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# Designing Hands-Free Technology to Support Real-Time Patient Data Collection and Documentation for Emergency Care Settings

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**ABSTRACT**
Using handheld electronic health record (EHR) devices to collect and document patient data poses significant challenges in dynamic, time-critical, and hands-busy medical settings. Prior research has proposed wearable technologies, such as smart glass, to enable hands-free clinical documentation. Building on this, we conducted a two-year, user-centered study to iteratively design and evaluate a smart glass application for enhancing real-time clinical documentation in settings like Emergency Medical Services (EMS). Our findings provide key design insights for addressing EMS documentation challenges through smart glass technology, as well as potential barriers for successful adoption. We conclude the paper by discussing the implications of these findings for developing smart glass to support documentation in fast-paced medical environments.

**KEYWORDS**
Smart glass; clinical documentation; emergency care; participatory design

## 1. Introduction

Clinical documentation is a crucial component of patient care (Jagannath et al., 2019). As healthcare continues to digitize, significant efforts have been made to "electronify" this key aspect of medical care through the widespread adoption of Electronic Health Records (EHRs). Despite their numerous benefits, HCI researchers have identified various challenges associated with EHR usage across different medical settings (Fitzpatrick & Ellingsen, 2013), such as the gap between the formal documentation procedures enforced by EHRs and practical clinical workflows (Chen, 2010; Park et al., 2012; Vanderhook & Abraham, 2017; Zahabi et al., 2015). Usability issues have also emerged as significant obstacles to the effective use of EHRs (Carayon & Hoonakker, 2019; Zahabi et al., 2015). These challenges become even more evident in time-critical medical settings due to their dynamic, rapid, and high-stress nature (Jagannath et al., 2021; Park et al., 2012; Park & Chen, 2012; Sarcevic & Ferraro, 2017).

Emergency Medical Services (EMS), where teams of two to three care providers deliver urgent medical care outside of hospitals, represent a time- and safety-critical medical setting. Unlike hospital-based critical care teams, which often have designated roles (e.g., a scribe nurse) for documentation, EMS teams typically lack dedicated personnel for this task, as all providers are engaged in hands-on, dynamic patient care activities (Zhang et al., 2022). These unique characteristics and work conditions impose high physical and cognitive workloads on EMS providers, leaving them with limited capacity to use handheld computing devices such as EHR in real-time (Pilerot & Maurin Söderholm, 2019; Zhang et al., 2021). Additionally, switching between hands-on care activities and computing devices increases the risk of cross-contamination and patient infection, which should be avoided (Pilerot & Maurin Söderholm, 2019). As a result, EMS providers often choose to jot down brief notes on gloves or scraps of paper, postponing comprehensive EHR documentation until after patient care is completed (Pilerot & Maurin Söderholm, 2019; Zhang et al., 2022). While such workarounds help manage the demanding EMS workflow, they can lead to information loss and contribute to delayed and incomplete data

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capture, posing significant barriers to the effective implementation of real-time decision-support systems for EMS providers (Ozkaynak et al., 2020; Pilerot & Maurin Söderholm, 2019; Zhang et al., 2021).

Given these challenges, there is a growing need for technologies that can seamlessly integrate into the fast-paced, hands-busy nature of EMS work to facilitate real-time patient data collection and documentation. Hands-free technologies such as smart glass (Schlosser et al., 2021; Zhang et al., 2022), armbands (Bloos et al., 2019), and smartwatches (Rahman et al., 2023), have emerged as potential solutions due to their ability to operate with minimal touch interaction. Among these, smart glass stands out for its capability to capture rich contextual information, such as patient symptoms and injury severity, which armbands and smartwatches—primarily designed for passive data collection—do not provide. However, despite the promise of smart glass, little is known about how to design applications that effectively address the unique constraints and requirements of EMS documentation. To bridge this gap, we conducted a two-year, user-centered design study engaging EMS providers in iterative system design and evaluation. Grounded in participatory design (PD), our study involved EMS providers with diverse backgrounds across two design phases to explore user preferences, challenges, and adoption considerations for hands-free documentation technologies in EMS settings.

Through this work, we identified several key design insights for leveraging smart glass technology to address critical EMS documentation challenges: (1) seamless integration with existing EHR systems to enable real-time data transfer; (2) a scanning tool that employs computer vision to extract demographic and medication information from IDs and medication bottles; (3) a hands-free photo and video capture function to preserve contextual information at the scene; and (4) a voice dictation feature to support semi-automated data entry. The design process also revealed important socio-technical considerations, including the need for rigorous evaluation of workflow impact, HIPAA-compliant handling of visual data, provider autonomy in reviewing and editing entries, and technical constraints such as noisy environments and difficulty recognizing small text. Nevertheless, the smart glass application was generally well-received by EMS providers across two design and evaluation phases. The application demonstrated a significant improvement in overall usability—reflected by an increase in System Usability Scale (SUS) scores from 73.5 to 82.0 ($p = 0.03$). Participants also rated the core features as highly useful on a 5-point Likert scale. These results suggest that the system is usable, user-friendly, and holds strong potential for supporting clinical documentation in dynamic EMS environments.

Our contributions are threefold. First, we provide insights into the challenges of clinical documentation in fast-paced, hands-busy medical environments such as EMS. Second, we present empirical findings on EMS providers' preferences for hands-free documentation technologies, including key considerations influencing the adoption and effective use of smart glass in time-sensitive medical settings. Third, we offer design insights for developing smart glass and other hands-free technologies that support real-time clinical documentation in dynamic, high-stakes healthcare environments.

## 2. Background and related work

### *2.1. Emergency medical services (EMS) work and documentation practices*

EMS is a fast-paced and dynamic medical domain where teams of two to three providers engage in complex, unpredictable, and cognitively demanding tasks related to patient care (Ozkaynak et al., 2023). Depending on the nature of the incident, such as car accidents or disasters, one or more EMS teams may be dispatched to provide urgent medical care in the field and transport patients to the most appropriate care facility. In the United States, there are various types of EMS providers, but the two primary ones are emergency medical technicians (EMTs) and paramedics. EMTs are certified professionals trained to provide basic life support services and handle tasks such as oxygen administration and wound treatment. Paramedics, on the other hand, receive an additional 1,200 to 1,800 hr of training beyond basic EMT training, equipping them with skills for advanced life support, such as advanced airway management and medication administration.

Although EMS documentation is a self-organized effort with no predefined role assigned for this task (Zhang et al., 2022), the EMS provider seated in the back of the ambulance with the patient often assumes responsibility for documenting the patient's assessment and treatment during transport.

However, the pressing need to manage severely injured or ill patients often relegates documentation to a secondary task. As a result, EMS providers commonly defer this task until after the patient has been handed off to the receiving hospital (Pilerot & Maurin Söderholm, 2019; Zhang et al., 2022). These unique aspects of EMS work pose significant challenges to the timely collection, integration, and documentation of patient information (Schlosser et al., 2021; Zhang et al., 2021).

### 2.2. Technology use in clinical documentation during fast-paced medical work

A widely used technology in clinical documentation is the EHR system. A significant body of HCI studies has examined its crucial role in supporting information sharing and team collaboration in medical work (e.g., Bossen, 2011; Chen, 2010; Fitzpatrick & Ellingsen, 2013; Reddy et al., 2001). However, the introduction of EHRs was found to complicate documentation tasks due to mismatches between real-world clinical workflows and the design of EHR systems (Chen, 2010; Collins et al., 2012; Davidson et al., 2004; Downing et al., 2018; Zhou et al., 2009). These challenges are more evident in time-critical medical settings. For example, research conducted in the context of emergency departments (Kenneth & Green, 2009; Park et al., 2012; Park & Chen, 2012) has shown that EHR implementation can increase documentation time, add cognitive burden on providers, and reduce the time available for patient care. Additionally, several studies (Coffey et al., 2015; Jagannath et al., 2018; 2019; Sarcevic & Ferraro, 2017) have found that the use of EHRs in trauma resuscitation often leads to incomplete or delayed data capture of procedural and temporal information. Similarly, EMS teams also have difficulties with the effective use of EHR systems (Hertzum et al., 2019), leading to incomplete or inaccurate data entries in patient records (Laudermilch et al., 2010). Taken together, these studies highlight the significant challenges with the use of EHR systems in dynamic and fast-paced medical settings.

To address the challenges of using EHRs in hands-busy, time-critical medical settings, prior research has explored the use of advanced sensing technologies for rapid data collection. Notable examples include the use of sensors, cameras, and computer vision (CV) techniques to track, capture, and monitor dynamic patient care activities and medical tool usage during trauma resuscitation (Chakraborty et al., 2013; Parlak et al., 2012). Despite their advantages (e.g., minimized human intervention), these technologies may not be fully applicable to EMS because EMS care providers are mobile and often perform a significant portion of patient care activities outside the ambulance, which cannot be captured by stationary cameras installed inside the ambulance. Some studies have also examined sensor-based, wearable technologies such as wristbands or smartwatches for passive data collection during patient care. For example, a study (Bloos et al., 2019) demonstrated the feasibility of using gesture-controlled armbands to passively collect data, such as the type and sequence of patient care procedures performed, to create an abbreviated care record. Another study (Rahman et al., 2023) used deep learning techniques and sensor data from smartwatches to detect and monitor cardiopulmonary resuscitation (CPR) compression performed by EMS providers. While these innovative approaches show promise in accurately detecting and capturing EMS interventions and activities, their capacity to capture a wide range of care activities is limited. For example, they cannot easily record contextual information such as a patient's symptoms or the severity of injuries. Therefore, there is a need to explore other workflow-compliant technological solutions that can capture comprehensive information during EMS care.

