of smaller effects.

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**KEYWORDS**

mixed reality; augmented reality; virtual reality; mental rotation task; visuospatial ability; medical education; video games

**Introduction**

The rise in augmented reality (AR) and virtual reality (VR) technology has greatly impacted a range of industries, including education, entertainment, and medicine [1,2]. AR enables the supplementation of real-world visibility with digital information, which can be shown through projections onto head-mounted displays (HMD) on headsets, smart glasses, or tablet-based displays. Within medicine, AR and VR applications continue to grow. While outcomes research remains preliminary given AR's relative infancy, studies have found that AR subjectively increases surgeon confidence in delineating tumor margins [3]. This observation was validated by a multicenter randomized controlled trial (n=113), which observed that AR-guided robotic prostatectomies were associated with a significant decrease in subsequent positive surgical margins, a key prognostic indicator for patient survival [4]. Other measured improvements have included decreased fluoroscopy time needed to navigate difficult tissue structures [5,6]. This technology has also expanded patient education [7,8] by helping patients gain a deeper understanding of their bodies and diseases while also demonstrably decreasing procedural anxiety [8,9] and improving satisfaction [8].

As applications of AR and VR continue to expand across specialties, these technologies hold tremendous potential as risk-free training modalities, allowing medical students and resident physicians to practice procedures without jeopardizing patient safety [10]. Recent literature has shown that AR can help resident physicians learn to identify aneurysms in surgical videos [11], support medical student and resident education as a reliable and predictive simulation-based medical education modality [12-14], and minimize mental workload while simultaneously improving learning capacity [15,16].

Despite this promise, there are still some important factors to consider. Although previous studies indicate that AR can increase mental resource availability [15], enhance working memory capacity [16], and facilitate long-term information storage [16], it may also serve as a distraction for some learners [17]. Research has shown broad educational benefits, from early childhood learning in preschool [18] to secondary education [19] and postgraduate medical education [13]. However, the extent of AR integration in medical education remains varied [20].

Within medical education specifically, previous studies have indicated mixed learning outcomes. For example, AR can be beneficial for anatomy learning compared to virtual dissection tables, but not when compared to the conventional atlas method [21]. Similarly, other studies have found no difference in learning among stereoscopic 3D AR models, monoscopic 3D desktop models, or conventional atlas learning [17]. Further complicating its role, evidence suggests that individuals who have lower spatial ability, as measured by mental rotation tasks (MRTs), may benefit more from AR than their peers with higher MRT scores [21,22]. These findings indicate that the mixed

effects of AR within medical education may be explained by individual differences in spatial ability.

Despite the importance of spatial ability across industries, including STEM [23-25] (science, technology, engineering, and math) and medicine [26-29], and the growing adoption of AR within medicine [30], there is still a critical gap in our understanding of how novice AR users learn to use the technology. Previous experiences, such as video game experience, have been shown to play a role in spatial ability [31] as well as in medically relevant tasks [32,33]. More recently, studies have demonstrated that video game experience is a strong predictor of baseline skills in gastrointestinal endoscopy learners [34] and of baseline performance in nonmedical VR tasks [35].

However, it remains unclear which learner characteristics (eg, visuospatial ability and previous video game experience) support the efficient adoption of AR in clinical applications and whether short, targeted exposure is sufficient for novice users to reach proficiency. This study addresses this gap by quantifying novice performance and short-term learning on a neurosurgical AR navigation task and examining how these outcomes relate to individual differences in mental rotation ability and video game experience. We hypothesize that individuals with higher visuospatial ability and, specifically, more video game experience will complete AR-based neurosurgical navigation tasks more quickly and with fewer errors. These results may indicate whether specific learner characteristics confer an advantage in AR or whether novice performance in AR is primarily influenced by learning.

**Methods****Research Design**

This study used a cross-sectional framework in which participants were recruited using convenience sampling to complete a pretest demographics survey and an assessment of visuospatial ability, followed by a series of standardized AR tasks and a posttest National Aeronautics and Space Administration Task Load Index (NASA-TLX) survey to assess subjective mental load. This paper was prepared in accordance with the Journal Article Reporting Standards [36].

**Inclusion and Exclusion Criteria**

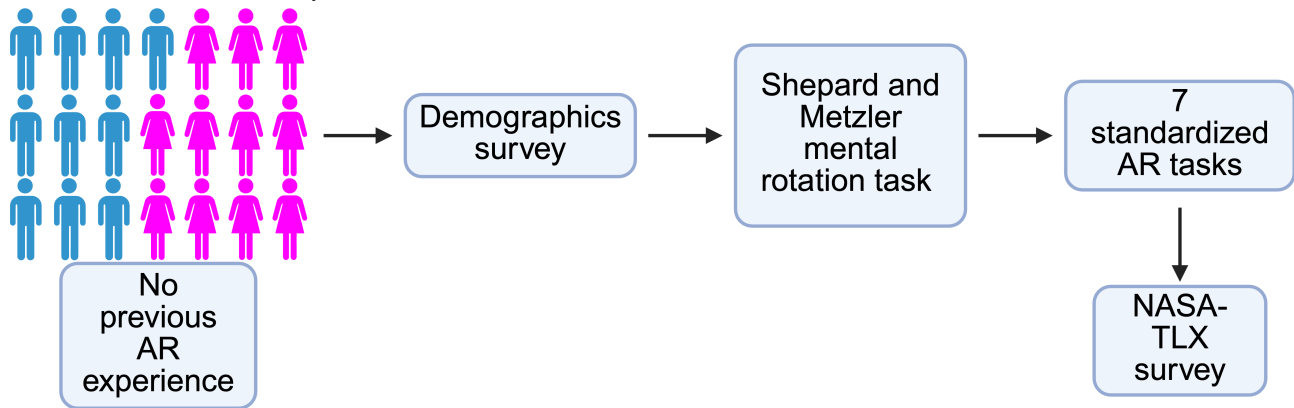
Participants comprised undergraduate, graduate, and medical students at the University of Pittsburgh between June 2024 and December 2024. Participants who had previous experience using AR were excluded.

**Ethical Considerations**

Participants gave their informed consent for participation in the study, for their performance to be recorded for analysis, and for any secondary analyses without additional consent. Participants were not compensated. The authors confirm that there are no images or identifiable features within this manuscript. All participant information was deidentified, and study data were

stored in an encrypted location. This study received institutional review board approval from the University of Pittsburgh (STUDY22040182). The study workflow is shown in Figure 1.

**Figure 1.** Study design. In total, 23 participants were recruited for this study between June 2024 and December 2024. Two participants did not successfully complete all tasks and were excluded from the analysis, resulting in a final cohort of 21 participants. There were 11 female (pink) and 10 male (blue) participants with no previous experience with augmented reality (AR). The demographics survey collected information such as experience with video games, comfort with new technology, and educational background. All participants then performed a series of mental rotation tasks before completing 7 standardized AR tasks. Following completion of the tasks, participants were given a posttest National Aeronautics and Space Administration Task Load Index (NASA-TLX) survey to assess workload.



## Surveys

Two pretest tasks were administered. The first task was a survey that collected demographic and experience information such as age, sex, level of education, experience with video games, comfort with new technology, and experience with surgical devices. The second pretest task was the MRT, a standardized paper-and-pencil measure of 3D spatial visualization derived from the mental rotation paradigm by Shepard and Metzler [37]. The MRT requires participants to decide whether comparison figures are rotated versions or mirror images of a target 3D object, providing a robust index of individual differences in mental rotation ability. Classic psychometric work has shown that the MRT has high internal consistency as indicated by the Kuder-Richardson Formula 20 (Kuder-Richardson Formula 20=0.88), which estimates how consistently dichotomously scored items measure the same underlying construct. Classic psychometric work has also demonstrated that the MRT has high test-retest reliability ( $r=0.83$ ) [38], and subsequent reviews describe it as one of the most commonly used and well-validated measures of spatial ability [39,40]. Moreover, mental rotation tests such as the MRT are routinely incorporated into spatial ability batteries and reliably predict performance in applied visuospatial tasks (eg, engineering design, navigation, and surgical endoscopy) [29,41,42]. Because our experimental tasks required participants to infer 3D relationships from 2D displays and mentally transform object orientations, we selected the MRT as the primary measure of visuospatial ability.

This task was composed of 2 sets of 12 problems. Participants were allotted 3 minutes to complete each set of questions. During this task, participants were given a warning when their remaining time reached 2 minutes, 1 minute, 30 seconds, and 10 seconds. Following AR testing, participants were given the

NASA-TLX survey, a clinically validated metric for measuring mental load [43].

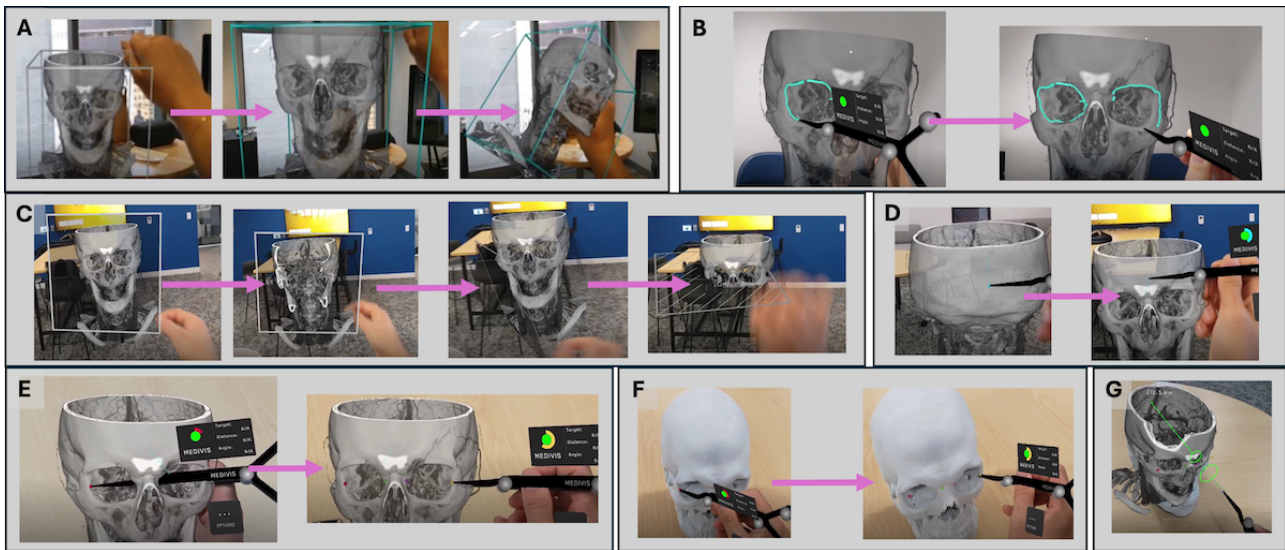
## Experimental Procedure

This study conducted AR-based tasks using SurgicalAR (version 1.6.1; Medivis Inc) software on Microsoft HoloLens 2. SurgicalAR is a surgical guidance system that volumetrically renders Digital Imaging and Communications in Medicine data and projects it onto an HMD, allowing for direct registration to patients. Participants were shown a generic, deidentified computerized tomography angiogram of the head. For tasks that required a stylus or pointer, a stylus tracked by the SurgicalAR system was used.

