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Using Google Glass To Support Time-Critical Medical Teamwork

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Aachen, May 2015
Daniel Kaulen

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Abstract

Trauma teams work under extreme time pressure while stabilizing critically injured patients and addressing life-threatening injuries. Over the years, several studies have analyzed different opportunities for technological innovations in this field. It was found that there is no optimal position for *team-based* displays and that large screens do not adequately address *role-based* information needs.

To compensate for this disadvantage, we analyzed the applicability of head-up displays during trauma resuscitations in an exploratory study. A generic prototyping framework for Google Glass was developed to support these efforts. As part of our user-centered design process, we conducted interviews with trauma doctors and observed training sessions that incorporated a human patient simulator. Finally, a working prototype offering HUD-based support for trauma teams was evaluated during two simulated resuscitations.

A qualitative analysis showed that the most important application area is the visualization of vital signs in the field of view (i.e. the doctors do not need to look away from the patient to check the vital signs on team-based monitors). Additionally, contextual checklists on individual head-up displays can lead to improved protocol adherence and team communication. Our results reduce the design space for future projects and serve as basis for upcoming quantitative evaluations of the efficacy of using head-up displays during trauma resuscitation.

Überblick

Während sie schwerverletzte Patienten behandeln und lebensbedrohliche Verletzungen versorgen, arbeiten Traumateams unter extrem hohem Zeitdruck. Über die Jahre hinweg haben mehrere Studien Möglichkeiten für technologische Innovationen in diesem Gebiet untersucht. Hierbei hat sich gezeigt, dass es keine ideale Position für *teambasierte* Bildschirme gibt. Zudem werden dadurch *rollenbasierte* Informationsbedürfnisse nicht angemessen adressiert.

Um diese Nachteile auszugleichen, haben wir in einer in einer explorativen Studie untersucht, wie gut Head-Up-Displays für die Unterstützung solcher Teams geeignet sind. Dazu wurde zunächst ein Framework entwickelt, welches die Entwicklung von Prototypen für Google Glass vereinfacht. Während eines benutzerzentrierten Designprozesses haben wir Interviews mit Ärzten durchgeführt und Trainingseinheiten beobachtet, in denen ein realistischer Patientensimulator verwendet wurde. Während zweier solcher Trainingseinheiten haben wir abschließend einen funktionsfähigen Prototypen evaluiert, welcher dem Traumateam Head-Up-Display-basierte Unterstützung bot.

Eine qualitative Analyse hat gezeigt, dass die Visualisierung der Vitalzeichen im Sichtfeld das wichtigste Anwendungsgebiet für Head-Up-Displays in diesem Bereich ist. Dadurch müssen die Ärzte nicht mehr von dem Patienten wegschauen, um die Vitalzeichen auf einem teambasierten Monitor zu überprüfen. Zusätzlich kann die Anzeige einer kontextabhängigen Checkliste auf den einzelnen Head-Up-Displays sowohl zu einer besseren Aufgabenausführung führen, als auch Teamkommunikation steigern. Unsere Ergebnisse schränken den Designraum für zukünftige Vorhaben ein und dienen als Basis für folgende quantitative Evaluationen, die die Wirksamkeit von Head-Up-Displays während der Behandlung von Traumapatienten untersuchen.

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- My family, girlfriend, and friends who supported me in many ways over the past years.

Daniel Kaulen

Conventions

Throughout this thesis we use the following conventions.

Text conventions

Definitions of terms are set off in colored boxes.

DEFINITION OF A TERM:
This is an empty definition of a term.

Definition of a term

Scenarios are set off in green boxes.

PRESENTATION OF A SCENARIO:
This is an empty scenario description

Presentation of a scenario

Source code and implementation symbols are written in typewriter-style text.

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myClass
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The whole thesis is written in American English.

Chapter 1

Introduction

"The extreme complexity of medicine has become more than an individual clinician can handle. But not more than teams of clinicians can handle."

—Atul Gawande

According to estimates of a recent study by James [2013], in the United States alone as much as 440,000 deaths per year can be associated with *preventable adverse events* in hospitals. This is roughly one-sixth of all deaths that occur nationwide per year. Thus, this problem must emerge from behind the "Wall of Silence" and needs to be addressed.

Many deaths in hospitals can be avoided.

PREVENTABLE ADVERSE EVENT (PAE):
An event that causes injury to a patient as result of a medical intervention that could have been avoided by following recognized, evidence-based best practices or guidelines.

Definition: *Preventable Adverse Event (PAE)*

Being a surgeon himself, Atul Gawande stresses that adverse events are not due to the lack of skills of clinicians, but because there is "complexity upon complexity" that no individual can handle anymore (Gawande [2010]).

Individual clinicians are not to blame.

Given that over a normal life-time nearly all of us will come to know an intensive care unit from the inside, this prob-

The problem affects everyone.

lem affects everyone. An important part of intensive care is *trauma* care where severely injured *trauma* patients are treated.

Definition: *Trauma*

TRAUMA:
"Trauma is an injury to the body that occurs when a physical force contacts the body. [It] may be blunt or penetrating. Examples of blunt trauma are motor vehicle collisions, falls, and assaults with a blunt object. Examples of penetrating trauma include gunshot wounds and stab wounds." *(mdguidelines.com/trauma)*

Trauma teams follow a fixed protocol.

Figure 1.1 illustrates the layout of a sample trauma bay and shows a typical team composition. In order to unify the care of treated patients, trauma teams follow the *ATLS* protocol.

Definition: *Advanced Trauma Life Support (ATLS)*

ADVANCED TRAUMA LIFE SUPPORT (ATLS):
ATLS is a training program that teaches a systematic concise approach to the care of a trauma patient and was first introduced in 1980. It specifies a detailed protocol (see American College of Surgeons [2012]).

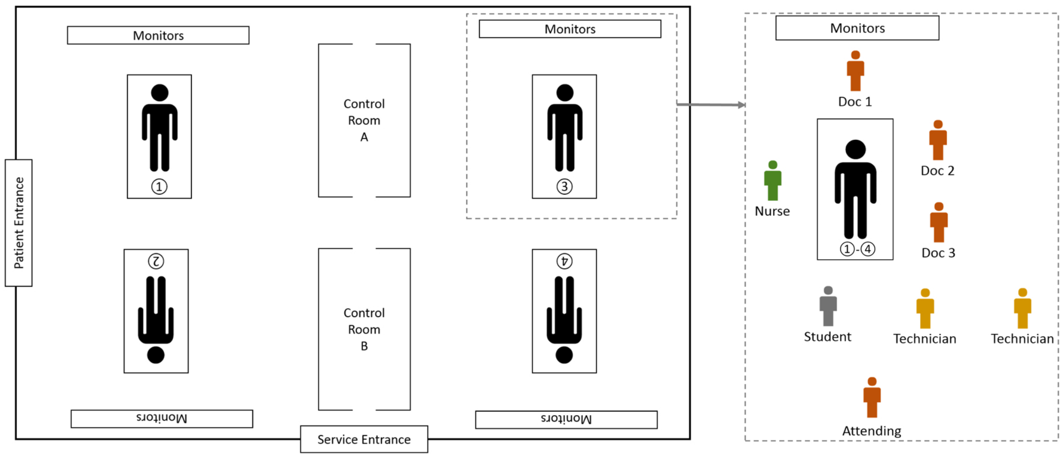


Figure 1.1: Layout of a trauma bay. The trauma bay inside the Hillcrest Medical Center at UC San Diego provides space for four patients. A typical team composition for severely injured trauma patients is illustrated on the right.

The following scenario illustrates the workflow of how a patient is treated in the trauma bay. More details will be discussed in section 4.3.2 - ”Roles and Responsibilities”.

Typical workflow in the trauma bay

TYPICAL WORKFLOW IN THE TRAUMA BAY:

1. **Pre-arrival notification.** Up to 10 minutes before the patient arrives, the team is provided with a one-liner about the mechanism of the injury. Subsequently, all team members start preparing and discussing roles and responsibilities.
2. **Briefing by paramedics.** As soon as the patient rolls in, everyone pays attention to the paramedic who provides the team with further details about the injury, prior treatment, and medication.
3. **Patient care**. In his role as team leader, Doc 1 starts to take care of the patient by following the ATLS protocol. The remaining team members assist, and the process is supervised by an attending. During the *primary survey* of the ATLS protocol, life-threatening injuries are identified, and resuscitation is begun. After completion, the *secondary survey* is started. It consists of a thorough physical exam of the patient: a head-to-toe evaluation.

We focus on the primary survey of the ATLS algorithm.

Performing well during the *primary survey* is most critical and highly influences the outcome of the patient. Therefore, we focus on this part of the ATLS protocol which is performed initially and when the condition of a patient changes. Figure 1.2 illustrates the high-level process. More details on required steps in each phase are attached in Appendix A - ”Additional Resources: ATLS”. The right order in which problems should be addressed can be memorized by the simple mnemonic A-B-C-D-E.

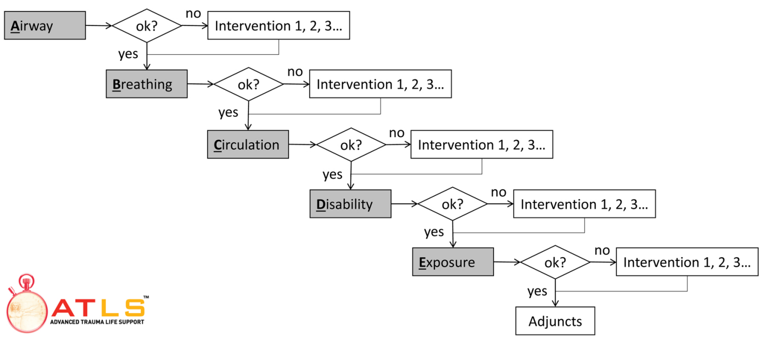


Figure 1.2: ATLS primary survey algorithm. The gray boxes indicate assessment steps. This illustration is based on information provided by J. Doucet, MD and A. Berndtson, MD.

1.1 Motivation

State of the art in the trauma bay.

Currently, important contextual information relevant for patient care is presented on shared, team-based displays in the trauma bay. This includes, among other things, the mechanism of the injury, patient data, and vital signs. Especially the vital signs may change frequently and need to be checked multiple times.

Shared displays have disadvantages.

This has a few disadvantages, as doctors only have limited attention windows for cognition. They have to look away from the patient or even turn around in order to look at a large screen. Not all information are relevant for all team members. This implies that unimportant information need to be filtered out, and the desired information need to be found first. This takes time, requires additional cognitive efforts and distracts from patient care.

We assume that HUDs can resolve these disadvantages and further improve trauma resuscitation.

It is assumed that the best position to display information is on the patient's body since that is where all team members are looking at. Therefore, we consider personal head-up displays as a promising way to further improve trauma resuscitation. They allow to visualize information in each doctor's field of view, and do not require to look away from the patient at all. Moreover, it has the advantage that information can be tailored to individual information needs.

Head-up display (HUD):
A transparent display that allows to present data without requiring users to look away from their usual viewpoints.

Definition:
Head-up display (HUD)

Since checklists have proven to be suitable to tackle the increasing complexity of medicine in general (e.g., Gawande [2010]), it was decided to take this concept into consideration and to explore benefits of combining interactive checklists and HUD-based visualizations.

The visualization of checklists on HUDs is expected to offer additional benefits.

1.2 Research Questions

Given the relative novelty of HUDs, we decided for a two-step research approach. First, assessing the technology and second, learning about user's needs. This leads to the following more concrete research questions that guided our work:

We need to assess the technology and learn about user's needs.

1. **Technological.** Is the technology available already mature enough to potentially address the disadvantages identified in the previous section? If so, what are risks limitations and capabilities?

2. **User-centered.** Are there potential application areas for HUDs in time-critical medical teamwork? How do role-based information needs need to be addressed?

Technology-wise, we decided to focus on *Google Glass (Explorer Edition 2.0)*. Nevertheless, we consider huge parts of our results generalizable to HUDs in general.

We use Google Glass as sample device.

Google Glass (abbrv.: Glass):
A head-mounted wearable computer that offers a HUD as output device.

Definition:
Google Glass (abbrv.: Glass)

1.3 Outline

The thesis is organized as follows:

- **Chapter 2.** We introduce the research space that guided our literature review. Related projects and additional background knowledge are classified along the three dimensions of our research space.
- **Chapter 3.** To address the first research question, this chapter describes how we assessed the applicability of Google Glass for early-stage research in HCI. A prototyping framework that has been developed in order to overcome the lack of fast prototyping opportunities is introduced.
- **Chapter 4.** This chapter outlines our iterative, user-centered design approach used to answer the second research question. It is described how insights from user interviews, observations of simulation sessions, and a focus group discussion influenced the development of early prototypes.
- **Chapter 5.** We present an overview and the results of two evaluation sessions. The high-fidelity prototype resulting from a user-centered design approach was used to support trauma teams during simulation sessions. Promising as well as negative feedback is summarized along with results of subsequent video analyses.
- **Chapter 6.** We highlight contributions and benefits. In addition, challenges that we had to face while working with domain specialists in health care are discussed. Finally, promising directions for future work are outlined.

Chapter 2

Background And Related Work

"Is there anyone so wise as to learn by the experience of others?"

—Voltaire

As outlined in the previous chapter, our work focuses on exploring opportunities for the integration of a novel *technology* (HUDs, Google Glass) into a specific *domain* (trauma resuscitation) by providing *added value* (e.g., checklist-based support).

We analyze opportunities for HUDs and Google Glass in trauma resuscitation.

This section reviews related work in these areas both in isolation (e.g., Gawande [2010]: foundations of checklists) and in combination (e.g., Kelleher et al. [2014]: effects of checklists on trauma resuscitation workflows). To structure this process, a research space is introduced.

A research space is created to structure the literature review.

2.1 Research Space

Related research projects and publications were classified according to the following dimensions (ordered by importance, starting with the most important one):

Three dimensions were used to classify related work.

1. **Medical setting.** Ternary classifier (manifestations: none, general care, urgent care).

2. **Usage of HUDs.** Binary classifier (have HUDs been incorporated in the research project).

3. **Usage of checklists.** Binary classifier (have cognitive aids such as checklists been incorporated in the research project).

Classification rules for the medical setting.

Medical research primarily focusing on *non-time-critical* settings (i.e. primary care) was classified as general care, whereas projects primarily focusing on settings in the emergency room, trauma center, or operating room were classified as urgent care as they differ in one key aspect: *time-criticality*. Teamwork plays a crucial role in both settings.

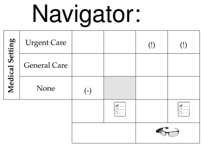
The research space consists of 12 distinctive areas.

The above dimensions along with their concrete manifestations yield a total of $3 \times 2 \times 2 = 12$ distinctive research areas under consideration (cf. Table 2.1). Due to the general nature of publications with no medical background neither involving HUDs, nor checklists, the corresponding part of the research space is excluded from the review. The following subsections are structured using the medical setting as primary classifier. Additional guidance is provided by *navigator widgets* that are based on Table 2.1.

2.2 Medical Setting: None

2.2.1 Foundations Of Checklists

Navigator:



The Checklist Manifesto by Atul Gawande provides a thorough overview about checklists in several domains including aviation and medicine (Gawande [2010]). Based on his longstanding experience as surgeon and public health researcher, he first describes the basic problem that motivates the use of checklists:

Medical Setting	Urgent Care			(!)	(!)
	General Care				
	None	(-)			
					
					

Table 2.1: A three-dimensional research space used to classify related work. The research focus our project is indicated by (!). Literature excluded in this section's review (e.g., general methodology) is indicated by (-).

How to address increasing complexity?

> "There is complexity upon complexity. And even specialization has begun to seem inadequate. [...] What do you do when expertise is not enough? What do you do when even the super-specialists fail?" (Gawande [2010])

Checklists are a simple tool to tackle increasing complexity.

His answer is simple: use a checklist. Anyhow, many people express a valid concern by saying that their jobs are too complex to be reduced to a checklist. Therefore, it is crucial to emphasize that checklists should not be designed to turn off people's brains but rather should act as a *cognitive aid*. One of his studies on incorporating checklists in eight hospitals all over the world revealed that this initial skepticism decreases over time. After 3 months of usage, nearly 80% of the participants reported that the checklist improved the safety of care.

There are many success stories.

In addition to that, Gawande mentions two out of many success stories which prove that something as simple as a checklist can help saving lives:

- On January 15, 2009, US Airways Flight 1549 ditched in the Hudson River after both engines broke down due to a prior bird encounter. Even though this was their first joint flight, Captain Chesley B. Sullenberger and First Officer Jeffrey B. Skiles transformed themselves from individuals into a team and managed to land the aircraft safely – thanks to the strict adherence to emergency procedure *checklists*.

- One day, one of Gawande's patients unexpectedly lost a lot of blood during a routine surgery. Only because the team has run through a *checklist* in advance and put blood reserves in a bank nearby, they were able to save the patient's life.

It is differentiated between two types of checklists.

That being said, we will move forward to concepts that are crucial to be aware of in order to be able to develop good and usable checklists. Gawande differentiates between two types of checklists:

- **Do-confirm.** Team members *do* their work by performing tasks from memory and experience. At certain points in time (pause points), they pause to run the checklist in order to *confirm* that everything that was supposed to be done was done.
- **Read-do.** People complete tasks as they check them off (e.g. cooking with a recipe).

The number of checklist items should be limited.

Depending on the given context, one of these types (or a combination of both) is more appropriate. In either case, the number of items on a checklist should be limited to 5-9 items per pause point. This can be explained by the limitation of our short-term memory which can – on average – handle only 7 chunks of information at a time (Miller [1956]).

Use a design guideline for checklists.

Figure 2.1 provides a design guideline that assists during the development, drafting, and validation of checklists.

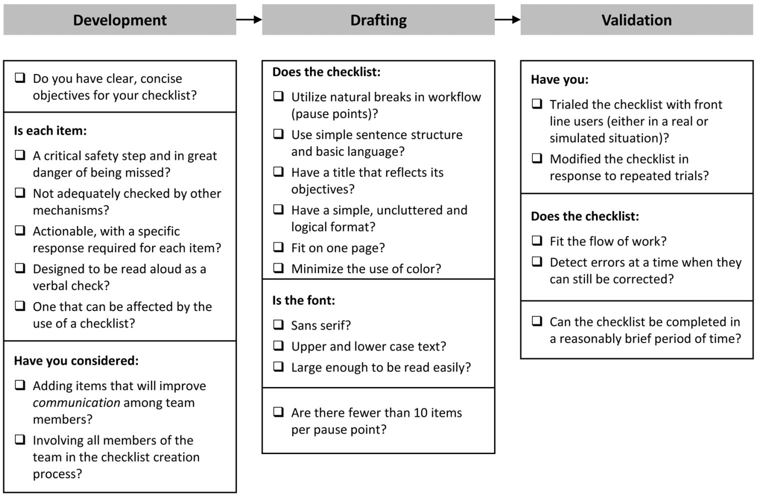
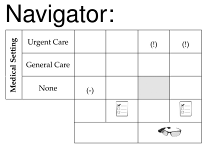


Figure 2.1: A checklist for checklists. It can be used as a design guideline. Adapted from Gawande [2010].

2.2.2 Google Glass: Status Of Research

Navigator:



As of January 2015, the official Glassware Appstore[1] featured 110 applications. Gaming and social media are the most prevalent application domains. Another group of applications aims at providing location aware services.

Glass has been used in many research projects.

Even though Glass is a relatively new device, it has already been used for many research projects. This section reviews concerns, sample projects and future potentials.

Concerns

There is a general skepticism towards Glass.

As with every new technology, people tend to be skeptical at the beginning. Main concerns outlined in literature are twofold:

The front-facing camera raises privacy concerns.

- **Social issue: privacy.** The main source of distrust is caused by the omnipresent, front-facing camera. Based on his longstanding experience with digital eye

[1] https://glass.google.com/glassware

glasses and wearable computing, Mann [2012] describes that he often found himself on the ”receiving end of some shocking behavior”. He found that people are probably frightened of being recorded and fear that the video might be used against them at a later point in time. Ironically, people working at large multinationals or government agencies were most frightened about his camera even though they already use a large number of surveillance cameras throughout their buildings.

People that feel monitored need to perceive any type of value in return.

Hong [2013] mentions that similar concerns have been observed several times in history, and what we can learn from these past developments. When researchers at PARC first introduced *Ubiquitous Computing* back in 1991, the reactions of popular press were mainly negative but changed as people started to see value in it. Therefore, it is generally assumed that “as long as those who bear the privacy risks do not benefit in proportion to the perceived risks, the technology is likely to fail.” Thus, negative perceptions about Glass are likely to continue as long as people that feel monitored by the camera do not perceive any type of value in return.

Automatic backup to the cloud cannot be disabled.

A final privacy issue is raised by the fact that one can not easily disable the automatic backup of data to the cloud when Glass is being charged and connected to a WiFi network (Muensterer et al. [2014]).

Battery lifetime is limited, and the surface temperature of Glass raises up to 50°C.

- **Technical issue: battery and heat characteristics**, Likamwa et al. [2014] pointed out limited battery lifetime due to weight restrictions on the design as a major technical limitation. Average battery lifetimes for several usage scenarios were analyzed and led to the following results: performing compute-intensive tasks such as face detection (38 minutes), continuous video capture (43 minutes), idle (95 hours). Additionally, heat characteristics were analyzed and showed that the surface temperature raises up to 50°C while performing compute-intensive tasks. Surface temperatures above 37°C are not well-suited for a head-mounted device worn over extended periods of time. This unpleasant heat generation was also confirmed by Kunze et al. [2014] and Dolan [2014]. In conclusion, the current Glass design was not considered suitable for frequent or always-on operation (Likamwa et al. [2014]).

Sample Projects

In non-medical settings, three research domains involving Google Glass stand out:

Three research domains are identified.

- Assisting the elderly and disabled
- Lifelogging
- Education and teaching

Findings of selected corresponding research projects will be summarized in the following.

Mcnaney et al. [2014] performed a *field study* investigating the use of Google Glass by people with Parkinson's disease (PD). Since PD mainly affects motor abilities, special focus was put on the acceptance and reliability of voice input.

Can people with motor disabilities profit from Glass?

Four participants were trained on Glass in an introductory workshop. This was followed by a 5-day field trial accompanied by daily phone interviews and an exit interview. Subsequent analysis of the transcribed data revealed that there is worth in exploring the technical feasibility of applications assisting people suffering from PD. However, the voice recognition system caused frustration amongst all participants. One participant claimed that his voice was not always working, and the device kept saying try again. Another one complained that he had to speak with a pretty loud voice for Glass to recognize his speech.

There is potential, but voice recognition caused frustrations.

Motivated by the fact that the development of Google Glass is directed towards early adopters, Kunze et al. [2014] carried out an *exploratory* study with three older adults (≥ 60 years) in order to find out about specific requirements and concerns of this generation. After a usage period of two days, semi-structured interviews were conducted.

Even older adults had no problems using Glass.

Three findings can be generalized to our context: (1) the head-mounted display does not hinder performing tasks, (2) users are expected to quickly get accustomed to carry Google Glass, (3) the activation tab and scrolling gesture usually work well, yet the cancel gesture (swiping down) is more problematic and often not recognized.

Chroma helped colorblind individuals to a better color recognition.

Results of Tanuwidjaja et al. [2014] show that Glass can also be leveraged for more complex scenarios and help to improve color recognition of colorblind individuals. A custom app called *Chroma* was developed for that purpose. Nearly all colorblind participants (5 out of 6) increased their scores in a standardized colorblindness test (within-group design, treatments: perform test with or without the aid of Chroma). Compare Figure 2.2.

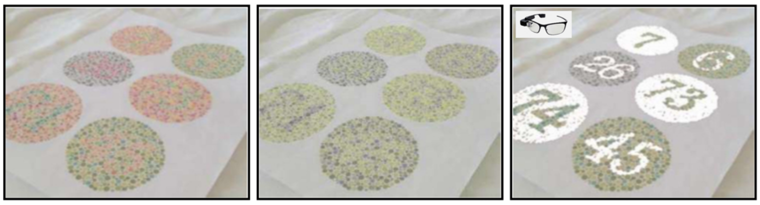


Figure 2.2: Example of a standardized colorblindness test. Contrasting normal vision (left), vision for a color blind individual (middle), and vision with the aid of *Chroma* (right). Adapted from Tanuwidjaja et al. [2014].

Lifelogging is an important application area.

Current developments in the second research domain, *lifelogging*, mainly focus on automatic activity recognition and unobtrusive interaction techniques. This knowledge is important for the development of *context-aware* systems.

Human activities can be differentiated with a high classification accuracy.