### 2.3. Applications of smart glass in critical care work

Over the past few years, smart glass—a wearable computing device worn like conventional eyeglasses—has emerged as a potential solution for supporting critical care work (Klinker et al., 2019; Schaer et al., 2016). This technology enables touchless operation (e.g., through voice commands), allowing healthcare providers to use both hands for patient care while simultaneously collecting, viewing, and sharing patient information at the point of care (Lee & Hui, 2018; Mitrasinovic et al., 2015; Zhang et al., 2024). These promising features have prompted explorations into their potential use in various demanding and hands-busy medical settings. For instance, smart glass has been used to enhance the wound documentation process by enabling providers to stabilize and interact with the patient while capturing photos and measuring the wound's dimensions (Klinker et al., 2019). A body of research has also explored how smart glass can facilitate communication and collaboration among healthcare providers in different locations. Notable examples include scenarios where a local surgeon, wearing a smart glass device, receives real-time guidance from a more experienced, remote surgeon (e.g., Gupta et al., 2016; McCullough et al., 2018; Mitrasinovic et al., 2015; Romare & Skär, 2020). These studies highlight the valuable role that smart glass can play in patient care, while also ensuring compliance with Health Insurance Portability and Accountability Act (HIPAA) regulations (Zhang et al., 2023).

Of particular relevance are the few studies focused on the use of smart glass in EMS contexts. Most of these studies explored the technical feasibility and effectiveness of using smart glass to transmit EMS providers' first-person point of view (e.g., live videos) to remote experts (e.g., emergency care physicians) for teleconsultation and decision support purposes (e.g., Broach et al., 2018; Cicero et al., 2015; Demir et al., 2017; Follmann et al., 2019; Zhang et al., 2024). These studies highlighted that smart glass could improve the proficiency and performance of patient care activities at the scene because remote experts could visually assess the patient to make informed decisions (Demir et al., 2017; Follmann et al., 2019). For example, in one study (Broach et al., 2018), EMS providers used Google Glass to perform secondary triage in a simulated mass casualty incident (MCI) and transmitted real-time visual data to remote emergency care physicians. This study demonstrated the usefulness of using smart glass to enable both EMS providers and remote physicians to make collaborative and optimal decisions for the triage of patients, as remote physicians could gain a better understanding of the number and severity of injuries and the demand for resources. In addition to serving as a telemedicine tool, a couple of other use cases of smart glass were also explored. For example, one study (Apiratwarakul et al., 2022) compared the overall accuracy and time spent using smart glass against manual counting in assessing the number of casualties in an MCI and found that EMS providers using smart glass had greater accuracy and spent less time than with manual counting. In another study (Follmann et al., 2019), smart glass was used as a decision support tool to display medical guidelines and protocols, assisting EMS providers in making better triage decisions during an MCI.

Despite this body of research, limited prior work has explored using smart glass to support real-time data collection and documentation in EMS care. Additionally, most studies have relied on off-the-shelf devices for testing purposes (e.g., assessing the technical feasibility of using smart glass as a telemedicine tool). Limited research has involved end-users, such as care providers, in the system design process. A lack of understanding of user needs and clinical workflows can lead to failures in implementing new healthcare information technologies (HITs) in complex medical settings (Carayon, 2006; Karsh et al., 2011; Romare & Skär, 2020; Zhang et al., 2022). Therefore, it is critical to understand how to effectively utilize smart glass to support fast-paced medical teams while taking into account their dynamic work environments and unique user needs (Schlosser et al., 2021; Zhang, Joy, Harris, 2022; Zhang, Joy, Harris, et al., 2022). To date, only two studies have employed qualitative approaches (e.g., interviews and observations) to elicit EMS providers' needs regarding the use of smart glass (Schlosser et al., 2021; Zhang et al., 2022). These studies identified several common use cases for smart glass in EMS care, including enhanced communication between distributed care providers, improved patient data collection, augmented clinical monitoring, and enhanced training. However, they did not investigate how smart glass should be designed to support the challenging documentation task in EMS care.

To address the mentioned research gaps, our study employs a participatory design approach (Gao et al., 2007; Kristensen et al., 2006; Sjöberg & Timpka, 1998; Viitanen et al., 2011), engaging EMS providers in an iterative system design and evaluation process to explore how smart glass should be designed to support real-time documentation in EMS while accounting for providers' needs and the dynamic, hands-busy nature of EMS work practices. To the best of our knowledge, our study is the first to adopt a co-design approach to explore the development of smart glass applications for clinical documentation—an understudied area of smart glass applications—within the high-pressure, time-critical context of EMS.

## 3. Methods

### 3.1. Overview of the study design

This study is part of a larger research effort aimed at examining the affordances of smart glass in supporting two major tasks of EMS providers: (1) real-time patient data collection and documentation and (2) communication between EMS providers and remote physicians. This article focuses on the first major component—the design of a smart glass application to support real-time patient data documentation.

In this project, we employed an iterative, user-centered design approach, which consisted of two phases of design requirements gathering, rapid prototyping, usability evaluation, and prototype refinement (Figure 1). Each study was conducted by a research team consisting of 3–5 researchers, all with extensive experience in user-centered design, including two (the first and last authors) with over 13 years of expertise in conducting research in the emergency care domains. Their experience facilitated building rapport with participants and understanding domain-specific terminology and medical knowledge.

### 3.2. Participants

We recruited EMS providers from four EMS agencies across various locations in the U.S. (e.g., rural mountain regions and urban areas). Three of these agencies were affiliated with hospitals, and one was part of a fire department. In total, 43 unique EMS providers participated in the project, with eight of them (18.6%) attending two or more sessions. The participants had diverse occupations and roles (paramedic versus EMT) and a wide range of experience levels (from less than one year to over 40 years). Specifically, 20 participants (46.5%) were paramedics, while the remaining were EMTs; 13 participants (30.2%) were affiliated with the rural EMS agency, with the rest recruited from urban areas. The diverse backgrounds of these EMS agencies and providers enhance the generalizability of this research and offer insights from various perspectives. Participation was entirely voluntary, and participants were compensated at a rate of $60 per hour. This research received ethical approval from the corresponding author's institution.

### 3.3. Study procedure and data collection

#### 3.3.1. Participatory design (PD) workshop

The PD methodology allows participants from diverse backgrounds to become directly involved in the system design process by articulating their desires and concerns (Kristensen et al., 2006; Kusunoki et al., 2014; Schuler & Namioka, 1993). In this study, we conducted four PD workshops in Phase 1 and three PD workshops in Phase 2, respectively. Each workshop took about two hours and involved four participants (Figure 1). Almost all the workshops (except one in-person workshop in Phase 2) were conducted online via teleconferencing tools (e.g., Zoom) due to either pandemic-related restrictions or participants' limited availability. During these virtual workshops, we used collaborative digital tools, such as Miroboard, to facilitate discussions, drawings, and design activities. As illustrated in Figure 2A and B, Miroboard was used to provide instructions to guide the workshop and organize the design activities. To facilitate the drawing experience and help participants quickly familiarize themselves with Miroboard, we first provided a 10-minute tutorial on how to use Miroboard to draw and create design

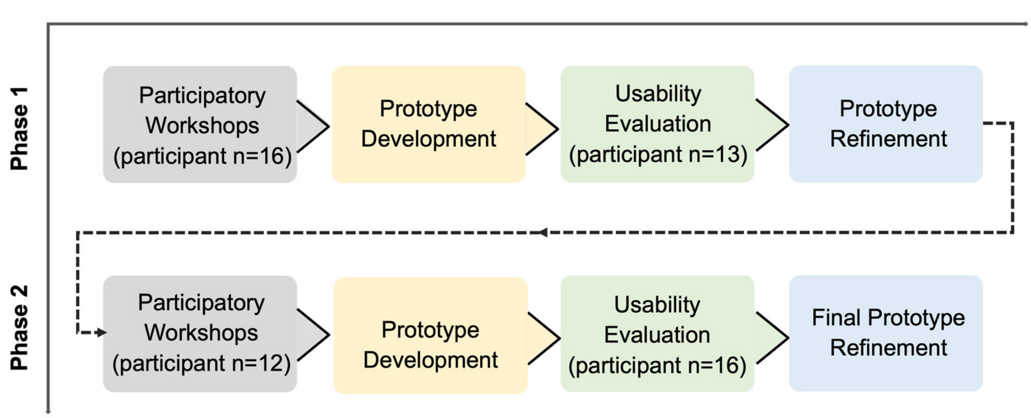


Figure 1. Iterative design and evaluation process: Two phases of design requirements gathering, rapid prototyping, usability evaluation, and prototype refinement.

