# From Chaos to Order: Evaluating a Mobile Triage System for Mass Casualty Incidents Through a Within-Subjects Experimental Study

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# From Chaos to Order: Evaluating a Mobile Triage System for Mass Casualty Incidents Through a Within-Subjects Experimental Study

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## Abstract

**Background:** Digitalization of disaster medicine has great potential to accelerate rescue operations and, therefore, to save lives. The handling of disasters with mass casualties requires a detailed picture of the situation. Currently, first responders manually write triage results of patients on cards. Short information is communicated to the command post using radiocommunication. While this procedure is established in practice, it also implies several time-consuming and error-prone tasks. We address these issues by design, implementation and evaluation of an App-based mobile system. Within the system, the user can document responder details, triage categories, injury pattern, GPS location among other important information and transfer it automatically to the incident commanders.

**Objective:** The aim of the study was to design and evaluate an App-based mobile system as a triage and coordination tool for emergency and disaster medicine compared to the widely used paper-based system.

**Methods:** Data of N=38 emergency medicine personal was assessed while they completed two triage sessions of 30 patient cards each: one session using the App-based mobile system and the other one using the paper-based tool. Accuracy of the triages and the time duration for each session were measured. Furthermore, we implemented the User Experience Questionnaire and further items to assess the participant's subjective ratings of the two triage tools.

**Results:** Our 2 (triage tool) x 2 (tool order) mixed MANOVA yielded a significant main effect for triage tool ($P<.001$), while post-hoc analyses indicated that participants were significantly faster ($P<.001$) and assigned more patients to the correct triage category ($P=.005$) using the App-based mobile system compared to the paper-based tool. In addition, analyses yielded significantly better subjective ratings for the App-based mobile system than for the paper-based tool in terms of school grading ($P<.001$) and the six scales of the User Experience Questionnaire (all $P<.001$). Overall, 94.7% (36/38) stated to prefer the App-based mobile system. There was no significant main effect for tool order ($P=.243$) in our model.

**Conclusions:** We were able to show that, that an App-based mobile system cannot only keep up with the conventional paper-based tool, but even surpass it in terms of efficiency and usability. This could further expand the potential of digitalization to optimize processes in disaster medicine, which could in turn save more lives.

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# 1. Introduction

## 1.1. Background

In recent years, the number of disasters with mass casualties has significantly increased [1] due to factors as terrorism, climate change, and war. While disaster medicine procedures are well-established and effective, there is potential for optimization through digitalization [2]. Currently, data collected manually and paper-based during a disaster is not available to decision-makers in a timely and detailed manner. This data, particularly from rescue teams who are first on the scene, is crucial for successful mass casualty and disaster management, saving lives and valuable for scientific research to improve future operations [3]. First responders must prioritize patients based on injury severity to ensure that those in critical condition receive immediate attention. Incident commanders coordinate rescue resources and connect with hospital capacities, requiring an overview of the number of patients, their injury severity, and locations. Upon arrival, rescue teams search for casualties and categorize patients [4] using triage algorithms like Simple Triage and Rapid Treatment (START)[5], modified Simple Triage and Treatment (mSTART)[6], and jumpSTART for children[7, 8] and classify them by health status with color codes (*Textbox 1*).

*Textbox 1. Triage categories following the mSTART algorithm.*

- RED: Patients with life-threatening injuries that immediately need an adequate treatment.
- YELLOW: Patients that are seriously injured, and not able to walk. The treatment is still urgent but can be delayed after the first group.
- GREEN: Patients that are slightly injured, able to walk and can be treated later. Sometimes they are also called “walking wounded”.
- BLACK: Deceased casualties or casualties that are dying and only need supportive treatment.
- Sometimes BLUE is used for patients that have no chance to survive under the given circumstances considering the available resources.

Biographic data and initial treatments are recorded on hand-written cards attached to patients, facilitating communication and tracking. All the information is relayed to incident commanders via radio, who coordinate with various rescue organizations, and manage resources and patient transport based on the triage data. Rescue services set up areas for further admission, treatment, decontamination and transportation, where patients are re-triaged to track changes in their health status. This process ensures that the most critical patients receive timely and appropriate care.

## 1.2. Weaknesses and problems with the current rescue process

Currently, triage data collected by rescue teams is communicated to the command post using radio communication, which must be very compact and minimal due to time constraints. While reliable, radio communication is not suited for transmitting large amounts of data. Communication from rescue teams to incident commanders and dispatch centres follows a many-to-one pattern, requiring recipients to manually compile information, which is time-consuming and error- prone. Rescue teams collect additional data during triage, such as patient biographic information and minor treatment details. Transmitting all this information via radio would be too time-consuming, leading to only the most critical data being communicated. This results in incomplete information, which can hinder effective disaster management. Incident commanders often need to call rescue teams to get missing details, adding to communication time. Additionally, verbal descriptions of patient locations are not as precise as GPS tracking, complicating fast evacuations. Rescue teams rush from patient to patient and can only inform the command post of their findings intermittently, leading to delayed updates. This slow development of the overall disaster picture can result in outdated or incorrect decisions, requiring reorganization and causing time loss. The manual and communication-intensive processes deteriorate work quality and increase task execution times. These weaknesses can have dramatic impacts on patient outcomes. Automating the process with a software system can address these issues by providing a common, central data source accessible to all involved parties.