Participants were given 7 different AR-based tasks that were deliberately selected to resemble the clinical workflow steps that a neurosurgeon would perform in the operating room. Specifically, tasks 1 to 3 mimicked basic hologram interactions that may be performed while visualizing key structures or planning an operative approach. Tasks 4 to 7 were designed to follow a standard hologram-to-object registration in which 4 corresponding points were placed on the hologram and the physical object. Then, a 3D transformation was computed using the method by Horn [44] to complete the registration.

Before participants began using AR, the study moderator demonstrated the task using the HoloLens 2 while participants viewed the task through the SurgicalAR system cart monitor, which was positioned near the moderator. Then, the moderator gave and adjusted the headset on each participant and instructed them on basic gesture interactions. All tasks were performed on and recorded using the HoloLens 2. Videos were analyzed for performance using predefined metrics, as defined below. A description of each task is provided below, and representations of the tasks can be seen in Figure 2.

**Figure 2.** Series of augmented reality tasks that participants were required to complete. (A) Baseline performance: resizing and rotating a hologram of a human skull model; (B) orbit tracing: outlining the orbital rims on the hologram; (C) plane visualization: viewing coronal, sagittal, and axial planes of the hologram; (D) anterior-posterior trajectory point: placing virtual trajectory markers on the hologram; (E) virtual landmark placement: placing 4 virtual landmarks on the hologram; (F) physical landmark placement: placing 4 physical landmarks on the 3D-printed human skull model; and (G) trajectory alignment: performing trajectory alignment.



- Task 1 (Figure 2A): participants resized and rotated a hologram of a human skull model. This task required participants to unanchor the hologram, detaching it from its fixed position and allowing free movement. They then needed to make the hologram larger (zoom in) and smaller (zoom out) and rotate the hologram 360°. Finally, participants reanchored the hologram, locking it back into its original orientation and size. This task was repeated 3 times. Task performance was measured by time taken to complete and by number of slips. Slips were defined as unintentional errors or mistakes [45,46].
- Task 2 (Figure 2B): participants outlined the orbits (eye sockets) of the hologram. Participants were instructed to perform the orbit tracing in one continuous motion for each orbit, without retracting the areas they had already outlined. Performance was measured by a qualitative analysis of orbit tracing quality.
- Task 3 (Figure 2C): participants moved a cut-plane tool fully through the hologram of computerized tomography angiogram of the head in 3 directions—coronal, sagittal, and axial. They were instructed to perform the task while keeping their body facing the front of the hologram. Performance was measured by the number of slips, defined as instances in which a person intends to do one action but unintentionally does something else [45,46].
- Task 4 (Figure 2D): participants placed 2 virtual trajectory landmarks. The first point was placed midline on the lambdoid suture, and the second point was placed midline on the frontal bone. Performance was measured by the time required to successfully place the posterior point and anterior point.
- Task 5 (Figure 2E): participants placed 4 virtual landmark points on the bilateral lateral and medial parts of the hologram's orbit. They began with the lateral left orbit and worked from left to right, finishing with the lateral right orbit. Performance was measured by the time to place each virtual landmark point.
- Task 6 (Figure 2F): participants placed 4 physical landmark points on a 3D-printed skull model, matched to the same locations as the virtual landmarks. They began with the lateral left orbit and worked from left to right, finishing with the lateral right orbit. Performance was measured by the time to place each physical landmark point.
- Task 7 (Figure 2G): participants registered the holographic computerized tomography projection onto the physical skull and then activated the trajectory alignment tool. To accomplish this, participants used the stylus to make the anterior-posterior trajectory turn green, indicating successful alignment. Performance was measured by time taken to align trajectory.

### Statistics

Descriptive statistics were used to summarize demographic variables and baseline characteristics. Group comparisons were performed using independent samples 2-tailed *t* tests for continuous variables and Pearson  $\chi^2$  tests for categorical variables, where appropriate. To assess learning effects, mixed-effects models with Tukey multiple comparisons were used for completion times. Friedman tests with Dunn post hoc comparisons were used for error counts and landmark placement times, and Wilcoxon signed-rank tests were used for paired comparisons. The overall effect of trial on performance was evaluated using a 1-way repeated-measures ANOVA with Greenhouse-Geisser correction. To evaluate whether learning effects were modified by MRT scores or video game experience, a covariate-adjusted repeated-measures general linear model was used. Linear regression was used to evaluate the predictive relationship between MRT scores and baseline task performance. Participants were stratified based on video game experience (>5 hours/week vs ≤5 hours/week) to assess group differences in task outcomes. Significance was set at  $\alpha=.05$  for all comparisons. All statistical analyses were conducted using GraphPad Prism (version 10.0.0; GraphPad Software Inc).

## Results

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### Overview

In total, 23 participants with no previous experience with AR were recruited for this observational study. Of these, participants 3 and 42 (8.69%) did not successfully complete all tasks and were excluded from the analysis, resulting in a final cohort of 21 (91.3%) participants. Within the final cohort, there were 11 (52.4%) female participants, and the median age was 22 (IQR

21-24) years. There were 15 (71.4%) participants who were undergraduate students. In total, 13 (61.9%) participants spent between 0 to 5 hours per week playing video games, and 10 (47.6%) participants spent between 0 to 10 hours per week interacting with a touch screen device or computer. Furthermore, 13 (61.9%) participants were completely comfortable with new technology. Specific demographic information and comfort with new technology are presented in [Table 1](#). Results of the NASA-TLX are presented in [Table 2](#).

**Table .** Participant demographics (N=21).

Variable	Value
Sex, n (%)	
Female	11 (52.4)
Male	10 (47.6)
Age (years), median (range; IQR)	22 (19-25; 21-24)
Level of training, n (%)	
Undergraduate student	15 (71.4)
Medical student	5 (23.8)
Master's student	1 (4.76)
Time spent playing video games per week (hours), median (range; IQR)	5 (0-55; 1.5-21)
Weekly video games use (hours), n (%)	
0-5	13 (61.9)
6-10	1 (4.76)
11-15	2 (9.52)
16-20	0 (0)
≥21	5 (23.8)
Time spent interacting with touch screen device or computer (hours), median (range; IQR)	15 (0-63; 5-40)
Weekly touch screen devices or computer use (hours), n (%)	
0-10	10 (47.6)
11-20	1 (4.76)
21-30	3 (14.3)
31-40	3 (14.3)
≥41	4 (19.0)
Comfort with new technology (scale 1-5), n (%)	
Totally comfortable (5)	13 (61.9)
Very comfortable (4)	4 (19.0)
More or less comfortable (3)	3 (14.3)
Not very comfortable (2)	1 (4.76)
Not comfortable at all (1)	0 (0)
Experience with other forms of surgical guidance, n (%)	
Endoscopy <sup>a</sup>	2 (9.52)
DaVinci <sup>b</sup>	1 (4.76)
Microsurgery	0 (0)

<sup>a</sup>Average experience with endoscopy was 13 (SD 4.49) hours.

<sup>b</sup>Total experience with DaVinci was 6 hours.

**Table .** National Aeronautics and Space Administration Task Load Index scores.

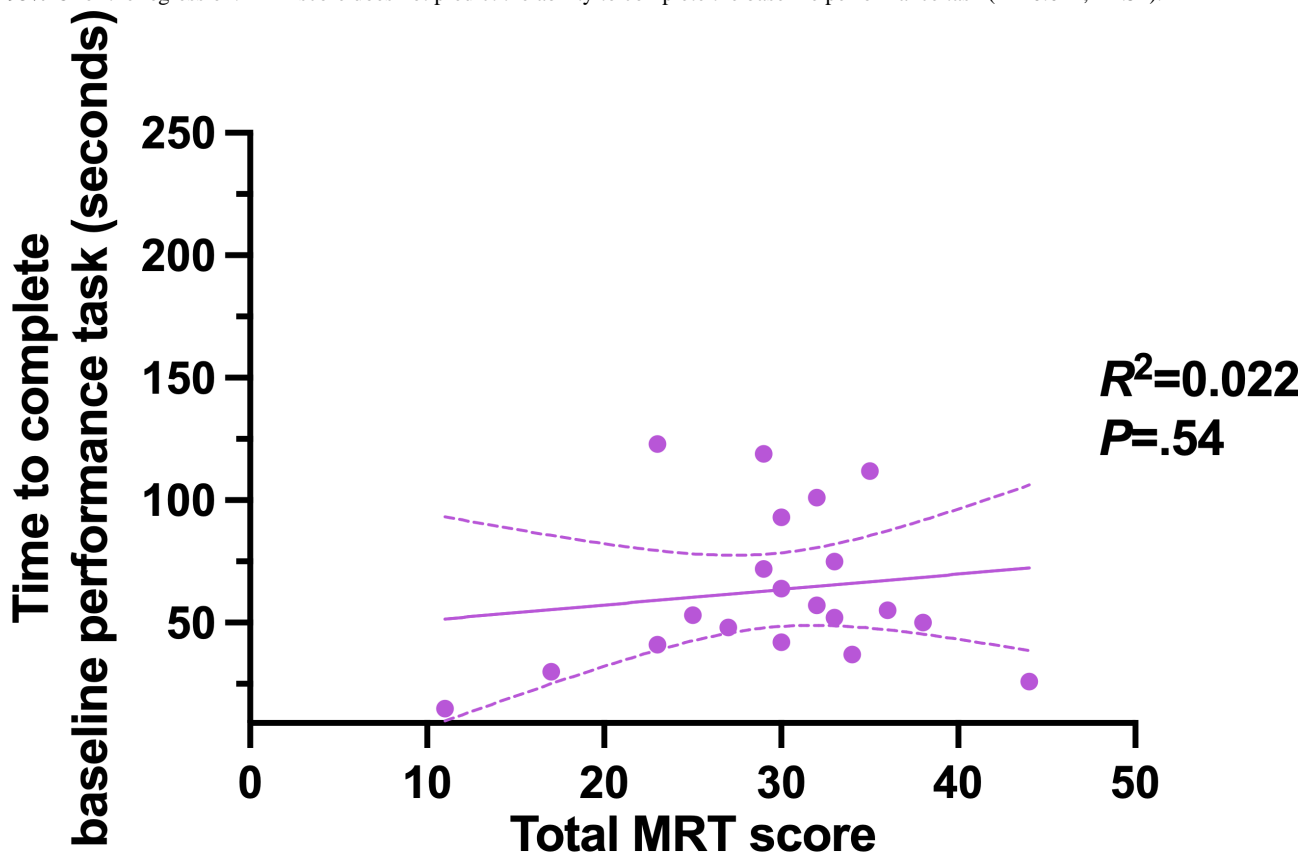
Category	Value, median (range; IQR)
Mental demand	50 (0-80; 25-67.5)
Physical demand	15 (0-70; 5-30)
Temporal demand	35 (0-75; 10-50)
Performance (lower is better)	50 (20-85; 37.5-67.5)
Effort	50 (0-90; 30-67.5)
Frustration	30 (0-85; 12.5-60)

**Overall Performance on MRT**

Visuospatial ability, as measured by the MRT, did not predict the time taken to complete the baseline performance task (Pearson  $r=0.15$ , 95% CI  $-0.32$  to  $0.55$ ;  $R^2=0.022$ ;  $P=.54$ ; Figure 3). Similarly, MRT scores did not predict error rates on the

baseline performance task ( $r=0.18$ , 95% CI  $-0.27$  to  $0.57$ ;  $R^2=0.034$ ;  $P=.43$ ). There were no statistically significant differences in baseline performance time ( $P=.65$ ) or number of slips ( $P=.62$ ) between individuals with MRT scores  $\geq 30$  and those with scores  $<30$ .