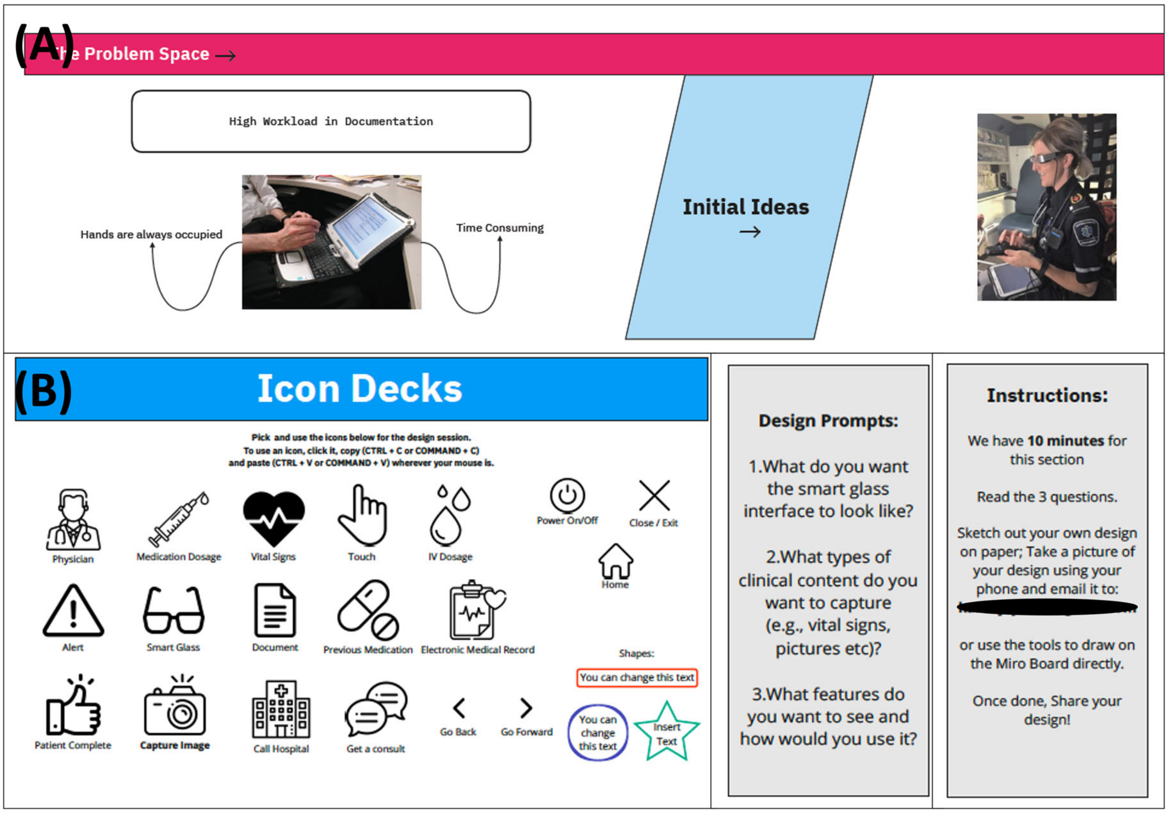


**Figure 2.** Materials and digital tools used for brainstorming, sketching, and guiding discussions during the participatory design workshops. (A) Materials used to explain and discuss the problem space for which the smart glass design was created, as well as to introduce the concept of smart glass. (B) Materials prepared to guide and facilitate the individual design activities during the design workshop.

sketches. Additionally, we prepared a set of icons and gadgets for participants to copy and paste to expedite their creation of the designs (Figure 2B).

In Phase 1, our primary focus was on uncovering key features of smart glass to support EMS documentation. The workshops consisted of the following activities: (1) Initial Discussions/Storytelling: We began by explaining the problem space for which the smart glass design was being created (Figure 2A). Participants were then prompted to discuss the challenges they faced in collecting and documenting patient data in the field and to envision how smart glass could assist them. We assumed that most participants, if not all, had no prior experience using or interacting with smart glass. To help them better understand the capabilities of the technology, we explained the hardware components of the smart glass device, used pictures and video recordings to demonstrate its default functionalities (e.g., taking pictures), and highlighted how prior research has utilized smart glass (e.g., for telemedicine purposes) (Figure 2A). (2) Individual Sketching: Following the initial discussion, participants were prompted to create design sketches envisioning how the smart glass could support their documentation task (Figure 2B). Participants who participated in the virtual workshops could either use the Miroboard to draw and sketch directly, i.e., by using the set of icons prepared in advance (Figure 2B), or sketch on paper, take a picture of their design, and email it to one of the researchers (Figure 2B). The researchers then organized the sketches on Miroboard and asked each participant to share and discuss their design with the group (Figure 3A). (3) Group Design: Participants then collaborated to refine their design ideas until reaching a consensus. An example of the group design is illustrated in Figure 3B. (4) Wrap-up Discussion: Participants discussed the perceived benefits and concerns related to the use and adoption of smart glass technology in their workflow. Additionally, we assessed EMS providers' preferred touchless interaction methods.

In Phase 2, the research team shifted the focus to validating the findings from Phase 1 and gathering providers' feedback on the updated design, which incorporated user insights from the Phase 1 usability

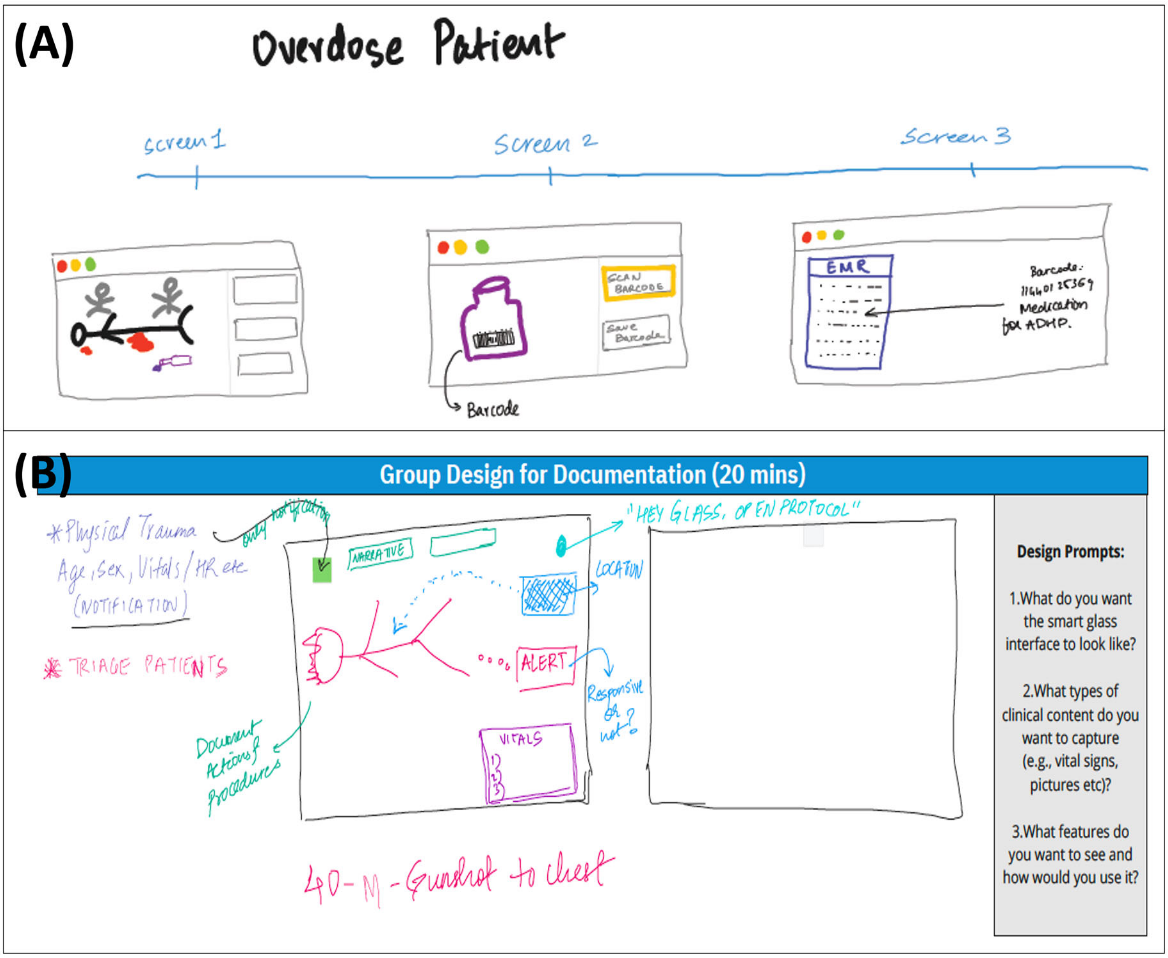


Figure 3. Design sketches created during participatory design (PD) workshops. (A) An example of individual design sketches depicting the participant's idea for using smart glass to scan medication barcodes for information capture and integration into the Electronic Health Record (EHR) system. (B) An example of group-based design sketches created during group design activities, where participants discussed and collaboratively developed design ideas based on the design prompts.

testing. The activities in Phase 2 followed a similar structure to the Phase 1 PD workshop, with some modifications. The research team began the workshop by presenting the revised prototype and then prompted the participants to share their thoughts on the revised design and suggest any additional features or adjustments. Additionally, participants were asked to brainstorm strategies and ideas for integrating smart glass into their existing EHR systems, including ways to populate EHR data fields with information collected via smart glass. While discussing ideas, they individually sketched out various design ideas and they then came back as a group to engage in collaborative design tasks to work together to refine their ideas until a final solution was achieved. Finally, the workshop concluded with discussions on general thoughts (e.g., concerns, suggestions, and strategies) for adopting smart glass in their work.

### 3.3.2. Prototyping

Following the PD workshops and usability testing, the research team began the (re)design process using Figma—a collaborative design and prototyping tool for creating visually appealing design concepts. Once the design ideas were finalized, we developed a functional application on the Vuzix M400 platform using their Software Development Kit (SDK) (Figure 4A). This device displays visual, three-dimensional content via a near-eye display and is equipped with a camera adjacent to the display for capturing still images and streaming video.