## 1.3. The App-based mobile system “KatApp”

### 1.3.1. Principles and Requirements

The weaknesses in the current rescue process arise from the lack of a common, central data source accessible to all involved parties. If rescue teams used software to triage patients, the results could be immediately stored in a shared data source. Incident commanders connected to this data source could access real-time information, customized to their needs, thus eliminating several weaknesses through process automation. This would remove the need for manual compilation of information and allow for the creation of complete data sets, minimizing data incompleteness and additional communication costs. The software could also automatically track GPS coordinates of triage locations and present real-time data, improving the overall quality and speed of the process. By eliminating several manual tasks, the overall quality of work would improve, reducing errors and allowing more time for important tasks, thereby accelerating process execution. From a functional perspective, building such a software system seems straightforward, but several non-functional requirements must also be considered, such as usability, data security, data privacy, and system availability. These requirements are crucial for the system to be effective in real disaster scenarios.

*Textbox 2* explains these requirements and their importance in more detail.

*Textbox 2. Non-functional requirements of a software system supporting the rescue process.*

- USABILITY: Medical staff using the software in the field is under stress. Sometimes also the environment is very challenging, e.g. if it is dark. Therefore, it is very important to provide user interfaces that are easy to understand and intuitive to handle.
- DATA SECURITY: The software system stores sensible, personal data and guarantees to protect it against unauthorized accesses.
- DATA PRIVACY: The software system must guarantee to follow the laws on processing sensible, personal data.
- SYSTEM AVAILABILITY: A software system that is not available in the context of a disaster may increase the number of casualties. Reliability is one important factor to achieve an available system.

### 1.3.2. Software Prototyping

To address the mentioned requirements, we used software prototyping [9] to design and develop a prototype named "KatApp," which was tested in several disaster medicine training sessions, where we collected quantitative data and qualitative feedback for evaluation. Given the widespread use of smartphones, which are already employed by rescue teams and available on every rescue vehicle, we chose smartphones as client devices for the software system. Tablets, with their larger screens, were used for command post members to benefit from various data visualizations. Both device types required a common shared data source, leading us to develop a front-end/back-end architecture [10]. Applications running on the clients belong to the front-end layer and use services of the back-end layer to read or write data, with the back-end services utilizing a persistence layer for permanent data storage. A fundamental design decision was how to connect patients with their digital data records during a disaster. We attached a QR code to each patient, representing a unique ID. Rescue teams scan the QR code before starting triage, linking patients to their digital records seamlessly. This approach is ensuring that patients can be identified throughout the disaster response. The idea behind this new digital triage process is illustrated in *Figure 1*.

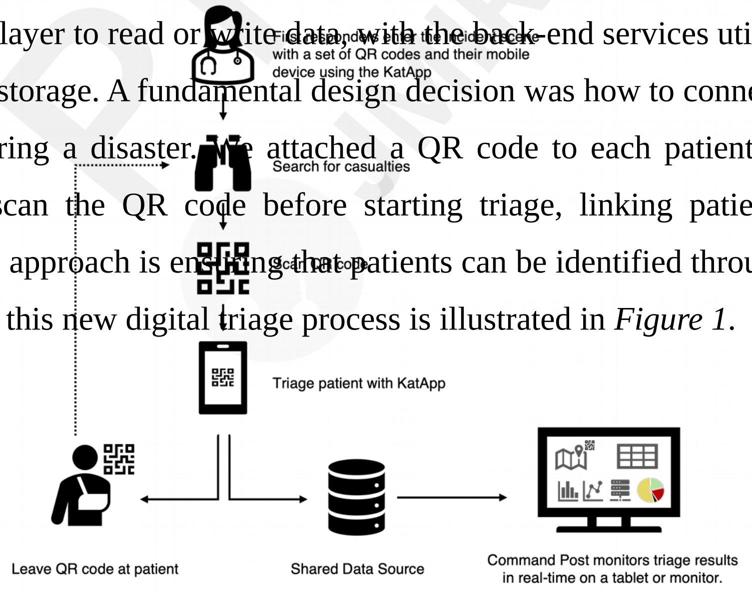

*Figure 1. Digital triage procedure using the KatApp Software System.*

### 1.3.3. Software Architecture

The software architecture of the KatApp system follows a modern cloud-based back-end to front-end architecture style. The front-end layer consists of two client applications: a native app for triaging patients used by rescue teams and a web application implementing a dashboard for the command post. Both client applications access services of the back-end layer, with the app using the REST API and the web application connecting via a web socket connection.