**Figure 3.** Association between visuospatial ability, measured by the mental rotation task (MRT), and baseline task completion time. Each dot represents an individual participant’s MRT score and corresponding completion time. The solid line indicates the linear regression fit, and the dashed lines represent the 95% CI of the regression. MRT score does not predict the ability to complete the baseline performance task ( $R^2=0.022$ ;  $P=.54$ ).



**Video Game Performance**

Participants were split into 2 groups based on video game experience (group with “extensive” experience of  $>5$  hours/week and group with “minimal” experience of  $\leq 5$  hours/week) for analysis. This distribution was determined empirically to yield approximately equal participants per group (8 and 13, respectively). Participants with extensive video game experience did not demonstrate faster completion times compared to those with minimal video game experience (Mann-Whitney test; median difference  $-22$  seconds, 95% CI  $-7.00$  to  $57.00$ ;  $P=.24$ ).

However, individuals who had extensive video game experience made fewer slips on average than those who had minimal video game experience (mean 4.00, SD 2.27 slips, 95% CI 2.10-5.90 vs mean 6.61, SD 3.36 slips, 95% CI 4.59-8.64; unpaired  $t$  test; mean difference  $-2.62$  slips, 95% CI  $-5.19$  to  $-0.04$ ;  $P=.047$ ).

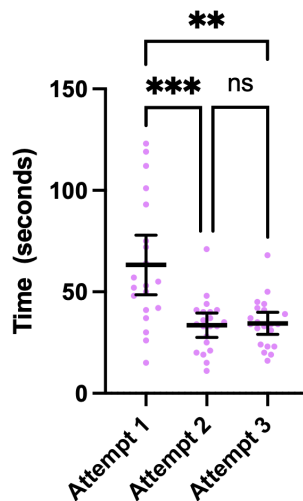
**Learning**

Participants learned to perform the baseline performance task (task 1) in a significantly shorter time between attempts 1 and 2 (mean 63.3, SD 31.4 seconds, 95% CI 48.5-78.0 vs mean 33.6, SD 13.1 seconds, 95% CI 27.6-39.6;  $P<.001$ ) and attempts

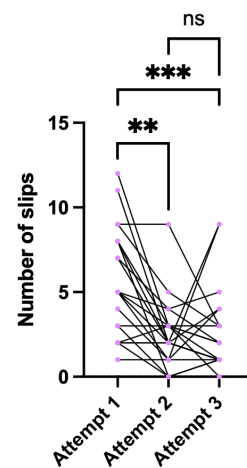
1 and 3 (mean 63.3, SD 31.4 seconds, 95% CI 48.5-78.0 vs mean 34.5, SD 12.0 seconds, 95% CI 29.0-40.0;  $P=.002$ ), but not between attempts 2 and 3 (mean 33.6, SD 13.1 seconds, 95% CI 27.6-39.6 vs mean 34.5, SD 12.0 seconds, 95% CI 29.0-40.0;  $P>.99$ ; Figure 4A).

**Figure 4.** Learning effects observed across various augmented reality tasks. (A) Time taken to complete baseline performance task across attempts. Each dot represents an individual participant, and the horizontal lines indicate the mean with 95% CIs. Participants performed the baseline performance task in a significantly shorter time between attempts 1 and 2 [\*\*\* $P<.001$ ] and attempts 1 and 3 [\*\* $P=.002$ ]. The comparison between attempts 2 and 3 was not significant [ns;  $P>.99$ ]. (B) Number of slips in the baseline performance task across attempts. Each dot represents an individual participant, and the connecting lines track each participant's performance across attempts. Participants improved in the accuracy of completing the baseline performance task, as demonstrated by fewer slips between attempts 1 and 2 [\*\* $P=.008$ ] and attempts 1 and 3 [\*\*\* $P<.001$ ]. The comparison between attempts 2 and 3 was not significant [ns;  $P>.99$ ]. (C) Time taken to trace orbits. Each dot represents an individual participant, and the connecting lines track each participant's performance between orbits. Participants significantly improved the time to trace the orbits on the second attempt [\*\* $P=.004$ ].

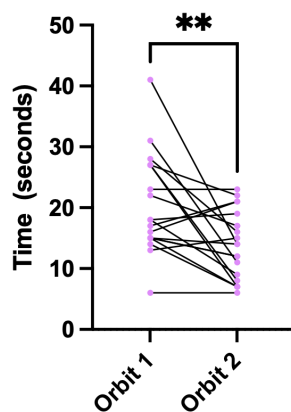
### A Time taken to complete baseline performance task



### B Participant slips in the baseline performance task



### C Time taken to trace orbit



A 1-way repeated-measures ANOVA indicated that there was a significant effect of trial time, consistent with improved performance across trials (Greenhouse-Geisser  $F_{1,135,22,691}=11.890$ ;  $P=.002$ ). However, a covariate-adjusted repeated-measures general linear model that included weekly gaming hours and MRT score indicated that the trial effect was not significant (Greenhouse-Geisser  $F_{1,112,20,021}=0.050$ ;  $P=.85$ ), and there was no evidence that trial-related changes depended on either covariate (trial $\times$ gaming hours:  $P=.62$ ; trial $\times$ MRT:  $P=.34$ ).

In addition to faster task completion times between attempts 1 and 2 and 1 and 3, participants also performed the task more

accurately. There was a decrease in the number of slips between attempts 1 and 2 (mean 5.62, SD 3.2 slips, 95% CI 4.2-7.1 vs mean 2.48, SD 2.02 slips, 95% CI 1.6-3.4;  $P=.008$ ) and attempts 1 and 3 (mean 5.62, SD 3.2 slips, 95% CI 4.2-7.1 vs mean 2.57, SD 2.52 slips, 95% CI 1.4-3.7;  $P<.001$ ; Figure 4B). Furthermore, participants completed the orbit tracing more quickly between the first and second orbit (mean 20.4, SD 8.15 seconds, 95% CI 16.5-24.4 vs mean 13.9, SD 5.52 seconds, 95% CI 11.31-16.5;  $P=.004$ ) without a change in quality of orbit tracing ( $P=.77$ ; Figure 4C).

Additionally, participants required less time to place virtual landmark points 2 and 3 (mean 7.2, SD 4.82 seconds, 95% CI

5.0-9.4 vs mean 4.2, SD 1.81 seconds, 95% CI 3.4-5.0;  $P=.009$ ) and points 2 and 4 (mean 7.2, SD 4.82 seconds, 95% CI 5.0-9.4 vs mean 4.0, SD 1.82 seconds, 95% CI 3.2-4.8;  $P=.02$ ). There was no learning effect observed for placing physical landmarks (Friedman test; Dunn post hoc: all pairwise  $P\geq.64$ ). There was no significant difference in the learning curve between participants with MRT scores  $\geq 30$  and those with scores  $< 30$  ( $P=.87$ ). Furthermore, there was no difference in learning curves between participants with extensive video game experience and those with minimal video game experience ( $P=.81$ ).

### Predictive Variables

MRT performance did not predict baseline performance, as measured by task 1 ( $P=.54$ ; Figure 3). Additionally, video game experience was not a predictor of baseline performance (Pearson  $r=-0.35$ , 95% CI  $-0.69$  to  $0.13$ ;  $R^2=.12$ ;  $P=.14$ ); however, it did predict the number of slips ( $P=.046$ ).

## Discussion

### Principal Findings

As AR technology continues to improve and integrate within health care and other industries, it becomes increasingly important to understand which factors contribute to technological proficiency among novice AR users. By identifying these factors, product designers can address the scarcity of implementation models that is hindering the widespread adoption of AR and VR in clinical settings [30] and develop programs to help guide novice users through more complex AR-based interactions, thereby proactively addressing areas of difficulty, minimizing the user learning curve, and increasing user adoptability. To address this growing need, our study aimed to identify predictors of performance in novice AR users. Our findings suggest that visuospatial ability does not predict AR task completion time, though extensive video game experience was associated with greater accuracy. Despite this result, neither visuospatial ability nor video game experience corresponded with an improved learning curve.

### Predictive Variables of Performance Gains

Existing literature has placed a strong emphasis on visuospatial ability as a predictor of performance in various clinical settings, including ultrasound [27], laparoscopic [28], and endoscopic procedures [29], as well as in nonclinical settings [47,48] and learning [26]. Given that factors such as depth perception and stereovision undoubtedly contribute to an individual's visuospatial ability [49], our study used one of the most popular validated ways of evaluating spatial ability, the MRT [50,51]. In our study, we found no relationship between MRT scores and baseline performance. This suggests that AR proficiency may be influenced by more nuanced visual processing skills that are not captured by the MRT.

Höhler et al [49] and Martin-Gomez et al [52] have suggested that depth perception and stereoacuity affect individuals' ability to estimate distances of objects in AR. Given the importance of interacting with virtual elements in AR, estimating the depth and position of these objects may play a larger role than

previously thought and could account for the visual processing skills that are not captured by the MRT.

The observed result that increased video game experience was correlated with increased accuracy in AR tasks may be explained by the beneficial effect of gaming on spatial cognition. Work by Bavelier and Green [53] indicates that specifically action video game play enhances spatial cognition; however, other literature has indicated that these cognitive improvements are not unique to only action games [54]. This indicates that the relationship between video game experience and accuracy in AR may be due to the cognitive benefits of extensively playing video games, regardless of genre.

The literature indicates that video game experience may be a positive predictor of performance in surgical tasks with respect to errors and time [55-57]. Our findings suggest that this relationship may extend to AR-based applications with respect to errors; however, more research is needed to evaluate its effect on performance time.

### Learning How to Use AR

One of the reasons AR can be challenging for novice users is the variability in the learning process [58]. However, as with other skills, increased AR exposure is associated with improved performance. Our unadjusted analyses demonstrated a rapid learning effect, with the most pronounced gains occurring during early task exposure. This suggests that novice AR users may rapidly familiarize themselves with the AR environment. However, covariate-adjusted models did not indicate that these improvements differed significantly based on user characteristics.

Users who initially performed tasks more slowly demonstrated the greatest improvement. Tasks requiring less depth perception showed more rapid learning, while those emphasizing higher depth perception and precision, such as the virtual landmark placement (task 5), improved more gradually. Notably, physical landmark placement (task 6) did not show a learning effect, possibly because participants could rely on tactile feedback from touching the skull with the stylus.

Given that covariate-adjusted models showed no significant influence of MRT or video game experience on learning, these findings suggest that inherent user characteristics, such as spatial ability, do not impact early AR learning capacity in novice users. However, given our modest sample size ( $N=21$ ), the nonsignificant covariate terms and interactions should be interpreted cautiously.