Ishimaru et al. [2014a] addressed the question whether it is possible to combine head-motion patterns and eye blink detection in order to recognize high-level human activities. In their initial prototype they differentiate between 5 activities: watching TV, reading, mathematical problem solving, sawing, and talking. Eight participants were asked to perform these activities (each lasting five minutes) while wearing Glass. By leveraging the sensor readings, an average classification accuracy of 82% was achieved which is still not good enough for many practical applications.

In a follow-up project, Ishimaru et al. [2014b] developed *Shiny*, an activity logging platform. They found Google Glass to be a suitable device because it targets *micro-interactions* which can be performed fast and with minimal interference with other cognitive or physical activity. They implemented two hands-free interaction techniques based on head gestures (cf. Figure 2.3) and evaluated the suitability with 5 users in an initial study. Average switch times from one list item to another were measured. On average, users needed 710 ms using the standard Google Glass swipe-interface (one-hand gesture), 782 ms using the *roll* head movement, and 1092 ms using the *yaw* head movement. Even though average switch times for head gestures are expected to be 10% (roll) respectively 54% (yaw) slower than using the standard interface, they provide promising alternatives where hand-based input is out of question.

The efficiency of head gestures was analyzed.

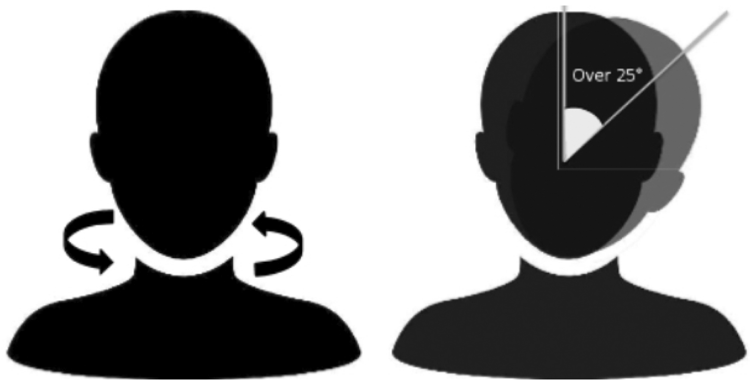


Figure 2.3: Illustration of two head gestures. *Yaw* head movement (left) and *roll* head movement (right) were used to interact with Glass (Ishimaru et al. [2014b]).

A new line of research in teaching and education has recently been started by Weppner et al. [2014]: Google Glass based experiments. In an initial publication, they present an application designed to help students to understand the relationship between the frequency of sound generated by hitting a water glass and the amount of water. Students are guided through a set of recordings of different frequencies based on the fill level. The differences between the frequencies are visualized graphically (line chart). This publication still lacks a comprehensive empirical evaluation.

Glass was used to make physical experiments more interactive.

Future Potentials

> "The camera hound of the future wears on his forehead a lump a little larger than a walnut [...] there is film in the walnut for a hundred exposures [...] a quick squeeze, and the picture is taken. As the scientist of the future moves about the laboratory or the field, he trips the shutter and in it goes [...]. Is this all fantastic?" (Bush [1945])

Glass realizes Bush's vision.

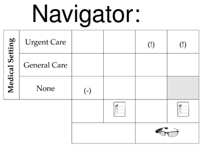
The above quotation illustrates that Vannevar Bush already envisioned more than 70 years ago what researchers today consider as one of the main potentials for wearable devices like Google Glass: *documentation* and *memory augmentation*. Scholl and Van Laerhoven [2014] support the statement that scientists will soon be able to enjoy the reality of this vision.

The disabled can profit from Glass.

There is also evidence that HUDs can provide a new measure of independence for disabled. Especially in combination with real-time crowd-sourcing approaches, wearable computers are expected to rapidly improve the independence of many disabled persons (Tsukayama [2013]).

2.2.3 Designing Checklists For HUDs

Navigator:



To the best of our knowledge, there is no previous research explicitly focusing on how to transfer basic principles of paper-based checklists (cf. 2.2.1 - "Foundations Of Checklists") to HUDs featuring only a very limited amount of screen space.

A sample checklist design for Glass was found.

Charades[2] – one of Google's showcase applications – provides simple examples for basic checklist designs and interaction techniques (cf. Figure 2.4). This app was used during initial user interviews and influenced the design of our checklist-based prototype (cf. 5 - "Evaluation").

[2]https://github.com/googleglass/gdk-charades-sample

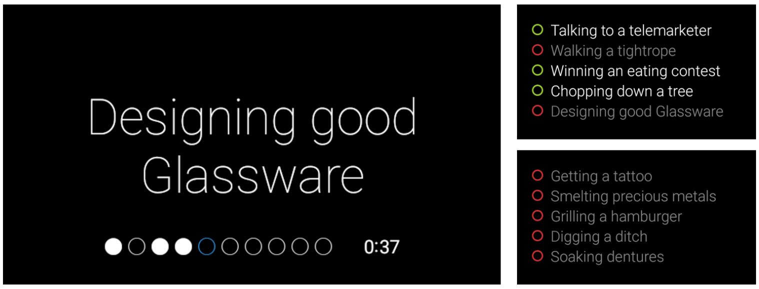
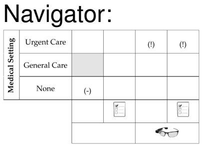


Figure 2.4: *Charades*, a checklist-based game. Sample screens on Google Glass. A filled white circle indicates a checked item, a blue circle the current item. A summary of previously checked (green circles) and missed items (red circles) is given on the right.

2.3 Medical Setting: General Care

2.3.1 Errors In Complex Health Care

Navigator:



15 years ago, the *Institute of Medicine* published a pioneering report entitled "To Err is Human: Building a Safer Health System" (Kohn et al. [2000]). Based on 1984 data developed from reviews of medical records, they estimated that up to 98,000 people die in US hospitals each year as a result of PAEs. Beyond the cost in human lives, these errors have been estimated to result in total costs of between $17 billion and $29 billion per year. The report concludes that "the majority of medical errors do not result from individual recklessness or the actions of a particular group [...] more commonly, errors are caused by faulty systems, processes, and conditions that lead people to make mistakes or fail to prevent them." Subsequently, the health system should be designed in a way that makes it harder for people to do something wrong and easier for them to do it right. Obviously, this does not mean that individuals can be careless, but blaming individuals when errors occur does not help to make the system safer and prevent someone else from committing the same error again.

It is estimated that up to 98,000 people die as a result of PAEs each year.

James [2013] published an updated estimate of Americans that die from PAEs per year in the *Journal of Patient Safety*.

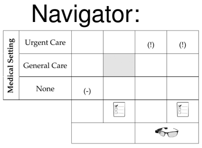
A more recent study estimates that around 440,000 deaths per year are associated with PAEs.

It is developed from modern studies published from 2008 to 2011. A lower limit of 210,000 deaths per year was associated with preventable harm in hospitals. Given the incompleteness of medical records and limitations in their approach, the true number of premature deaths associated with PAEs was estimated at around 440,000 per year. The underlying reasons were separated into five distinct categories of errors that need to be addressed (James [2013]):

- **Error of commission.** A mistaken action harms a patient (either because it is the wrong one or it is the right one but performed improperly).
- **Error of omission.** An obvious action is necessary to heal the patient but not performed at all.
- **Error of communication.** Information loss occurring between 2 or more health providers or between providers and patients.
- **Error of context.** Unique constraints in a patient's life are not considered.
- **Diagnostic error.** Wrong diagnosis resulting in delayed, wrong, or ineffective treatment.

2.3.2 Introducing Checklists In Medicine

Navigator:



Despite demonstrated benefits, checklists are still used rarely.

Hales and Pronovost [2006] discuss the checklist as an important tool for error management and performance improvement. Areas such as aviation, aeronautics, and product manufacturing already heavily rely on checklists in order to reduce errors or to improve best practice adherence. Even in high-intensity fields of medicine, checklists have demonstrated to be effective (cf. 2.4.2 - "Cognitive Aids For Time-Critical Medical Teamwork"). Despite these demonstrated benefits, the integration of checklists into medical practice in *general care* has not been as rapid and widespread. The authors start the discussion of the reasons behind that by critically asking the following questions:

> "If pilots are not expected to recall from memory each crucial step of their complex tasks – why is this required of clinicians who are also responsible for the lives of others? Is the aviation industry willing to take these extra measures because their own lives are put at risk by their performance?" (Hales and Pronovost [2006])

Without giving concrete answers to these questions, the authors argue that two main barriers exist that still hinder the regulation or enforcement of checklist use in health care:

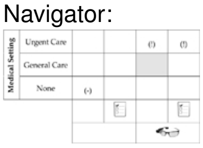
There are two barriers that hinder the introduction of checklists in health care.

- **Cultural Barriers.** There is often an assumption that the use of memory aids is an admission of weakness or lack of medical knowledge. In addition to that, clinicians often see the use of standardized tools as a limitation to their clinical judgment.
- **Operational Barriers.** It is very difficult to standardize certain procedures. Since many unpredictable human factors can influence the approach to treatment, the design and implementation of checklists becomes exceedingly challenging.

2.3.3 Doctors As Early Adopters of Google Glass

Healthcare is considered to be one of the most obvious application areas for Google Glass. Researchers and practitioners alike see manifold application areas (Glauser [2013]). Therefore, research projects as well as startups[3] have started using Google Glass in general care. Less-obtrusive *documentation*, faster *information-retrieval* and simplified *communication* are three promising application areas in which it could make a difference.

Navigator:



[3] E.g., Augmedix (http://www.augmedix.com), a startup that uses Google Glass as an electronic medical record solution and raised $16 million in series A venture funding in January 2015.

The feasability of Glass in a forensic setting for documentation purposes was evaluated.

The objective of a study performed by Albrecht et al. [2014] was to determine the feasibility of Google Glass in a forensic setting for *documentation* purposes. They evaluated a custom app called *Blink App* that allowed to take pictures in a hands-free manner. After a picture was taken, it was shown on the HUD, and the forensic pathologist could use a nodding motion to keep or a head-shake to delete the image. Based on subsequent interviews, subjective ratings of the user experience were obtained. The participants deemed the system as suitable tool for examiners in situations where they need both of their hands for fulfilling tasks. The integrated gesture control (nodding and shaking) was perceived as natural. Since no macro function was available, especially close-ups required higher physical efforts than with a regular camera. In order to obtain pictures of the regions they wanted, the examiners had to bring their head closer to the findings than they would have preferred.

The HUD of Glass cannot replace output devices for advanced medical imaging techniques.

In their efforts to improve the quality of care in primary care medicine, Monroy et al. [2014] conducted an *exploratory study* and integrated a hand-held primary care optical imaging system with Google Glass. Thereby, the physician was able to have both the patient interaction and the generated data within the visual field (cf. Figure 2.5) which allowed him to focus on the patient during the entire exam. They conclude that the HUD is too low resolution and appears physically too small to be used as *single* output device for advanced medical imaging techniques.

Figure 2.5: Imaging systems in the primary care office. A typical use case of the current imaging system in the primary care office (left) contrasted with the use of Google Glass allowing for more personal interaction (right). Adapted from Monroy et al. [2014].

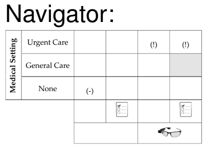
The first systematic evaluation of Glass in general care was performed by Muensterer et al. [2014]. Their findings are based on a 4-day wearing experience in a children's hospital by the primary author, various discussions, and brainstorming sessions. They envision that Glass can change the work routine mostly in three areas: (1) hands-free photo documentation and video recording, (2) real-time online search of complex medical condition and rare syndromes, (3) hands-free 2-way communication by telephone or videoconferencing. While most people (including parents, patients, nurses, and physicians) had a favorable attitude towards Glass, a few were concerned that Glass could be filming or recording them.

Glass can change the work routine mostly in three areas.

2.3.4 Medical Checklists On HUDs

Dolan [2014] describes a small panel discussion about the the rise of wearables in health care particularly focusing on the early days of Google Glass adoption by doctors. The discussion was kicked off by suggesting that it might be an ideal device to implement Atul Gawande's famous checklist manifesto – especially when a physician or surgeon is not able to touch a smartphone or tablet to review a checklist (cf. 2.2.1 - "Foundations Of Checklists"):

Navigator:



Are HUDs ideal for medical checklists?

> "What if in the course of delivering care [...] the checklist via F-16 head-up display says: 'Today it is the right kidney that is being removed. That's the right kidney.'"

The panelists, Dr. Steven Horng (department lead for a Google Glass project at a New York hospital) and Pelu Tran (Co-Founder of the Glass-focused company Augmedix), both agreed that wearables have great promise for that type of support in a clinical setting.

The panelists see great promise for that type of support.

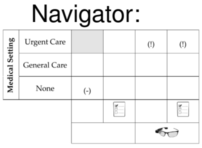
On the other side, they also admit that they are still encountering some limitations, and that Google Glass is still an early device that was originally designed for other uses.

There are still limitations.

2.4 Medical Setting: Urgent Care

2.4.1 Trauma Resuscitation

Navigator:



Several team members work together under high time pressure during trauma resuscitation. A deeper understanding of *communication patterns*, *information needs*, and common *teamwork errors* is required when analyzing how to improve current practices. In the following, we review related work along these dimensions and conclude with a section on ATLS training using *patient simulators*.

Communication And Information Needs

Verbal communication amongst team members during trauma resuscitations was examined.

Verbal communication is especially essential during high-intensity performances. Bergs et al. [2005] performed an *observational study* in order to examine verbal communication from physicians to other team members during trauma resuscitations. They equipped a trauma room of a Level I trauma center with a digital video recording system. Based on the severity of the injury, patients were either resuscitated by a major (high severity) or a minor trauma team.

Oftentimes, communication during the primary survey was not understandable.

Recordings of 193 resuscitations were captured and analyzed over the course of 4 months. Special focus was put on communication during the primary survey. Non-verbal communication in the resuscitation room was not analyzed. The minor trauma team assessed 119 patients, and communication was understandable in 33%. The major trauma team assessed 74 patients, and communication was understandable in 44% during the primary survey.

Team communication needs to be improved.

These findings show a trend towards better communication during the exposure of severely injured patients. However, it is still obvious that good communication during trauma resuscitation is not self-evident. The authors complain that knowledge transferral is often suboptimal, and that the guidelines for communication outlined in the ATLS course are not as clearly structured as in similar professions such as aviation. They claim that there is a general lack of awareness of the need for communication. It is suggested that quality improvement programs should focus on that.

Three years later, Sarcevic et al. [2008] published a more detailed analysis of communication patterns that support information acquisition and sharing. They conducted an *ethnographic study* to explore the possibilities for future design and development of technological support for trauma teams. Their results are based on qualitative and quantitative analyses of trauma teamwork.

Communication patterns were analyzed.

Figure 2.6 is the main outcome of a quantitative analysis of the transcripts of recordings of 10 trauma resuscitations. It lists frequencies of responses and inquiries by role. About one in ten questions remained unanswered. This was either due to the fact that it was not heard or that nobody felt addressed. As expected, the team leader was involved in most inquiries and responses.

Frequencies of inquiries and responses were summarized per role.

A deeper analysis revealed that, surprisingly, the team leader asked the attending very few questions given that the team leader's role is subordinate to the attending's role. The authors see the reason behind that in the urgency of the situation where collaborative problem solving happens rarely.

Surprisingly, the team leader asked few questions to the attending.

The report concludes with main challenges for interaction design for trauma teams that also guided our efforts:

Challenges for interaction design were identified.

> "The challenge is to design an effective mechanism that allows the leader [Doc 1] to retrieve and manipulate information efficiently while minimizing the amount of attention and cognitive effort needed for performing these tasks."
> (Sarcevic et al. [2008])

In order to gain a better understanding about what type of information is actually needed, Sarcevic and Burd [2008] reused the same transcripts and assigned a category to each question. Patient *evaluation* (32%), patient's *medical history* (11%), and *vital signs* (8%) were identified as main categories of questions asked by the trauma team. The authors

Categories of required information were identified.

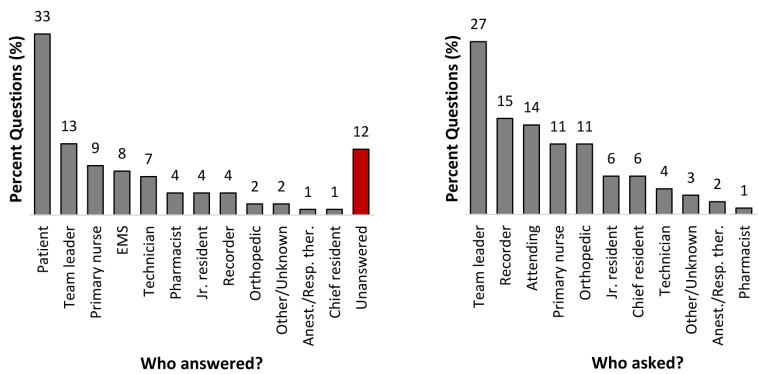


Figure 2.6: Frequencies of responses (left) and inquiries (right) by role (581 questions in 10 resuscitations). Adapted from Sarcevic et al. [2008].

see important opportunities for using technology to support to reduce the number of questions and to improve the overall workflow.

The vital sign monitor is consulted frequently.

Kusunoki et al. [2013] support this assumption by highlighting that the vital sign monitor is central to patient care and team performance. Based on the analysis of recordings of 12 resuscitations, the authors aggregated frequencies and durations of vital sign monitor looks for individual team members. It turned out that the team leader consults this monitor most frequently (across all 12 simulations: 98 looks, total duration = 483 s, average duration = 4.92 s). In order to minimize the time spent switching between looking at the monitor and the patient, it is suggested that displays should be placed as near to the patient as possible.

Teamwork Errors

An observational study was conducted to identify teamwork errors.

Human errors in trauma resuscitation can have cascading effects leading to poor patient outcomes. Motivated by that, Sarcevic et al. [2012] conducted an *observational study* in a trauma center over a two-year period to determine the nature of teamwork errors.

Table 2.2 presents the novel classification scheme that emerged from their analysis. As opposed to a more general error classification scheme introduced in section 2.3.1 - "Errors In Complex Health Care", these error types are more specifically applicable to *time-critical teamwork*.

Four types of teamwork errors were identified.

In order to minimize these errors, the authors concluded that the key role of technology would be to externalize situational information for easy access. The two most critical information structures that need externalization include "(1) evidence gathered up to the present; and (2) procedure steps that were successfully completed up to the present." Especially the last-mentioned aspect was addressed by our prototypic system (cf. 5 - "Evaluation").

Technology can help to minimize teamwork errors.

Error Type	Description
Communication error	Failure to communicate information; partial reports and partial orders
Vigilance error	Failure to intercept and prevent errors of others
Interpretation error	Incorrect or delayed diagnosis based on available information
Management error	Loss of track of progress for a multistep procedure

Table 2.2: Classification scheme for teamwork errors. Adapted from Sarcevic et al. [2012].

Training Using Patient Simulators

Holcomb et al. [2002] were one of the first to evaluate the use of a human patient simulator as an effective teaching and evaluation tool in the field of trauma resuscitation. Ten three-person military resuscitation teams that participated in a rotation at a specialized trauma center took part in the study. These teams were compared with five expert teams composed of experienced trauma surgeons and nurses. For that purpose, a trauma team evaluation form that allows for reproducible evaluations of trauma team performance was developed.

The use of human patient simulators as an effective training tool was evaluated.

Significant improvements were observed.

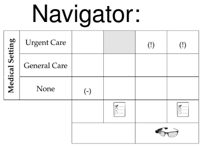
After the 28-day trauma refresher course using the simulator, the military teams demonstrated significant improvements in 80% of the scored tasks and 75% of the timed tasks (in both cases: $p \leq 0.05$) and showed significantly higher improvement rates than the expert groups ($p \leq 0.05$). This leads to the assumption that simulators are especially useful to teach trauma resuscitation to beginners.

Not all important aspects can be replicated in simulations.

Kusunoki et al. [2013] still consider high fidelity simulations as a very valuable for training but highlight that it is not possible to replicate all aspects of patient injuries and responses to interventions in such settings.

2.4.2 Cognitive Aids For Time-Critical Medical Teamwork

Navigator:



Since the complexity of medical condition seems to be increased in urgent care, checklists have slowly begun to make their way into this field (Hales and Pronovost [2006]). Many research projects in this field mainly focus on how to appropriately design cognitive aids with the goal of inferring *design principles*, while others analyze the *effects* of these aids on team performance. The following review is structured accordingly.

Design Principles

Nurses should check off tasks for doctors.

In one of his early crisis care projects, Wu [2012] initially thought that one could build interactive checklists where medical doctors click on items. However, observation and gaze analysis revealed that even these seemingly simple interactions were in fact heavyweight. As a result, it turned out that giving tablet input to nurses and allowing doctors to give them verbal commands is way more suitable.

Two main design tensions were identified.

By using a *participatory design approach*, Kusunoki et al. [2014] developed an information display prototype for trauma resuscitation teams in order to improve shared situational awareness. As one outcome of this process, they conceptualized two main design tensions useful for guiding future design decisions:

- **State- vs. process-based displays.** State-based, snapshot-like designs that present information about patient and teamwork status were preferred over process-based, checklist-driven designs that present information organized by the order of activity.
- **Team- vs. role-based displays.** Team-based displays were slightly preferred over role-based displays because mounting displays for each role is not considered as as cost- and space-effective and may introduce confusion about where to look.

Figure 2.7 shows an intermediate and the final display design that evolved out of the participatory design process.

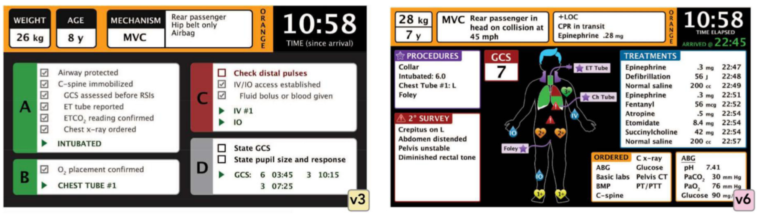


Figure 2.7: Two designs for a display in the trauma bay. A *process-based* design used to improve shared situational awareness (left) contrasted with a *state-based* one (right). Adapted from Sarcevic et al. [2008].

Cirimele et al. [2014] aim at creating *crisis checklists* that are easy and fast to use. In order to find effective design strategies, they compared five diverse checklist styles and analyzed gaze patterns to assess the effectiveness of each.

Five different styles for crisis checklists were compared.

Their results show that checklists should use *dynamic focus* (i.e. change focus based on the context). This is important since gaze times are short, and doctors attention is a limited resource in crisis situations.

The focus needs to adapt dynamically based on the context.

Four key problems and emerging design concepts were identified.

Based on these initial findings, Wu et al. [2014] generalized key problems and emerging concepts that are crucial for the successful introduction of procedure aids such as checklists in *time-critical care*:

- **Information is often hard to find and share.** Aids need to be made visible to the whole team.
- **It is hard to multi-task with patient care.** The display needs to be simple and allow for speed reading.
- **Mixed acceptance discourages use.** Aids need to be reframed as part of the resource management system.
- **Attention is a limited resource.** The focus needs to be adapted dynamically based on the context.

Effects

Many studies have shown that checklists can improve the safety of care.

There is evidence that checklists can improve team performance and patient outcome in critical care. Haynes et al. [2009] measured performance metrics of 8 hospitals and showed that death- and error rates decreased after introducing checklists. Kelleher et al. [2014] and Parsons et al. [2014] analyzed the effect of a checklist on ATLS performance during trauma resuscitations. Their results show unanimously that the checklist led to improved performance scores and better protocol adherence. Thereby, the care provided became more uniform.

The effects of using checklists during teamwork were examined.

A thorough study on how checklists help to shape behavior and team dynamics during trauma resuscitations was conducted by Zhang et al. [2014]. They examined the use of a paper-based checklist during 48 simulated trauma resuscitations. Two different checklist administration methods were contrasted: *read-do* and *do-confirm*[4].

The reporting behavior of leaders was improved.

The results show that checklist usage doubled leaders reporting behavior. When using the *read-do* checklist use

[4] The authors used the synonymous terms *do-list* and *challenge-response*.

style, the leader's communication was equally distributed throughout the resuscitation. In contrast, the *do-confirm* checklist required the leader to call for a pause at the end of each phase. As a result, his communication behavior spiked towards the end of each phase. Even though this is a good mechanism for reflection, it is more time-consuming than the other approach. Since leaders never actively checked off items, it did little to distract them from other tasks.

Not only the leader's behavior was changed.

Moreover, both checklist styles increased the amount of communication between team members that led to fewer solo decision-making instances, a better role awareness, and better acknowledgment of communication (e.g., it was reported back that instructions were understood).

Negative implications were observed as well.