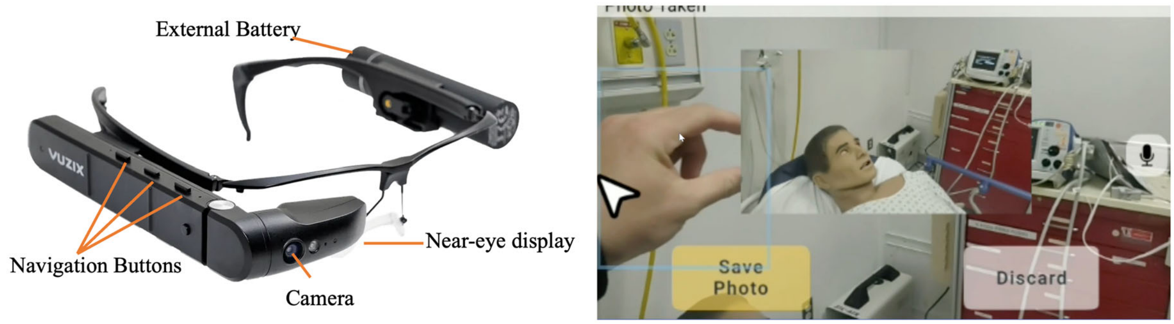


**Figure 4.** (Left) the smart glass device (Vuzix M400) that was used in the project. (Right) a study participant interacted with the application using hand gestures.

By default, the device is operated using tangible buttons on the side (Figure 4 Left). To facilitate the use of smart glass in the hands-busy EMS environment, we also implemented the most preferred touchless interaction methods (hand gestures and voice commands) identified in the Phase 1 PD workshops. We used the Vuzix SDK to create a set of simple voice commands, such as "take a photo" and "record a video." For gestural interaction, we used a third-party SDK from CrunchFish (Sweden) (Crunchfish, 2024), which offers several hand gestures suitable for smart glass interaction. For example, to select an option, a user first performs an open pinch to summon the cursor, then executes a pinch-click by tapping their thumb and index finger together (Figure 4 Right). More details on the selection and assessment of touchless interaction methods for the smart glass application have been reported in Zhang et al. (2024).

### 3.3.3. Usability testing

Following prototype development, we conducted individual usability testing sessions with 13 EMS providers in Phase 1 and 16 in Phase 2, all within controlled environments (e.g., an office or a simulation lab). The goal was to assess whether the application's design met the needs of EMS providers and to identify areas for design improvement. Each session lasted approximately one hour. At the beginning of each session, participants were introduced to the key features of the application and trained to interact with the device. Participants were given time to practice through sample tasks until they felt confident using the device independently (we created a dummy application with virtual buttons, which allowed each participant to practice different interaction methods and navigate the interface, such as clicking a button and returning to the home screen).

During the testing of the application, each participant was asked to complete a set of tasks, which aligned with the system's major features (described in Section 4). After completing the tasks, participants filled out a survey that included the System Usability Scale (SUS)—a widely used and validated instrument for evaluating the usability of interactive systems (Brooke, 1996)—as well as Likert-scale questions specifically tailored to assess the perceived usefulness of individual features (ranging from "1—strongly disagree" to "5—strongly agree"). These instruments were used to evaluate participants' opinions on the usability and usefulness of the application. Each session concluded with a semi-structured interview to gather further feedback on the perceived benefits and challenges of using the application in real practice. All sessions were both audio and video-recorded.

## 3.4. Data analysis

Our study collected a variety of data, including design sketches, interviews, discussions, and survey responses. To analyze this mixed data, we used different methods, as described below.

The design sketches collected during the PD workshops, as illustrated in Figure 3, were analyzed in combination with the discussions on system features to understand the features participants desired. Additionally, we analyzed the sketches to understand how participants envisioned the user flow and the interface layout, such as where they preferred to place buttons (e.g., top, bottom, left, or right) to avoid blocking their vision, and what steps they envisioned for using a feature. For instance, in most design sketches, such as the one illustrated in Figure 3A, we observed that participants wanted to complete the operation of each feature within three steps, considering that the navigation and operation of smart glass are not as intuitive as other mobile devices (e.g., smartphones). All these findings informed our design, such as the goal of enabling users to use any feature within three clicks.

All interview and discussion audio recordings were transcribed and analyzed iteratively using open coding—a method that is particularly useful when researchers have limited prior knowledge about the specific problem under study (Blair, 2015). Our analysis aimed to uncover user requirements, gather feedback on system features, and explore the perceived benefits and challenges of using smart glass in EMS. The data analysis process involved several steps. Two researchers began by reviewing the transcripts to immerse themselves in the data and gain an overview of what had been discussed during the study sessions. They then independently analyzed a small set of transcripts to generate an initial list of codes, which were discussed with the rest of the research team members to resolve disagreements on the codes. We then created codebooks to standardize the coding process. To assess inter-rater reliability, Cohen's Kappa coefficient was used after both researchers independently coded another two or three transcripts based on the codebook and compared their results. Once a "substantial" agreement was reached, they proceeded to code the remaining transcripts individually, adding new codes to the codebook as needed. Any disagreements were discussed and resolved in weekly group meetings. After completing the coding process, the codes were categorized into broader themes to identify key insights (Creswell & Poth, 2016).

Descriptive statistical methods were used to analyze the SUS scores for the major design versions tested in Phase 1 and Phase 2 usability testing, as well as the user ratings for each feature. This approach aligns with our design-oriented evaluation, which aimed to understand user experiences during iterative prototype development. To supplement the descriptive analysis, we also conducted inferential statistical tests. Specifically, we applied the Kruskal-Wallis test, followed by post hoc Mann-Whitney U tests with Bonferroni correction, to examine group differences—for example, between EMTs and paramedics, and between providers in rural versus urban settings. These tests allowed us to assess whether statistically significant differences existed in user ratings and SUS scores across demographic and contextual subgroups.

## 4. Results

In this section, we present key design insights for using smart glass to support clinical documentation in the EMS context. While presenting each design insight, we describe the current challenges and user needs in EMS documentation, our design solutions for addressing these issues, and considerations for implementing the design solutions. A summary of these findings is provided in Table 1.

**Table 1.** A summary of user needs and challenges in EMS documentation, our design solutions, and considerations for implementing the solutions in EMS settings.

| User needs or challenges to address | Design solutions | Considerations for implementing the solution |
|---|---|---|
| Smart glass should act as an extension of existing EHR systems.<br>Data should be stored on EHR systems rather than on the smart glass. | Integrated smart glass with EHRs via Bluetooth for real-time data transfer. | Rigorous evaluation of the impact on EMS workflow before wide adoption. |
| Manual entry of demographic and medication information is prone to errors and time-consuming. | Utilized the smart glass camera in conjunction with advanced computer vision techniques to scan patient IDs, insurance cards, and medication bottles for text extraction. | The texts (e.g., medication names) on small medication bottles are not easily recognizable using computer vision techniques. |
| Need for capturing and sharing visual/contextual information. | Enabled hands-free photo and video capturing. | Protection of privacy for patients and bystanders. |
| Limited time for detailed EHR documentation. | Provided audio dictation for semi-automated EHR entry. | Using voice recognition techniques face challenges due to chaotic EMS environments and the use of abbreviations and jargon. |
| Need to quickly capture key medical information as it emerges. | Added a review and edit option to ensure data accuracy and provider autonomy. | |

## 4.1. Augmenting and integrating with current EMS work practices

### 4.1.1. Current challenges and technology needs

As we learned from discussions with EMS providers, the smart glass system should be designed to integrate with the current EHR system used in practice, functioning as an extension of the EHR for data collection. Additionally, the collected data should be transferred to the EHR for storage and further processing, as sensitive patient data should not be stored on any devices other than the EHR, according to HIPAA regulations: "*You should be able to document the information [using smart glass] and have it transmitted or synced directly to the EHR system on my tablet.*" [P#1]

Furthermore, during the PD workshops, EMS providers were prompted to discuss how to integrate the use of smart glass into their current work practices, such as who should use the device and whether one or two providers should operate it. Most participants agreed that only one provider should use the device, as the self-organized EMS team members typically assign responsibilities before each shift—one provider handles patient care, while the other focuses on driving and documentation. Therefore, the provider in charge of the documentation task should use the smart glass: "*When one person is taking care of treatment, the other person is documenting demographics. So, you know, I could start an IV while my partner is on the side, putting in the patient's demographics and scanning all the medications. So, it's definitely going to be the one who is doing patient charting.*" [P#8]. However, it is worth mentioning that a few participants argued that both EMS providers should operate the devices because it could facilitate a more collaborative documentation practice: *"Would it be possible for two providers wearing the glass and being able to syn and document into the same EMR? Like in our work, one person draws up a medication and hands it to the other person to maybe push it. The person who drew the medication could [use the smart glass to] look at it, scan it, and the other person dictates 'Okay, we are giving it [the medication] at this time.' So, since we are working together, I think something like that [two providers each operating a device to collect data collaboratively] would make it a lot easier."* [P#6]

### 4.1.2. Design solutions

As EMS participants emphasized that the smart glass application should augment existing EHR systems rather than duplicate their functionalities, we designed the application to integrate with any EHR system through Bluetooth connectivity for real-time data transfer. For testing purposes, we developed a simplified EHR prototype based on the system currently used by one of the participating EMS agencies. This prototype included essential data fields, such as demographics, assessment details, vital signs, and incident information.

Additionally, since most participants mentioned that the smart glass should be used by only one provider—who is responsible for documentation based on their agreement before their shift—we designed the application for individual use in this study.

### 4.1.3. Considerations for implementing the solution

While we did not test the application in real-world settings, participants emphasized the importance of rigorously evaluating its impact on EMS workflow. They noted that even minor changes to existing practices could significantly hinder system adoption. An EMS director shared their experience with integrating an EHR system into routine operations: "*In EMS, for anything has even the smallest change to our practice, we just won't use it. We used to have everything in books and paper. So when we switched to EHR, that was a huge pushback until we literally said you must use it. It had to be basically mandated. Because for a lot of people, even if this makes it simpler for them, people will stick with what they already know even though that is a harder route.*" [P#25] Due to these concerns, EMS providers rated the extent to which they agree that the smart glass application seamlessly fit into their workflow as only 3.71 and 3.69 (out of 5) in the Phase 1 and Phase 2 post-usability study surveys, respectively (Table 2).