### Importance of Depth Perception With AR

There is a possibility that depth perception and stereoacuity play a larger role in novice AR performance due to inherent technological limitations of the HMD. The AR device used in this study, the Microsoft HoloLens 2, uses a traditional fixed plane optical display. Research with the HoloLens has supported that visual rendering factors such as shadows [59] and lighting conditions [60] may impact the depth perception of users. Additionally, binocular disparity and the occlusion of an object are other important cues for depth perception [61].

If a user attempts to interact with a virtual object in AR, they may experience an occlusion error, in which the object appears translucent despite the user's hand not being at the appropriate distance to interact with it. Uehira and Suzuki [61] identified that this depth perception error was highly varied between individuals, particularly at short distances where the difference in binocular disparity is especially pronounced. Most of the tasks in our study were performed at short distances, mimicking clinical interactions with AR. Our study did not quantify the distances of the virtual objects, nor did we measure how many times users missed targets due to misjudgment of depth. Given that interaction with virtual objects is a fundamental component of AR use, it is likely that individuals who have stronger depth perception abilities may outperform those with weaker depth perception [49].

Concurrently, these findings provide new evidence that traditional measures of visuospatial ability do not reliably predict novice AR performance, while unmeasured factors, including depth perception, may contribute more than previously thought. The early performance gains observed in unadjusted analyses suggest that novice AR proficiency can be rapidly developed, a result supported by short-format training within urology [14]. Importantly, these learning effects, combined with the scarcity of existing implementation models [30], suggest that successful AR adoption may benefit from short, targeted training programs that guide all novice users to a competency threshold rather than prioritizing users based on traits such as visuospatial ability or video game experience. Furthermore, this emphasizes that predictive measures of novice performance should be interpreted in the context of this rapid rate of improvement.

### Limitations

This study has some notable limitations. The potential sampling bias introduced by the inclusion of only undergraduate and graduate students may limit the generalizability of the findings to broader populations, such as resident and attending physicians who represent actual AR users in health care settings. Given that our sample size was 21 nonsurgeon participants, we believe that further research evaluating the learning curve within

intraoperative environments is necessary before concluding that task-specific guides will reduce the learning curve.

Additionally, as the sample was modest (N=21) and the covariate-adjusted model included multiple predictors (gaming hours and MRT), this study may be underpowered to detect small-to-moderate covariate effects and trial-by-covariate interactions. Accordingly, nonsignificant covariate terms (eg, gaming hours  $P=.80$ ; MRT  $P=.17$ ) and interaction terms (trial×gaming hours  $P=.62$ ; trial×MRT  $P=.34$ , Greenhouse-Geisser corrected) should be interpreted cautiously. Additionally, video game experience was self-reported and categorized based on hours per week. Our study found it challenging to obtain the genre of video games played and therefore did not analyze whether different categories of video games influenced performance with AR. The cognitive demand effects and the type of video games were not collected; however, these factors may have an influence on how participants perform in the tasks we evaluated in this study. Furthermore, technical limitations of the Microsoft HoloLens 2 cannot be discounted, such as ambient lighting conditions in the room during experimentation, which may have affected hologram visual quality. Finally, some outcomes, such as orbit tracing quality, were evaluated qualitatively and may be subject to observer bias.

### Conclusions

As AR technology continues to grow in adoption across different industries, there is an increased need to identify the factors that contribute to effective AR use. Our research found that extensive video game experience was correlated with decreased error frequency, while neither visuospatial ability nor video game experience predicted novice user performance time. We believe that future research should focus on how depth perception, stereoacuity, and learning play a role in novice user performance, while also evaluating the learning curve of surgeons in intraoperative environments. This area of research holds important promise and may shape how industry professionals and product developers design and train future users to adopt AR systems more effectively.

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### Data Availability

The data presented in this study are available from the corresponding author on reasonable request and with institutional approval.

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### Conflicts of Interest

EGA, JTB, and GH are shareholders of SymphonyMR Inc.

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## Abbreviations

**AR:** augmented reality

**HMD:** head-mounted display

**MRT:** mental rotation task

**NASA-TLX:** National Aeronautics and Space Administration Task Load Index

**STEM:** science, technology, engineering, and math

**VR:** virtual reality

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# Perceived Usability, User Experience, and Technology Acceptance of Role-Specific Augmented Reality Decision Support Tools for Cardiac Arrest Resuscitation: Prospective Observational Pilot Study

Ryan Kang<sup>1</sup>, MSc; Adam Cheng<sup>2,3</sup>, MD; Yiqun Lin<sup>2,3</sup>, MD, MHSc, PhD; Hyeongil Nam<sup>1</sup>, PhD; Jennifer Davidson<sup>2,3</sup>, RN; Donovan Curtis Duncan<sup>2,3</sup>, MD; Johan N Siebert<sup>4,5</sup>, MD, PD; Sergio Manzano<sup>4,5</sup>, MD, PD; Alexandre De Masi<sup>5</sup>, PhD; Ana Rajic<sup>4,6,7</sup>, MS; Sharleen Kayne Olanka<sup>4,6,7</sup>, MS; Frederic Ehrler<sup>5,7</sup>, PhD; Kangsoo Kim<sup>1</sup>, PhD

<sup>1</sup>Department of Electrical and Software Engineering, Schulich School of Engineering, University of Calgary, 2500 University Drive NW, Calgary, AB, Canada

<sup>2</sup>KidSIM Simulation Program, Alberta Children's Hospital, Calgary, AB, Canada

<sup>3</sup>Department of Pediatrics and Emergency Medicine, Cumming School of Medicine, University of Calgary, Calgary, AB, Canada

<sup>4</sup>Department of Pediatric Emergency Medicine, Geneva University Hospitals, Geneva, Switzerland

<sup>5</sup>Faculty of Medicine, University of Geneva, Geneva, Switzerland

<sup>6</sup>Educational Technologies and Learning Sciences (TECFA), Faculty of Psychology and Educational Sciences, University of Geneva, Geneva, Switzerland

<sup>7</sup>Division of Computer Sciences, Geneva University Hospitals, Geneva, Switzerland

## Corresponding Author:

Kangsoo Kim, PhD

Department of Electrical and Software Engineering, Schulich School of Engineering, University of Calgary, 2500 University Drive NW, Calgary, AB, Canada

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## Abstract

**Background:** Cardiac arrest is a critical medical emergency that requires strict adherence to clinical guidelines to achieve optimal outcomes. Deviations from these guidelines, often due to task complexity, can adversely affect patient outcomes. Augmented reality (AR) offers a way to deliver role-specific, in-view guidance, but evidence on its perceived usability, user experience, and acceptability in cardiac arrest resuscitation remains limited.

**Objective:** This study aimed to design, develop, and evaluate a role-specific AR decision support system for resuscitation team leaders and medication nurses. In this observational study, we assessed clinicians' perceived usability, user experience, and technology acceptance of the new AR system in a high-fidelity simulated cardiac arrest scenario.

**Methods:** We conducted a prospective observational pilot study using a high-fidelity simulated pediatric cardiac arrest scenario. A total of 10 clinicians were recruited from Alberta Children's Hospital, including 5 (50%) of 10 pediatric emergency physicians serving as team leaders (men: 3/5, 60%, and women: 2/5, 40%; median age 41, IQR: 40-42 y) and 5 (50%) of 10 emergency nurses serving as medication nurses (men: 1/5, 20%, and women: 4/5, 80%; median age 45, IQR: 42-46 y). Participants used role-specific AR decision support interfaces deployed on HoloLens 2 head-mounted displays. Following the simulation, perceived usability, user experience, and technology acceptance were assessed using validated questionnaires: the System Usability Scale, User Experience Questionnaire, and Technology Acceptance Model. Data were collected via postsimulation surveys and analyzed descriptively.

**Results:** Descriptive analyses were performed without inferential statistical testing. The mean System Usability Scale scores were 75.5 (SD 9.25, 95% CI 64.0 - 87.0) for team leaders and 82.0 (SD 11.20, 95% CI 68.0 - 96.0) for medication nurses. User experience was positive across roles, with mean User Experience Questionnaire scores indicating favorable attractiveness (team leaders: 1.87, SD 1.14, 95% CI 0.45 - 3.28; medication nurses: 2.43, SD 0.52, 95% CI 1.79 - 3.08), pragmatic quality (team leaders: 1.88, SD 0.87, 95% CI 0.80 - 2.97; medication nurses: 1.80, SD 0.69, 95% CI 0.94 - 2.66), and hedonic quality (team leaders: 2.40, SD 0.89, 95% CI 1.30 - 3.50; medication nurses: 2.28, SD 0.69, 95% CI 1.42 - 3.13). Technology acceptance was high, with mean combined Technology Acceptance Model scores of 5.92 (SD 0.46, 95% CI 5.35 - 6.49) for team leaders and 6.02 (SD 0.56, 95% CI 5.32 - 6.71) for medication nurses.

**Conclusions:** This study introduces a novel role-specific AR decision support system that delivers tailored, in-view guidance to resuscitation team leaders and medication nurses during cardiac arrest. Unlike prior cognitive aids that present uniform or device-agnostic information, this system explicitly adapts interface content and structure to distinct clinical roles and workflows. The findings contribute early empirical evidence on the perceived usability, user experience, and acceptability of role-tailored

AR support in high-acuity team settings and yield transferable design principles for developing role-aware AR interfaces. In real-world contexts, such systems may support protocol adherence and team coordination during resuscitation training and early-stage clinical deployment, informing future evaluations that incorporate objective performance and workflow outcomes.

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## 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 (CAs) each year in North America [1]. Guideline-compliant basic life support and advanced life support guidelines significantly improve patient outcomes following CA [2,3]. However, health care providers often face challenges in consistently adhering to these guidelines during in-hospital CA events. 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 [7-11]. By reducing errors and improving the timing of key interventions, cognitive aids can enhance clinical performance [12]. However, traditional cognitive aids, such as pocket cards, sometimes introduce delays in initiating CPR or administering drugs due to their design limitations or complexity, highlighting the need for more efficient, role-specific decision-support solutions. Recent scoping and systematic reviews published in the past few years highlight a growing interest in immersive technologies, including augmented reality (AR), for resuscitation training and emergency care, while also identifying variability in system design, evaluation approaches, and integration with clinical workflows [13,14].

AR overlays digital content onto the physical environment, enabling real-time delivery of context- and role-specific prompts directly in the user's field of view [15]. AR systems have been explored in CPR and emergency care training contexts, with some evidence of improved engagement and task performance compared with conventional approaches, although results remain heterogeneous and context-dependent [16,17]. Previous AR-based work in resuscitation and safety-critical domains further suggests that spatially registered visual cues can support situational awareness and reduce reliance on external reference materials during time-sensitive tasks [15,18,19]. Despite this growing body of work, recent reviews emphasize that evidence regarding the usability, user experience, and acceptability of wearable AR systems in CA resuscitation—particularly from the perspective of end users—remains limited [13,14].

To address these gaps, this study presents the design, development, and formative evaluation of an AR-based decision

support system tailored to the resuscitation team leader (physician) and medication nurse roles during CA resuscitation. The objectives of this study were to (1) describe how team leaders and medication nurses perceive the AR system's usability and user experience when used during a simulated resuscitation scenario and (2) describe how team leaders and medication nurses perceive the system's acceptability and its potential for future integration into clinical practice.