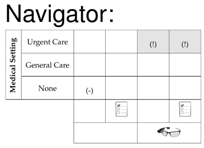
On the other hand side, increased communication caused some team members to become *reactive* as opposed to being *proactive*. Thereby, they became more dependent on the leader by waiting for prompts and questions.

Experts and novices can benefit from checklists.

Overall, the authors came to the conclusion that checklists are capable of improving the quality of critical care offering potential for experts and novices alike. By using checklists, the chance of deviating from the protocol or skipping tasks is reduced.

2.4.3 HUDs For Emergency Medical Teams

Navigator:



To the best of our knowledge, only Wu et al. [2013] published a short note in this field so far. They present preliminary work in the design and evaluation of head-mounted and multi-surface displays in supporting emergency medical teams with dynamic cognitive aids – such as interactive checklists.

Doctors need to split their attention.

Based on experiences gained in early projects, the authors state that doctors have to split attention between vital sign monitors, cognitive aids, the patient and other peripheral artifacts.

HUDs can offer support.

This easily leads to distraction, PAEs, and provides a challenge for the design of appropriate interactive information technologies. Personal HUDs offer opportunities to support effective aid use. Expanding the research in this direction is the goal of our project.

Chapter 3

Google Glass In Early-Stage HCI Research Projects

"Nothing ever becomes real till it is experienced."

—John Keats

As shown by the following timeline, Google Glass – as one of the first devices with a personal HUD – is still in its infancy:

A timeline for the introduction of Google Glass.

- **April 2012.**

  Google Glass was publicly announced.

- **April 2013.**

  Google Glass became available for Google I/O[1] developers.

- **May 2014.**

  As part of Google's *Explorer Program*, a more open beta became available to anyone in the US.

[1] Annual conference held by Google in San Francisco.

- **January 2015**.

  The beta period ended (i.e. the *Explorer Program* was closed).

- **February 2015.**

  It was announced that Glass will be completely redesigned under the lead of Tony Fadell, a former Apple executive. No public beta is planned.

A systematic, project-independent assessment is motivated.

Given both: the *beta status* and *novelty* of the used device, we decided for a systematic evaluation of the applicability for early-stage HCI research projects in general before considering it for the setting of this particular project: trauma resuscitation.

We assessed the applicability of Google Glass for early-stage HCI projects along four dimensions.

Even though every project is different, early-stage projects are often *exploratory* and open-ended. Beside other aspects, they might reveal manifold areas for technological support. If a technology such as HUDs is considered potentially suitable, researchers may want to try and evaluate many different ideas without wasting time of researchers or participants. Therefore, appropriate devices should be *reliable*, *socially accepted*, offer a large *design space* and allow for quick iterations of *prototypes*. The following section assesses Google Glass along these dimensions.

3.1 Assessing Applicability

The results of a 3-week wearing experience were triangulated with other sources.

The following assessment is mainly based on a 3-week wearing experience but also includes findings of others and considers experiences gained during the development of several *Hello World* applications for Google Glass.

3.1.1 Technological Maturity

Even though Glass works reliably, we do not see added value for private users.

We have not experienced any crashes or major problems but were able to confirm short battery lifetime and unpleasant heat generation while performing compute-intensive tasks as analyzed by Likamwa et al. [2014]. A TechChrunch[2] article entitled "As Developers Depart, Google Glass Is Ready To Become This Era's Segway" (November 2014) corresponds with our notion that it offers no added value for *private* users. It is mentioned that several app makers who targeted private users abandoned their efforts. However, they claim that *industrial* applications (e.g., training) offer a more promising future for Glass.

Head gestures, touch gestures, and voice input worked well. A literature review revealed that the device has successfully been applied in several research domains (cf. 2 - "Background And Related Work"). Hence, we do not see general *technological* problems that would hinder the use of Glass in early-stage HCI projects.

Technology-wise, Glass is mature enough for research purposes.

3.1.2 Social Acceptance

Especially the front-facing camera of Google Glass bares a privacy risk which is controversially discussed in literature (Mann [2012]). This might restrict the number of possible application domains – even for research purposes.

The front-facing camera raises privacy concerns.

Most publications that involved Glass did not explicitly address the issue of social acceptance. Others reported contradicting reactions (e.g., Muensterer et al. [2014]). For that reason, we decided to expose ourselves to this experience by wearing it for an extended period of time. We mainly observed other people's reactions but also noted our own feelings and concerns at different places (cf. Figure 3.1):

We paid attention to other people's reactions at various places while wearing Google Glass.

- **Workspace.** In the multidisciplinary research lab that we worked in, most people knew our objectives and did not express any concerns about being recorded. We felt comfortable wearing Glass.

No questioning glances were noticed in the research lab.

- **University campus.** We observed many interested looks that lead to subsequent conversations ("Why

Many people were interested in Glass on the university campus.

[2] A news website focused on information technology companies.

are you wearing that device?", "Are you recording me?"). The most memorable conversation was initiated by a librarian. She shared her impression that most people who wore Glass seemed to be *arrogant jerks*: "They gave the impression as if they would feel special because of Glass." This insight somehow influenced our own behavior, too. It suggested that one should try to forget about wearing Glass while being in public. Mostly, we felt comfortable wearing Glass on-campus since most students inferred that it was used for some type of research.

The interaction with Glass in public felt awkward and caused confused glances.

- **Public.** The very first experience was at the same time the most unpleasant one. When we picked up the prescription glasses for Google Glass and put it on for the first time, the responsible optician called together a few colleagues: "Look at him, he looks like a cyborg." Following this, people did not really notice us wearing Glass for a long time. Subsequent conversations showed that although most people have heard about Google Glass, most of them have not seen it yet. Neither in grocery stores nor while commuting we felt awkward *wearing* it. This changed drastically as soon as we started *interacting* with it. We responded to emails using voice input and navigated through the menu using touch input several times. Both interactions caused confused glances. Additionally, voice input often met with incomprehension. We experienced two situations that raised security and privacy concerns due to the head-mounted camera: (1) withdrawing money from an ATM, (2) using public restrooms.

Our impressions are not generalizable but motivate the need for further research.

Note that we do not claim that these behavior patterns and impressions are generalizable. We deem these experiences worthwhile sharing, though, as they motivate the need for further investigations.

Social acceptance is less of an issue in certain professions.

We consider implications of social acceptance especially relevant for *field-based* studies involving Google Glass and less important for certain professions as highlighted by Rebecca Greenfield, a staff writer at Fast Company:

Figure 3.1: Sample pictures taken with Google Glass. Research lab (left), public transportation and grocery shop (middle), ATM (right). Colored borders indicate subjectively perceived concerns (green = no concerns, orange = few concerns, red = high concerns).

> "Glass's main challenge in the real world – that it looks alien and is literally alienating – doesn't exist to the same extent in certain workplaces, where people already wear uniforms."

3.1.3 Design Space

A design space for Google Glass was created.

Having a design space to systematically brainstorm and discuss high-level system designs is especially helpful in early phases. To the best of our knowledge, we are the first who compiled an overview to serve that purpose (cf. Figure 3.2). We only included features *integrated* in Google Glass and deliberately omitted those that can additionally be leveraged by communicating with a connected cell phone (e.g., location sensor, vibration).

The design space is intended as a brainstorming aid.

It is suggested to use the design space as a *brainstorming-aid* and to work through it in the following order (anti-clockwise, starting with user interaction):

1. **User Interaction.** Choose one or more *general* interaction techniques (e.g., touch gestures) that might be suitable for your setting. Refine your ideas by adding *concrete* forms of interactions (e.g., short tap using 1 finger).

   The Glass Development Kit (GDK) includes a speech recognizer and a gesture detector that simplifies the detection of the listed touch gestures. Other forms of interaction can *be used but require manual processing of sensor readings. The main gestures available to navigate through Glass by default are illustrated in Figure 3.3.*

2. **Input Channels.** First, think of sensors needed for input of *control* (i.e. for navigating through the app). Assess possible risks associated with it (e.g. voice input leveraging the microphone is less reliable in noisy environments). Second, think of sensors needed for input of *data* (e.g., pictures, sounds, ...) captured by your application (if any).

   Note that the sensors needed for input of control are determined by the type(s) of interaction chosen in the first step: camera for video-based input, IMU sensors for head gestures, microphone for voice input, proximity sensor for winking, touchpad for touch gestures.

3. **Output Channels.** Think about output channels required for your application. Glass is mainly designed for visual but also offers support for auditory output.

   A HUD is used for visual output. Thereby, the information is constantly displayed in the upper right of the visual field of the user. It is important to note that – contrary to most peoples' intuition – this still requires to change the attentional focus for looking at the screen. According to the technical specifications, the screen is the equivalent of a 25 inch (63.5 cm) high definition (translucent) screen from 8 feet (2.4 m) away.

   Glass uses a Bone Conduction Transducer (BCT) to directly conduct sound to the inner ear through the bones of the skull. Alternatively, a regular earphone can be used. We consider the last-mentioned being less comfortable and audible, though.

4. **Connectivity.** Decide whether your application needs to run locally or requires communication with other devices using Bluetooth or WiFi.

   By connecting Glass to an Android cell phone using Bluetooth, additional sensor readings and output modalities that have not been considered in this design space can be leveraged (e.g., location, haptic feedback: vibration).

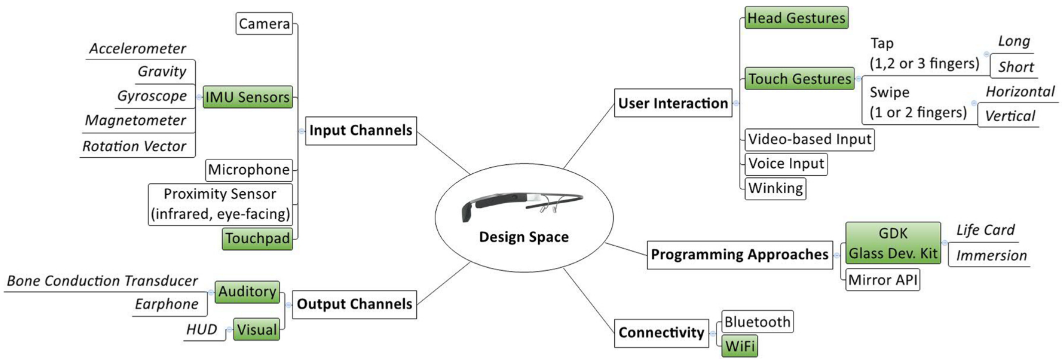


Figure 3.2: A design space for Google Glass. Those parts of the design space that were covered by a prototype introduced and evaluated in chapter 5 - "Evaluation" are highlighted in green. IMU stands for Inertial Measurement Unit.

5. **Programming Approaches.** Lastly, decide which basic programming approach to use to *realize* your application.

   The Google Mirror API allows to build web-based services that interact with Glass and provides functionality over a cloud-based API. Thereby, it does not require running code on Glass. For applications that run on Glass, the Glass Development Kit needs to be used. While life cards only appear in the present section of the timeline display (a default menu of Glass), immersions allow for more ways to create user interfaces and consume user input. It allows to create the most custom experience but involves the most work.

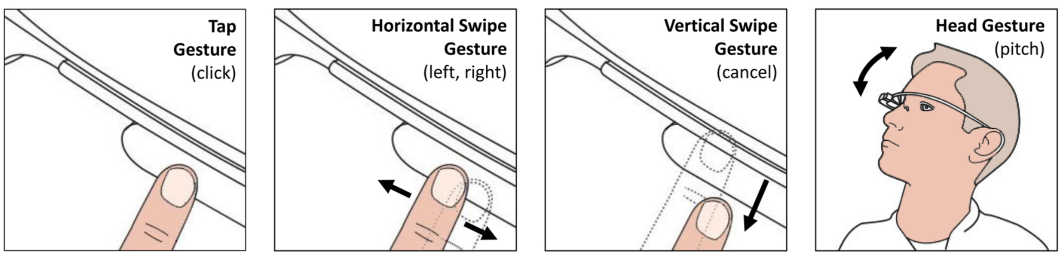


Figure 3.3: Gesture control for Google Glass. Illustration of 3 touch gestures and a head movement gesture that are supported by default.

3.1.4 Fast Prototyping Opportunities

Paper prototypes are suitable when designing for everyday devices.

Paper prototypes offer a simple way to get early feedback on user interfaces for everyday devices (e.g., tablets, smart phones, remote controls) by offering a similar *look* and *feel*. Additionally, it is worth noticing that most people have already used such devices before: they know how to navigate a mouse and click a button.

HUDs and interaction techniques offered by Glass are new to most people and require a different approach.

Figure 3.4 shows screenshots from a *video prototype* used by Google suitable to promote concepts and possible application areas for Glass. It is also shown how these concepts have been realized later on. By looking at these examples, though, it is hard to get a notion about how it feels to change the attentional focus between the screen and the world when wearing the device. This is because HUDs and interaction techniques offered by Google Glass are still new to most people. Therefore, we see the need for early-stage software prototyping on the device itself to convey the right *look* and *feel*.

Deep technical knowledge is required to realize prototypes on Glass.

During the development of several *Hello World* applications, we noticed that one needs profound knowledge in the following areas for that purpose:

- **Android.** One needs to understand several concepts used by Android in general (e.g. services, activities, activity lifecycle). Additionally, specialties only relevant for Google Glass need to be considered.

  Useful resource: "Beginning Google Glass Development" (Tang [2014])

- **Multi-threading.** In order to keep the UI responsive, long running computations should be taken off the Android UI thread. Callbacks become important.

  Useful resource: "Java Network Programming" (Harold [2014], chapter 3: Threads)

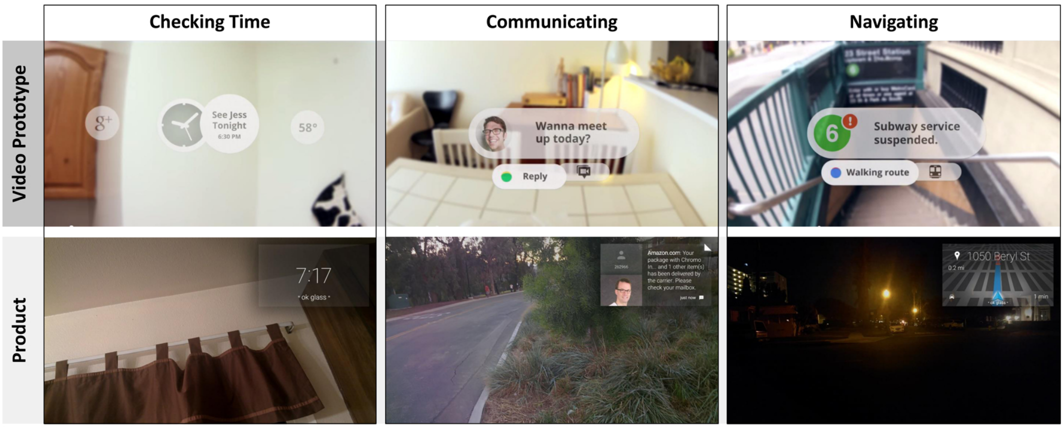


Figure 3.4: Video prototyping for Google Glass. Contrasting prototypes shown in an early concept video with the HUD-based visualization provided by Glass.

- **Network programming.** At latest when it comes to driving the content shown on the HUD externally (e.g. Wizard of Oz), a network connection to another application is required.

  Useful resource: "Java Network Programming" (Harold [2014])

We do not consider this as common knowledge that most HCI researchers have (including us at the beginning). It is desirable to allow for faster iterations and to simplify prototyping on Glass. To address these drawbacks, a prototyping framework was developed.

The need for a prototyping framework was identified.

3.2 Google Glass Prototyping Framework

Motivated by the need for a faster and simpler way to realize software prototypes, the *Google Glass Prototyping Framework (Google Glass PF)* was developed. It was kept project-independent and allows for manifold use cases across multiple domains.

A generic prototyping framework was developed.

An initial brainstorming session led to five high-level functional requirements:

We specified five functional requirements.

(F10) The framework must simplify the implementation and invocation of Android activities on Google Glass.

(F20) It must provide features that are reusable across multiple projects.

(F30) It must allow for transparent communication between multiple devices and applications.

(F40) It must fully handle network communication.

(F50) The user of the framework should need as little technical knowledge as possible.

Only one non-functional requirement was specified.

We constrained the development of the initial version only by a single non-functional requirement:

(N10) The framework should be easily maintainable and extensible.

The use of design patterns ensures maintainability and extensibility.

We addressed (N10) by using well-established design patterns as proposed in Gamma et al. [1994] throughout all modules in a consistent way. Most commonly, we used the *Observer* and *Singleton* patterns. A detailed source code documentation is provided. Therefore, only very few implementation details are included in this report.

The remainder of this section gives an architectural overview the framework, describes how the functional requirements have been addressed and discusses current limitations.

3.2.1 Overview

Figure 3.5 gives a high-level overview of the *Google Glass PF*. It consists of two main components.

A central server ensures transparent message distribution.

The central communication component is the *Dispatching Server* implemented in Java. Its main purpose is the

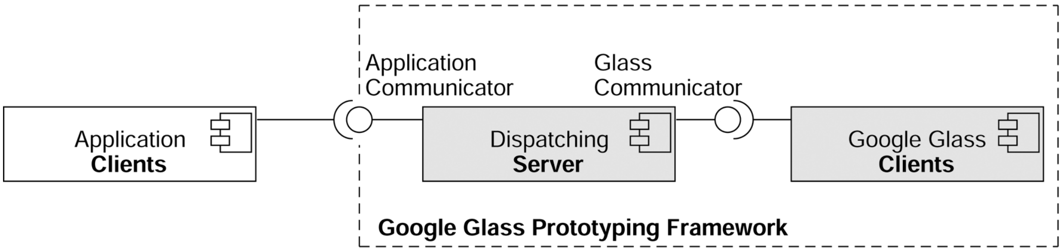


Figure 3.5: Composite diagram of the Google Glass PF. Required (socket symbol) and provided (lollipop symbol) interfaces allow for bi-directional communication.

transparent distribution of messages between multiple connected clients. Application Clients (here: arbitrary client applications) can connect using the Application Communicator interface provided by the server. In addition, multiple Google Glass Clients can connect using the Glass Communicator interface. Information exchange between all components must follow a specified *communication protocol*.

A *Google Glass Client* application is the second component of the framework. It simplifies the development of Android activities (i.e. user interfaces that allow for interactions with the user). It can either run in a *stand-alone* or *network mode* in which it connects to the Dispatching Server.

A client application simplifies the implementation of Android activities.

3.2.2 Communication Protocol

The communication protocol specifies how clients need to register at the Dispatching Server after a TCP/IP connection has been established, as well as the required format for subsequent exchange of information.

A communication protocol was specified.

After a connection has been established, the *Glass Communicator* interface only keeps client connections open if a unique identifier (e.g., Alicia) followed by a role (e.g., Trainee) is provided first. The *Application Communicator* interface only keeps connections open if a unique identifier is provided first (e.g., TrainerApp).

Initially, clients need to register at the server.

Subsequently, JSON is used as data exchange format.

For subsequent information exchange, JSON messages following a specified format must be used. Details of that format are explained based on the sample messages in Figure 3.6:

- **Payload (gray highlighting).** Independent of the client type, a `data` and `command` object must be included in the message. Each of them can contain a list of arbitrary key-value pairs (i.e. these lists may also be empty). In addition, messages sent to a Google Glass Client need to specify the targeted Android `activity`. Usually, receivers of messages use data items to update the UI (e.g., sample message 1 and 2) or for logging purposes (e.g., sample message 3).
- **Sender data (yellow highlighting).** This part includes information about the sender of a message. It only becomes relevant for settings where more than one Google Glass Client or more than one Application Client are involved. Only in these cases, the assignment of messages to senders is not obviously clear.
- **Receiver data (green highlighting).** This part includes information about the receiver of a message. Messages sent to an application must contain its unique identifier (`app.receiver.id`). Messages sent to Google Glass Clients may either include no recipient data, specify the recipients by a non-unique role (`recipient.role`), or a unique identifier (`recipient.id`). Semantically, that implies that a message is either broadcasted to all Google Glass Clients, to all clients of the specified role, or only to one specific client. The most specific information is used [3].

JSON is used for many reasons.

We decided for JSON as data exchange format because it is human-readable and thereby allows for a transparent communication (F30). Additionally, it only requires little technical knowledge (F50). For Java-based applications, JSON.simple[4] simplifies encoding and decoding of JSON messages.

[3]If a message specifies a recipient id and role, the role is ignored.
[4]https://code.google.com/p/json-simple

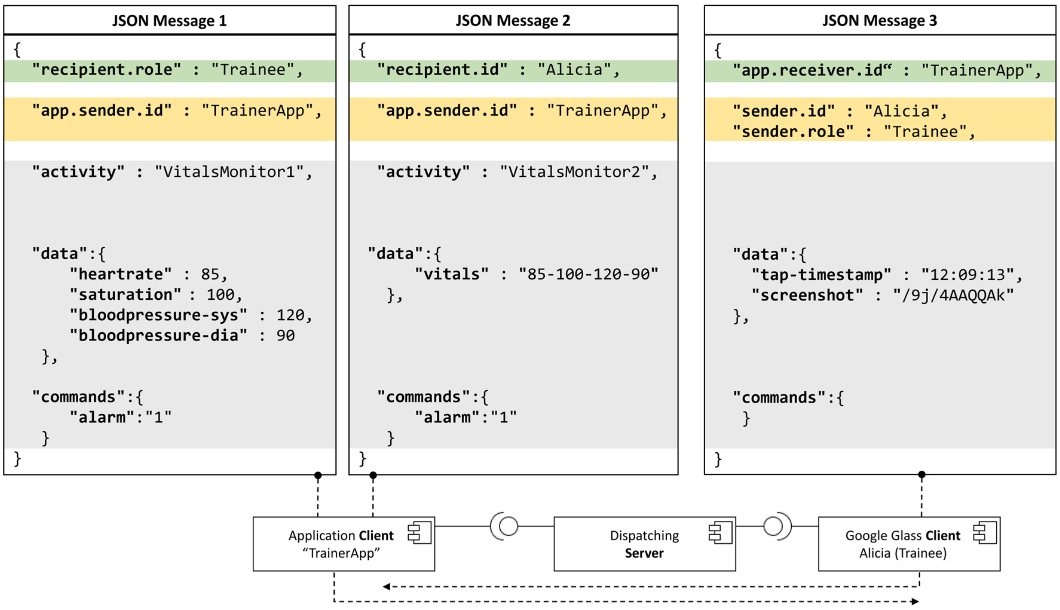


Figure 3.6: Sample JSON messages. Message 1 and 2 are sent from an application to Glass (via the server). Message 3 is sent from Glass to an application (via the server). Gray highlighting: data added by sender and interpreted by receiver(s), yellow highlighting: data added by server and interpreted by receiver(s), green highlighting: data added by sender and interpreted by server.

Despite the above constraints on the message format, developers can still balance performance considerations themselves by trading readability for shorter messages. This becomes clear when contrasting the lists embedded in the data objects of message 1 and 2 in Figure 3.6. Both messages transmit the same content. Message 1 is easier to understand, but the format used in message 2 has a better *information theoretic efficiency* (i.e. the ratio between the length of the payload and the overall length is higher):

Developers can trade readability for better performance.

- **Message 1**. The data list is 78 characters long (whitespaces ignored). The length of the payload[5] is 10. Information theoretic efficiency: 12.8%.

- **Message 2**. Overall, the data list is 24 characters long (whitespaces ignored). The length of the payload[6] is 15. Information theoretic efficiency: 62.5%.

[5] 8510012090 (concatenation of all numeric values)

[6] "85-100-120-90"

3.2.3 Dispatching Server

The server allows for a transparent exchange of messages between multiple clients.

The Dispatching Server handles the transparent exchange of messages between Glass and Application Clients (F30). It abstracts away details of network communication (F40) and does not require project-specific customizations (F50). Nonetheless, it also helps to understand the internals for troubleshooting purposes. An overview of the layered architecture is given in Figure 3.7.

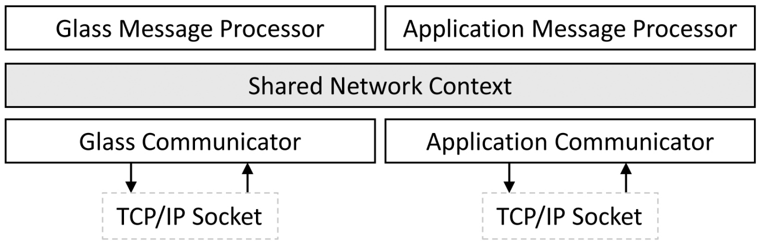


Figure 3.7: Layered architecture of the Dispatching Server.