**Table 2.** Average user ratings for SUS and system features in phase 1 and phase 2 usability testing, along with significant differences between the two phases.

| Survey questions | Phase 1 mean | Phase 2 mean | Sig. Diff. |
|---|---|---|---|
| **SUS Questionnaire** | | | |
| Q1: I think that I would like to use this system frequently. | 4.19 | 4.21 | 1 |
| Q2: I found the system unnecessarily complex. | 1.93 | 1.50 | 0.08 |
| Q3: I thought the system was easy to use. | **4.13** | **4.64** | **0.05*** |
| Q4: I think that I would need the support of a technical person to be able to use this system. | 2.13 | 1.64 | 0.14 |
| Q5: I found the various functions in this system were well integrated. | 4.06 | 4.07 | 0.78 |
| Q6: I thought there was too much inconsistency in this system. | 1.93 | 2.00 | 1 |
| Q7: I would imagine that most people would learn to use the system very quickly. | **3.67** | **4.36** | **0.04*** |
| Q8: I found the system very awkward to use. | 2.13 | 1.71 | 0.23 |
| Q9: I felt very confident using the system. | 3.87 | 4.21 | 0.27 |
| Q10: I needed to learn a lot of things before I could get going with this system. | 2.40 | 1.86 | 0.17 |
| SUS Total Score | **73.5** | **82** | **0.03*** |
| **Likert-scale Questions** | | | |
| The "Scan" feature is useful. | 4.57 | 4.63 | 0.86 |
| The "Camera" feature is useful. | 4.50 | 4.56 | 0.79 |
| The "Dictation" feature is useful. | 4.64 | 4.38 | 0.20 |
| The layout of the interface is intuitive and easy to navigate. | 4.57 | 4.31 | 0.41 |
| The glass screen does not block my vision. | 3.21 | 3.75 | 0.37 |
| It is easy to recover from errors. | 3.64 | 3.94 | 0.47 |
| The application does not interfere with my work and can fit into my workflow. | 3.71 | 3.69 | 1 |
| I am willing to use the application to support my documentation task in the future. | 4.50 | 4.50 | 0.90 |
| I would like to store all the information collected through smart glass (e.g., picture, dictation, etc.) in a dedicated section of EHR for later review/editing. | N/A | 4.63 | N/A |
| It is convenient that all the patient information collected through smart glass is automatically processed and available to be added to the corresponding data fields in the EMR. | N/A | 4.63 | N/A |

*Note:* All the survey questions were based on whether the participant agreed with a statement on a scale of 1–5: "1" represents strongly disagree, while "5" represents strongly agree. The $p$-value is reported in the last column, with a threshold of $p < 0.05$ indicating a significant difference.

### 4.2. Leveraging computer vision (CV) techniques to expedite the recording of patient demographic and medication information

#### 4.2.1. Current challenges and technology needs

Upon arriving at a scene, EMS providers need to collect and record various patient demographic details (e.g., age, gender, home address, phone number), insurance information (e.g., provider, insurance number), and patient medication information (e.g., medications prescribed for treating illnesses or chronic conditions). However, as participants explained, manually entering such data into the EHR is not only time-consuming ("*This task [recording patient medication information] is perhaps one of the most time-consuming aspects of our job. We have a list of medications with which we're unfamiliar. If the name isn't found on the tablet [EHR], we must add it manually.*" [P#10]) but also prone to errors ("*Spelling errors, which is bad for billing, making the care we provided unbillable.*" [P#6)]).

Given these challenges, participants asked about the possibility of using smart glass to expedite the capture of such information. As one participant envisioned, EMS providers could use the smart glass camera to scan the patient's driver's license, insurance card, or medication bottles, which could then be processed by advanced technologies to extract the information from the image and automatically populate the corresponding fields in the EHR: "*For a patient with 30 medications, it would be awesome if you could take a clear, readable picture of multiple medications and use software to recognize the medication names from the picture.*" [P#13]

#### 4.2.2. Design solutions

In response to these needs, we designed a feature for smart glass that facilitates the scanning of personal identification (e.g., driver's licenses or insurance cards) and medication bottles (Figure 5a). We

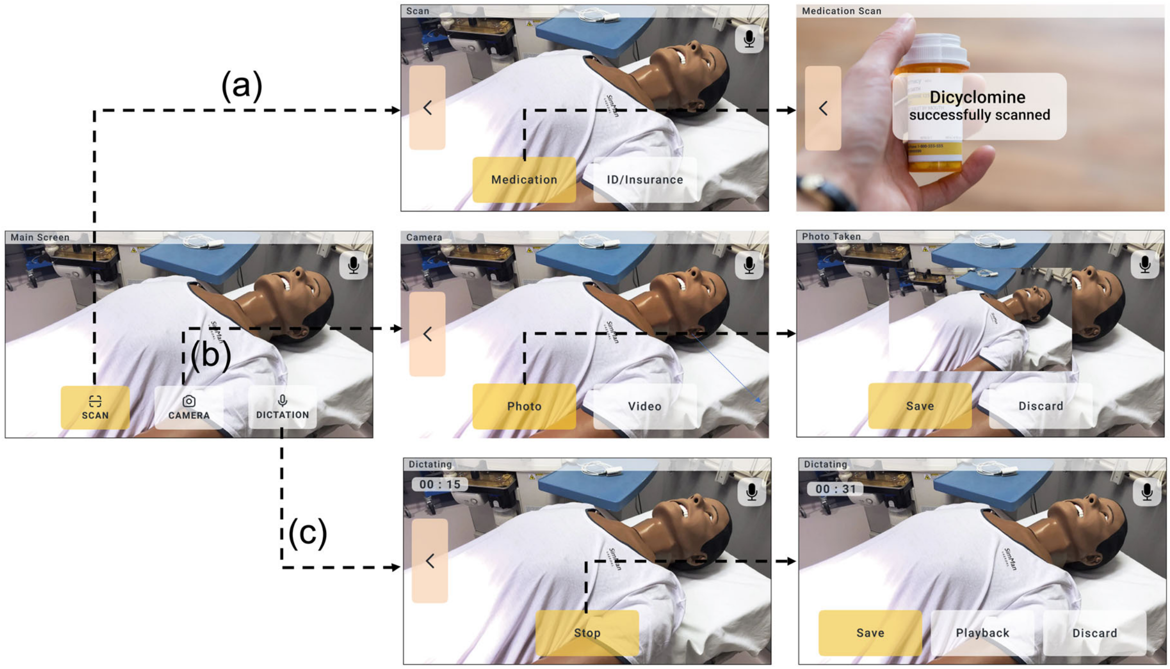


**Figure 5.** The final design of the smart glass prototype includes three major features: (a) the "Scan" feature utilizes computer vision techniques to enable providers to scan medications as well as patients' IDs or insurance cards; feedback on whether the scan was successful is displayed to the provider toward the end. (b) The "Camera" feature allows providers to capture photos or short videos of the patient or scene to preserve hard-to-describe contextual information; providers have the option to preview the photo/video and decide whether to save or discard it. and (c) The "Dictation" feature lets providers record voice notes, which are processed by an NLP algorithm to semi-automate data entry into EHR fields; a timer in the top-left corner indicates the duration of the dictation, and providers can choose to save, play back, or discard the recording. Across the entire application, a microphone icon is placed in the top-right corner as an indicator that the application is listening for user inputs (e.g., voice commands). The top banner on each screen indicates the user's current location and the status of the application (e.g., "Dictating" indicates that the provider is currently dictating to the smart glass, while "Photo Taken" indicates that the provider is viewing the captured photo).

developed a prototype using existing text detection and recognition tools, such as PaddleOCR (Du et al., 2020), to demonstrate the potential of applying CV techniques to recognize and extract text from patients' identification or insurance cards, as well as medication bottles. To use these features, users simply select the "Scan" option on the home screen and then choose either "Medication" or "ID/Insurance" on the subsequent screen to start scanning (Figure 5a).

We gathered feedback and opinions from EMS providers on this solution during usability testing in both design phases. The perceived usefulness of the ID or medication scanning feature was rated 4.57 (out of 5) in Phase 1 and 4.63 (out of 5) in Phase 2 usability testing (Table 2). Nearly all participants found this feature promising for more accurate and rapid collection of patient demographics and medication information compared to manual data entry: "*For the most part, I think especially like scanning the ID is a pretty nice feature. Because I've spent a lot of time just typing them into our current system, which could delay moving the person from the scene to the truck [ambulance]. If we could just scan it, that'd be pretty, pretty helpful.*" [P#24]

#### *4.2.3. Considerations for implementing the solution*

During Phase 2 usability testing, we identified a potential challenge with this technical solution: difficulty in scanning small-sized medication bottles due to the text being too small for the implemented text detection and recognition tool (PaddleOCR) to recognize easily. This issue was also highlighted by one participant: "*You have to find the right focus. You have to keep coming back and forth. Too far or too close (to the medication bottle) is not gonna work.*" [P#1]

### 4.3. Gathering Hard-to-describe contextual information

#### 4.3.1. Current challenges and technology needs

Although not compliant with HIPAA regulations, the practice of using personal cell phones to capture images of scenes (e.g., car accidents) is common among EMS providers. These photographs help preserve contextual information and convey the severity of incidents to the hospital's receiving care team: "*We've been instructed recently to take pictures. So, for instance, with an MVC [motor vehicle collision], now more than before, I end up taking a lot of pictures with the actual tablet to document the mechanism of injury, such as wounds or injuries. This way, when we arrive at the hospital, the nurse can get a better understanding.*" [P#2] Furthermore, participants acknowledged the usefulness of recording videos to capture real-time situations: "*With the ability to record snippets that could go into your EHR report, I think it has great potential to make documentation much easier and more accurate because you're documenting literally as it happens.*" [P#13]

#### 4.3.2. Design solutions

In our design, we implemented two features for capturing visual information—taking a picture and recording a short video—both accessible under the "Camera" option (Figure 5b). The perceived usefulness of these features consistently received high ratings from EMS providers during both phases of usability testing: 4.5 out of 5 in Phase 1 and 4.56 out of 5 in Phase 2 (Table 2). While EMS providers can use their phones to take pictures or videos, participants emphasized the convenience of using smart glass for such tasks, as it allowed them to be hands-free and stay focused on patient care: "*(Being) hands-free would make it a lot easier to take these pictures versus me, obviously, pulling out a tablet or a phone to snap a picture. Because that tends to offend people.*" [P#6]

Two key design decisions were made for this solution. First, we originally added a 5-second countdown for picture-taking, allowing providers time to find the right angle and alerting them in case of a misclick or accidental trigger. The idea of adding a countdown clock was praised, but the 5-second timer was deemed unnecessarily long. Therefore, we changed the design to a 3-second countdown, which was well-received in Phase 2 testing. Second, several participants highlighted the time required to transmit video files from the smart glass to the EHR system as a potential barrier in practice: "*The video just takes up way too much memory. And can they be transmitted in a reasonable amount of time?*" [P#1] To address this, we set a 60-second limit for video recordings to prevent excessively long recordings and ensure timely file transfers, while also reducing the risk of accidental recordings.