## Methods

### Ethical Considerations

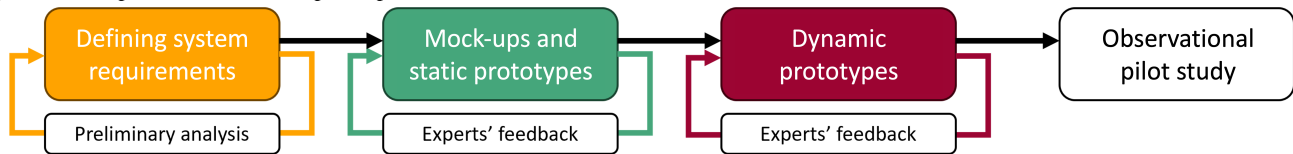
Ethics approval was obtained from the University of Calgary (REB23-1007) and the University of Geneva Health Research Ethics Boards (Req-2023 - 00162). Before participation, all participants were provided with written information describing the study purpose, procedures, potential risks, and data handling practices, and written informed consent was obtained. Participation was voluntary, and participants were informed that they could withdraw from the study at any time without consequence. Consent included permission to collect survey data and to use nonidentifiable data and images generated during the simulation for research and publication purposes. Privacy and confidentiality were ensured for all study participants. No images included in the manuscript or supplementary materials contain identifiable information about individual participants. Participants did not receive any compensation for their role in this study.

### Study Design: Experimental Setting

This study was designed as a prospective observational pilot study conducted in a high-fidelity pediatric CA simulation setting. The following section describes the overall process of the AR system design and development, which was used in the study.

### Iterative Design and Development Process of the AR System

For our study, role-specific AR decision support systems for team leaders (physicians) and medication nurses were developed following a 4-phase, iterative prototyping process grounded in user-centered and clinician-informed design practices (Figure 1). Phases 1 to 3 focused on system design and development, whereas phase 4 evaluated the final prototype in a simulation-based clinical environment through an observational pilot study. The objective of this process was to progressively refine AR design concepts into a stable, simulation-ready system through iterative feedback and close collaboration with clinical domain experts.

**Figure 1.** Four-phase iterative development process.

### ***Phase 1: Defining System Requirements***

This phase focused on identifying the clinical, informational, and workflow requirements necessary to guide the content and design of the role-specific AR interfaces. A total of 30 health care professionals (15, 50%, emergency physicians and 15, 50%, emergency nurses) from Alberta Children’s Hospital (ACH) and Geneva University Hospitals were surveyed to assess preferences for role-specific information, AR layout components, timer placement and behavior, and medication-related display features. Clinicians viewed role-specific, task-focused information as important elements of the AR system. Both physicians and nurses emphasized the utility of receiving targeted, step-relevant prompts through the AR headset. Real-time updates regarding current and upcoming

tasks (“next steps”) were perceived to enhance workflow by reducing the need to reference external materials visually. Both groups rated time-based cues highly, with the integration of a CPR timer (for the team leader) and an epinephrine timer (for the team leader and medication nurse) described as highly important for the AR headset. A detailed list of resuscitation medications and associated dosages was also rated highly for both groups of providers. Physicians expressed the desire to be notified when medications were given. These insights directly informed the layout, information hierarchy, and alerting behavior of the static (phase 2) and dynamic (phase 3) prototypes, ensuring that the AR interface design aligned with clinicians’ informational needs and workflow demands. [Table 1](#) provides a summary of key insights from phase 1.

**Table .** Key insights from each phase of the iterative development process.

Phase	Key insights
Phase 1: Defining system requirements	<ul style="list-style-type: none"> <li>• Role-specific, task-focused clinical prompts</li> <li>• Current tasks (prioritized)</li> <li>• Next steps (prioritized)</li> <li>• CPR<sup>a</sup> timer (team leader)</li> <li>• Epinephrine timer (team leader and medication nurse)</li> <li>• Medication reference</li> <li>• Medication given—notification for team leader</li> </ul>
Phase 2: Mock-ups and static prototypes	<ul style="list-style-type: none"> <li>• Interface separation by user role improves clarity and relevance of displayed information.</li> <li>• Visually simple, structured layouts are preferred for rapid information recognition.</li> <li>• Timers and other time-sensitive elements should be placed in the upper peripheral field of view to avoid obstructing the patient.</li> <li>• Current tasks should be listed on the left and next steps to the right.</li> <li>• Cardiac rhythm should be displayed in the physician's augmented reality headset.</li> <li>• Patient weight should be displayed on the medication nurse display.</li> <li>• Other UI<sup>b</sup> elements should be fixed in space (e.g., clinical algorithm, Hs and Ts, medication reference) to avoid interference when team members move through the field of view.</li> </ul>
Phase 3: Dynamic prototype	<ul style="list-style-type: none"> <li>• Functional CPR and epinephrine timers included escalating visual cues.</li> <li>• The UI was visually refined with higher contrast, low-profile components, reorganized medication content, and larger fonts.</li> <li>• Medication card (team leader): categorized drug details with interactive dose counters</li> <li>• Guideline algorithm panel (team leader): full cardiac arrest algorithm visualization with a stage-tracking arrow.</li> <li>• Hs and Ts reference (team leader): a structured list of reversible causes for rapid diagnostic review.</li> <li>• Medication card (medication nurse): categorized drugs with strength, dose, volume, and instructions, plus an interactive syringe counter for tracking prepared or administered doses.</li> <li>• UI elements were arranged to maximize visibility and minimize occlusion during dynamic resuscitation.</li> </ul>

<sup>a</sup>CPR: cardiopulmonary resuscitation.

<sup>b</sup>UI: user interface.

### **Phase 2: Mock-Ups and Static Prototypes**

In this phase, the requirements identified in phase 1 were transformed into static prototype designs. Initial mock-ups were created to visualize the AR layout, role-specific information elements, and overall display functionality. To optimize role-specific design, separate static layouts were developed for the team leader and medication nurse roles. The team leader interface focused on 4 key elements (i.e., the CPR timer, epinephrine timer, current task list, and next task list), whereas the medication nurse interface incorporated 3 core elements (i.e., epinephrine timer, current task list, and next task list). A total of 9 static prototypes were created for the team leader, and 5 prototypes were created for the medication nurse, exploring variations in spatial arrangement and visual hierarchy (Figures S1 and S2 in [Multimedia Appendix 1](#)).

In total, 5 emergency room physicians and 5 emergency room nurses from ACH were selected to provide feedback on static layouts for their corresponding profession. Participants were shown each static layout in sequence and asked to provide verbal

feedback regarding spatial organization, information grouping, font and icon size, color and contrast of user interface (UI) elements, and the position of UI elements relative to equipment and providers in the clinical space. Physicians rated their top 3 display options, and nurses were asked to rate their top 2 options. Feedback was documented using annotated screenshots and meeting notes. On the basis of this feedback, 3 dynamic prototypes for the team leader and 2 dynamic prototypes for the medication nurse were developed to ensure that UI elements were easy to identify, accessible, and minimally intrusive within the AR field of view. [Table 1](#) provides a summary of key insights from phase 2.

### **Phase 3: Dynamic Prototypes**

This phase involved developing and iteratively refining dynamic AR prototypes for both the team leader and medication nurse roles. Dynamic interface layouts were implemented using Unity and deployed on the Microsoft HoloLens 2. The initial dynamic versions preserved the core components established during the static prototyping phase, while introducing functional timers,

refined visual elements, and interactive components. For the medication nurse interface, an adjustable epinephrine dose counter was implemented, allowing users to adjust the number of doses prepared or administered. To guide iterative refinement, the 10 participants from phase 2 returned to provide feedback on the dynamic prototypes. Participants were asked to evaluate layout preferences, timer behavior, visual clarity, and ease of interaction. Additional role-specific questions were directed to team leaders and medication nurses to capture feedback aligned with each role's clinical responsibilities.

Feedback sessions identified refinements to visual hierarchy, timer behavior, text sizing, and the placement of role-specific components. Experts also evaluated the positioning of fixed elements such as the CA algorithms, reversible causes (Hs and

Ts), and the medication card, providing insight into potential visual obstruction during active resuscitation. Feedback informed key improvements to support clarity, usability, and workflow alignment. Functional CPR and epinephrine timers were revised to include escalating visual cues (yellow flash at 10 s and rapid red flash at 1 s). The UI was visually refined with higher contrast, low-profile components, reorganized medication content, and larger fonts. An interactive epinephrine dose counter was added for medication nurses. Participants also emphasized the need to reposition or hide large reference panels to prevent obstruction and maintain clear grouping of current and upcoming tasks. Table 1 provides a summary of key insights from phase 3. All recommended changes were incorporated into one final updated dynamic prototype for the team leader (Figure 2) and medication nurse (Figure 3).

**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 cardiac arrest (CA) scenario. When in use, the CA algorithm, reversible causes, and medication card are positioned out of view when the team leader is looking straight ahead. To view each of these items, the team leader must turn to the left (to see the algorithm), to the right (to see the reversible causes), or look slightly down (to see the medication card). CPR: cardiopulmonary resuscitation; PEA: pulseless electrical activity; pVT: pulseless ventricular tachycardia; ROSC: return of spontaneous circulation; TEP: Treatment Escalation Plan; VF: ventricular fibrillation.



**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.



### Final System Architecture and Components

The AR system used in this study was developed using a server-client architecture to enable seamless, real-time synchronization between a web-based control system operated by the experimenter and the role-specific AR interfaces used by the team leader and medication nurse (Figure S3 in Multimedia Appendix 1). This architecture ensured that each user received only the information relevant to their role while maintaining consistent timing, event updates, and algorithm progression across devices.

- Web-based control system (server): A centralized web-based control system was implemented to manage scenario flow and synchronize data to both AR devices (Figure S4 in Multimedia Appendix 1). During the simulation, the experimenter used this interface to advance the CA algorithm, trigger event notifications, reset timers, and record medication administration (Figure S5 in Multimedia Appendix 1). All adjustments made on the server were immediately transmitted to the AR clients, enabling real-time display without perceptible delay.
- AR interfaces for team leader and medication nurse (client): Two separate AR client applications were deployed on the HoloLens 2 devices, one for each role. These interfaces displayed synchronized timers, role-specific prompts, algorithm guidance, medication information, and interactive elements (e.g., dose counters). The client applications integrated incremental refinements derived from clinician feedback during dynamic prototyping, ensuring that the displays aligned with each role's workflow and cognitive demands.

Together, the server-client architecture, real-time synchronization, and role-specific display features formed a

cohesive system for supporting resuscitation team members during high-acuity pediatric CA scenarios.

### Phase 4: Simulation-Based System Evaluation

Phase 4 consisted of a prospective, observational pilot study in which participants managed a simulated CA scenario using the final prototype of the AR system.

### Participants and Sample Size

Participants were recruited from the pediatric emergency department at ACH. All participants had completed basic life support and pediatric advanced life support training. There were no specific exclusion criteria. A convenience sample of 10 health care professionals participated, consisting of 5 (50%) pediatric emergency physicians (team leaders) and 5 (50%) emergency nurses (medication nurses). The same 10 participants who provided feedback in phases 2 and 3 were paired into physician-nurse dyads, with each clinician assigned the AR interface corresponding to their respective profession.