- The *Communicator Modules* on the lowest layer handle connection requests and aborts. They register and unregister clients in the Shared Network Context using the provided id and role (cf. 3.2.2 - ”Communication Protocol”). Additionally, they provide support for receiving data from and sending data to the clients. Received messages are forwarded to the next layer for further processing.
- The *Shared Network Context* keeps track of the current runtime status (e.g., number of received and sent messages, details on connected clients). As soon as an incoming or outgoing message is passed to it, appropriate modules that need to further process the message are notified.
- The *Message Processors* decode and interpret incoming JSON messages and encode outgoing ones.

We illustrate how a sample message is processed by the Dispatching Server.

JSON message 1 introduced in Figure 3.6 is used as an example to explain how a message sent by an Application Client (TrainerApp) and addressed to all Glass Clients of a specified role (Trainee) is processed within the Dispatching Server. Figure 3.8 gives an abstract representation of message processing internals. Given the *direction* of the message flow of the above example, the *Application Message Processing Pipeline* is relevant here:

- **Logger.** As soon as the message is received by the Glass Communicator, it is logged by default. The Log4J[7] framework is used for that purpose and allows to configure multiple output destinations and formats.
- **Verifier.** Ensures that the message conforms with the communication protocol as specified in section 3.2.2 - "Communication Protocol". The sample message does. If it would not, it would be discarded and not further processed.
- **Enricher.** The Dispatching Server knows that the message was received from the Application Client with the identifier TrainerApp since it keeps track of the registration data in the Shared Network Context. To reduce the message size, this information does not need to be included in the JSON message from the Application Client to the Dispatching Server (cf. Figure 3.6, yellow highlighting). However, this information would be lost as soon as the message is passed on. The Enricher therefore adds this information to the message (if not already included).
- **Optimizer.** Removes unnecessary whitespaces and redundant information to reduce the message size to a necessary minimum. While doing so, recipient data (role=Trainee) is extracted, temporarily stored and removed from the message (cf. Figure 3.6, green highlighting).
- **Dispatcher.** Based on the stored recipient data, the message is sent to appropriate clients (i.e. to all connected Glass Clients with the role Trainee).

[7] http://logging.apache.org/log4j/2.x

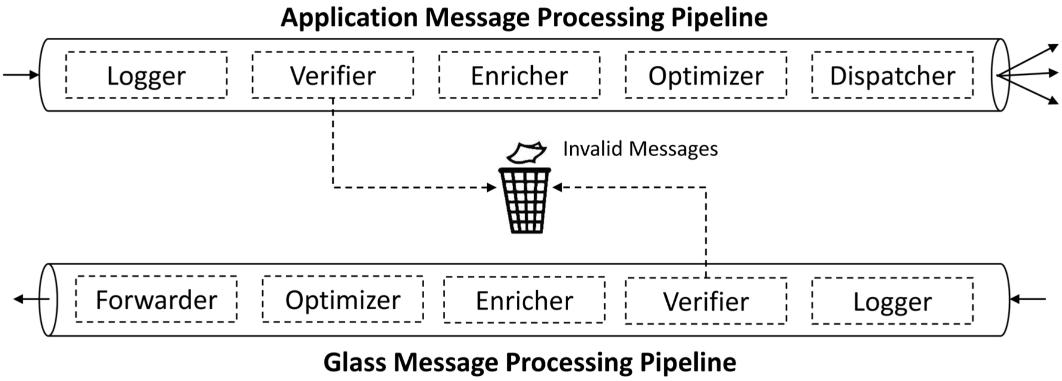


Figure 3.8: Message processing pipelines. The *Application Message Processing Pipeline* handles messages that Application Clients send to Google Glass Clients. The *Glass Message Processing Pipeline* handles messages that are sent in the opposite direction.

There is a slight difference in the two message processing pipelines.

Messages sent by a Glass Client and addressed to an Application Client are analogously processed by the *Glass Message Processing Pipeline*. Messages in this direction can only be forwarded to a single recipient. This explains the slight difference between the two processing pipelines (using a *forwarder* instead of a *dispatcher*).

3.2.4 Glass Client

The development of prototypes for Google Glass is simplified.

The Glass Client runs on Google Glass and simplifies the development and evaluation of prototypes on the device (F10). Figure 3.9 gives an overview of the underlying menu structure which is designed to be extended by project specific data. To allow for a consistent experience across all applications, it follows the Google Glass Design Patterns[8].

Two different modes support user-centered design processes.

The remainder of this section discusses how the two different modes of the Glass Client can be used during *user-centered* design processes. We use the development of a sample screen that visualizes vital signs as a running example.

[8]https://developers.google.com/glass/design/patterns

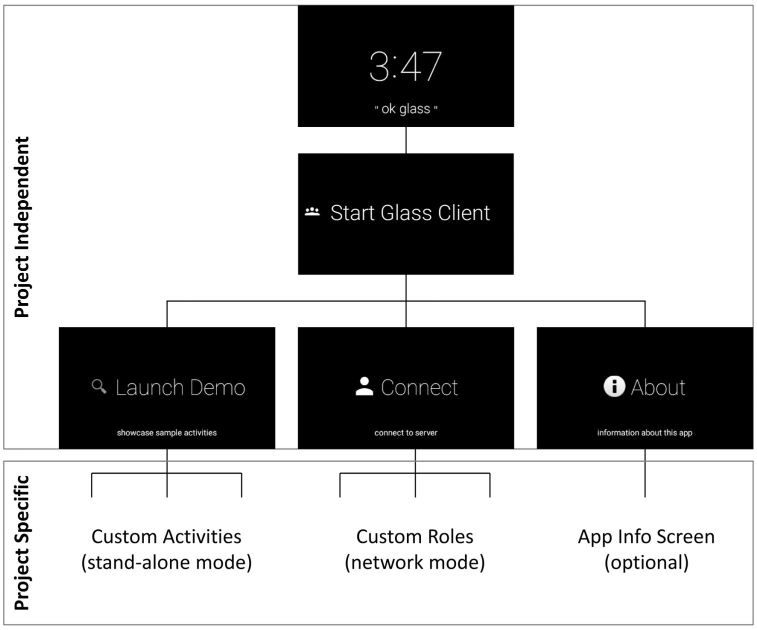


Figure 3.9: Menu structure of the Glass Client. It allows for project specific extensions. Tap (down) and cancel (up) gestures can be used to navigate vertically through the menu tree. Swipe gestures allow for horizontal navigation.

Stand-Alone Mode

The stand-alone mode allows to quickly present ideas on the device itself and to invoke custom activities via a simple menu (F10). Exemplary, this mode is used to contrast text-based with graph-based visualizations of vital signs on the HUD. The steps required to realize corresponding low-fidelity software prototypes are described in the following.

This mode allows to quickly try software prototypes locally.

At first, two Android activity classes need to be created: `VitalsMonitor1` and `VitalsMonitor2` (cf. Figure 3.10). They subclass from `GlassBaseActicity` that offers access to commonly used functionality (F20). Android's Layout Editor [9] is used to design the user interface for both activities. Subsequently, only three methods need to be implemented for each class:

It only requires a few steps to add custom activities.

[9] https://developer.android.com/sdk/installing/studio-layout.html

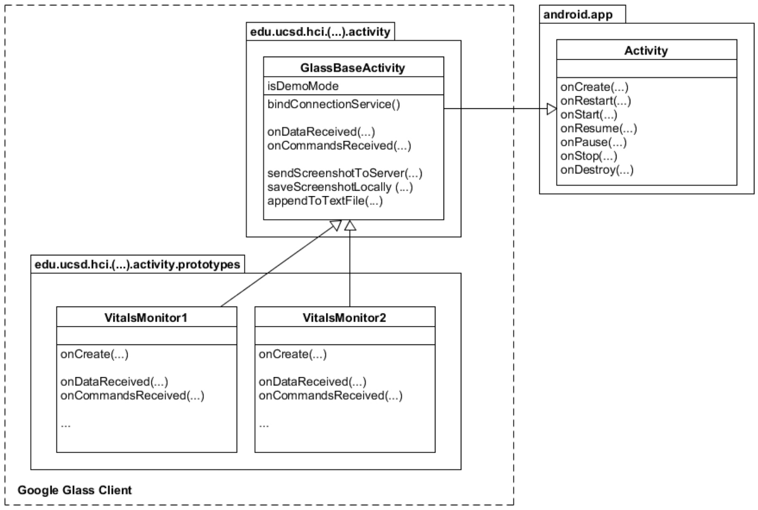


Figure 3.10: Partial class diagram for two sample activities (VitalsMonitor1, VitalsMonitor2).

- `onCreate(...)` This method is part of the Android activity lifecycle and invoked as soon as an activity is started. It is used to create a binding between UI widgets and code elements. Additionally, we specify how to react on user input. In this case, random values for the vital signs are generated every time the user taps on the touchpad. These values are passed to the `onDataReceived` method for further processing.

- `onDataReceived(...)` This method specifies how to react on incoming data (e.g., vital signs). In this case, corresponding UI elements are updated accordingly.

- `onCommandsReceived(...)` This method specifies how to react on incoming commands (e.g., play alarm sound).

Use this mode for early design decisions.

Afterwards, the activities can be invoked locally via the *Launch Demo* menu (cf. Figure 3.9) and discussed with users at early stages. For our example, it is used to identify which of the two options is more appropriate to visualize vital signs on the HUD.

Network Mode

The network mode allows to simply exchange data with other applications using the specified communication protocol (cf. 3.2.2 - "Communication Protocol"). Exemplary, we use this mode in the following to retrieve vital signs provided by an external application.

This mode allows to communicate with other systems.

A connection to the Dispatching Server needs to be established first. For that purpose, the Connect menu is used and a role is selected (e.g., Trainee). Thereby, an Android *background service* is started that abstracts away network communication details (F40). We assume that an external application (e.g., TrainerApp) periodically sends messages containing information about the vital signs. Based on these information, the vital signs can be updated in real-time on the HUD. Moreover, custom messages can be sent back to the application. Figure 3.11 illustrates how such messages are processed by the Glass Client:

It is possible to retrieve and process data from external sources in real-time.

- **Connection Service.** Long-running Android background service that forwards in- and outgoing messages and manages the connection to the Dispatching Server.
- **Message Handler.** Decodes messages and forwards payload (data, commands) embedded in a `HashMap` to targeted activities. If they are not already active, they are started first.
- **Activity.** Processes incoming data and commands within the `onDataReceived` respectively `onCommandsReceived` methods. Sample message 1 (cf. Figure 3.6) would cause an update of the values of the vital signs and trigger an alarm sound. Again, helper methods implemented in the `TraumaGlassBaseActivity` can be used. Exemplary, we use it to periodically send screenshots of the HUD to the application (TrainerApp).

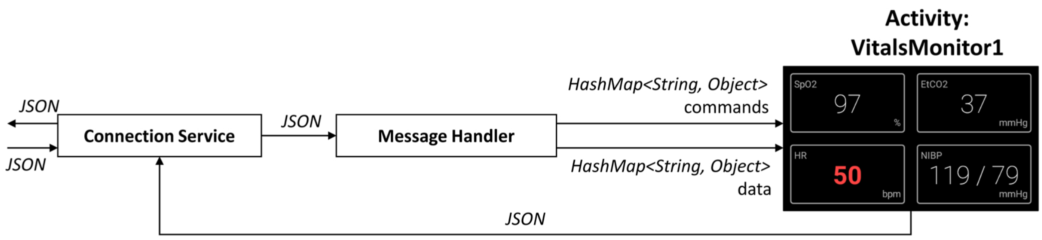


Figure 3.11: Internals of the Glass Client. An overview of key modules and message flows.

3.2.5 Limitations

Three issues limit its applicability.

We are aware of three issues of the current version (V1.0) of the *Google Glass PF*.

- **Reliance on stable WiFi connections.** The Dispatching Server as well as the Glass Client follow a send-and-forget paradigm for sending messages. As long as the network connection is stable, the usage of the Transmission Control Protocol (TCP) guarantees delivery of data. However, we have experienced unexpected connection issues caused by Google Glass.

  Workaround: place the WiFi router as close to the devices as possible while using the network mode of the Glass Client. This limits the number of connection resets to a reasonable level.

- **Performance.** Our tests revealed that the Glass Client could not process more than one incoming message per second in real-time when rendering a more complex UI (e.g., a line graph). Additional performance tweaks are necessary.

  Workaround: keep it simple and limit the frequency of incoming messages. Always remember: you are designing a prototype that should give users only a first feeling of your idea.

- **Glass-to-Glass communication.** The Dispatching Server does not support directly forwarding messages from one Glass Client to another. Direct communication between two Glass Clients is not supported.

  Workaround: Send a message from Glass Client A to an Application Client and have it forward the message to Glass Client B. Even though this causes additional transmission delays, it should still be acceptable for most scenarios.

Despite the above limitations we were able to benefit from the Google Glass PF in a first project. We used the Glass Client in the *stand-alone* mode to get feedback on early software-prototypes (cf. 4 - "Design Approach"). Based on the input we got in that phase, we developed a setup that allowed for a more thorough evaluation using the *network mode* and the Wizard of Oz technique (cf. 5 - "Evaluation").

We benefitted from the framework during the following design and evaluation process.

Chapter 4

Design Approach

"Fail frequently, fail fast."

—David Kelley

This chapter addresses the second, human-centered research question. We conducted interviews with trauma doctors and observed training sessions to get a better understanding of workflows and current practices during trauma resuscitation. Based on these insights, problem areas that offer opportunities for technological support were identified. Finally, it was assessed which of these could be addressed by HUDs.

Problem areas that offer opportunities for HUD-based support needed to be identified first.

Figure 4.1 presents an overview of the design and evaluation process that guides the elaboration in this (steps 1-5) and the following chapter (steps 6-8). Note that even though we followed a linear process, concept drafts and prototypes were improved iteratively along the way. Our approach is tightly aligned with IDEO's *Human Centered Design Toolkit* (IDEO [2011]).

Our design and evaluation process consists of 8 steps.

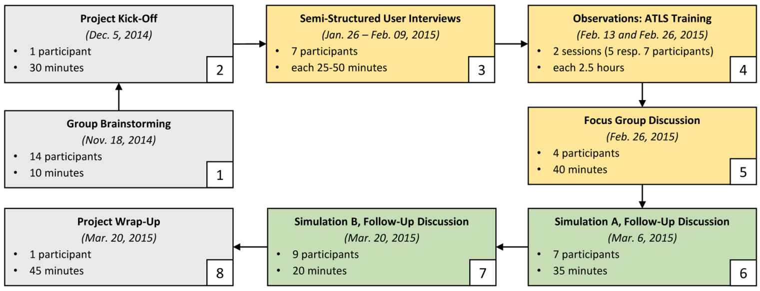


Figure 4.1: Overview of our design and evaluation process. Preparatory discussions and a debriefing session are highlighted in gray, user-centered design methodology is highlighted in yellow, and evaluation steps are highlighted in green. Steps 1-5 are discussed in this chapter, steps 6-8 in chapter 5 - "Evaluation".

4.1 Group Brainstorming

14 people from multidisciplinary backgrounds participated in a brainstorming session.

In order to get feedback on risks and opportunities at an early stage, we organized a brainstorming session in a multidisciplinary design lab. In total, 14 people with various levels of academic and professional experiences attended. The participants had diverse backgrounds in areas such as computer science, cognitive science, design, and psychology.

The participants were split into groups and discussed three different questions.

After a short introductory presentation about previous work, motivations, and goals of our work, the participants were split into three groups (cf. Figure 4.2). Each group was assigned a different guiding question, a specific thinking style (see de Bono [1985]), and provided with note-taking sheets. Individual group discussions were limited to ten minutes. Subsequently, each group provided us with the results of their discussions.

- **Group A. Green hat thinking style (creativity).** How to find out what kind of additional support trauma teams need?

  Feedback summary: The most suitable approach at the beginning is ethnographic research. This helps to gain a bet-

ter understanding of what is really going on today. People often cannot describe what they really need. The head-mounted camera of Google Glass is useful to capture where people are looking at in different situations. A subsequent discussion of these recordings with the doctors can help to identify unexpected issues.

- **Group B. Green hat thinking style (creativity).** What needs to be considered during evaluations of system designs?

  Feedback summary: One needs to take care to consider acceptance at two different levels: doctors and patients. It is important to differentiate between effectiveness (doing it right) and efficiency (doing it fast) when evaluating whether or not a system improves specific workflows. It needs to be noted whether or not people are really using the system or if there are any unforeseen shortcuts or workarounds. If time and resources do not allow for realistic simulations, the narrative simulation paradigm introduced in Wu et al. [2014] is a promising alternative that enables rapid, controlled experiments of how supporting aids affect medical performance.

- **Group C. Black hat thinking style (cautions).** What are typical pitfalls? What could go wrong?

  Feedback summary: Do not try to design the system such that it motivates people to completely rely on automation. In time-critical medical settings, there must always be a way that allows people to continue working when the system fails. HUDs as such might be too distracting for this setting in general as they still require a switching of attention – even though the display is in the field of view. People may not be able to focus on the actual tasks while looking at a HUD.

Some ideas influenced our approach, others relate to future work.

Even though not all aspects and concerns were applicable to our project, the above feedback influenced parts of the further design process. We used Google Glass, for example, to record where people are looking at in order to find out what kind of additional support trauma teams need. Other aspects that could not be applied to our project were considered to give recommendations for future work (cf. 6.3 - "Future Work").

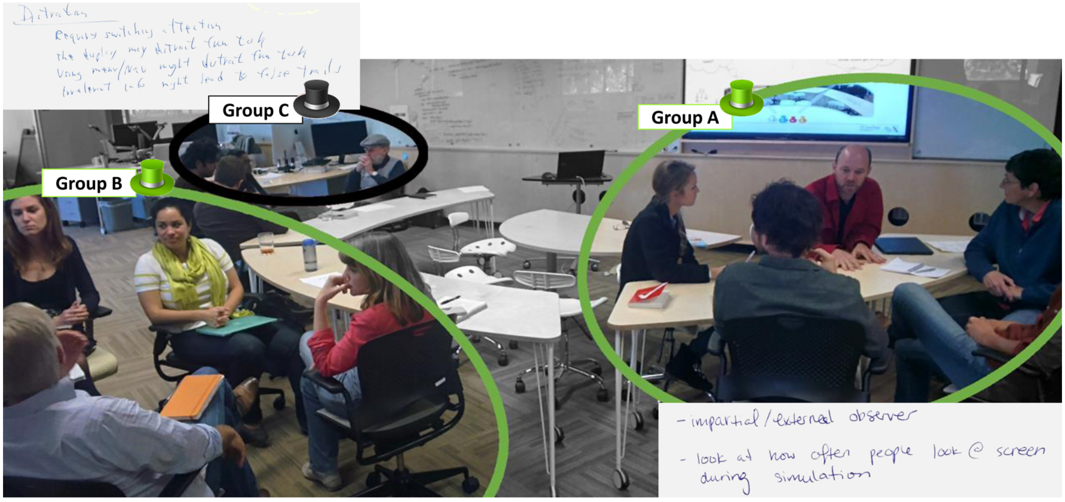


Figure 4.2: A preparatory brainstorming session. It was conducted in the multidisciplinary Design Lab at UC San Diego. Each group was assigned a different guiding question and a specific thinking style. Compare *Six Thinking Hats* (de Bono [1985]).

4.2 Project Kick-Off Meeting

We identified people to speak with.

A kick-off meeting with a fully trained trauma surgeon at the Hillcrest Medical Center at UC San Diego was scheduled to discuss the scope of this project and to initiate the collaboration with further trauma doctors that are willing to share their insights.

A collaboration with a Level I trauma center was initiated.

The Medical Center meets high quality criteria, is capable of providing the highest level of surgical care to trauma patients 24/7, and is therefore ranked as a Level I trauma center by the American College of Surgeons. A high-fidelity patient simulator is available on-site and used on a (bi-)weekly basis for training purposes.

We got contact information of trauma doctors and were offered access to training sessions.

We were provided with contact information of 13 trauma doctors with different experience levels. All of them were told in advance that we might contact them and that we are working on a research project involving Google Glass. Additionally, we were offered the chance to observe ATLS training sessions that incorporate the aforementioned patient simulator.

Due to legal and privacy concerns, video reviews of real trauma resuscitations were not considered suitable. Although shadowing trauma doctors during real resuscitations is generally possible for research scientists, it would have required time-consuming paperwork and additional vaccinations. Given the limited remaining time, we decided – for our initial project – against doing this and focused on user interviews and observations of training sessions instead.

Due to time, legal and privacy reasons it was decided not to observe real resuscitations.

4.3 Semi-Structured User Interviews

We conducted 6 semi-structured user interviews with trauma doctors as a first part of our user-centered design approach (cf. Figure 4.1). The interviews were conducted over the course of 2 weeks. On average, each interview lasted 45 minutes (min. duration: 25 minutes, max. duration 50 minutes). 4 out of 7 interviewees (57%) were female. The participants had between 1 and over 10 years of experience in trauma resuscitation. Details are presented in Table 4.1.

6 semi-structured interviews with trauma doctors were conducted.

All interviews were recorded (audio) and transcribed with the consent of the interviewees. We used InqScribe[1] to transcribe the recordings and the Transcript Annotator – a self-developed tool based on Microsoft Excel – to simplify annotation, categorization, and filtering of transcribed data. Details can be found in Appendix B - "Transcript Annotator".

The interviews were recorded and transcribed.

4.3.1 Interview Guideline

An interview guideline was created to support the interview process. It is attached in Appendix C - "Interview Guideline". We classified our questions as suggested by Liz Danzico at a UX design conference in London: User Interview Techniques - The Art of the Question[2]. Addi-

An interview guideline was used.

[1]https://www.inqscribe.com
[2]http://www.slideshare.net/edanzico/user-interview-techniques

Interview Details			Interviewee Details		
Id	Date	Duration	Id	Gender	Experience
A*	01/26/15	45 min.	I1	f	1 year
B	01/28/15	50 min.	I2	m	3 years
C	02/02/15	40 min.	I3	m	7 years
D	02/06/15	25 min.	I4	f	$>$ 10 years
E*	02/06/15	50 min.	I5	f	3 years
			I6	m	6 years
F	02/09/15	30 min.	I7	m	$>$ 10 years

Table 4.1: Interview and participant details. * = interviews included site visits to the trauma bay while no patients were treated there.

The guideline consists of 4 parts.

tionally, tips for user interviews mentioned in IDEO [2011] were included (e.g., using the aspiration cards method to learn about aspirations for the future). The resulting interview guideline is divided into 4 parts. A typical interview procedure is outlined in the following.

1. **Assessment of medical experience.**
   - Interviewees were given a short introduction about our short- and long-term project goals to stress the importance of their insights.
   - Information about the interviewee's experience with trauma resuscitations were queried as this influenced how to interpret their statements. However, their age was not considered important for this purpose and therefore disregarded.
2. **Open-ended questions.**
   - The interviewees were asked to walk us through a typical trauma resuscitation. Thereby, they should reflect on different aspects such as time-critical tasks or team communication issues.
     Question type: sequence.
   - We asked about past changes (e.g., technological support, workflows) to learn about potential for future improvements.
     Question type: look back.

- Tools used during trauma resuscitation (e.g., technical devices, protocols or personal strategies) should be listed and described.

  Question type: exhaustive list.

- Interviewees were asked what they think it will be like to work in the trauma bay in 10 years. They were asked to think of things that might stay the same and things that might change.

  Question type: project ahead.

- Based on insights gained from related work and own ideas, we compiled several cards that listed possible application areas for personal HUDs in the context of trauma resuscitation. We asked the interviewees to add their own ideas and to choose two cards that represent most promising application areas. They should explain why they think so.

  Method: aspiration cards

- Google Glass was presented to the interviewees, but they were not allowed to try it yet. They should imagine it would be introduced in the trauma bay soon. Without focusing on specific functionality, participants were asked to mention their two biggest concerns.

  Question type: scenario-based.

3. **Google Glass hands-on experience.**

- Interviewees were offered the chance to try Glass (optional). For that purpose, three scenarios were prepared that covered multiple ways of user interaction (touch and voice input) as well as both output channels: visual and auditory (cf. 3.1.3 - "Design Space"). A sample scenario that helped to familiarize the interviewees with Glass is presented in Figure 4.3.