#### 4.3.3. Considerations for implementing the solution

Patients' privacy was a commonly raised concern among participants when discussing the potential issues of recording visual and contextual information through the smart glass camera. Several EMS providers highlighted that certain patients might refuse to be recorded in pictures or videos for personal reasons: "*Some people just don't want to be recorded, like people that just got into a fight, and they are getting arrested. And then we show up and we will be recording him, he will be very upset about it, probably he will not want to share certain information, because he's going to be like 'Oh, no, I'm getting recorded.'* [P#10] Furthermore, concerns were raised about bystanders accidentally appearing in the background of captured pictures or videos: "*If that person happened to like, walk through the background of my video that I was taking, would that be a security breach or something? Would they have to then sign something? If I was in their facility, was I allowed to use it? I don't know. Those are some kind of rules that I wouldn't know. They may be like 'Hey, turn that off.' Like 'What are you doing?' Because you know, that is a problem. Just like lay people are taking videos and stuff while I'm doing patient care. And I'm like 'Can you please stop doing that?'*" [P#5]

In light of these concerns, the system must comply with HIPAA rules and regulations to ensure secure data collection and management when using smart glass: "*HIPAA would be a hard pass if you guys are unable to make that software HIPAA compliant, because as soon as start transferring information back and forth between agencies, if that is not a secure network, then our care is at risk. And we as an agency would be at risk for releasing obviously private information and then causing a lot of issues.*" [P#25]

### 4.4. Integrating voice recognition techniques within smart glass to semi-automate EHR documentation

#### 4.4.1. Current challenges and technology needs

Consistent with issues reported in existing literature (Pilerot & Maurin Söderholm, 2019; Zhang et al., 2021, 2022), our study also identified challenges related to EHR usage faced by EMS providers. These challenges include situations where EMS providers are hindered from using EHRs due to their hands being occupied with patient care, or their reluctance to handle computing devices with dirty hands. To cope with these challenges, EMS providers shared that they often jot down notes on their gloves or on paper artifacts to record the most critical information: "*We're not using the tablet (EHR) a lot of times when attending to patients or talking to family members. We sometimes grab a four-by-four piece of paper or use our gloves to jot down notes. And then later on when we get to the ambulance or the hospital, we put the information into the tablet.*" [P#4] Despite these workarounds, EMS providers frequently experience information loss or recall issues when attempting to complete patient records at a later time: "*The issue is all about time. We are under a time constraint to do the job, have the paperwork ready, take care of the patient, and have the presentation ready to get to the receiving triage nurse. The issue is trying to do all these, especially on a serious call. So a lot of times, a lot of things either get lost or forgotten.*" [P#1]

To address these issues, participants extensively discussed and evaluated the feasibility of combining voice recognition techniques and smart glass to quickly capture essential information: "*I would ask it to annotate something in the notes for me that I just didn't want to forget about. So it'd be easier if we could just be like 'Hey, glass, can you write down this? The patient's name and date of birth, and this is the time that I gave this medication.' Just important stuff like that, so I can have that annotated. So I can go back to it and like write more stuff about it later on when I have time, but at least I have the most important stuff recorded.*" [P#5] Moreover, multiple participants complained about redundancies in EHR design that required them to input the same information in various sections. This led to brainstorming a feature that could automatically populate information collected through smart glass into the appropriate data fields within the EHR. One participant elaborated: "*When it comes to entering the narrative in the EHR, you've really hit the nail on the head. It's not just focusing on the narrative, it's about placing the information where it needs to go. Because there are too many redundancies in the EHR system, you need to repeat the information in different sections.*" [P#3]

#### 4.4.2. Design solutions

To meet the user requirements we identified, the smart glass application was designed to enable EMS providers to verbally dictate patient information to the device (Figure 5c). The recorded audio was then transmitted to the EHR system for further processing. In our original design, using natural language processing (NLP) techniques (Zhang et al., 2022), our system could transcribe the audio-recorded patient details, identify key medical information (e.g., age, medication administration, symptoms, etc.) from the transcript, and automatically populate these details into the corresponding data fields within the EHR. During Phase 1 usability testing, EMS providers expressed some concerns regarding this system design. A primary concern was the accuracy of transcription and processing, as inaccuracies could lead to erroneous documentation and potential medico-legal issues: "*Do you have the ability to go in and edit the transcription? I've done some dictation before where it's not completely accurate. And so I'd have to go in and fix the grammar.*" [P#14] A related concern was the automatic population of data fields in the EHR. Providers found it challenging to track which specific fields or sections had been auto-filled. They emphasized the importance of maintaining control over designating the appropriate EHR section for recording the extracted data, as one provider stated: "*I need to decide the section that it needs to go to at that particular moment. I don't need a program to make that determination.*" [P#1]

Informed by insights from the Phase 1 usability testing, our focus during the Phase 2 PD workshops shifted to redesigning this feature. There was a consensus among participants that a separate section should be added to the EHR system specifically for recording all types of data collected through smart glass. Within this dedicated section, EMS providers would have the opportunity to review the data, assess its accuracy, and make any necessary edits. This new design approach also allowed EMS providers to decide which specific section within the EHR should be automatically populated with the extracted data: "*So to have that auto-fill is awesome, but you have to have that ability to be able to add and edit stuff manually.*" [P#40]

Based on the user feedback from the Phase 2 PD workshops, we integrated a separate section into the EHR system prototype to record the following data types: demographics (collected through ID scans), medication information (collected from medication barcode scans), photos and videos, and processed audio recordings (Figure 6). Notably, all types of data could be edited within this dedicated section. A key aspect of this new design was the autonomy it granted EMS providers in determining which data fields within the EHR should be auto-populated (Figure 6, Left). To prevent conflicts during information entry, we also implemented a feature that alerts providers about the risk of overwriting existing information in EHR fields (Figure 6, Right). We evaluated this revised design in Phase 2 usability testing and found a notable increase in user satisfaction, with the average ratings for the perceived usefulness of the dictation feature rising from 4.5 (out of 5) in Phase 1 to 4.73 in Phase 2 (Table 2). Additionally, participants highly praised the design of having a dedicated section for storing information collected via smart glass for further editing or reviewing (a user rating of 4.63), as well as having the information automatically processed and available for them to determine which EHR data fields to populate with a click (a user rating of 4.63) (Table 2).

### 4.4.3. Considerations for implementing the solution

The most frequently discussed technical barrier to implementing this design solution was whether voice recognition technology is advanced enough to semi-automate EHR documentation. Many EMS