### Study Procedure: Simulated CA Scenario

The simulation scenarios took place in the KidSIM Pediatric Simulation Center at ACH using a high-fidelity pediatric manikin (Laerdal SimJunior). Each dyad (1 physician team leader and 1 medication nurse) was embedded within a larger clinical resuscitation team composed of 3 additional research actors playing the roles of airway provider, bedside clinician, and CPR provider to recreate an authentic team-based resuscitation environment. The 2 study participants wore HoloLens 2 devices displaying their respective role-specific AR interfaces.

The scenario simulated an in-hospital pediatric CA involving a 5-year-old boy who presented with pulseless ventricular tachycardia, progressing through ventricular fibrillation and

pulseless electrical activity, before achieving return of spontaneous circulation at the 18-minute mark. 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 medications. The medication nurse handled medication preparation and administration, following role-specific cues on the AR interface. Research actors were trained to function in their role as they would in a real CA.

## Measures

To provide a comprehensive assessment of the AR support system's perceived usability, user experience, and acceptance, we used 3 well-established instruments. The System Usability Scale (SUS) was used to measure perceived usability. It consists of 10 statements that assess users' perceptions of system ease of use and overall usability [20,21]. Each statement is rated on a 5-point Likert scale, ranging from "strongly disagree" (1) to "strongly agree" (5), capturing both ease of use and learnability. 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 statement are summed, and the total is multiplied by 2.5 to convert the raw score to a range of 0 to 100. On the basis of empirical benchmarks reported by Bangor et al. [21], SUS scores above 68 are generally interpreted as above average, whereas scores around 80 or higher are commonly associated with excellent usability. These benchmarks provide a practical reference for interpreting system usability levels. The SUS has demonstrated strong psychometric properties across diverse systems and application domains, including high internal consistency and established construct validity. Prior validation studies have shown that SUS scores are robust and interpretable even in small-sample usability evaluations, making the instrument suitable for early-stage and pilot studies [20,21].

The User Experience Questionnaire (UEQ) evaluates multiple dimensions of perceived user experience, including *attractiveness*, *pragmatic quality*, and *hedonic quality* [22]. The UEQ consists of 26 items rated on a 7-point semantic differential scale ranging from -3 (most negative) to +3 (most positive), capturing users' subjective impressions of different aspects of system interaction.

- **Attractiveness:** reflects the overall appeal of the system and represents users' general impression.
- **Pragmatic quality:** captures perceived task-oriented aspects of the system use, focusing on how well users feel the system supports task accomplishment through three subdimensions: (1) *perspicuity*: ease of understanding and familiarization, (2) *efficiency*: perceived smoothness and effort associated with task execution, and (3) *dependability*: user's perceived sense of control and predictability during interaction.
- **Hedonic quality:** captures the emotional and experiential aspects of interaction, covering (1) *stimulation*: how engaging and motivating the system feels; and (2) *novelty*: perceived originality and creativity of the system.

UEQ scale values above 0.8 are commonly interpreted as indicating a positive experience, whereas higher values may be

classified as above average or excellent when compared against UEQ benchmark distributions, depending on the specific scale [23,24]. By distinguishing between pragmatic and hedonic qualities, the UEQ provides insight into both task-oriented interaction perceptions and experiential aspects of system use. The distinction is particularly relevant for AR systems, where perceived interaction support and user engagement jointly shape overall user experience. Validation studies of the UEQ have demonstrated acceptable to good internal consistency across its subscales and established construct validity for distinguishing between pragmatic and hedonic dimensions of user experience across a wide range of interactive systems [22-24].

The Technology Acceptance Model (TAM) assesses user acceptance of new technologies based on the relationship between two main dimensions: (1) perceived usefulness (PU), which measures the extent to which users believe that using a given technology enhances their job performance; and (2) 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 [25]. For this study, TAM was adapted to include 12 items across 2 primary dimensions, each rated on a 7-point Likert scale, ranging from "strongly disagree" (1) to "strongly agree" (7). Scores are averaged for each dimension. High scores across both dimensions suggest that users view the system as both beneficial and user-friendly—key factors for ensuring sustained use [26]. The PU and PEU constructs within TAM have demonstrated strong reliability and predictive validity for technology adoption and use intention across numerous information systems and health care technology studies, supporting their use in evaluating acceptance of emerging technologies, such as AR [25,26].

## Statistical Analysis

In this observational pilot study, there were no missing data for survey responses, and all analyses were descriptive in nature and aimed at characterizing perceived usability, user experience, and technology acceptance of the AR system across clinical roles. For each outcome measure, summary statistics were computed separately for the team leader and medication nurse roles. For the SUS, UEQ, and TAM measures, central tendency and variability were summarized using means and SDs. SEs and 95% CIs for the mean were calculated to indicate the precision of the estimates. Where appropriate, medians and IQRs were visualized using box plots to illustrate score distributions.

Given the small sample size and the exploratory nature of this pilot evaluation, no formal hypothesis testing or inferential comparisons between roles were performed. Instead, overlapping CIs were used to support cautious interpretation of observed differences, consistent with recommendations for early-stage usability and feasibility studies.

## Results

### Participant Demographics

A total of 10 health care professionals participated in the study, comprising 5 (50%) pediatric emergency physicians (team

leaders) and 5 (50%) emergency nurses (medication nurses). Participants varied in age and clinical experience, with medication nurses generally reporting longer durations of practice and greater exposure to CA events. Most participants

had limited prior experience with AR technologies, particularly in professional clinical contexts. [Table 2](#) provides an overview of the participants' demographic characteristics.

**Table .** Participant demographics.

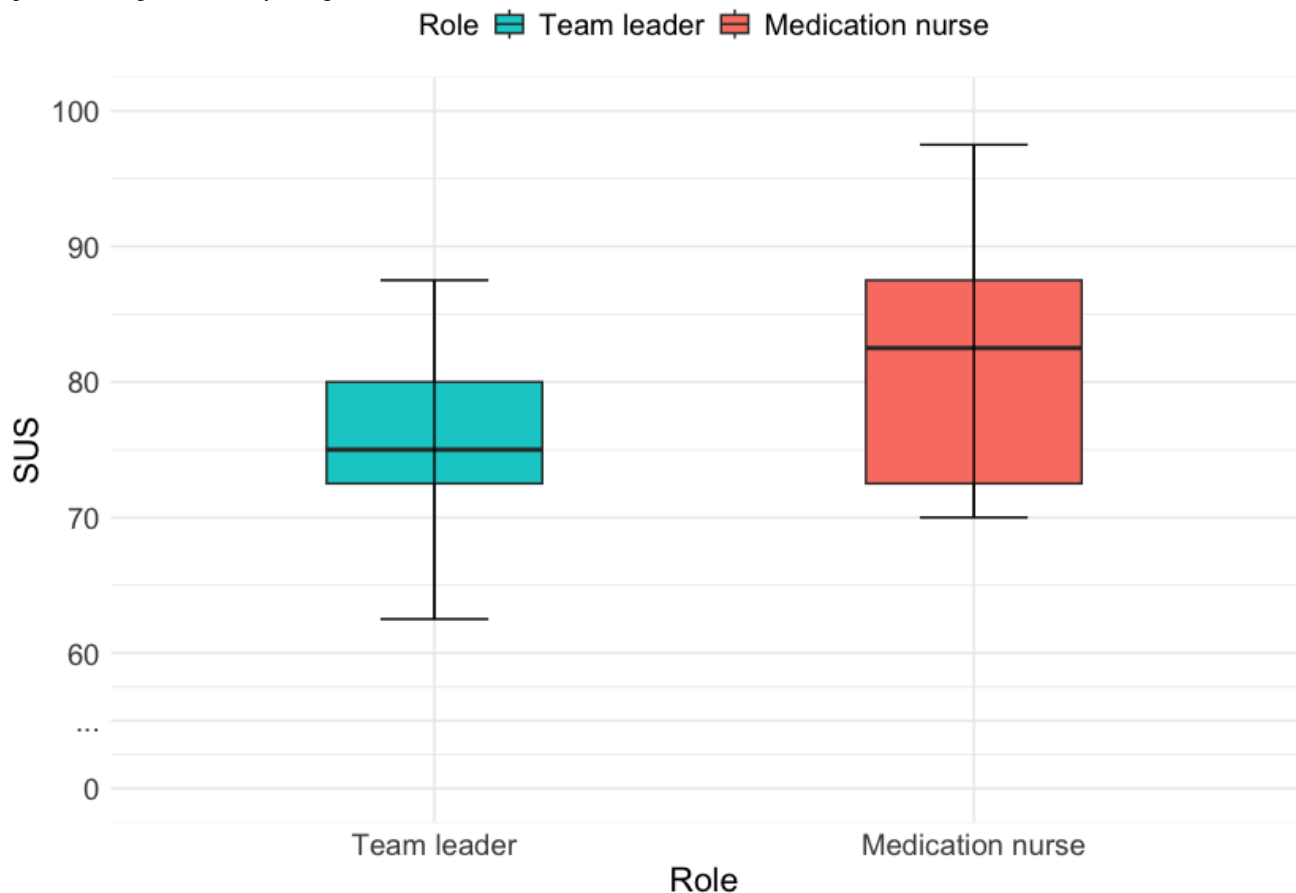
	Team leader (n=5)	Medication nurse (n=5)
Gender, n (%)		
Male	3 (60)	1 (20)
Female	2 (40)	4 (80)
Age (y), median (IQR)	41 (40 - 42)	45 (42 - 46)
Duration in practice (y), median (IQR)	12 (11 - 13)	20.5 (17 - 24.25)
How many times have you had to care for a child in cardiac arrest during a <i>real, live event</i> in the past 2 y?, median (IQR)	1 (1 - 4)	2 (2 - 3)
How many times have you had to care for a child in cardiac arrest during a <i>simulated event</i> in the past 2 y?, median (IQR)	4 (2 - 4)	5 (4 - 6)
Have you ever used any type of augmented reality device for <i>professional use</i> ?	1 participant with prior experience (>10 times)	No prior experience
Have you ever used any type of augmented reality device for <i>recreational use</i> (e.g., gaming)?	3 participants (>10 times)	1 participant (1 - 4 times)

### Perceived Usability

The AR system demonstrated favorable perceived usability for both roles ([Figure 4](#)); however, the precision of these estimates varied across 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) on the SUS grading scale, categorized as “good” ([Multimedia Appendix 2](#)). The score generally suggests that team leaders perceived the system as usable and user-friendly; however, the relatively wide CI reflects uncertainty associated with the small sample size and indicates that this estimate should be interpreted cautiously.

**Figure 4.** Box plot displaying System Usability Scale (SUS) scores for the team leader and medication nurse roles using the augmented reality support system. Higher median SUS scores for medication nurses indicate greater ease of interaction and workflow support, reflecting an “excellent” grade compared to the “good” usability rating for the team leader role.