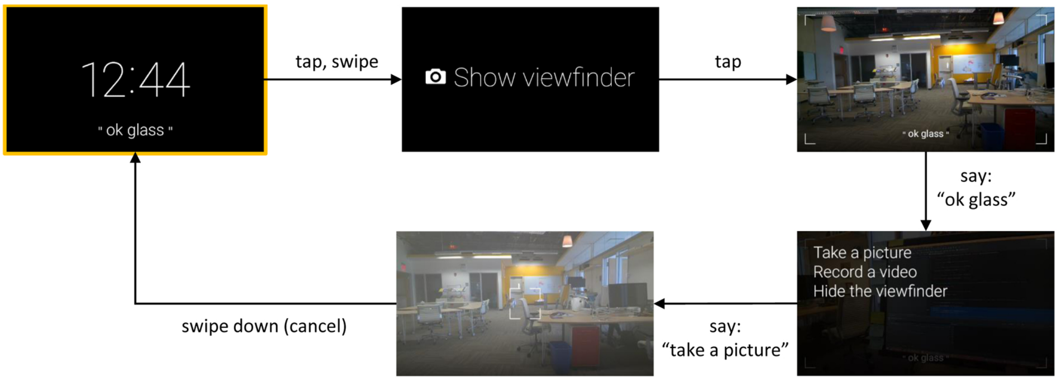


Figure 4.3: Google Glass scenario walk-through. This example scenario was used (inter alia) to familiarize the interviewees with the device.

4. **Post-interview questionnaire**[3].

   - Interviewees were asked to self-assess their interest in new technology and to rate potential for HUDs during real trauma resuscitations or trauma resuscitation trainings.

Not all interviews strictly followed that guideline.

Subsequent to the interviews, we offered the chance to ask questions and share further information. While the first interviews (A-C) were tightly aligned with the above guideline, we decided for a more open discussion during the remaining interviews (D-F).

4.3.2 Findings

We got a better understanding of trauma resuscitation.

The interviews gave us a better understanding of roles, responsibilities, and current issues in the trauma bay. We got an initial feeling of opportunities for additional technological support and learned which concerns interviewees had towards Google Glass. The following discussion is organized along those dimensions.

[3] Due to the small number of interviewees, we only mention general trends in the following discussion and decided against a quantitative analysis.

Roles and Responsibilities

An overview of a typical trauma team composition was created based on insights gained during the interviews. It is presented in Figure 1.1 in the introduction. Further details are discussed in the following.

An illustration of a typical trauma team composition was created.

A few minutes before a trauma patient arrives at the hospital, all members of the trauma team are paged and start preparing for the case in the trauma bay. A trauma team usually involves several doctors, nurses as well as technicians. One interviewee gave the following overview while walking us orally through a typical trauma resuscitation:

All team members are paged before the patient arrives.

> "Doc 1 – the head person – runs the trauma. There are two assistants [Doc 2 and Doc 3]. Also, there is a nurse that helps with IVs [intravenous injections] and vitals (...), and then there's any number of helpers that can lend their hands. The tech [Technician] will be running orders, running blood. There are radiology techs that are also here to take x-rays and then there are ultrasound techs that come and get ultrasounds in (ehm) for immediate trauma evaluation. An attending supervises the team while filling out the trauma attending form [cf. Appendix A - "Additional Resources: ATLS"] and makes sure that things are flowing ok. If anyone needs help or cannot – for whatever reason – function effectively, then the attending will step in and kind of take lead." (I2)

There is a fixed distribution of tasks during trauma resuscitations.

Doc 1 is usually a mid-level resident, Doc 2 and 3 can also be interns or medical students (I4). All these roles are subordinate to the attending as most experienced team member (I1).

Roles are assigned based on experience levels.

Running the trauma means that Doc 1 starts with the primary survey of the ATLS protocol. This can be done in about 1-5 minutes unless the patient is severely unstable (I1). In parallel, Doc 1 communicates his or her findings

One differentiates between a primary and secondary survey.

and instructs other team members how to assist. Subsequently, it is continued with a head-to-toe evaluation of the patient: the secondary survey (I1-I6).

The exact procedures differ from hospital to hospital.

It was reported that even though trauma is a highly protocolized domain, the team composition and general procedures can differ between hospitals (I3, I6). The trauma team that we cooperated with does not have a dedicated scribe for instance. Therefore, preexisting knowledge about team roles and responsibilities cannot directly be transferred from research projects in other trauma bays (e.g., Kusunoki et al. [2014] or Sarcevic et al. [2008]).

Trauma Resuscitation Issues

Most issues occur during the care of critically injured patients.

Trauma resuscitation is a very protocolized area of medicine. Every team member has their own role, and it is the same procedure over and over again (I2, I3). Therefore, no problems or general issues were reported for routine cases that are treated multiple times a day. "I mean I think the system works pretty well" (I5). However, when very instable patients are admitted to the trauma bay, it can get chaotic at times (I1). Especially in these cases, the interviewees see room for further improvements and mentioned miscommunication and the positioning of the vital sign monitors as major issues.

Communication issues are the greatest barrier.

The following quotations underline why communication still is a big problem source:

- "I think one of the biggest difficulties and one of the things where we go wrong on the service or any service at all is team communication. Especially with a high-volume service as this one where little things can get miscommunicated or not communicated at all." (I1)
- "We sometimes get a lot of people trying to speak. Then it's harder to decide who is the team leader, what is going on, what's the next step we should do." (I2)

- ″I think that we still have a problem in communicating all of our findings and concerns really well.″ (I3)
- ″If they are actually sick, there are so many people, there is so much noise (...) I usually can't hear anything.″ (I5)
- ″Many errors happen when there is false communication.″ (I5)

In summary this means that both environmental conditions (noisy environment, many people) and a lack of awareness about the importance of communication may often lead to problems.

There are many reasons behind communication problems.

Other complaints reported by the majority of the interviewees are due to the positioning of the vital sign monitor at the head end of the patient table (cf. Figure 1.1). The problem that there is no optimal position for shared screens was already recognized in previous work (see Wu et al. [2014]) and is evidenced by the following statements:

Doctors need to turn around or look up to check the vital signs on a monitor.

- ″Doc1 is so focused on things that even to turn around to look at the vital signs takes up too much time (...) you'd be surprised, but in that stressful situations even the slightest inconvenience seems like it's quite a big inconvenience.″ (I1)
- ″I mean that's the thing: I don't look up, you know. Yeah. I tend not to look up [to check the vitals].″ (I5)

Another minor issue that was reported is that the attending – in his role as passive supervisor – cannot always see what is going on because there are so many people actively involved in patient care: ″[...] we [as an attending] sometimes just can't simply get in there and see what Doc 1 is looking at [even though that is important for supervision].″ Interviewee I2 does not see a solution to this problem, though: ″You just can't tell the nurse to not be there cause she has to get vitals (...) people simply take up space.″ However, participant I5 sees it differently: ″the attending is the boss, the attending gets just everyone out of their way.″

The supervising attending cannot always see what is going on.

Opportunities For HUD

The aspiration card method was used to identify opportunities for HUD-based support.

By using the aspiration card method, we asked the interviewees to choose from possible application areas for personal HUDs and explain the reasoning behind their choices. A HUD was described as a way to visualize arbitrary information in the field of view. Table 4.2 gives an overview of approval ratings for the selected cards. We did not use this method during interview D and F due to lack of time.

Aspiration Cards / Interviewee Ids	I1	I2	I3	I5	I6	Score
Improving training procedures.	+		++		+	4
Improving team communication.	+	++	+			4
Increasing shared situational awareness.	++					2
Improving ATLS compliance.				−		-1
Reducing cognitive load.				−−		-2

Table 4.2: Approval ratings for aspiration cards that present possible application areas for personal HUDs (++: interviewee strongly agreed, + interviewee agreed, − interviewee disagreed, −− interviewee strongly disagreed). Since all cards have not been discussed in all interviews (cf., empty cells), the cumulative score only has a limited significance.

Trauma resuscitation training offers manifold application areas for HUDs.

Improvement of *training procedures* is the favored application scenario for HUDs. I1 came up with the idea of watching instructional videos while performing tasks (e.g. in order to learn how to put in chest tubes). Two others (I3, I6) had a different idea: ”if there was a way to put on a screen exactly what needs to be done, when it needs to be done and who is responsible for doing it (...) I do think for training that would be helpful.” The general notion of training being a better initial application area for HUDs than real resuscitations was confirmed by the post-interview questionnaire that showed consistently higher ratings in this area.

It remains unclear whether HUDs can help to improve team communication.

Three interviewees chose *team communication* as suitable application area but only mentioned very vague ideas of how HUD could offer additional support. We attribute the high approval rates to the fact that team communication is one of the biggest difficulties that needs to be addressed. However, whether or not this offers an opportunity for which HUDs are specifically suitable still remains an open question.

Only interviewee I1 reported that she sees opportunities for HUDs to *increase shared situational awareness* amongst team members. Sometimes, she finds it hard to follow along the exam and doubts that everyone else does. She would like everyone to know what is going on at any point in time. Given her experience level (1 year), we assume that this only applies to doctors that are relatively new to trauma resuscitation.

For unexperienced trauma doctors it is hard to follow along the exam without further assistance.

Interviewee I5 chose to discuss areas where he definitely does *not* see opportunities for HUDs. He does not see a need to reduce cognitive load during trauma resuscitation since there is already enough redundancy built into the system. Doctors that have run many trauma resuscitations do not need assistance that aims at improving protocol compliance.

It is unlikely that experienced trauma doctors need further assistance.

During the course of an interview with another experienced trauma doctor (I4), it was revealed that she sees only one useful application scenario for HUDs: "[...] for somebody who has done tons of thousands of resuscitations, the only thing that might be helpful is to have vitals so they are always in front of my face. Otherwise – when I get really busy doing something on the patient – I may not see that the vitals have changed."

The visualization of vital signs on a HUD is deemed to be the only useful application scenario for experienced trauma doctors.

Concerns Towards Google Glass

Part of the incentive for the trauma doctors to share their insights with us despite their long shifts and busy schedules was the fact that we announced to offer an optional hands-on experience with Google Glass as part of our interviews. All interviewees made use of this chance and provided us with valuable feedback. Figure 4.4 shows the perspective of two participants while trying Google Glass for the first time. In the following, we will focus on concerns they had before, during, and after their hands-on experience.

We identified concerns of the interviewees before, during, and after they tried Glass for the first time.

Half of the interviewees were short-sighted. They were concerned that they would not see anything at all ("Do they go over my prescription Glasses?" (I5), "I don't know of my

Two interviewees expected the HUD to be in the way.

contacts if that would be a problem." (I2)). Affordability-wise, it was not considered suitable to have new lenses for everyone if Glass would be rolled out to the trauma setting in the future. I1 and I3 suspected that the screen would be in the way and hinder the view on the patient. This became less of a concern when the participants tried Glass afterwards: "This is very nice. It's not even in the way, I thought it would be." (I1)

The interviewees wondered if and how it is possible to interact with the device during trauma resuscitations.

During the hands-on experience, many interviewees started wondering whether or not there are appropriate forms of interactions that are doable during trauma resuscitations. The majority agreed that touch gestures are not possible at all: "we are wearing gloves to take care of the patient and sometimes the gloves just get bloody and so you don't wanna touch that." (I3) However, head gestures (e.g., shaking or nodding) were deemed to work perfectly (I1, I2). Interviewee I4 sees that differently and is convinced that especially those team members that are very busy anyway (e.g., Doc 1) should not be actively interacting with Glass at all: they should be doing patient care and nothing else."

It takes time to get used to wearing it.

Subsequent to wearing Glass, one interviewee pointed out another important concern that can influence it's acceptance – especially in early projects where participants usually do not have much time to get used to a new technology: "I think it's gonna take some getting used to it to wear this, and there is gonna be some degree of distraction initially. At least when I first put it on because I thought it'd be something I could just easily tune out, but when I look at it both of my eyes track towards it as a simple habit." (I2)

4.3.3 Resulting Design Artifacts

Two concrete design artifacts were created.

We have not started working on specific system designs after the interviews. However, they resulted in the following two concrete artifacts that supported the further design process.

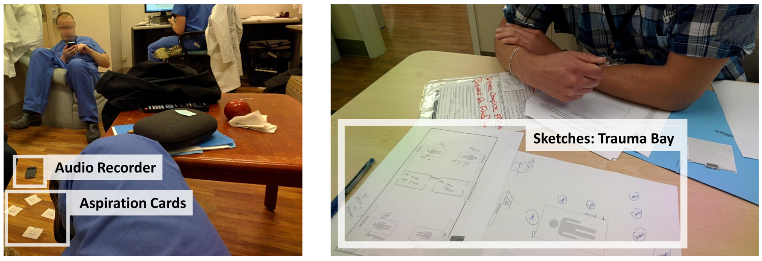


Figure 4.4: User interview scenes. Pictures were taken by the interviewees while trying Google Glass.

- **Layout of the trauma bay and team composition.** Figure 1.1 has already been used in chapter 1 – "Introduction" to provide the reader with a high-level overview of the setting.
- **Personas**. As an alternative way to present the interview findings described in previous sections, we created personas (cf. Figure 4.5). We only used them internally during the design process of upcoming prototypes. They simplified discussions about different roles, information needs, and concerns that needed to be addressed.

In addition, new questions have emerged that influenced the subsequent observation approach (cf. 4.4.1 - "Observation Framework"). Since our findings suggest that there is potential for supporting trauma resuscitation *training* using HUDs, it was decided to observe 2 realistic training sessions. Methodological details and new insights are discussed in the following section.

We need to learn more about trauma resuscitation training.

4.4 Observations Of ATLS Training

We observed 2 ATLS training sessions that incorporated a high-fidelity human patient simulator in order to triangulate the interview findings and to better understand current training practices. Both training sessions lasted 2.5 hours and were led by trauma doctors with many years of prac-

2 ATLS training sessions were observed.

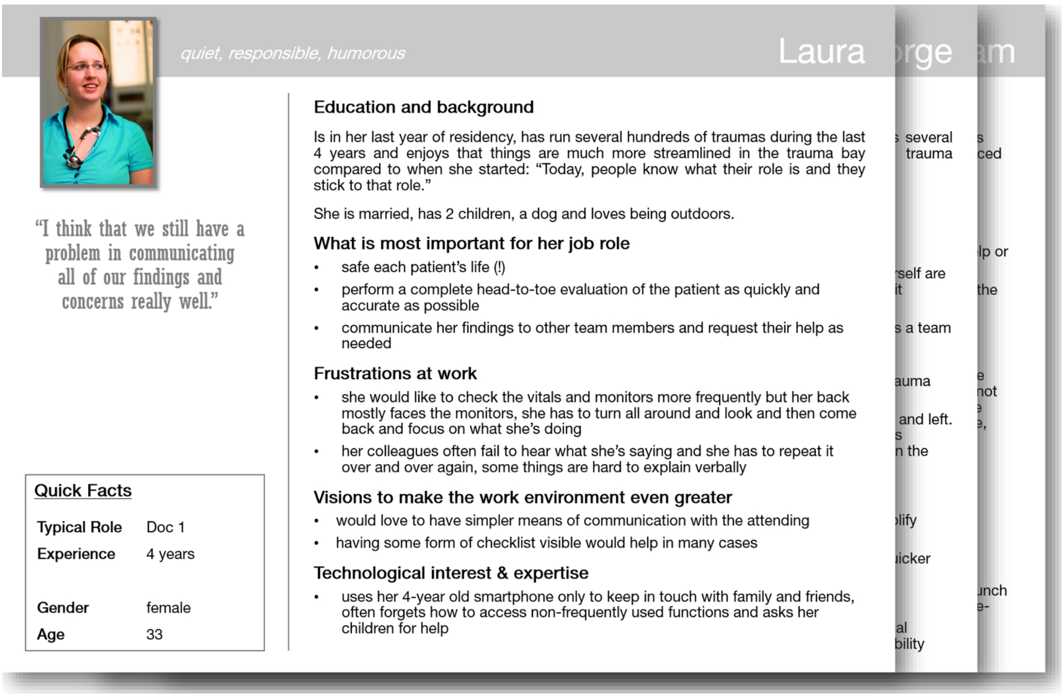


Figure 4.5: One sample persona that was created based on the interview results.

tical experience (*trainers*). The two groups of senior medical students were on a 6-week rotation in the trauma unit (*trainees*). They were relatively new to the trauma setting but have already assisted during several real resuscitations. The second session was additionally supported by two assistant physicians that supported the trainees during the simulation upon request (*assistants*). An overview is given in Table 4.3.

ATLS Training Details			**Participant Details**		
Id	Date	Duration	Trainer (m/f)	Trainees (m/f)	Assistants (m/f)
A	02/13/15	2.5 hrs.	2 (1/1)	3 (2/1)	0
B	02/26/15	2.5 hrs.	1 (1/0)	4 (3/1)	2 (2/0)

Table 4.3: ATLS training and participant details for the observed sessions.

Both training sessions were recorded (video) with the consent of the participants. We used Google Glass to record from a first-person perspective where the trainees that were assigned the role of Doc 1 where looking at during the simulations. Those parts of the recordings that were related to goals that we had specified in advance were transcribed using InqScribe.

The training sessions were recorded and partially transcribed.

4.4.1 Observation Framework

To structure the observation process and in order to ensure that we would focus on *relevant* aspects, the following framework had been created prior to the observations. It was decided to particularly focus on five different aspects of trauma resuscitation training:

The observations were guided by a framework.

- **Environment.** What is the physical space like and how is it laid out?
- **Equipment.** Which equipment is used for training purposes?
- **Timings.** How long does a training session take and can it be subdivided into different stages?
- **Workload of different team roles.** Is the distribution of roles the same as in real trauma resuscitations? Do all roles have a similarly high workload?
- **Critical incidents.** What are the most critical incidents? In which of those could HUD make a difference?

We used the following definition for the identification of *critical incidents*. Given that the trauma doctors were not available to discuss the video recordings in depths during the course of this project, we needed to stick to those critical incidents only that are clear to observers with limited medical knowledge.

Critical incidents needed to be obvious for outside observers.

Definition:
Critical Incident (CI)

CRITICAL INCIDENT (CI):
"By an *incident* is meant any specifiable human activity that is sufficiently complete in itself to permit inferences and predictions [...]. To be *critical* the incident must occur in a situation where the purpose or intent of the act seems fairly clear to the observer and where its consequences are sufficiently definite to leave little doubt concerning its effects." (Flanagan [1954])

4.4.2 Findings

We learned about the training environment and available equipment.

The training takes place in a dedicated simulator room (SLR). One can oversee the whole scene from an adjacent room through a one-way mirror. However, both trainer and trainees stayed in the SLR throughout all training sessions. The SLR offers one training bay on either side of the room, but only one of those bays was used during our observations. Figure 4.6 provides an overview of the layout of such a bay. Like in the real trauma bay, a vital sign monitor is located at the head end of the patient. The patient simulator lies on a movable table and can be controlled wirelessly by an instructor application. It offers realistic feedback based on the treatment. Besides many other features, the pupils react to light, you can feel the pulses, and see respiratory movements. Depending on the training scenario, different medical appliances (e.g. respiratory mask, chest tube) are available to treat the patient.

Each training session consisted of three parts.

Both training sessions took 60 minutes longer than planned due to technical problems when starting the simulator. Apart from that, a training session can be divided into three different stages that require the same amount of time (about 30 minutes each):

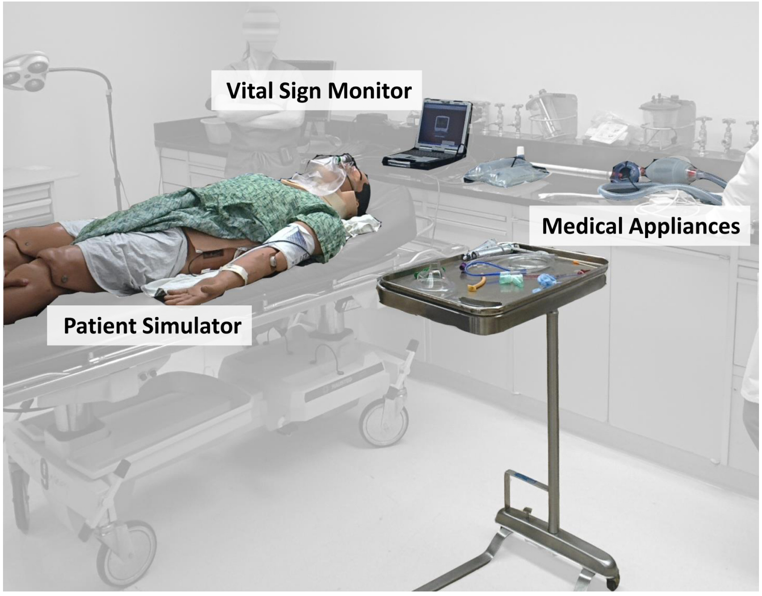


Figure 4.6: Training bay and equipment. A human patient simulator, a vital sign monitor, and various medical appliances are available.

A TYPICAL TRAINING SESSION:

1. **Briefing.** The trainees are introduced to the patient simulator and repeat theoretical foundations of the ATLS algorithm. Special focus is put on the primary survey.
2. **Simulation.** The trainees practice the ATLS algorithm using the patient simulator which is run through a medical scenario by the trainer. The simulation is based on the typical workflow of real trauma resuscitations (cf. 1 - "Introduction").
3. **De-briefing.** The trainers provide feedback and it is discussed how it went.

A typical training session

We mainly focus on the actual simulation in the following. The leading trainer was the most busy person as he or she needed to operate the simulator, observed the progress and provided feedback to the trainees if necessary. A secondary

Roles and workloads were identified.

trainer and additional assistants were less busy and mainly supervised the team to provide real-time assistance if anything went wrong or important steps were missed. Due to his role as team leader, Doc 1 was constantly involved with patient care whereas the remaining trainees were oftentimes patiently waiting for instructions. This observation is in accordance with a remark from one of our interviewees: "everything is a little bit slower paced with the simulator cause we know that it's a simulation and we don't have to be as fast about it."(I3)

Four critical incidents were identified.

Figure 4.7 and 4.8 visualize sample instances of four types of critical incidents that were identified during the observations of the two simulations in a static respectively storyboard-like format:

CI-1: Trainees look away from the patient to check the vital signs.

The trainees got distracted from their tasks by checking the vital signs.

This CI was caused by auditory alarms that attracted the attention of the trainees to changes in the vital signs (e.g., a dropping heart rate). In order to check the details, the trainees turned around to look at the vital sign monitor. As a consequence, they got distracted from their ongoing exam and lost focus of the patient. A sample instance is illustrated by perspective A in Figure 4.7. It was observed 17 times (simulation A: 8 times, B: 9 times).

CI-2: Trainees have problems performing procedures.

The trainees got more reliant on the trainer after assistance was offered.

The second CI was caused by the inability of the trainees to perform tasks that required a certain experience (e.g., inserting a chest tube). The trainer stepped in for demonstration purposes. As a positive consequence, the trainees were able to perform the task themselves afterwards. However, a negative consequence was noticeable as well: the trainees got more reliant on the trainer and seemed to wait for his help instead of trying to solve the problem as a team during critical situations. Thereby, the simulation became less of a realistic situation. A sample instance is illustrated by perspective B in Figure 4.7. It was observed 3 times (simulation A: 2 times, B: 1 time).

CI-3: Doc 1 does not report findings.

Another CI was observed when Doc 1 did not properly announce the findings of an examination as prescribed by the ATLS protocol. As a consequence, the other trainees were uncertain how to continue and needed to explicitly ask for missing information which caused delays in the work process that can quickly lead to PAEs. A sample instance is illustrated by scene A in Figure 4.8. It was observed 8 times (simulation A: 6 times, B: 2 times).

Miscommunication caused delays.

CI-4: Doc 1 does not give explicit instructions.

This CI was observed when Doc 1 did not give explicit instructions to the team in case of uncertainties. It was caused by the lack of protocol knowledge in which the required steps are precisely described. As a result, the trainees stopped functioning as a team and everyone did what he or she considered best. A sample instance is illustrated by scene B in Figure 4.8: while Doc 2 was palpating the chest, Doc 1 checked the pupils. The two trainees with role 3 kept waiting for instructions. It was observed 4 times (simulation A: 1 times, B: 3 times).

Miscommunication led to poor collaboration.

We see obvious potential for HUDs for making a difference in CI-1 by presenting the vital signs in the field of view. Having a personal checklist on a HUD that gives guidance might also influence CI-3 and CI-4. While design can easily convey declarative knowledge (”what”, facts and rules), procedural knowledge (”how”) is best learned through demo and practice (Norman [2013]). Therefore, HUDs are unlikely to change that the trainer needs to step in to convey procedural knowledge as outlined in CI-2.

CI-1, CI-3, and CI-4 offer opportunities for HUD-based support.

4.4.3 Resulting Design Artifacts

The outcomes of the observations triangulated with the literature research and user interview findings allowed us to come up with first concrete prototypes designed to address the identified issues: a tablet application should allow to easily drive the content which is shown on the trainee’s

First prototypes designed to address the identified issues were created.