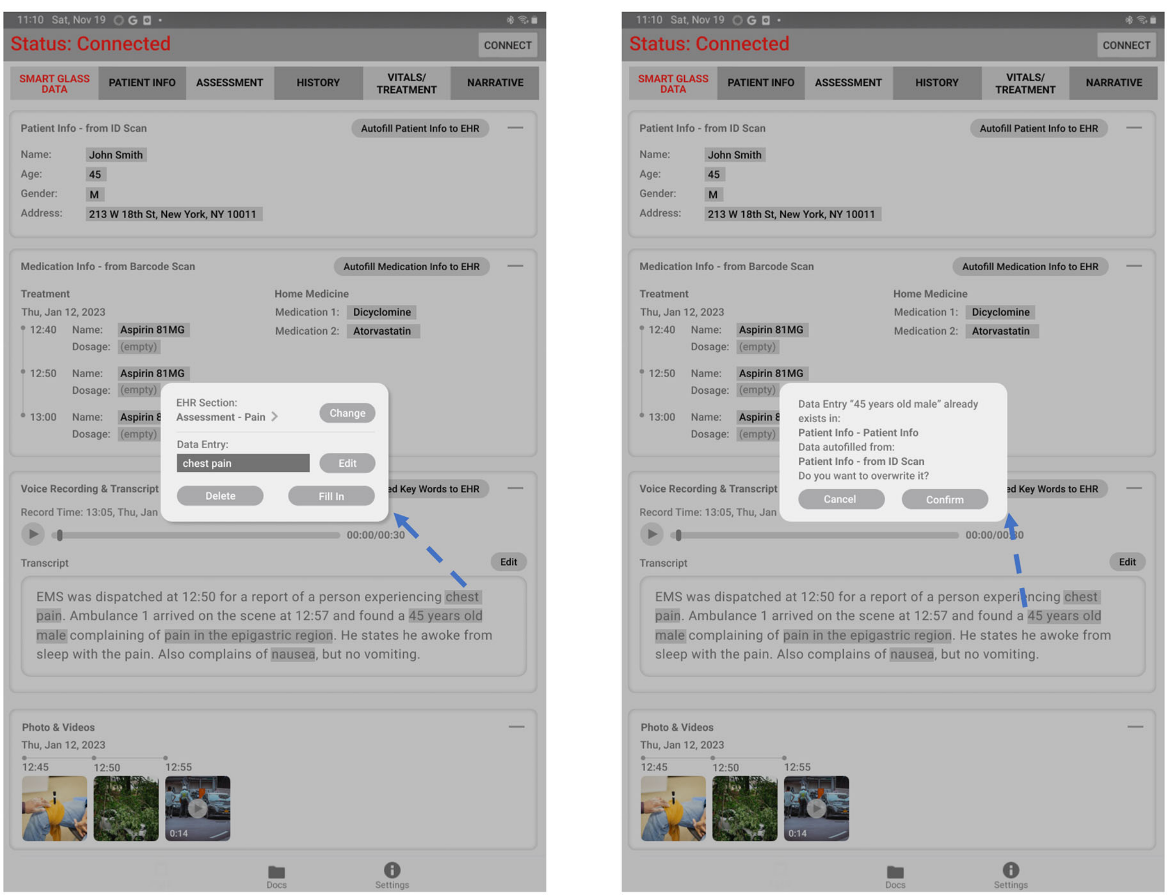


**Figure 6.** The design for integrating data collected through smart glass into the EHR interface. (Left) Providers can edit the processed dictation data, where voice dictations are transcribed, and key medical information is highlighted and extracted in real-time. Providers can also specify which EHR data fields should be auto-filled with this information. (Right) The system alerts users when they attempt to overwrite existing information in an EHR field with the processed data collected through the smart glass application.

providers emphasized that they often operate in dynamic and chaotic environments, which can significantly affect the accuracy of dictating patient information. As a result, the effectiveness of voice recognition for dictation largely depends on its ability to filter out ambient noise: "*The dictation is great, as long as it's not overly loud on the scene… I don't know how it works, but can it filter out some background noises, like if you're in the back of an ambulance with lights and sirens on?*" [P#40] The accuracy of transcribing and processing dictated data could be further compromised by the frequent use of medical jargon and abbreviations by EMS providers when describing patient care. For example, one participant shared their prior experience using a dictation tool for taking notes in EMS care: "*The only issues I ever have with the transcribing is that we use a lot of abbreviations in EMS… The simple dialogue we use sometimes just doesn't translate well. I end up having to speak it, transcribe it, and then go back to correct it a lot of the time.*" [P#9]

### 4.5. Minimal design with easy-to-operate icons

Given the small screen size of smart glass, almost all participants noted that the interface should contain as few icons as possible to avoid distractions. Additionally, the icons should be easy to notice and operate. For instance, in the prototype tested during Phase 1 (Figure 7 Left), we placed a "Back" button in the top-left corner, following the conventional layout used in many mobile and web applications. However, during Phase 1 usability testing, users reported difficulty interacting with this button due to its small size and its placed in the corner, especially when using hand gestures: "*When I was using the hand commands, maybe I was just doing it wrong, but it's so hard for me to click on the back button. Maybe moving it or making it slightly bigger so that I could click on them a little easier.*" [P#24] To address this issue, we increased the size of the "Back" button and moved it to a more central position on the left side of the screen (Figure 7 Right). Phase 2 usability testing results showed a significant reduction in issues related to clicking the "Back" button using hand gestures, with instances decreasing from 24 in Phase 1 to 8 in Phase 2.

In another example, we enlarged the microphone icon to better indicate the system's responsiveness to voice commands. In the prototype tested in Phase 1 (Figure 7 Left), we placed a small microphone icon in the status bar at the top of the interface to indicate the active or inactive state of the listener. However, user feedback suggested that the icon was too small and easily overlooked, with one participant commenting: "*That symbol in the corner was too little, I think it'd be cool if that was even bigger.*" [P#25] To address this, we repositioned and enlarged the microphone icon in the Phase 2 prototype for enhanced visibility (Figure 7 Right).

It is also worth noting that we made a number of minor yet important design changes throughout the process. For instance, in the original prototype, black outlines were used to indicate the primary action or highlight the button the cursor was on. However, participants in Phase 1 testing reported that the buttons were visually indistinct and the black outlines were hard to see at night. In response, we introduced colored buttons in the Phase 2 prototype to make the selected options more visually distinct and prominent. All the design changes contributed to a significant increase in the SUS score from 73.5

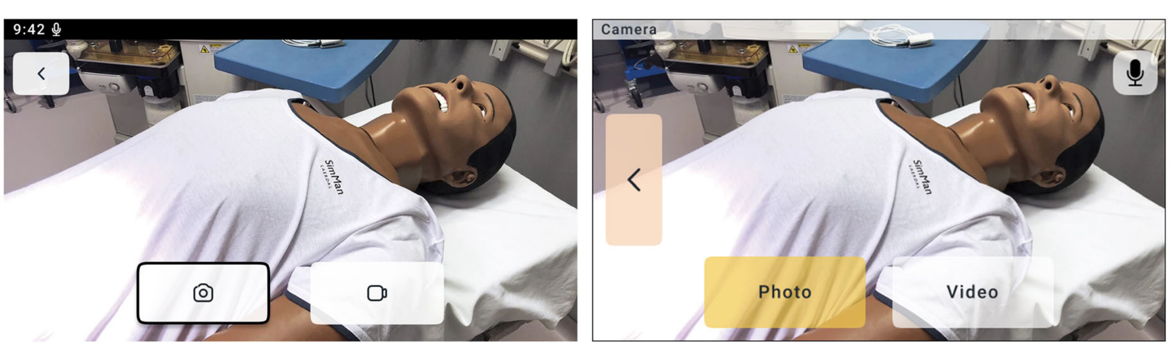


Figure 7. Design comparison of the prototypes tested in Phase 1 (left) and Phase 2 (right). Major differences included the size and position of the "Back" button and microphone icon, as well as the button appearance and text labels on the button.

("Acceptable") in Phase 1 to 82.0 ("Excellent") in Phase 2 ($p = 0.03$; Table 2). In particular, as shown in Table 2, we found that the "ease of use" aspect (SUS Question #3) and the "ease of learning" aspect (SUS Question #7) of the smart glass application received significantly higher user ratings in Phase 2 testing ($p = 0.05$ and $p = 0.04$, respectively, for these two aspects).

Finally, we tested the significant differences in the SUS scores and all user ratings of system features between EMTs and paramedics, and between providers in urban and rural areas. No significant differences were found in any of the user ratings. This finding may indicate that the system's usability and feature designs were perceived similarly across these groups, regardless of the providers' roles or region differences.

## 5. Discussion

In this section, we discuss the implications of our findings and share our experiences and lessons learned from working on this research project.

### 5.1. Study implications

#### 5.1.1. (Semi-)automating clinical documentation with advanced NLP and AI techniques

Voice-based dictation and NLP-powered data processing for semi-automating EHR documentation are considered highly useful for addressing the time-consuming nature of EMS documentation. However, their effectiveness might be compromised in noisy and chaotic EMS environments, leading to user concerns about the accuracy of voice-based dictation transcription and processing. To improve voice input feasibility in these noisy contexts, researchers are developing advanced NLP techniques to increase the accuracy of voice-based clinical documentation. For instance, one study (Maruri et al., 2018) explored the use of these techniques to achieve high-performance automatic speech recognition in smart glass. Additionally, industry advancements like Amazon Transcribe Medical and Google Speech-to-Text for Clinical Conversations have been introduced to capture and transcribe medical terms and clinical dialogues more accurately. These developments have significant potential for enhancing the accuracy of EHR documentation through voice inputs (Tran et al., 2023).

EMS providers also appreciated the potential of smart glass to automatically recognize and extract text from photos of patients' identification cards and medication bottles. With unprecedented advancements in AI and CV, fully implementing this feature is now feasible. Recent studies have developed AI and CV techniques that have proven effective and feasible in processing and identifying medication names from physicians' handwritten prescriptions (Palani & Sampath, 2022), and in assisting visually impaired patients by scanning medication names on bottles (Almuzaini & Abdullah-Al-Wadud, 2019). In the industry, Meta's most recently released Orion prototype has powerful AI capabilities that can recognize objects in the real world (Meta orion ar smart glass prototype, 2024). These techniques and advancements have demonstrated the technical feasibility of using smart glass to expedite data collection in time-critical medical settings.

Lastly, our work explored the possibility of fully automating EMS documentation by populating EHR data fields using data collected through smart glass (e.g., transcribed dictation or extracted medication names from bottles). However, during evaluations, it became clear that EMS providers preferred to review the automatically processed data and decide which EHR fields to populate. This finding underscores the importance of preserving care providers' autonomy, as they are reluctant to relinquish full control over the documentation process to AI. Therefore, we argue that when designing AI systems to assist or automate care tasks, it is crucial for researchers and engineers to consider the autonomy of providers and their stance on automation, particularly in tasks like clinical documentation. This aligns with discussions in the literature regarding the extent of AI's decision-making power in clinical settings, which requires careful design and collaboration with end-users (Kim et al., 2024; Wang et al., 2021).