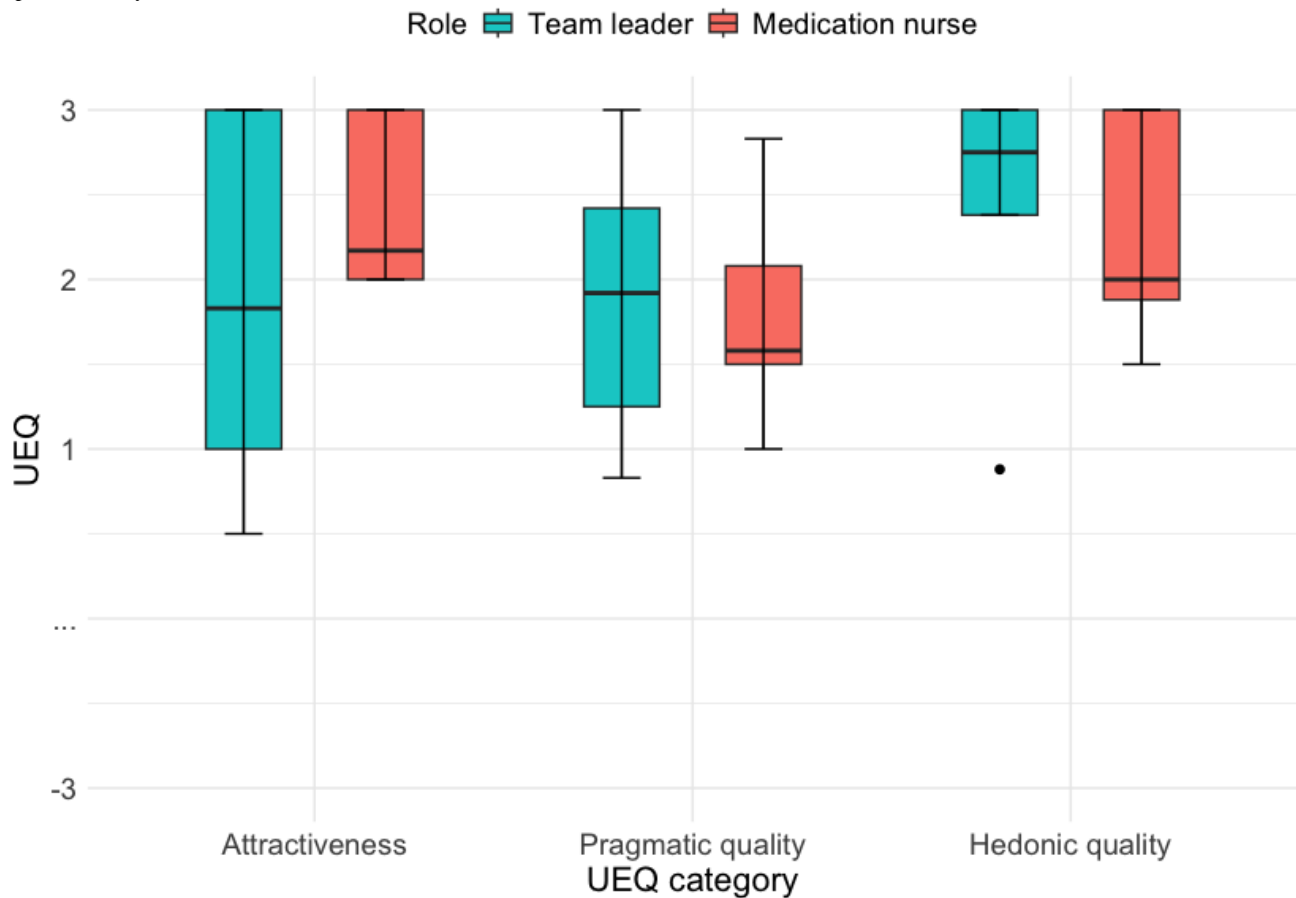
The medication nurse role achieved a higher mean score of 82.00 (SD 11.20, SE 5.02, 95% CI 68.00-96.00), corresponding to an “A” grade (80.80 - 84.00), which falls within the “excellent” usability range (Multimedia Appendix 2). Although the point estimate suggests a stronger perceived usability for medication nurses, the overlapping CIs between roles indicate that differences should not be interpreted as definitive in this pilot study. Overall, both roles reported favorable usability perceptions, with variability reflecting limited precision.

### Perceived User Experience

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

Perceived user experience was assessed using the UEQ, capturing participants’ subjective evaluations across attractiveness, pragmatic quality, and hedonic quality. The following results summarize mean scores and associated uncertainty for each dimension by clinical role (Figure 5).

**Figure 5.** Comparison of User Experience Questionnaire (UEQ) scores—attractiveness, pragmatic quality, and hedonic quality—across roles. Both groups rated the system well above benchmark levels.



- **Attractiveness:** The team leader role scored a mean of 1.87 (SD 1.14, SE 0.51, 95% CI 0.45-3.28), whereas 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, but the wider CI for team leaders indicates greater variability in perceived appeal ([Multimedia Appendix 3](#)).
  - **Pragmatic quality:** Pragmatic quality scores were similarly positive across roles, with team leaders reporting a mean score of 1.88 (SD 0.87, SE 0.39, 95% CI 0.80-2.97) and medication nurses reporting a mean score of 1.80 (SD 0.69, SE 0.31, 95% CI 0.94-2.66). The overlapping CIs suggest comparable perceived task support.
  - **Hedonic quality:** The team leader role scored a mean of 2.40 (SD 0.89, SE 0.40, 95% CI 1.30-3.50), whereas the medication nurse role scored a mean of 2.28 (SD 0.69, SE 0.31, 95% CI 1.42-3.13). These high scores highlight that users perceived the system as engaging and stimulating, contributing to a positive user experience, but the width of the CIs underscores the preliminary nature of these findings.
- **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 perceived efficiency benefits, although precision remains limited.
  - **Dependability:** The team leader role achieved a mean score of 1.70 (SD 1.02, SE 0.46, 95% CI 0.43-2.97), whereas the medication nurse role scored slightly lower at 1.45 (SD 1.30, SE 0.58, 95% CI -0.17 to 3.07). These scores indicate that users felt a good level of control (predictable), but the CI spanning zero indicates uncertainty regarding perceived control, highlighting this dimension as an area requiring further investigation.

### Hedonic Quality Subdimensions

The analysis of hedonic quality subdimensions (Figure S7 in [Multimedia Appendix 1](#)) focused on stimulation and novelty, capturing the emotional and experiential aspects of user interaction with the AR system.

### Pragmatic Quality Subdimensions

The analysis of pragmatic quality subdimensions (Figure S6 in [Multimedia Appendix 1](#)) revealed similar patterns across roles.

- **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
- **Stimulation:** The team leader role achieved a mean score of 2.25 (SD 0.94, SE 0.42, 95% CI 1.09-3.41), whereas 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, but overlapping CIs and moderate width reflect limited precision in this pilot evaluation.

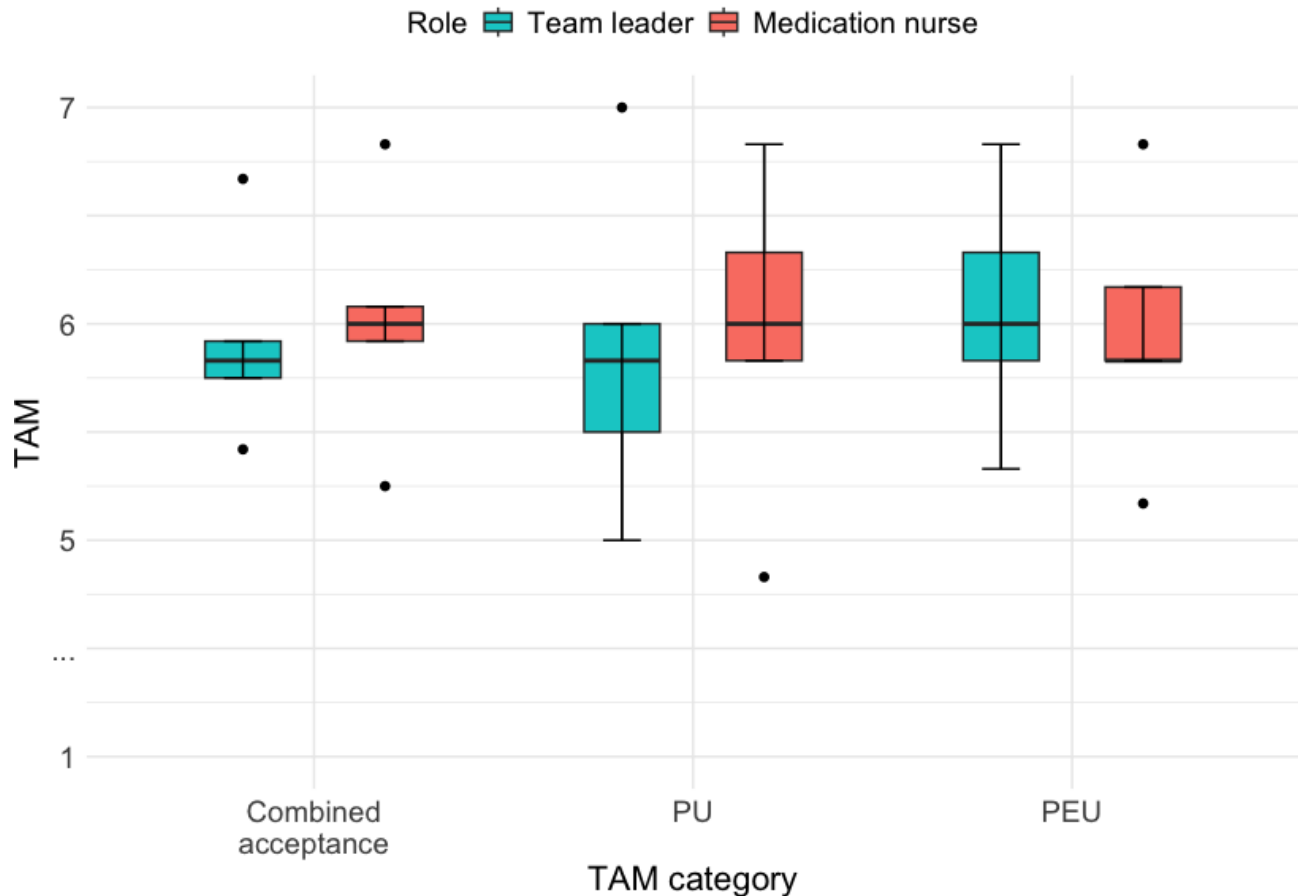
- **Novelty:** This subdimension assesses the system's originality and innovative aspects. The team leader role scored a mean of 2.55 (SD 0.87, SE 0.39, 95% CI 1.47-3.63), whereas the medication nurse role scored a mean of 2.35 (SD 0.86, SE 0.38, 95% CI 1.28-3.42). These

results indicate that users perceived the AR system as innovative, contributing to a unique and satisfying experience, but overlapping CIs again reflect limited precision.

### Perceived 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 6).

**Figure 6.** Technology acceptance model (TAM) results showing high perceived usefulness (PU) and perceived ease of use (PEU) for both roles, suggesting strong intention to adopt the augmented reality system in clinical training or practice.