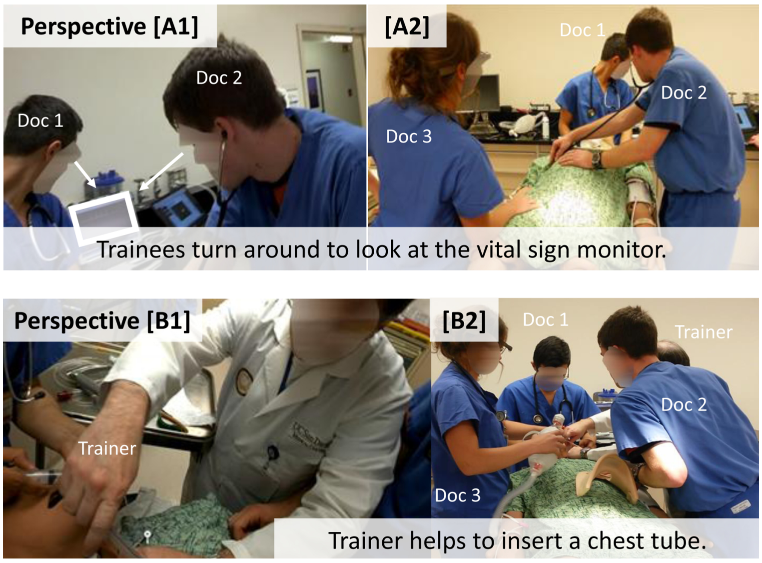


Figure 4.7: Static illustration of two CI-1 (A) and CI-2 (B). Each of them is captured from two perspectives (1, 2).

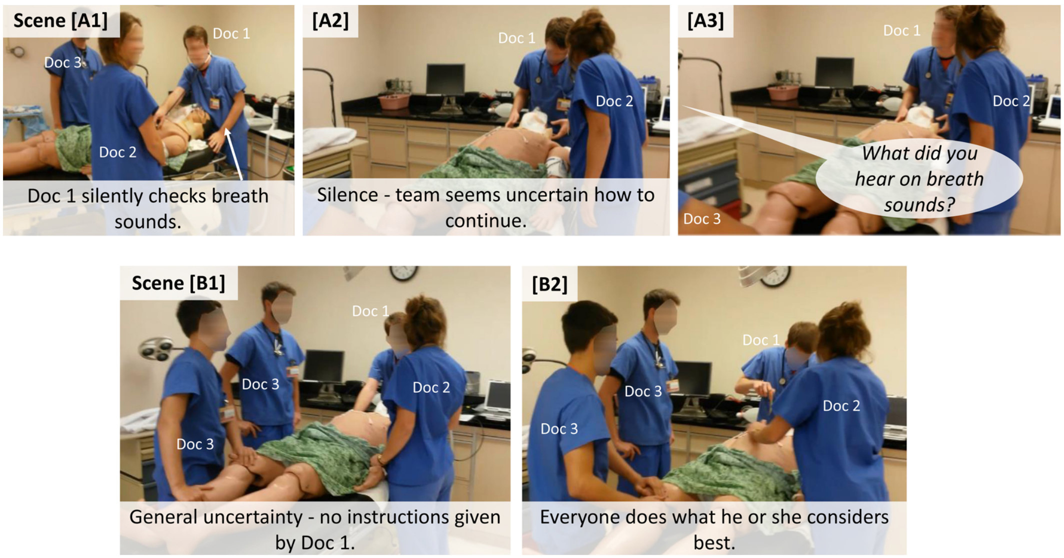


Figure 4.8: Storyboard-like illustration of CI-3 (A) and CI-4 (B). CI-3 is illustrated by 3, CI-4 by 2 excerpts from the recordings.

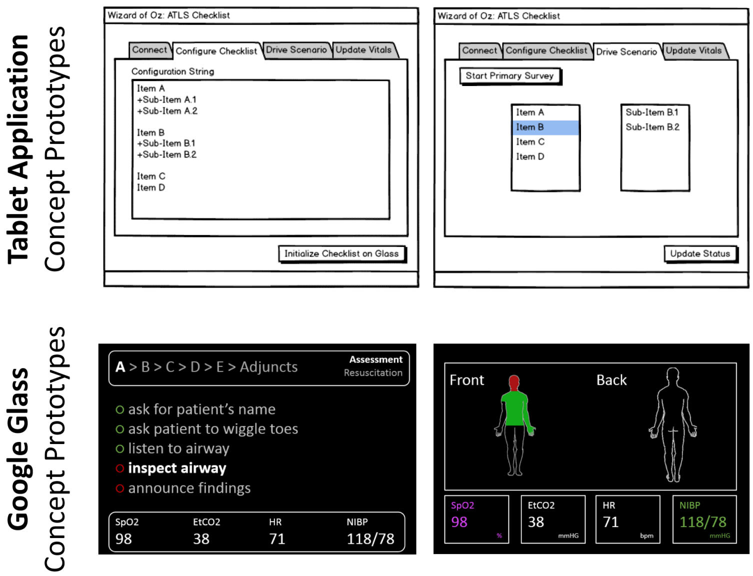


Figure 4.9: Low-fidelity concept prototypes for the tablet application and HUD screens.

HUDs. They should be provided with real-time, checklist-based guidance and relevant vital signs. Figure 4.9 shows samples of the low-fidelity prototypes.

Our prototyping framework simplified the implementation.

The *Google Glass PF* allowed us to quickly realize a few of these ideas on the device. Figure 4.10 shows which activities could be demoed on a HUD in the stand-alone mode of the framework.

User's feedback is discussed in the following.

Both, for the concept and software prototypes we asked for feedback during a focus group discussion. Details are discussed in the following section.

4.5 Focus Group Discussion

Low-fidelity prototypes were discussed with four domain experts.

We used the prototypes resulting from the previous step (cf. 4.4.3 - "Resulting Design Artifacts") as a basis for a 40-minute focus group discussion. Four participants attended, half of which were male. Three of the participants were senior international medical students with less than a year of

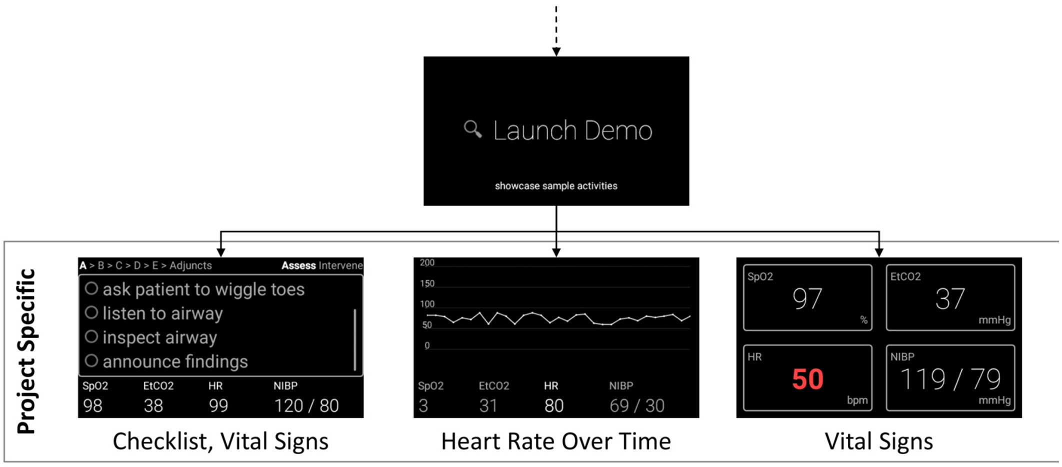


Figure 4.10: First software prototypes embedded into the Google Glass PF. The black background appears translucent on the HUD.

trauma experience (*trainees*). One participant was a highly experienced trauma doctor (*trainer*). The fact that she had to leave earlier simultaneously ensured that a large part of the discussion was not biased by differing experience levels. An overview is given in Table 4.4.

The discussion was recorded (audio) and transcribed with the consent of the participants.

Discussion Details			Participant Details		
Id	Date	Duration	Id	Gender	Experience
A	02/26/15	40 min.	P1	female	< 1 year
			P2	male	< 1 year
			P3	male	< 1 year
			P4*	female	> 10 years

Table 4.4: Focus group discussion and participant details. * = participant had to leave after 10 minutes due to an incoming emergency case.

4.5.1 Discussion Guideline

The discussion was split into two parts.

We only prepared a high-level guideline and decided to divide the discussion into two phases:

1. **Discussion of concept prototypes.** It was started with an introduction of the overall idea of how we plan to extend the training experience with Google Glass. Amongst others, printouts of the prototypes shown in Figure 4.10 were used to illustrate details. The group was asked for comments and thoughts. Thereby, a free discussion was initiated.

2. **Discussion of software-prototypes.** All participants were provided with Google Glass and instructed how to launch the Glass Client and the prepared prototypes (cf. Figure 4.10). They were asked to tap the touchpad to mock incoming data. Thereby, different checklist items were highlighted or vital signs changed. Additionally, they could try to scroll through a list by looking up and down. A free discussion was initiated.

4.5.2 Findings

In the following we summarize the key findings from the discussion that influenced the development of the next iteration of prototypes.

We got feedback for the checklist-based idea.

The trainer liked the ability of being able to drive what is shown on the trainees screens and to adjust the content of the checklist dynamically (P4). In terms of visualizing the checklist on Glass, the trainees preferred the text-based visualization of tasks over a graphical representation of the patient's body as a status indicator which was considered as an over-simplification (cf. Figure 4.9, P1 and P2).

Surprisingly, head gestures were considered skeptically.

As opposed to the conviction of many interviewees that head gestures were doable during trauma resuscitations in order to interact with Google Glass, the participants had a more skeptical attitude towards that after they tried it as highlighted by the following quotations:

- ”The problem is that Glass doesn't know when I'm just moving my head and when I'm moving my head to scroll.” (P1)

- ”The head moving thing might be a nice feature when you are sitting at home and browse through your home cinema but not during busy codes.” (P3)

However, one participant also liked the ability of scrolling through the checklist just by moving his head: ”It’s kind of cool to use” (P3).

Voice input was discussed controversially.

The applicability of voice input was controversially discussed, too. Two trainees came up with the idea of using voice input to navigate through the lists. The trainer (P4) strongly disagreed: ”[...] but it gets so loud in the trauma bay and it [Google Glass] may not understand”. P3 added another concern: ”[...] and somebody next to you might accidentally put the voice commands on yours.”

The HUD-based vital sign monitor needed changes.

In contrast to that, the group agreed on required changes for the vital sign monitors. One value (EtCO2) is only rarely used and can be neglected. A graph of the past development of the heart rate was deemed to be irrelevant (cf. Figure 4.10).

Software prototypes allowed for better feedback.

A general insight we gained from this discussion is the importance of being able to show prototypes on the device itself to get better feedback. During the discussion of the concept prototypes, P2 had the idea that ”it would be nice if it [the vital sign] would pop-up in big for *half a second* [if it exceeds a certain range]”. While trying the software prototypes, it was noticed that this would not help to attract one’s attention as one still needs to switch the attentional focus to notice changes on the screen.

Chapter 5

Evaluation

"The only way to really know whether an idea is reasonable is to test it."

—Don Norman

Steps 6-8 of our design and evaluation process (cf. Figure 4.1) guide the elaboration in this chapter. It is described how Google Glass was used to provide HUD-based support during simulated trauma resuscitations. The results – that are based on feedback, video, and log file analyses – are presented in detail. The chapter concludes with insights gained during a wrap-up meeting with one of the trainers.

The evaluation process consists of 3 steps.

5.1 ATLS Simulation Sessions

We tested two different supportive setups during two simulated trauma resuscitations that lasted 30 respectively 25 minutes. The ideas resulted from the user-centered design process described in the previous chapter. Each training was led by 1 or 2 trainers and consisted of three parts: briefing, simulation, and debriefing (cf. 4.4.2 - "Findings"). Both simulations focused on the primary survey of the ATLS algorithm only. Simulation A was additionally supported by an assistant physician and 6 trainees attended. Simulation

We evaluated two prototypes during two simulations.

B was attended by 7 trainees (all but one trainee attended both sessions). All of them were senior medical students that were on a rotation in the trauma unit. They have assisted during several trauma resuscitations before but this was their first training experience with a simulator. Before the simulations were started, the trainees got an introduction to the simulator and to Google Glass. An overview is given in Table 5.1.

Both sessions were recorded and partially transcribed.

Both training sessions were recorded (video) with the consent of the participants. We used InqScribe for transcription purposes.

Simulation Details			**Participant Details**		
Id	Date	Duration	Trainer (m/f)	Trainees (m/f)	Assistants (m/f)
A	03/06/15	30 min.	1 (1/0)	6 (3/3)	1 (1/0)
B	03/20/15	25 min.	2 (1/1)	7 (3/4)	0 (0/0)

Table 5.1: Overview of ATLS simulation sessions that were supported by Google Glass.

5.1.1 Experimental Setup

The trainer used a tablet application to administer the checklist during simulation **A**.

The setup for simulation A is illustrated by Figure 5.1. The *trainer* operated the simulator and remotely influenced the content shown on the trainee's HUDs by using a dedicated tablet application. Before the simulation was started, the checklist was tailored to the experience level of the trainees and the chosen medical scenario. For each state of the primary survey algorithm (cf. Figure 1.2), a set of tasks was specified. The default checklist is included in Appendix A - "Additional Resources: ATLS". During the simulation, the trainer checked off tasks and switched between primary survey states to represent the progress of the group. The changes were reflected in real-time on the HUDs of the trainees. Additionally, individual alarm sounds could be triggered. This was intended to direct the focus of a particular trainee to the HUD. The lower part of the UI provided the trainer with an overview of the contents on the trainee's HUDs. To avoid performance issues, the screenshots needed to be requested manually.

When the simulation sessions took place, we were not able to interface with the simulator directly in order to access the vital signs. Therefore, an additional observer manually provided the trainees with updated vital signs on their HUDs (*Wizard of Oz*).

The Wizard of Oz technique was used to update the vital signs on the HUDs.

Doc 1 was provided with a read-do checklist (cf. 2.2.1 - "Foundations Of Checklists") administered by the trainer to provide guidance and feedback. At any given point in time, the last (indicated by a green circle), current (highlighted in bold) and upcoming (indicated by a red circle) task was visualized on the HUD. We hoped that this implicitly and explicitly (task item: "announce findings") would improve team communication and lead to a better protocol adherence. The *upper* part of the screen visualized the current state of the primary survey. The *lower* part provided an overview of the most important vital signs (ordered by decreasing importance from left to right).

Doc 1 was supported by a dynamic checklist.

Doc 2 was provided with a larger representation of the vital signs. Additionally, the values were color-coded: as soon as a vital sign was outside a specified range, it was colored in red. Since Doc 1 may be too busy to notice relevant changes, it was the responsibility of Doc 2 to call the attention of the team to the vital signs in those situations.

Doc 2 was provided with color-coded vital signs.

Doc 3 was supposed to assist the efforts of Doc 1 and should not give instructions to the team or perform tasks independently. The trainee was provided with the same view like Doc 1 with two exceptions: the task list was scrollable by looking up and down, and the task states (todo, in progress, done) were not highlighted (do-confirm checklist). It was suspected that this allowed Doc 3 to check what Doc 1 was doing and to provide additional feedback if steps were missed.

Doc 3 was supported by a task list.

The setup for simulation B is illustrated by Figure 5.2. It slightly differed from the setup for simulation A. Instead of having a trainer checking off tasks and switching between

The trainees needed to trigger content changes themselves during simulation **B**.

Figure 5.1: Experimental setup for simulation A. The three highlighted trainees are wearing Google Glass. By using a tablet application, the trainer administered the checklist remotely and the "Wizard of Oz" updated the vital signs manually.

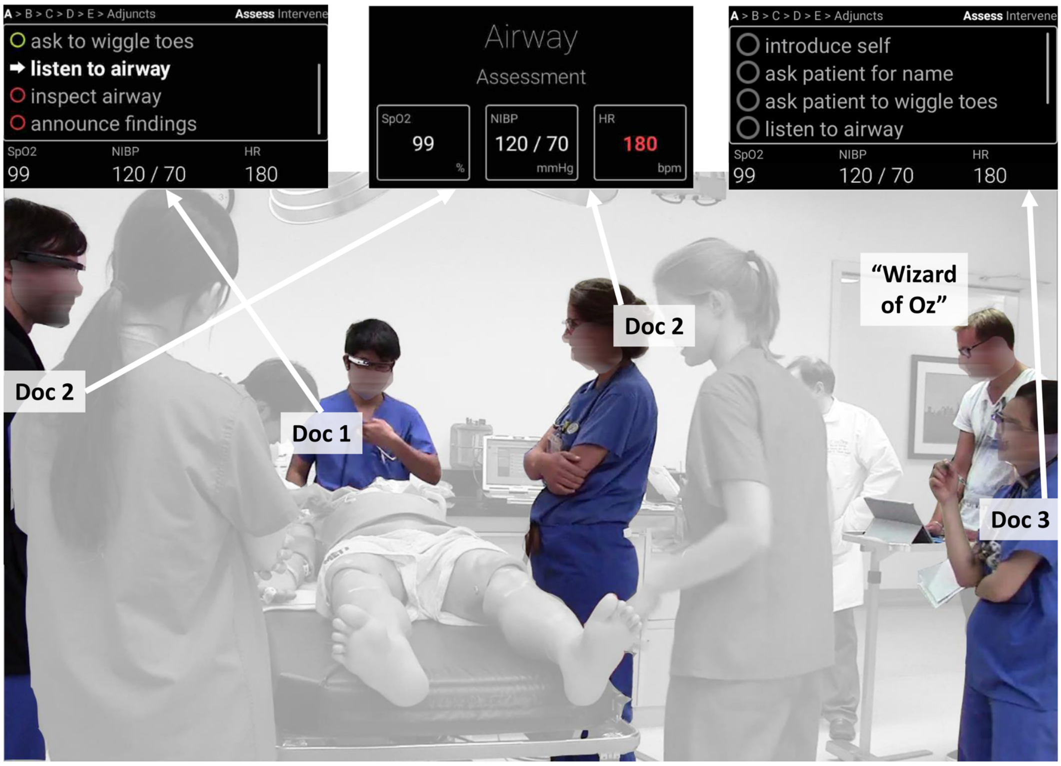


Figure 5.2: Experimental setup for simulation B. The four highlighted trainees are wearing Google Glass. By using a tablet application, the "Wizard of Oz" updated the vital signs manually.

states of the survey remotely, the trainees were required to interact with Glass such that the HUD reflected the current state of the primary survey. Doc 1 was required to check off task items by tapping on the touchpad. By swiping back and forth, all trainees could navigate through the different survey states individually.

The key differences and commonalities of both setups are highlighted.

In both simulations, the vital signs on the HUDs of all trainees were updated remotely. The key *differences* between simulation A and B are summarized in Table 5.2. In simulation A, the trainees were not required to actively interact with Glass and content changes were triggered remotely by the trainer. In simulation B, the trainees needed to interact with Glass themselves to trigger those changes. That put less burden on the trainer but could result in inconsistent information displayed on the HUDs as illustrated by the following example: Doc 1 is still looking at tasks related to the airway intervention survey state but Doc 3 has not changed to that view yet and is looking at tasks related to the airway assessment state.

Assignment		User Interaction			HUD Content	
Simulation Id	Trainee's Role	Touch (tap)	Touch (swipe)	Head (pitch)	Survey State Changes	Task State Changes
A	Doc 1	-	-	-	X_{remote}	X_{remote}
	Doc 2	-	-	-	X_{remote}	-
	Doc 3	-	-	X	X_{remote}	-
B	Doc 1	X	X	-	X_{local}	X_{local}
	Doc 2	-	X	-	X_{local}	-
	Doc 3	-	X	X	X_{local}	-

Table 5.2: Differences between the experimental setups for simulation A and B at a glance. X_{remote} indicates that changes were triggered remotely by the trainer, X_{local} indicates that changes needed to be triggered individually by the trainees.

The Google Glass PF enabled us to realize the above setups.

We used the Google Glass PF to realize the above setups. It allowed a single developer to implement, test, and integrate the individual components over the course of 2.5 weeks. Additional screenshots of the tablet application used by the trainer and the "Wizard of Oz" are included in Appendix D - "Tablet Application".

5.1.2 Triangulating Evaluation Approach

To analyze the results, three different evaluation methods were used in combination.

Positive and negative impacts were identified during a video analysis.

A subsequent *video analysis* of both simulation sessions was performed to analyze how the four previously identified critical incidents (CI-1 to CI-4) have been impacted (positively or negatively) by the different supportive setups (cf. 4.4.2 - "Findings"). In addition, we ensured to also look for problems that have not been observed during previous simulation sessions.

We asked for subjective feedback of the trainees.

The observations were compared to *subjective feedback* we got from the trainees during short debriefing sessions after each simulation. The feedback sessions were initiated by putting three open-ended questions up for discussion

("What did you like and dislike?", "Do you see further potential for HUDs in the trauma bay? Why or why not?", "Do you have any concerns regarding the use of HUDs during trauma resuscitation?"). Positive and negative feedback was accepted without further comments or justifications.

In certain cases, an additional *log file analysis* helped to validate the findings that resulted from the observations and feedback sessions.

Log files were analyzed.

5.1.3 Positive Impacts

The observations showed that the trainees got less distracted by checking the vital signs in both simulations supported by HUDs. A sample scene illustrated in Figure 5.3 makes this clear. Doc 3 was actively engaged in a discussion with Doc 1 and Doc 2 when all of a sudden the value of the oxygen saturation dropped to a critical level. The log files and stored screenshots prove that at that very moment the corresponding value on the HUD changed from 96 to 36. Having the information in the field of view allowed Doc 3 to keep track of further changes in the vital signs without losing focus on the patient or the discussion with the other trainees. These benefits are also highlighted by feedback provided by multiple trainees after the simulations:

It is less distracting to check the vital signs on the HUDs.

- "It is super helpful to see [the vital signs] and you don't have to turn around and look at the screen all the time." (Simulation A, Doc 2)
- "What was really good were the vitals." (Simulation A, Doc 3)
- "I think it was helpful because we [Doc 2] could see the changes and then tell them [the other trainees]." (Simulation B, Doc 2)

Independent of the role of the trainee and the corresponding visualization of the vital signs, this feature was liked. Benefits of the color-coding of the vital signs on the HUD of Doc 2 could neither be observed nor were they reported.

Benefits of color coding are still questionable.

Figure 5.3: Sample scene from simulation A. It illustrates how CI-1 (trainees look away from the patient to check the vital signs) was influenced by HUD-based support. The three trainees wearing Google Glass discussed changes in the vital signs (the saturation dropped from 96 to 36). A trainee not wearing Glass tried to look at the vital sign monitor behind Doc 3 (highlighted in red).

Vital signs need to be updated in real-time.

An important concern that shows the skeptical attitude towards the technology was mentioned by Doc 2 after the earlier simulation: "It would be a problem, though, if they [the vital signs] were not accurate. If that would happen once in a really severe situation, I would never trust it again."

In total, improvements for CI-1 were observed 9 times (simulation A: 6 times, B: 3 times).

When the trainees are reliant on the trainer to check off tasks, they are forced to communicate.

During simulation A – where a trainer checked off the tasks remotely – improved team communication was observed. None of the trainees mentioned during the feedback session that they were aware of that, though. Figure 5.4 shows a situation that proves that the checklist can help to force the trainees to properly announce the findings. This was due to the fact that the trainer only checked off a task as soon as its completion was properly reported: "I guess I

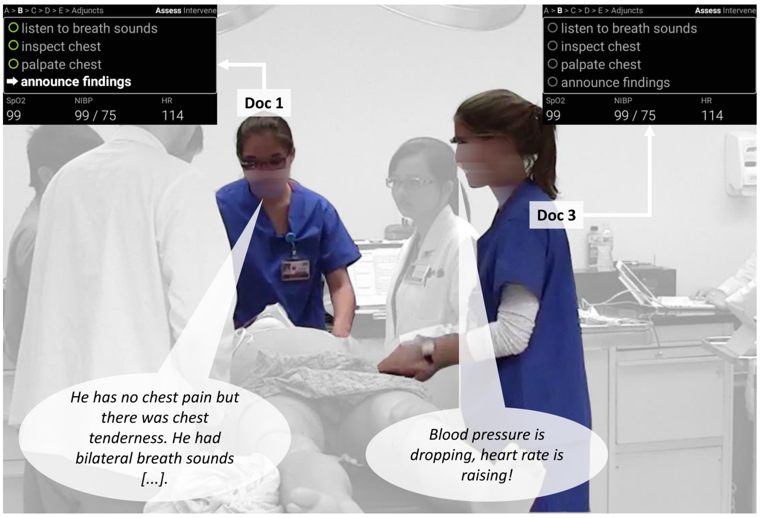


Figure 5.4: Sample scene from simulation A. It illustrates how CI-3 (findings are not reported) was influenced by the primary survey checklist on the HUDs during simulation A. Doc 1 announced detailed findings of the previous exam steps and Doc 3 reported current changes in the vital signs.

did not realize at first that I had to really say everything that I did, I though I just do it. And so it [the checklist item] would just stand there for a while." (Simulation A, Doc 1) During simulation B – where the trainees checked off the tasks themselves – improved communication was not observed. We attribute this to the fact that the trainees could silently move to the next step and were not dependent on another person to notice that a task has been completed.