#### 5.1.2. Minimizing the impact on clinical workflow

Prior research has highlighted the significant benefits of adopting smart glass in EMS work practices. For instance, smart glass was found to enhance the quality of care by enabling real-time visual communication between EMS providers and remote physicians, allowing for immediate, context-rich input that could facilitate critical decision-making (Apiratwarakul et al., 2023; Follmann et al., 2019; Schaer et al., 2016). Despite these reported benefits, limited research has investigated the potential impact of using smart glass on EMS workflow in real scenarios. To realize the benefits of smart glass, it should be seamlessly integrated into EMS workflows to avoid potential disruptions to EMS providers' work. Many failures in HIT implementation can be attributed to a misalignment between the design of HIT and actual clinical workflow (Chen, 2010; Patel & Kannampallil, 2014). Our participants expressed concerns about integrating smart glass into their work practices, particularly questioning the interoperability with existing computing and medical devices, such as EHR systems. While our application was designed to augment EHR systems, achieving its full potential depends on seamless integration with these systems. Although technically feasible, the challenge lies in the considerable effort required to collaborate with various EHR vendors for system integration. Without proper integration with EHR and other systems, the effectiveness and potential of smart glass could be significantly compromised.

Furthermore, it will be crucial to understand how the current application of smart glass might affect the teamwork dynamics of EMS providers—an area that has been understudied in prior research evaluating the use of smart glass in medical contexts. For example, will the use of smart glass affect communication and collaboration between EMS providers, particularly when one provider is focused on operating the smart glass device? How will this impact the division of labor during critical tasks, and will it introduce delays or inefficiencies in care delivery? Additionally, how do other team members perceive their colleagues using smart glass—do they see it as an enhancement of their performance, or could it create distractions or misunderstandings? It is also worth exploring whether the use of smart glass might affect the trust and coordination between team members, which are essential elements of effective teamwork in high-pressure environments like EMS. These questions are not only interesting but also critical for ensuring that smart glass can be integrated into EMS workflows without undermining team dynamics. Future work should explore these aspects to fully understand the impact of smart glass on EMS providers' collaborative practices, such as through interviews or surveys with all EMS providers in a team during the testing of smart glass, as well as through observations and post-testing video reviews of their communication and interaction behaviors while using smart glass versus not using them.

Finally, an important consideration is that the device should not become a source of distraction, as distractions from smart glass devices have been identified as a significant user concern in previous studies (Follmann et al., 2019). For instance, EMS providers already manage multiple devices, such as tablet-based EHR systems and vital signs monitors, adding another device to manage could be perceived as an additional burden by some providers. In those studies where smart glass were used as a telemedicine tool (e.g., connecting EMS providers with remote physicians for decision support) (Apiratwarakul et al., 2023; Follmann et al., 2019; Schaer et al., 2016), the researchers found that the use of smart glass could increase patient care time and providers' workload, while another recent study (Davidson et al., 2023) reported that workload and patient care performance appeared not to be affected when using smart glass in the EMS context. Given these mixed outcomes, future research should thoroughly evaluate the impact of smart glass usage on EMS providers' cognitive load, attention, and situational awareness. For example, researchers can conduct simulated and real-world testing to evaluate the use of smart glass against current documentation tools. Measurements such as documentation completeness and accuracy (through log data), time spent on documentation (through post-study video review), situational awareness (which could be measured through eye-tracking and post-study video review (Zhang et al., 2023)), and users' perceived workload (which could be assessed through the NASA Task Load Index (Hart, 2006) and qualitative interviews (Kremer et al., 2022)) could be used to measure the effectiveness of smart glass in EMS documentation tasks and EMS providers' workload.

#### *5.1.3. Ensuring compliance with privacy rules and regulations*

Privacy is one of the most critical factors to consider when designing and implementing HITs. Nearly all EMS participants emphasized the importance of ensuring HIPAA-compliant data access, processing, and storage while using smart glass. Any potential violation of HIPAA regulations could impede the technology's adoption. Therefore, the data transferred between smart glass and the EHR should be encrypted, and the data should only be processed (e.g., transcribing voice dictation) and stored on EHR devices, which typically have more computing power, storage space, and higher security protections (e.g., using passwords, fingerprints, or even facial recognition to use the device).

Although our study did not explicitly examine patients' perspectives on and acceptance of integrating smart glass into their care, our EMS participants discussed some concerns that patients might have. For instance, patients might feel uncomfortable being recorded by smart glass. Additionally, similar to issues reported in the use of commercial smart glass for general purposes (Hofmann et al., 2017; Kudina & Verbeek, 2019), using smart glass in the field may inadvertently record bystanders or other individuals in close proximity, potentially raising privacy concerns.

To address these concerns, it is essential to establish clear guidelines and policies around the use of smart glass in EMS settings. Researchers should investigate the potential ethical and privacy issues related to unintentional recordings and devise strategies to mitigate these risks. One approach could be to implement automatic data anonymization or facial blurring features to protect the identities of bystanders or non-patients (Zhang et al., 2019). Furthermore, organizations need to define rules, policies, and regulations specifying when and how smart glasses can be used during patient care and determine whether obtaining patients' verbal consent for device usage is necessary. However, obtaining informed consent poses unique challenges in emergency situations where patients may be unable to provide explicit consent due to injury or unconsciousness. To address this, we recommend clear, context-sensitive consent protocols. Depending on the setting and context, it may be necessary to implement verbal consent procedures for using smart glasses to record patient data or to disclose when the device is in use, and to offer patients the option to decline when they are conscious and able. Additionally, using visual cues (e.g., indicator lights on the device) or auditory notifications to alert individuals that recording is ongoing could enhance transparency and informed consent. Finally, educating EMS providers about the ethical and privacy implications associated with smart glasses is essential. Training should extend beyond basic device operation to include detailed guidance on privacy standards, data handling best practices, and ethical responsibilities. Regular, mandatory refresher courses can ensure providers remain aware of their ethical obligations and understand evolving privacy concerns and regulatory changes associated with wearable technologies.

#### 5.1.4. Addressing learning curves in smart glass use

During usability testing across both phases, some participants expressed unfamiliarity with the smart glass device and its interaction methods. They indicated that substantial training and practice would be essential to effectively use this novel technology. This highlights the importance of comprehensive training for onboarding EMS providers, a need also emphasized by previous studies on smart glass in medical settings (Brewer et al., 2016; Chai et al., 2015; Mitrasinovic et al., 2015). Given the varying levels of technological proficiency among providers, the intensity and duration of training may need to be tailored to individual requirements. Moreover, it is crucial to establish a feedback loop mechanism that enables EMS providers to share their real-world experiences with smart glass and identify areas for improvement. System designers and developers should address any practical use issues promptly, as delays in resolving users' concerns can lead to ineffective utilization and hinder adoption, as reported in Hertzum et al. (2019).

### 5.2. Reflections and lessons learned

We would like to share our lessons learned from this two-year-long project and discuss the limitations of this study. First, smart glass and its interaction methods were novel concepts and technologies for almost all EMS providers; none of our participants had reported using this type of technology in the past. In Phase 1 testing, we initially allocated 10–15 min for training. However, we found this duration was too short for EMS providers to get familiar with the device, and many participants frequently encountered issues in the following interaction with smart glass, such as forgetting what voice commands to use or how to operate the device. As such, in Phase 2 testing, we extended the training time to allow participants to use as much time as they needed (up to half an hour), ensuring they had sufficient time to practice and familiarize themselves with the smart glass. This extended training time helped mitigate the impact of users' unfamiliarity with the technology, enabling participants to focus more on system design and features rather than on how to operate the device.

Second, as this study focused on the iterative design of smart glass features, we did not evaluate their impact on EMS workflow, provider awareness, or workload. While some studies suggest smart glass may increase workload and patient care time (Apiratwarakul et al., 2023; Follmann et al., 2019; Schaer et al.,

2016) others report no significant effect (Davidson et al., 2023). Given these mixed findings, our future work will involve simulations and real-world testing to assess their effectiveness, potential workload impact, and implications for EMS teamwork—an area that remains underexplored in the literature.

Third, the optimal use of the device remains an open question—whether a single provider should operate it or if both providers should use it for collaborative documentation. This question has not been addressed in prior work but emerged in our study. While most participants in our study favored a single-user approach, some preferred dual usage to enhance collaboration—a key aspect of EMS documentation (Zhang et al., 2022). Future work should explore the best deployment strategy and EMS practice, considering user preferences, financial constraints, and workflow implications.

Fourth, collaboration with various organizations and companies is essential to fully realize the potential of our smart glass application. For instance, it is critical to work with EHR vendors to integrate these systems for seamless data transfer and to fully implement the smart glass application in EMS work. Addressing these implementation challenges will be a key focus for the research team in future efforts.

Finally, while our study provides valuable insights into the design and usability of smart glasses in emergency care, it does not directly assess the impact of the system on clinical outcomes such as documentation efficacy, patient safety, or workflow efficiency. Establishing causal links between smart glass usage and outcome improvements requires rigorous evaluation designs. In future work, we plan to conduct real-world studies using methods such as target trial emulation, which allows researchers to estimate causal effects using observational data under a trial-like framework. This approach, along with other advanced statistical modeling techniques, will enable a more robust assessment of how smart glass integration affects care delivery and patient outcomes in EMS work.

## 6. Conclusion

This article presents the iterative design process of a smart glass application aimed at supporting real-time EMS documentation. To the best of our knowledge, this is the first study to explore the design of smart glass for supporting clinical documentation in emergency care settings. Through this study, we identified key challenges in the EMS documentation process and explored how participants envisioned smart glass could help address these challenges. Additionally, we reported on our design solutions, detailing the decisions and changes made throughout the iterative process, which may provide valuable insights for researchers investigating the use of smart glass in other fast-paced work settings (e.g., firefighting and surgical operations). We also highlighted critical socio-technical considerations shared by EMS providers that are essential for the successful deployment of smart glass technology in time-sensitive medical environments. The article concludes by discussing the broader implications of our findings and the lessons learned. Future work can investigate the impact of using smart glass on EMS workflow, documentation accuracy, and efficiency through simulations, field deployments, and testing.

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