- **Combined acceptance:** The team leader role scored a mean of 5.92 (SD 0.46, SE 0.21, 95% CI 5.35-6.49), whereas the medication nurse role achieved a slightly higher score of 6.02 (SD 0.56, SE 0.25, 95% CI 5.32-6.71). The overlapping CIs suggest broadly comparable acceptance levels.
- **PU:** The team leader role achieved a mean score of 5.87 (SD 0.74, SE 0.33, 95% CI 4.95-6.78), whereas the medication nurse role scored slightly higher at 5.96 (SD 0.74, SE 0.33, 95% CI 5.05-6.88). While this indicates strong acceptance, CI width reflects uncertainty inherent to the small sample size.
- **PEU:** The team leader role scored a mean of 6.06 (SD 0.56, SE 0.25, 95% CI 5.37-6.76), whereas the medication nurse role scored similarly at 5.97 (SD 0.60, SE 0.27, 95% CI 5.22-6.72). These point estimates indicate strong acceptance, but CI width again reflects uncertainty.

## Discussion

### Summary of Main Findings

This study examined the feasibility and perceived usability, user experience, and acceptance of a role-specific AR decision support system designed for resuscitation team leaders and medication nurses. Consistent with the study objectives, clinicians generally perceived the system as usable, intuitive, and acceptable within a high-fidelity simulation context. Perceptions varied by role, reflecting differences in information needs, visual attention demands, and task responsibilities during CA management. These findings suggest that role-tailored AR interfaces are a potential tool for supporting cognitive work in resuscitation settings [15,27], while also underscoring that the present system represents an early-stage, proof-of-concept interface evaluated primarily through subjective measures.

## Interpretation of Findings and Relation to Prior Work

Across instruments assessing perceived usability, user experience, and technology acceptance, participants reported favorable impressions of the AR system. These results indicate that clinicians were able to understand and interact with the interface with minimal difficulty and perceived the system as appropriate for use in a simulated resuscitation workflow. Differences in perceived usability and acceptance between team leaders and medication nurses likely reflect role-specific cognitive and visual demands, as team roles in dynamic, safety-critical environments impose distinct situation awareness requirements and attentional burdens depending on task responsibilities and information density [28]. In particular, the team leader interface presented a higher density of information intended to support situational awareness and decision coordination, which may have contributed to comparatively lower—but still positive—perceptions of ease of use.

Participants' responses suggest that the interface aligned with expectations for workflow support in emergent care contexts, where information must be rapidly accessible and interpretable at a glance. These findings are consistent with prior AR and mixed-reality research in clinical and safety-critical domains, which has shown that spatially anchored, role-relevant visual cues can be perceived as supportive when they reduce the need for external references and centralize task-critical information [29,30]. Importantly, these findings reflect perceived support rather than measured improvements in performance, workload, or coordination.

Several participants noted during postsimulation debrief discussions that the AR displays helped them maintain focus on the resuscitation process and reduced reliance on external reference materials. These observations represent subjective reflections elicited during informal debriefing rather than systematically collected performance data and should therefore be interpreted as experiential insights rather than evidence of objective benefit.

## Ease of Use, Learnability, and PU

High PEU and learnability indicate that clinicians felt they could quickly become comfortable with the interface, an important consideration for emergency contexts where training time is limited [31]. The visual organization of information, use of glanceable timers, and limited interaction complexity appeared to align with clinicians' expectations for decision support during resuscitation [28,29].

Clinicians also viewed the system content as relevant and supportive of their respective roles, as reflected in ratings related to PU and pragmatic quality. These perceptions are consistent with the underlying design rationale of emphasizing medication-specific information for nurses and algorithmic pathway cues for team leaders. Although prior research suggests that highly usable systems can reduce cognitive load and support more fluid task execution [27], such perceptions should not be interpreted as evidence of improved task performance, guideline adherence, or efficiency. None of these outcomes were directly measured in the current study, and future evaluations must

incorporate objective task-level metrics to determine whether perceived utility translates into measurable clinical benefits.

## Novelty, Engagement, and Hedonic Experience

Participants rated the AR system highly on hedonic quality dimensions—novelty and stimulation—indicating that the interface was perceived as original, engaging, and distinct from existing tools. These responses reflect perceived innovativeness and experiential engagement rather than satisfaction or effectiveness. Such hedonic responses are encouraging for simulation-based training contexts, where engagement can influence motivation and willingness to adopt new tools [23]. Especially in AR, prior research demonstrated that spatially registered visual cues can increase engagement and perceived control [15,18,19].

At the same time, novelty effects are well documented in evaluations of emerging technologies, particularly during short-term exposure. Perceptions of engagement and stimulation may change with repeated use or prolonged deployment, emphasizing the need for longitudinal studies to assess sustained acceptance and experiential quality over time.

## Role-Specific AR Design Implications

A central contribution of this study is the identification of actionable design principles for AR support during CA resuscitation. The iterative prototyping process revealed that AR interfaces should prioritize role-relevant information to minimize unnecessary visual load, use dominant and easily glanceable timers for actionable intervals such as CPR cycles and epinephrine dosing, maintain algorithmic transparency to allow clinicians to view the full pulseless arrest algorithm, and organize spatial layouts clearly by separating medication instructions, procedural steps, and timing cues. These principles provide practical guidance for developers of future AR support tools. While these design choices were intended to support coordination, anticipation, and situational awareness, their operational impact on team performance and guideline adherence remains to be empirically evaluated in future studies. These design considerations align with prior work on situation awareness, cognitive aids, and role-specific information presentation in safety-critical and resuscitation contexts [28-30].

## Real-World Implementation Considerations

Although the system achieved promising perception-based results in a controlled simulation environment, translating AR decision support into real clinical workflows presents substantial challenges. Cost, hardware maintenance, device sterilization, and user training remain key considerations for AR deployment in clinical settings [13,30]. Furthermore, seamless interoperability with existing electronic health record systems, secure handling of patient data, and efficient user training are essential for successful integration. Although none of our participants reported discomfort related to the headset bulkiness or fatigue, future iterations should explore lightweight, cost-effective head-mounted devices and web-based synchronization frameworks that ensure data security and workflow continuity. Addressing these implementation barriers will be critical to realizing the clinical impact of AR-based decision support systems. Given that the current evaluation

involved standardized scenarios, conclusions about clinical applicability should be viewed as preliminary.

### Limitations and Future Work

While the AR system demonstrated high usability, user experience, and technology acceptance, several limitations should be acknowledged. The most notable limitation is the small sample size ( $n=10$ ), which restricts statistical generalizability and inferential power. Participants had prior exposure to an early prototype, which may introduce some bias in perceived usability and novelty but also provide more implementation-focused feedback due to their familiarity with the system. Future studies will distinguish between first-time and repeat users to maintain objectivity.

This study was designed primarily to assess initial technical and interaction viability and user experience rather than to test hypotheses or perform comparative statistics. Accordingly, future formal evaluations with larger and more diverse participant samples are planned to validate reproducibility and strengthen external validity. The current evaluation also relied primarily on subjective self-report measures. Incorporating objective performance metrics—such as time to defibrillation, time to epinephrine administration, adherence to CPR cycles, and error frequency—will be crucial in future work. These indicators, combined with physiological or behavioral measures (e.g., eye-tracking, gaze-based workload assessment, or speech-based coordination analysis), can provide richer evidence for the system's real-world effectiveness in improving team performance and reducing cognitive load. Additionally, the study's simulated pediatric CA 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.

To address these limitations, future research will involve testing the AR system in various CA simulation scenarios to assess its adaptability and reliability before clinical implementation. No major hardware stability issues were observed during testing, and participants, including those wearing corrective glasses, were able to use the device comfortably. Nonetheless, extended use may cause mild visual fatigue or vertigo in a small subset of users, as reported in prior AR literature [27], which warrants monitoring during longer clinical sessions. Plans include

conducting an international multisite 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 favorable perceived usability, user experience, and acceptance of a role-specific AR decision support system designed for pediatric resuscitation team leaders and medication nurses. Clinicians perceived the system as intuitive, clear, and appropriately tailored to their roles, supporting its potential use in simulation-based training and early-stage clinical exploration. Importantly, the present findings are limited to perception-based outcomes and do not provide evidence of improved performance, workload reduction, or guideline adherence. Rather, this work establishes a foundation for future evaluations that integrate objective measures and assess real-world impact. More broadly, the study illustrates how role-specific AR interfaces can be systematically designed and formatively evaluated as cognitive aids in high-stakes, team-based health care settings.

The innovation of this work lies in its explicit focus on role-specific, in-view AR decision support, which differs from prior studies that primarily evaluated role-agnostic cognitive aids delivered via tablets, posters, or nonadaptive AR displays. By empirically examining clinicians' perceptions across distinct team roles, the study contributes early evidence and practical design guidance for developing role-aware AR interfaces aligned with differing cognitive demands and workflows. In real-world contexts, such role-tailored AR systems may inform the design of next-generation simulation training tools and guide the integration of wearable decision support into clinical resuscitation environments, contingent on future validation using objective performance metrics.

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All content in this manuscript was conceived and written by the authors. OpenAI ChatGPT-5.2 (2025) was used solely as an editorial aid to improve language quality, such as identifying grammatical issues and suggesting alternative phrasing to enhance clarity and readability of the authors' original text. No artificial intelligence-generated content was incorporated verbatim. All suggestions were critically reviewed, revised as necessary, and approved by the authors, who retain full responsibility for the content and accuracy of the manuscript. Use of generative artificial intelligence was limited to language refinement.

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### Data Availability

The datasets generated and analyzed during this study are not publicly available but are available from the corresponding author upon reasonable request.

### Authors' Contributions

The study's initial ideation was led by AC, JNS, and SM, with contributions to the overall study design from RK, YL, JD, DCD, ADM, AR, SKO, FE, and KK. RK was responsible for system development, while RK, AC, JD, YL, DCD, and KK conducted data collection. Data analysis was carried out by RK, HN, and KK. Manuscript writing was undertaken by RK, AC, HN, and KK, with YL, JD, DCD, JNS, SM, ADM, AR, SKO, 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.

### Conflicts of Interest

None declared.

#### Multimedia Appendix 1

Supplementary figures illustrating augmented reality (AR) interface design prototypes, system architecture and control interfaces, and usability evaluation results for the role-specific AR decision support system.

[[DOCX File, 7546 KB](#) - [xr\\_v3i1e72013\\_app1.docx](#) ]

#### Multimedia Appendix 2

Grading scale for System Usability Scale scores with corresponding percentile ranges, usability adjectives, and acceptability levels [32].

[[XLSX File, 17 KB](#) - [xr\\_v3i1e72013\\_app2.xlsx](#) ]

#### Multimedia Appendix 3

Interpretation criteria for User Experience Questionnaire scores across different scales [33].

[[XLSX File, 17 KB](#) - [xr\\_v3i1e72013\\_app3.xlsx](#) ]

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## Abbreviations

**ACH:** Alberta Children's Hospital  
**AR:** augmented reality  
**CA:** cardiac arrest  
**CPR:** cardiopulmonary resuscitation  
**PEA:** pulseless electrical activity  
**PEU:** perceived ease of use  
**PU:** perceived usefulness  
**SUS:** System Usability Scale  
**TAM:** technology acceptance model  
**UEQ:** User Experience Questionnaire  
**UI:** user interface

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