In total, improvements for CI-3 were observed 3 times (simulation A: 3 times, B: 0 times).

Checklist-based support leads to better protocol adherence.

The availability of the checklist on the HUDs also led to increased protocol adherence. During both simulations, Doc 1 seemed certain what needed to be done next. If assistance was needed, other trainees were instructed how to assist based on upcoming tasks listed on the HUD (cf. Figure 5.5). This notion was confirmed by Doc 3 during the feedback session of simulation B: "I think we [the team] have accomplished all the tasks that were listed on the checklist. And pretty much in the right order."

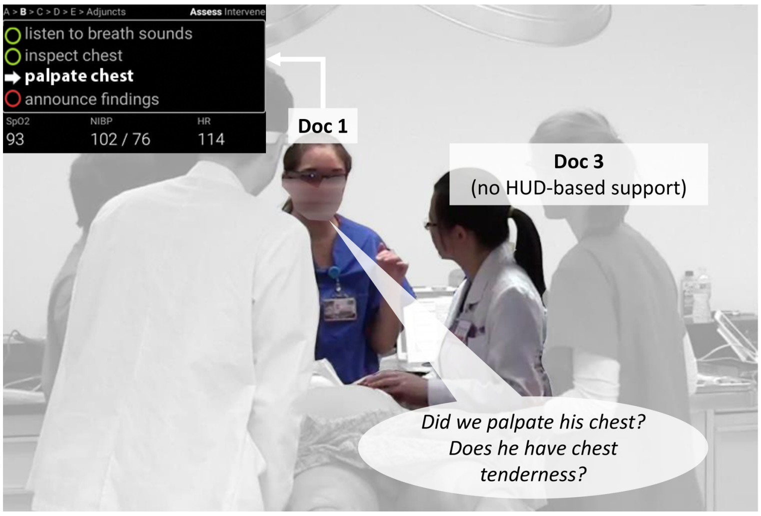


Figure 5.5: Sample scene from simulation A. It illustrates how CI-4 (Doc 1 does not give explicit instructions due to missing protocol knowledge) was influenced by the primary survey checklist on the HUD. Doc 1 asked Doc 3 whether the patient had chest tenderness. In turn, she (Doc 3) started palpating the chest and reported the findings.

In total, improvements for CI-4 were observed 4 times (simulation A: 2 times, B: 2 time).

5.1.4 Negative Impacts

Previously identified CIs were not negatively affected.

We could not observe negative impacts of HUD-based support on previously identified critical incidents during both simulations. However, it caused two additional problems that negatively affected the training procedure. Both of them are related to how task items on the HUD are checked off.

If the content is not updated in real-time, new issues arise.

During simulation A, it turned out that the trainer was oftentimes too busy to remotely check off tasks and change survey states in real-time. This caused confusion – especially for Doc 1. Figure 5.6 illustrates how Doc 1 got distracted by the delayed task updates. She looked questioningly at the trainer and told him that the list was not updat-

Figure 5.6: Sample scene from simulation A. It illustrates that Doc 1 got distracted by the list on the HUD when it was not updated in real-time. At the same moment the trainer was busy with controlling the simulator and could not check off tasks in real-time on the tablet.

ing even though all tasks had already been performed. A log file analysis revealed the underlying issue: the state displayed on the HUDs of the trainees oftentimes did not appropriately reflect the current progress of the examination since the trainer triggered those changes very infrequently. Large parts of the negative feedback were due to this reason:

- "I thought it was really distracting. Why is it telling me to do that even though I've already done it?" (Simulation A, Doc 1)
- "I didn't really have an eye on the list after I had noticed that it wouldn't change anyway." (Simulation A, Doc 3)

Trainees start ignoring it.

Even Doc 2 who was not provided with a list of tasks but with the current state of the examination only, started ignoring it: "I wasn't really sure what I was supposed to do with that as it hardly ever changed."

In total, we observed 9 scenes where at least one of the trainees got obviously confused due to delayed task or survey state updates.

The trainees wanted to administer the content themselves to overcome the above issuse.

Given these issues, both the trainer and the trainees expected it to be better if the trainees could check off the tasks themselves:

- ”They could just tap as they go.” (Simulation A, Trainer)
- ”I could check them off myself rather than having to wait until someone else recognizes that I did it.” (Simulation A, Doc 1)

Doc 1 gets distracted by interacting with Glass.

Such a setup was evaluated during simulation B where the trainees could interact with Glass to change the states and check off tasks themselves. Figure 5.7 shows a scene where Doc 1 checked off that he had listened to breath sounds before he continued with the survey. Based on subsequent feedback and the impression that we got during the video analysis, this was perceived as distracting and hindered the examination.

Doc 2 and 3 have time to administer the checklist.

Doc 2 and 3 who were not that actively involved in patient care seemed to be less distracted by the interaction with Glass. Both of them considered it desirable to have the devices communicate and synchronize state changes across all devices automatically.

It is unclear whether to swipe back or forth to switch to the next state.

Another issues was neither reported nor noticed during the observations but detected during the log file analysis: it was not obvious to the trainees whether to swipe forwards or backwards in order to switch to the next state. This is attributed to the lack of a *natural mapping* between swiping the touchpad and switching to the next or previous state (see Norman [2013]).

Head gestures do not offer enough control.

We could not find further evidence, but one trainee reported that it was annoying to scroll through the list using head gestures: ”I had the feeling that I couldn’t control it as much as I wanted to. If that hadn’t been a training session, it would have stressed me a bit.” (Simulation A, Doc 3)

Figure 5.7: Sample scene from simulation B. It illustrates how Doc 1 got distracted by interacting with Google Glass. He tapped the touchpad to check off tasks.

5.1.5 Conclusions

HUDs are capable of impacting trauma resuscitation. The simulation sessions that we supported were changed both in positive and negative ways by two different experimental setups.

Our supportive setups impacted the training sessions.

All trainees unanimously liked the ability to check the vital signs on the HUD and it was proven that having them in the field of view is less distracting than having to turn around to look at the vital sign monitor.

One application area for HUDs stood out.

In those situations where the checklist items and survey states on the HUDs were updated in real-time, it resulted in better protocol adherence and improved team communication. However, the right way to administer the corresponding content on Glass still remains an open question. Our simulations have shown that neither the trainer nor Doc 1 has time to take over another task.

Both checklist administration styles caused problems.

The alarm sound that could be triggered by the trainer to direct the focus of specific trainees to the HUD (cf. 5.1.1 - ”Experimental Setup”) was used twice. In none of the cases it was noticed by the trainees, though. We suspect that this is due to the fact that doctors (even during the sim-

Additional auditory alarms were overheard.

ulation) are exposed to a large number of frequent alarms and thereby become desensitized to them (”alarm fatigue”). Therefore, additional auditory alarms are not expected to support the usage of HUDs in this setting.

The need for further trials in simulation environments was identified.

We have shown that information provided on HUDs can help but also distract from patient care during trauma resuscitation. This highlights the importance of trying ideas in training and simulation environments first even though this might be a little less of a realistic experience.

5.2 Project Wrap-Up Meeting

Feedback from the trainers was gathered in a separate meeting.

In order not to *bias* the opinion of the trainees, the trainers were not explicitly asked to provide feedback during the group discussions after the simulation sessions. Hence, a project wrap-up meeting with both trauma doctors that acted as trainers during the simulations was scheduled. We presented intermediate results, asked for their opinions and discussed if and how the project would be continued. One of them could not attend at a short notice due to an emergency surgery.

Our observations were confirmed.

The trauma doctor agreed that neither of the two checklist administration techniques seemed suitable. According to her opinion, the trainees should not be distracted from patient care by interacting with any device. On the other hand-side, checking off tasks using the tablet application definitely puts too much additional burden on the trainers. The only application area that she considers helpful not only for training but also for real resuscitations is the visualization of the vital signs on HUDs.

The cooperation will be continued.

It was agreed that the simulation sessions will remain open to researchers that continue working in this field which will allow for more thorough evaluations of these initial and further ideas.

Chapter 6

Conclusion

6.1 Summary, Benefits And Contributions

In this work, we analyzed application areas for HUDs and evaluated their utility in the area of trauma resuscitation. To support that process, Google Glass was used as an exemplary device that is (inter alia) capable of visualizing information on a personal HUD in the field of view.

Opportunities for HUDs during trauma resuscitation were identified.

Given the novelty and beta status of Google Glass, its applicability for early-stage HCI research projects – such as this one – was assessed first (cf. 3 - "Google Glass In Early-Stage HCI Research Projects"). Based on insights gained during a 3-week wearing experience and a thorough literature review, we concluded that Glass is capable of supporting such projects in a variety of ways. However, privacy concerns are expected due to the front-facing, head-mounted camera. A design space was created that acted as a brainstorming aid during the design process of Glass-based applications. It helped to think through different interaction and implementation opportunities in a structured way. To facilitate and accelerate the creation of software prototypes on the device, a prototyping framework was developed. It was kept project-independent, abstracts away many implementation details, reduces the amount of boilerplate code, offers commonly used functionality, and thereby allows for faster design iterations.

We used Google Glass and developed a prototyping framework.

We collaborated with trauma doctors, learned about current issues, and how HUDs can help to address them.

Subsequently, a collaboration with the Hillcrest Medical Center at UC San Diego was initiated. We conducted 6 semi-structured interviews with trauma doctors, observed 2 trauma resuscitation training sessions, and asked for feedback on concept prototypes during a focus group discussion (cf. 4 - "Design Approach"). Even though we followed a *user-centered* (as opposed to a technology-centered) design approach, Google Glass was used to support that process. As an incentive to take time for sharing their insights, we offered the trauma doctors an optional introduction to Glass subsequent to the interviews. Additionally, it was used to capture the training sessions from a first-person perspective. The Google Glass PF allowed us to quickly create software prototypes that gave the participants of the group discussion a first feeling of having medical information visualized in their field of views. Several design artifacts were created in parallel to the above process that led to a high-fidelity prototype that was evaluated during subsequent training sessions.

We evaluated the impact of HUD-based support on simulated trauma resuscitations.

Based on issues identified during interviews and observations, two high-fidelity prototypes leveraging HUD-based support were designed and evaluated during trauma resuscitation simulations with a realistic patient simulator (cf. 5 - "Evaluation"). The Google Glass PF helped to create that fairly comprehensive setup within a short amount of time. Based on their roles in the team, the trainees were provided with different information on the HUD of Google Glass: the vital signs of the patient and a dynamic checklist designed to guide through the primary survey of the ATLS algorithm. The visualization of the vital signs was identified as suitable application area that could also help during real resuscitations. However, the checklist-based support was considered skeptically even though the trainees liked the unobtrusive visualization on the HUD. The reasons were due to the lack of an appropriate way to trigger content changes.

We see two ways to benefit from our work.

Researchers can *benefit* from our work in two different ways: At first, the *Google Glass Prototyping Framework* can be leveraged to simplify the creation of software prototypes. It needs to be emphasized that this framework is not limited to a single domain but allows for various use cases in many areas. A larger number of HCI researchers is enabled to realize prototypes on Glass – even if they do not have deep technical knowledge in areas such as network programming, multi-threading, or Android. Secondly, the research community is provided with additional *domain knowledge* of trauma resuscitation (e.g., setup of the trauma bay, role distribution). It will allow to identify further issues in this area faster.

We were the first who incorporated multiple personal HUDs in trauma resuscitation and identified sample application areas.

We identified general potential for HUDs during time-critical medical teamwork. To the best of our knowledge, we were the first to analyze the impacts of using *multiple* personal HUDs addressing *role-based* information needs during trauma resuscitation. The visualization of the vital signs in the field of view turned out to be the most promising application since it resolves a current problem in trauma bays: the doctors need to look away from the patient to check the vital signs on team-based vital sign monitors. Providing individual trainees with a checklist on the HUDs to guide them through the trauma resuscitation process helped to increase protocol adherence and team communication in an unobtrusive way.

6.2 Collaborating With Domain Specialists: Challenges

One needs to be aware of challenges entailed by the work with trauma doctors.

While we considered the work with trauma doctors as highly insightful, we were faced with a few challenges that resulted from this collaboration with medical domain specialists. Two of them are considered worth sharing:

- **Scheduling.** It was hard to schedule appointments due to busy and unpredictable schedules. Due to this reason, the interview process was significantly delayed. As it seemed even harder to find a date and time for a joint training session with multiple fully trained trauma doctors, we focused our efforts on ATLS training sessions with senior medical students as they took place regularly.

Sarcevic [2014] faced the same challenge and describes further lessons she learned from 7 years of field work in different trauma centers.

- **Reliance on willingness of others to support evaluations of prototypes.** Due to missing domain knowledge, we were not able to run the evaluation sessions ourselves (e.g., we were not able to identify the current state of the primary survey or to recognize all tasks that have been completed by the trainees). It turned out to be especially challenging to convince the trainers to support evaluation sessions even if they – personally – were not fully convinced of the idea.

6.3 Future Work

Further research on how to visualize vital signs on HUDs is needed.

We are planning to further explore appropriate ways to visualize vital signs on HUDs. It is expected that there are better ways than pure text-based visualizations and that different team members may need different representations at different times. Additionally, suitable ways to direct the attention to values that are outside an expected range need to be found.

The establishment of a research cooperation will allow to access the vital signs of a patient simulator in real-time.

To support that process and allow for a more realistic experience during upcoming simulation sessions, a collaboration between *UCSD* and *CAE Healthcare* – the company behind the used patient simulator – was established as part of the initial project. Scope and type of this collaboration are summarized in a memorandum of understanding (cf. Appendix E - "Collaboration With CAE Healthcare"). Due to time reasons, we were not able to benefit from the provided SDK yet, but it will allow us (inter alia) to subscribe to changes in the vital signs and display these information in real-time on the HUDs. For confidentiality reasons, no further details are provided in this report.

Additional field work is required to better understand the differences between simulated and real trauma resuscitations. We have to shadow trauma doctors to explore further potential and assess if and how it is possible for certain team members to interact with an additional device to drive the content on a HUD. Our findings suggest to expect that Doc 1 needs another person to take over that task remotely. Wu [2012] faced similar issues in the operating room and resolved them by giving tablet input to nurses instead of doctors.

Appropriate ways to interact with wearables during trauma resuscitation need to be found.

A quantitative study needs to be conducted to analyze whether or not HUD-based support using checklists improves ATLS primary survey performance. Team communication, quality (effectiveness), and speed (efficiency) need to be reflected by the measured performance metrics (cf. Appendix A - "Additional Resources: ATLS", skills simulation test).

The effect of HUD-based support on team performance needs to be analyzed.

Two further promising ways of how Google Glass could improve trauma resuscitation do not leverage its HUD but are enabled through the front-facing camera: remote imaging and simplified documentation.

Use cases for the front-facing camera of Glass should be identified.

Appendix A

Additional Resources: ATLS

Courtesy of J. Doucet, MD and A. Berndtson, MD.

Appendix A includes additional important resources that our collaborators at UC San Diego Health System provided us with.

Primary Survey Checklist

Airway	Assessment steps	Resuscitation options
	Introduce self	Oxygen mask
	Ask patient "what is your name?"	Nasal Airway
	Ask patient to "wiggle your toes!"	Oral Airway
	Listen to airway	Bag-valve-mask
	Inspect Airway	"Prepare to intubate"
	Announce findings	

Breathing	Assessment steps	Resuscitation options
	Listen to breath sounds	Needle thoracentesis
	Inspect chest	"Prepare to insert chest tube"
	Palpate chest	Occlusive dressing
	Announce findings	"Prepare to intubate"

Circulation	Assessment steps	Resuscitation options
	Look for bleeding sites	IV fluid bolus 2 liters
	Palpate central pulses	Massive transfusion protocol
	Palpate distal pulses	Tourniquet
	Check blood pressure	Advanced dressing
	Check heart rate	
	Announce findings	

Disability	Assessment steps	Resuscitation options
	Check Pupils	Mannitol
	Glasgow coma scale	Hypertonic saline
	Did the toes wiggle?	"Prepare to intubate"
	Announce findings	

Environment	Assessment steps	Resuscitation options
	Disrobe entire patient	
	Warm blankets	

Primary Adjuncts	Assessment steps	Resuscitation options
	Chest Xray	Nasogastric tube
	Pelvis Xray	Foley catheter
	FAST ultrasound	
	Announce findings	

- The left column shows required actions for the assessment.
- The right column shows possible interventions based on the assessment, none, one or more than one option may be desired.

Figure A.1: Primary survey checklist. A high-level list of assessment steps and resuscitation options that need to be performed during the primary survey of the ATLS protocol. This list was used to develop a HUD-based information display.

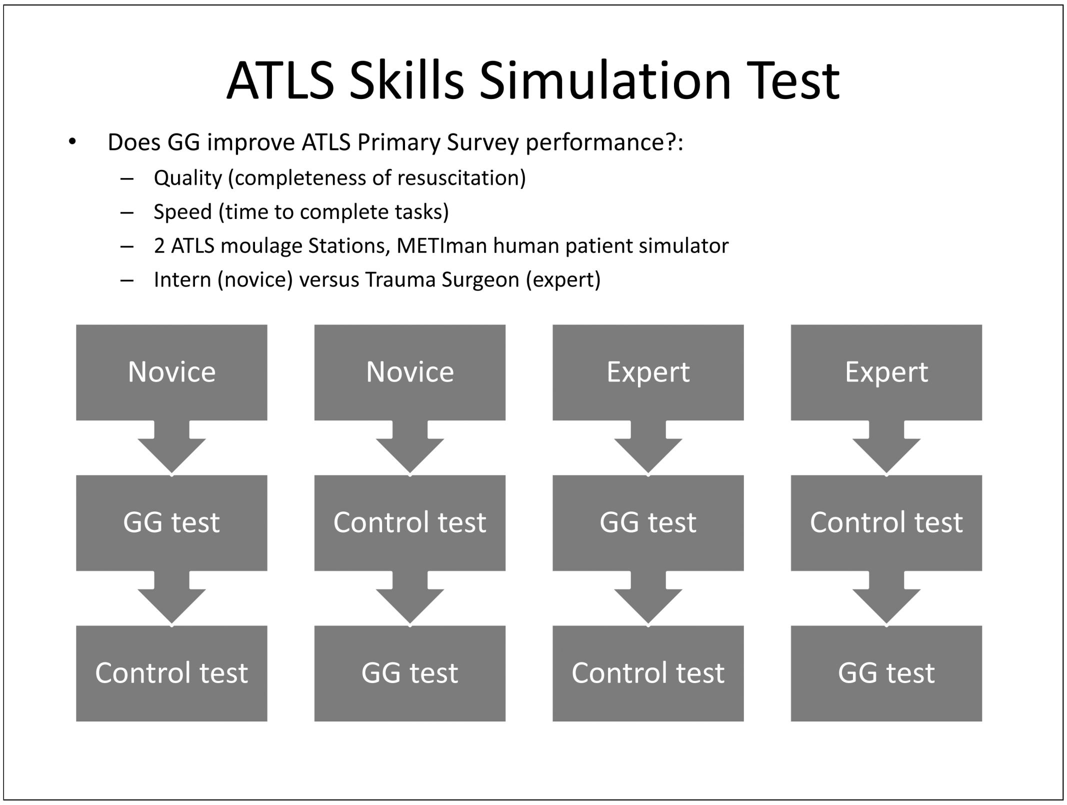
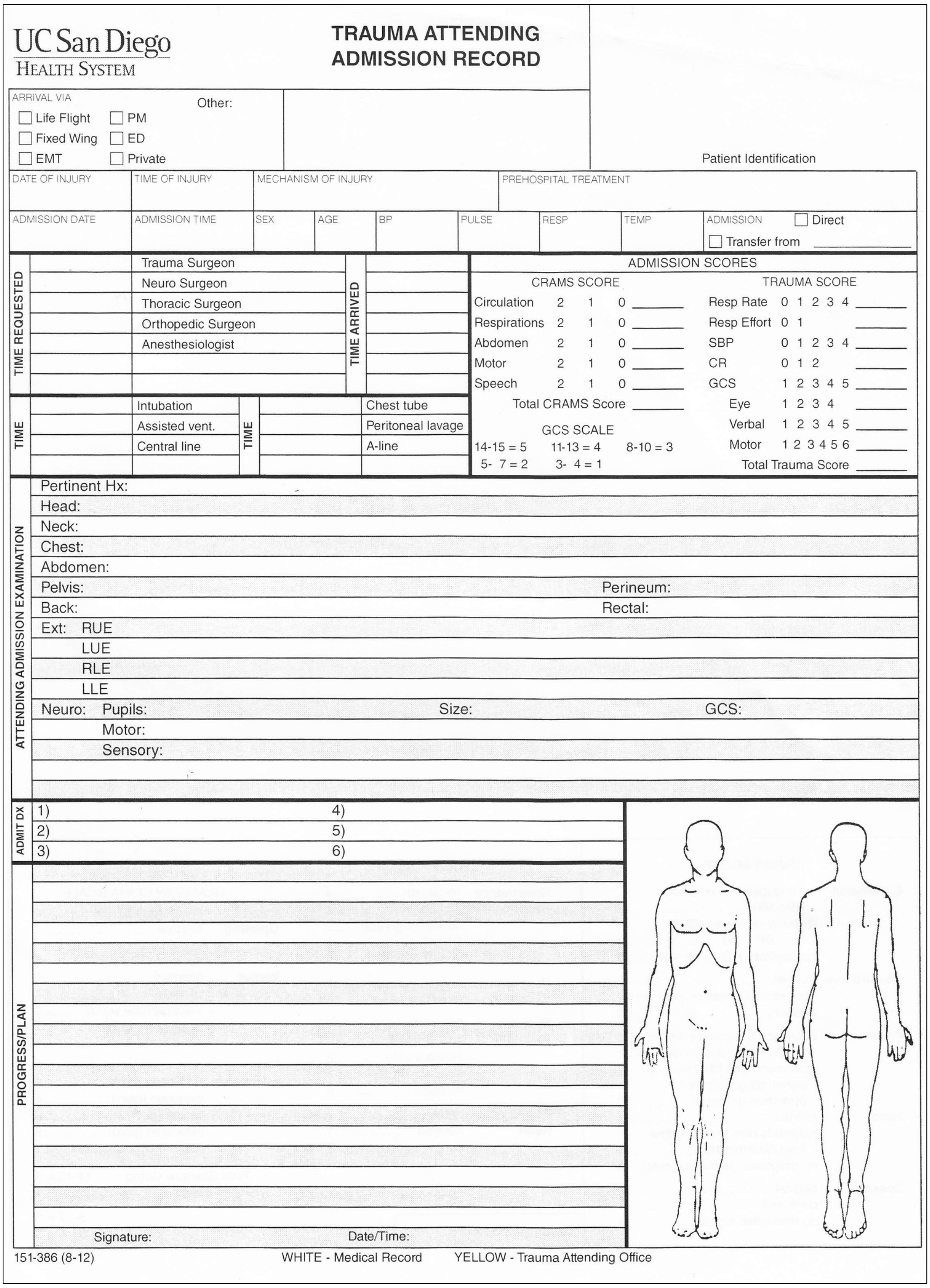


Figure A.2: ATLS skills simulation test. This test was suggested by our collaborators to evaluate whether or not HUD-based support improves ATLS primary survey performance. It should be considered for future work.



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TRAUMA ATTENDING
ADMISSION RECORD

ARRIVAL VIA
☐ Life Flight ☐ PM
☐ Fixed Wing ☐ ED
☐ EMT ☐ Private

Other:

Patient Identification

DATE OF INJURY	TIME OF INJURY	MECHANISM OF INJURY	PREHOSPITAL TREATMENT

ADMISSION DATE	ADMISSION TIME	SEX	AGE	BP	PULSE	RESP	TEMP	ADMISSION ☐ Direct ☐ Transfer from ______

TIME REQUESTED		TIME ARRIVED
	Trauma Surgeon	
	Neuro Surgeon	
	Thoracic Surgeon	
	Orthopedic Surgeon	
	Anesthesiologist	

TIME		TIME	
	Intubation		Chest tube
	Assisted vent.		Peritoneal lavage
	Central line		A-line

ADMISSION SCORES

CRAMS SCORE					TRAUMA SCORE		
Circulation	2	1	0	______	Resp Rate	0 1 2 3 4	______
Respirations	2	1	0	______	Resp Effort	0 1	______
Abdomen	2	1	0	______	SBP	0 1 2 3 4	______
Motor	2	1	0	______	CR	0 1 2	______
Speech	2	1	0	______	GCS	1 2 3 4 5	______
Total CRAMS Score				______	Eye	1 2 3 4	______
					Verbal	1 2 3 4 5	______
					Motor	1 2 3 4 5 6	______
					Total Trauma Score		______

GCS SCALE
14-15 = 5 11-13 = 4 8-10 = 3
5- 7 = 2 3- 4 = 1

ATTENDING ADMISSION EXAMINATION
Pertinent Hx:
Head:
Neck:
Chest:
Abdomen:
Pelvis: Perineum:
Back: Rectal:
Ext: RUE
LUE
RLE
LLE
Neuro: Pupils: Size: GCS:
Motor:
Sensory:

ADMIT DX
1) 4)
2) 5)
3) 6)

PROGRESS/PLAN

Signature: Date/Time:

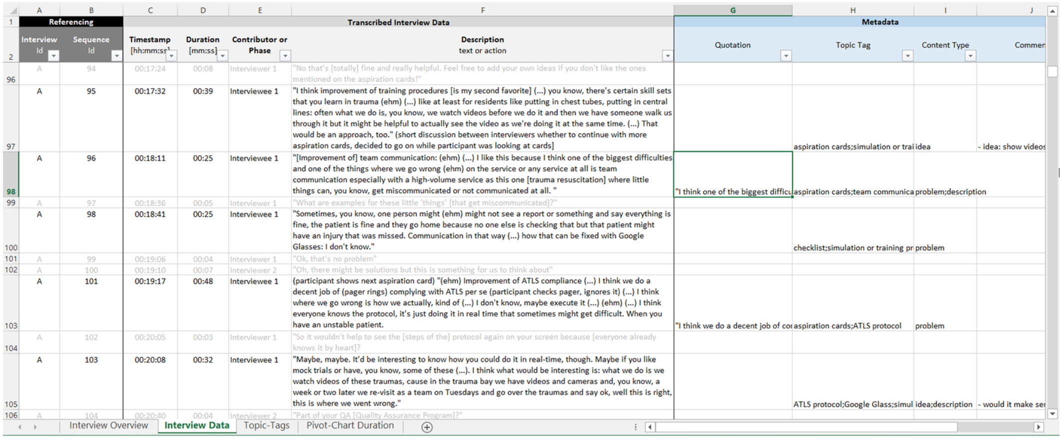
151-386 (8-12) WHITE - Medical Record YELLOW - Trauma Attending Office

Figure A.3: Trauma attending admission record. A checklist-like paper form that is filled out during or after each trauma resuscitation by the attending.

Appendix B

Transcript Annotator

Appendix B includes screenshots of a Microsoft Excel based tool that has been developed in order to simplify annotation and categorization of transcribed recordings. VBA (Visual Basic for Applications) was used as a programming language.



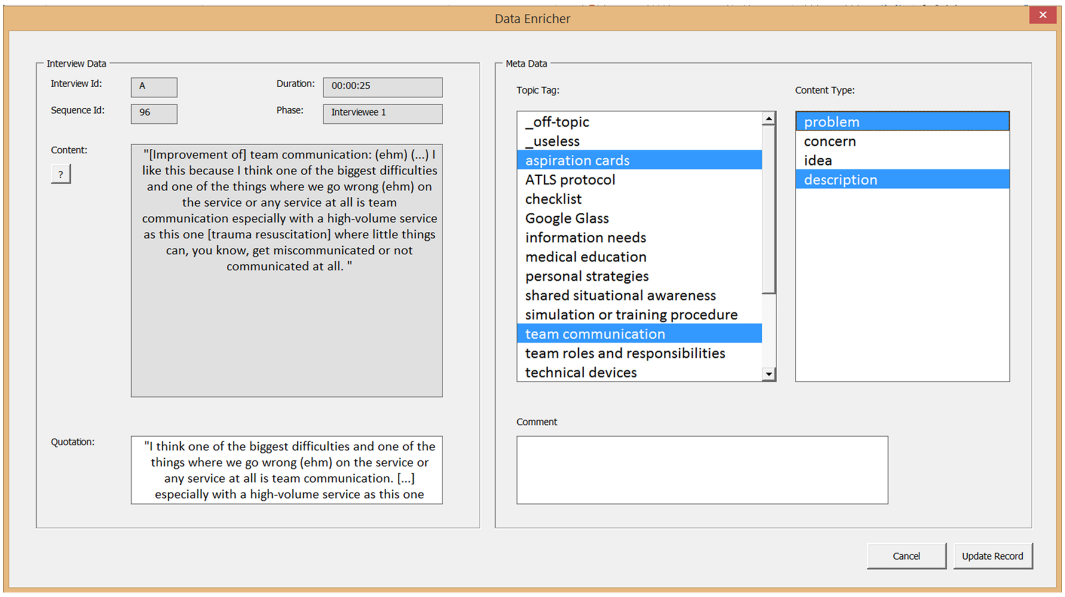


Figure B.1: Screenshots of the Transcript Annotator. A double-click on a cell containing the transcript (top) opens a window that allows to easily edit meta data (bottom). The enriched transcript can later be filtered by using Microsoft Excel's filter functions.

Appendix C

Interview Guideline

Appendix C includes the document that was used as guideline and note-taking sheet during semi-structured user interviews. It consists of four parts and was designed for interviews with 1-3 participants:

- **Assessment of medical experience.**
  (cf. Figure C.1)
- **Open-ended questions.**
  (cf. Figures C.2 - C.6)
- **Google Glass hands-on experience.**
  (cf. Figure C.7)
- **Post-interview questionnaire.**
  (cf. Figure C.8)

A debriefing form was included and allowed to write down most memorable statements and additional notes subsequent to the interviews (cf. Figure C.9).

Interview Guideline TraumaGlass Project

(designed for 1-3 participants per session)

main resources that guided the development of this guideline

- Human Centered Design Toolkit, 2nd Edition
- User Interview Techniques, The Art of the Question (UX London, Liz Danzico)

Introduction: Project Scope

Design challenge emerging from previous work:

"How can personal head-up displays (such as Google Glass) be used to support current practices and workflows in trauma centers?"

Our goals:

- short-term (next 2 months)
  - gain better understanding of workflows and current practices in trauma center and during resuscitations (interviews, observations)
  - based on findings: build and evaluate early prototypes during training or simulated trauma resuscitations
- long-term (following 1-2 years)
  - develop most promising ideas further, continue cooperation

Assessment: Participant's Medical Experience

ID	m / f (gender)	Name (last name, first name)	Experience Level (e.g. intern, resident, chief resident)	Trauma Resuscitations (number of completed trauma resuscitations)
P1 (left)				☐ < 10 ☐ < 100 ☐ < 1000 ☐ > 1000
P2 (middle)				☐ < 10 ☐ < 100 ☐ < 1000 ☐ > 1000
P3 (right)				☐ < 10 ☐ < 100 ☐ < 1000 ☐ > 1000

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Figure C.1: Interview guideline, page 1.

Open-Ended Questions

Question Type: Sequence

Can you walk us through a *typical* trauma resuscitation from beginning till end?

Reflect on

- compliance to *ATLS* protocol
- most *time-critical* tasks
- *team* communication

... during last trauma resuscitation

(if more than 1 participant: ask least experienced one first, everyone who attended a few resuscitations can probably explain it equally good)

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Figure C.2: Interview guideline, page 2.

Question Type: Look Back

What used to be different 10 years ago?

(if more than 1 participant: ask **most** experienced one first since he or she might be best suited to reflect on past changes)

Question Type: Exhaustive List

What are all the *tools* that you typically use during resuscitation?

(if more than 1 participant: common brainstorming)

General

Technical Devices	Protocols	Personal Strategies

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Figure C.3: Interview guideline, page 3.

Question Type: Project Ahead

What do you envision it will be like in 10 years? Do not consider potentials of Google Glass **only**!

- What will stay the same?
- What will change?

(if more than 1 participant: ask group, opinions are expected to differ in some and be consistent in other points)

Common Viewpoint:		
Viewpoint P1:	Viewpoint P2:	Viewpoint P3:

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Figure C.4: Interview guideline, page 4.

Method: Aspiration Cards

Speaking about the future: Choose **two** of the following cards that represent what you think are most promising application areas for personal head-up displays in the context of trauma resuscitation. Feel free to add and choose your own ideas.

- What did you choose and why?
  (if more than 1 participant: let them think aloud and choose collaboratively)

improvement of **team communication**	improvement of **shared situational awareness**	improvement of **ATLS compliance**	reduction of **cognitive load**	improvement of **training procedures**		
☐	☐	☐	☐	☐	☐	☐

reasons for choosing selected card 1 (leftmost checkmark):	reasons for choosing selected card 2 (rightmost checkmark):

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Figure C.5: Interview guideline, page 5.

Question Type: Scenario-based

Take out glass and let participants imagine the following scenario

"Last week, your boss announced that this wearable computer capable of assisting different workflows in trauma centers will be introduced here shortly. I am here to train you on this device and you don't know anything about concrete functionality yet. "

- What would be your **two** biggest concerns?

(if more than 1 participant: address the one who has contributed at least so far):

(1)

(2)

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Figure C.6: Interview guideline, page 6.

Google Glass: Sample Scenario Walkthrough

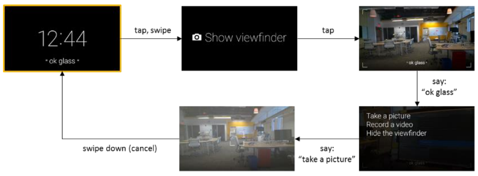
Has anyone already used Google Glass before?

☐ P1 ☐ P2 ☐ P3

Depending on interest and time of the participants, this part might also be skipped (especially if all participants are already familiar with Google Glass)

Optional: Hands-On

- **Scenario A**
  basic touch gestures, camera, voice commands,



- **Scenario B**
  basic touch gestures, simple checklist

- **Scenario C**
  portability to medical domain, basic touch gestures, sound feedback

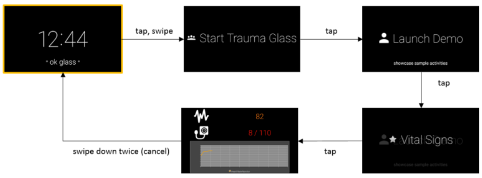


Figure C.7: Interview guideline, page 7.

Post-Interview Questions

On a scale of 1-5 (5 being highest), rate your agreement to each of the following statements.

1) I see future potential for personal, head mounted displays such as Google Glass

		1	2	3	4	5
... during real trauma resuscitations.	P1	☐	☐	☐	☐	☐
	P2	☐	☐	☐	☐	☐
	P3	☐	☐	☐	☐	☐

		1	2	3	4	5
... during trauma resuscitation trainings or simulations.	P1	☐	☐	☐	☐	☐
	P2	☐	☐	☐	☐	☐
	P3	☐	☐	☐	☐	☐

2) In general, I consider myself ...

		1	2	3	4	5
... as being **interested** in new technology.	P1	☐	☐	☐	☐	☐
	P2	☐	☐	☐	☐	☐
	P3	☐	☐	☐	☐	☐

		1	2	3	4	5
... as being an **early adopter** of new technology.	P1	☐	☐	☐	☐	☐
	P2	☐	☐	☐	☐	☐
	P3	☐	☐	☐	☐	☐

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Figure C.8: Interview guideline, page 8.

Debriefing: Summary

- date of interview ____ / ____ / 2015
- duration ____ minutes
- most memorable

(1)
(2)
(3)

- Additional notes

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Figure C.9: Interview guideline, page 9.

Appendix D

Tablet Application

Appendix D includes screenshots of the JavaFX-based tablet application used during our evaluation sessions. The design is optimized for a Microsoft Surface 3 Pro. It is divided into 4 functional parts.

- **Connect tab** (cf. Figure D.1).

  Allows to specify details required to connect to the Dispatching Server of the Google Glass PF.

- **Configure tab** (cf. Figure D.2).

  Allows to configure a training checklist in an intuitively understandable domain-specific language. This flexibility allows to address diverse experience levels and training scenarios.

- **Train tab** (cf. Figure D.3).

  Used by a trainer during the simulation to control what the trainees see. Auditory alarms can be triggered remotely to focus their attention on the screen.

- **Vitals tab** (cf. Figure D.4).

  As long as we do not have real-time access to the vitals of the simulator, we can manually update the vitals on the trainees devices using this interface.

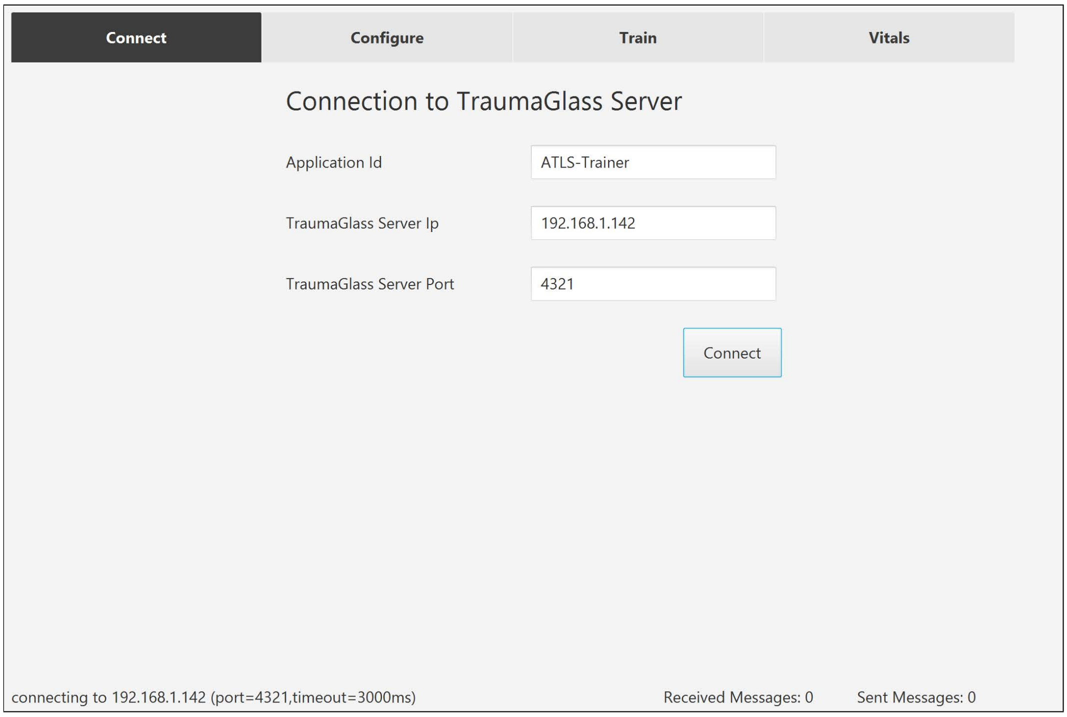

Figure D.1: Tablet application (tab: connect). Specification of connection details.

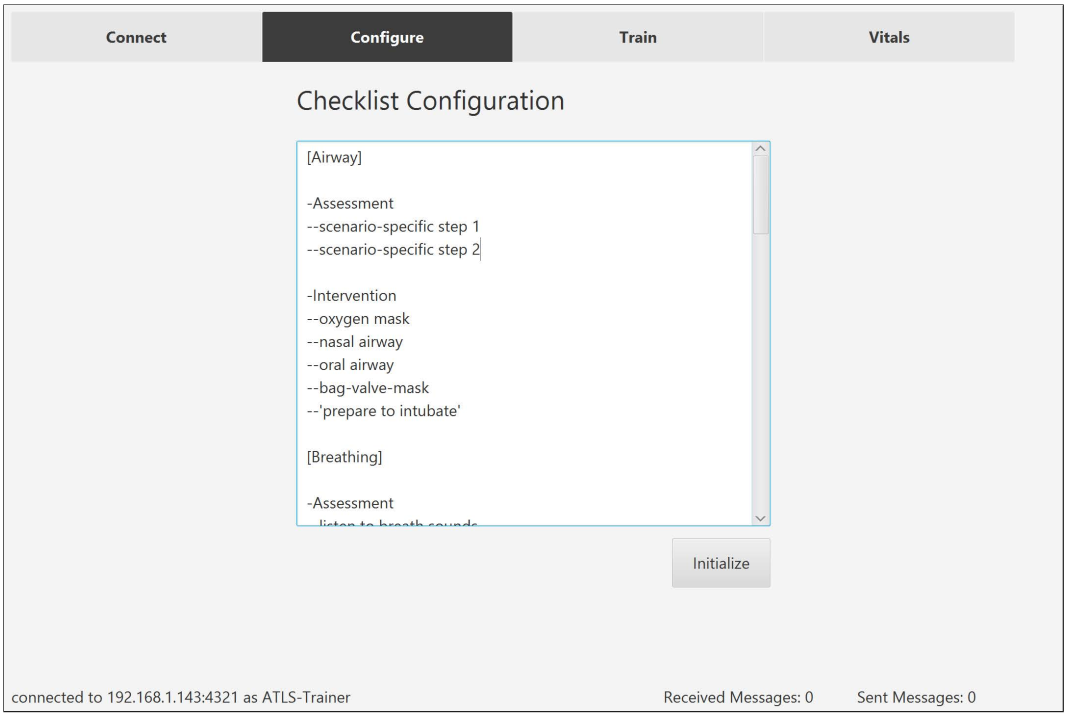

Figure D.2: Tablet application (tab: configure). Dynamic checklist configuration.

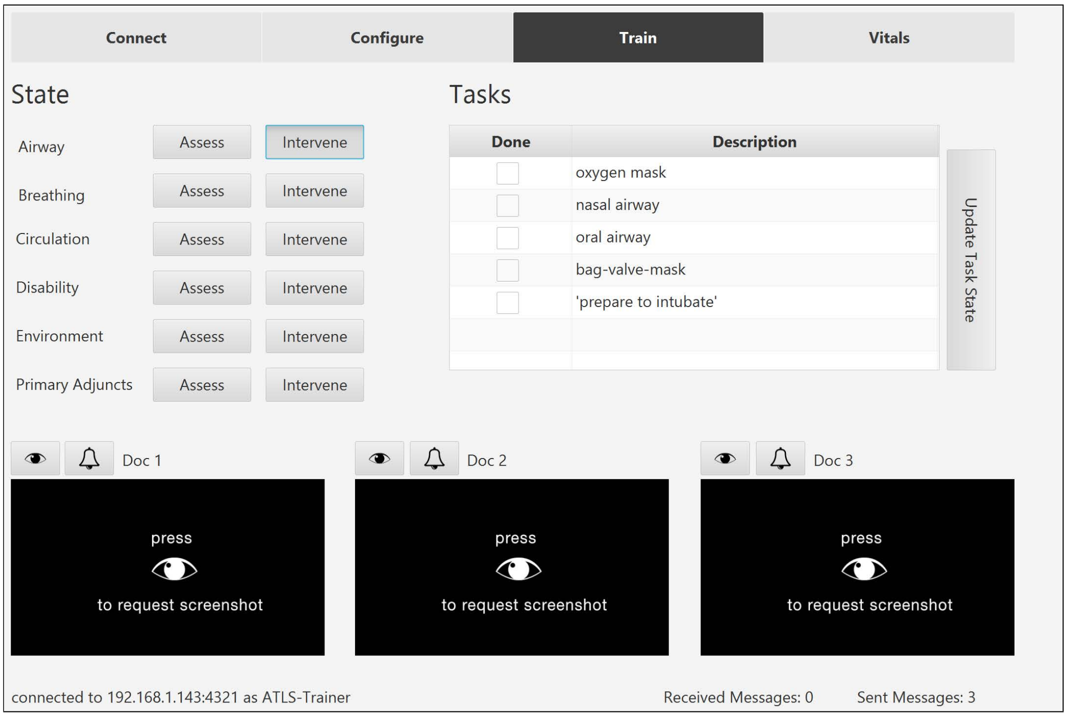

Figure D.3: Tablet application (tab: train). Interface used by the trainer.

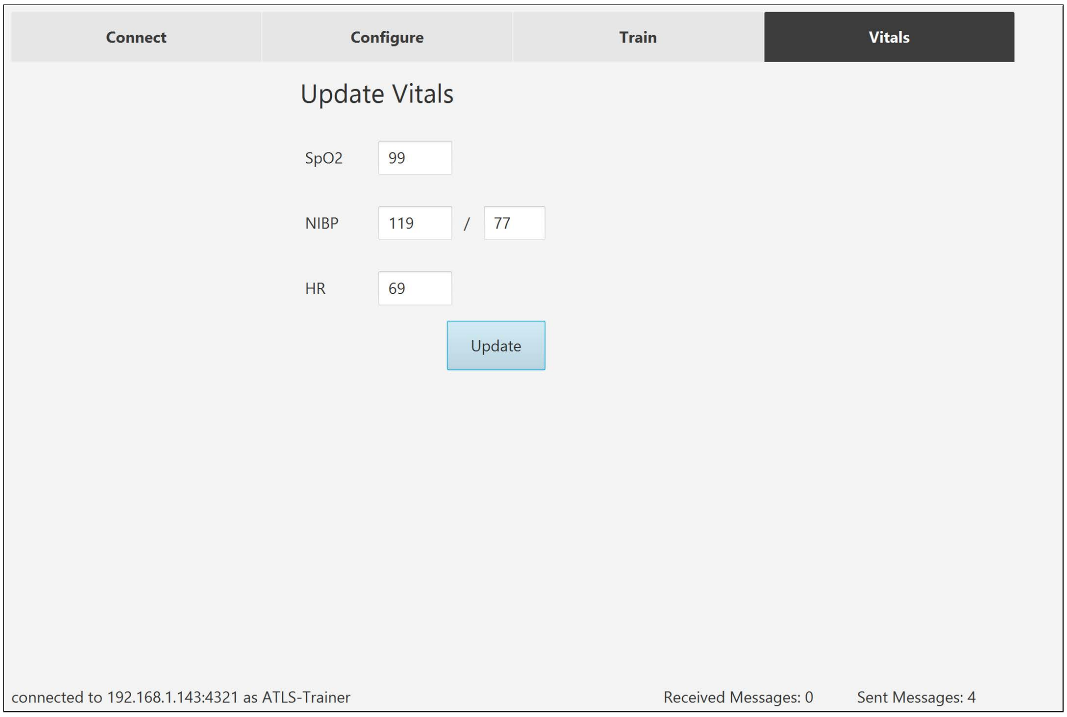

Figure D.4: Tablet application (tab: vitals). Interface used by the "Wizard of Oz".

Appendix E

Collaboration With CAE Healthcare

Appendix E includes a memorandum of understanding between UC San Diego and CAE Healthcare.

The initiation of this collaboration will allow to benefit (inter alia) from real-time access to the vital signs of CAE Healthcare's patient simulators. One of those simulators is currently being used during trauma resuscitation simulations at the Hillcrest Medical Center at UC San Diego.

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February 18, 2015

Memorandum of Understanding Between UCSD and CAE Healthcare

University of California, San Diego (UCSD) and CAE Healthcare (CAE) enter into this memorandum of understanding in order to support researchers at UCSD by providing access to a SDK for a patient mannequin developed by CAE. Researchers will use the SDK for academic purposes only.

(I) Background

The overall design challenge of the *TraumaGlass* project emerging from previous work is to explore if and how personal head-up displays (HUD) can be used to support current practices and workflows in trauma centers. Researchers at UCSD have recently started collaborating with a Level 1 Trauma Center in San Diego that uses a patient simulator of CAE for training purposes. Initial user interviews and observations in the trauma bay have proven potential for HUDs.

(II) Short-Term Goals

As part of a master's thesis project, a prototype that visualizes the vital signs (amongst others) on Google Glass has been developed. It shall be extended such that it allows to display basic vital signs of the mannequin in real-time by leveraging the SDK of CAE. The acceptance of this type of support will be evaluated during an upcoming trauma resuscitation training.

(III) Long-Term Goals

Based on the results of (II), additional application scenarios might be explored and further prototypes evaluated. Accessing more data of the mannequin through the SDK or being able to drive clinical scenarios with the aid of augmented reality devices are two potential future directions.

(IV) Partnership Plans

UCSD will share the results on a regular basis and CAE Healthcare will be provided a one week time-frame to review any manuscripts originating from this project for confidential information prior to publication. Feedback and project ideas of CAE are welcome at any time.

Nadir Weibel, Ph.D.
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Figure E.1: Memorandum of understanding. It defines scope and type of the collaboration between UC San Diego and CAE Healthcare.

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