The triage app is developed with Google's Flutter framework [11] to support multiple platforms from a single codebase, including iOS and Android, which is crucial for training and future use by different organizations. The app's user interface was designed to be easy to use during triage, moving from flowchart-based designs to a page flow representing the triage algorithms. Besides the implementation of the triage algorithms (mSTART and jumpSTART) additional features include day and night modes, QR code scanning with a pocket lamp, and an overview of completed triages. We developed the command post dashboard as a web application using the React framework [12, 13], focusing on usability and consists of several tiles displaying different types of information, such as patient lists with injury severity a map and timing (*Textbox 3*).

*Textbox 3. Dashboard tiles.*

- OpenStreetMap [14]- based map showing the location of patients around the incident scene.
- List of patients triaged so far. All information collected of a certain patient can be viewed as well. The list also shows the development of triages of a patient during the disaster.
- Time since the start of the triage handling, as well as the current time.

The dashboard application is developed as a modular system that can be easily extended by new tiles. It is connected to the back-end service using a web socket connection. As soon as new triage records are received by the back-end service from the apps of the rescue teams, they are pushed to the dashboard application over this connection, ensuring the command post always has the most current information without needing to manually pull data. The system's nature fits well with serverless computing [15, 16], as it is only needed during real disasters or training sessions, thus being billed accordingly.

### 1.3.4. System Architecture

All software components are managed using repositories on GitHub (2024 GitHub, Inc). Automatic deployments are implemented using GitHub Actions and custom scripts [17]. The iOS app is deployed to TestFlight from Apple, while the Android app is deployed to Firebase. Rescue teams can install the desired version from these platforms in advance of a training. The dashboard web application and the back-end are both deployed to Amazon Web Services AWS (2023 Amazon Web Services, Inc.). The dashboard is hosted as a web application on AWS, while the back-end services are implemented as AWS Lambda functions [18]. These services use AWS DynamoDB for user management, logging, and triage records, and AWS S3 for binary data. *Figure 2* depicts the architecture in more detail.

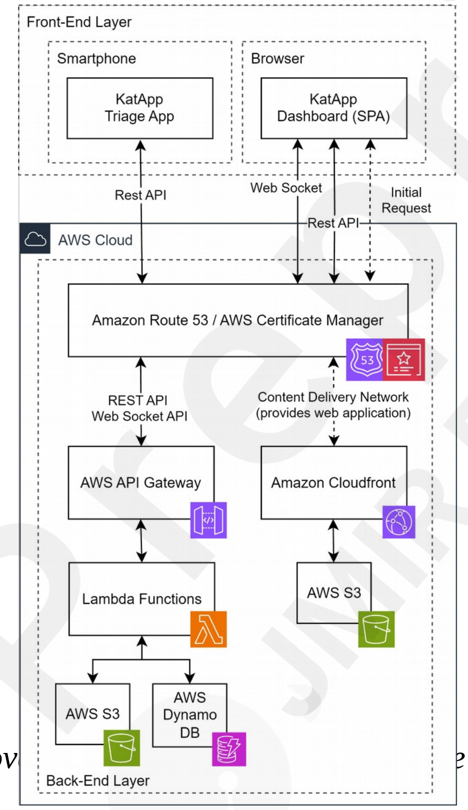


*Figure 2. Schematic ov… e without deployment and identity and access management.*

The KatApp system is a distributed system that relies on the connectivity of its nodes, including the mobile devices of rescue teams, the tablets of the command post, and the back-end services. The standard operation mode assumes an internet connection is available around the incident scene, allowing the web application and back-end services deployed in the cloud to be accessed by the apps on the rescue teams' mobile devices. The dashboard web application is reachable via browsers on the command post's tablets or computers and can establish a web socket connection to the KatApp back-end. In a perfect world, this operation mode would be sufficient. As we know from the fallacies of distributed computing [19], networks are not reliable in many respects, especially during disasters when critical communication infrastructure might be destroyed or overstressed, or in regions with poor network coverage. To address this, the KatApp system implements a caching mechanism in the triage app, allowing rescue teams to continue triaging patients even without an internet connection. The triage records are stored locally and transmitted automatically once the connection is restored. Additionally, the KatApp system supports an operation mode independent of an internet connection. A local wireless network can be set up by the command post or a technical organization on-site, with a server containing the dashboard application and back-end services. Mobile devices connect to this network, allowing the system to function as usual. Since the back-end services were developed as AWS Lambda functions, they cannot run locally. Therefore, an additional abstraction layer was implemented to use alternative open-source or self-written components for each AWS component.

### 1.3.5. Prototype Refining

After prototyping the KatApp, we used it in several training courses to gather early qualitative feedback and quantitative data for ongoing development and discussions with domain experts. Initially, we focused on qualitative feedback to refine the prototype. Subsequently, we extended logging functionalities to measure the time and quality of triages. Post-training, the triage app approach was discussed in debriefings, and individual feedback was collected via questionnaires. *Table 1* shows early implementations of our prototype in pilot studies. Several usability insights for the app and dashboard were immediately added to the backlog. To standardize the evaluation of our refined prototype against the conventional paper-based triage tool, we conducted an experiment using a within-subjects design.

*Table 1. Early-stage implementations of the KatApp prototype.*

| | Objective | Sample | Procedure | Results |
|---|---|---|---|---|
| **Training 1** | Obtain first qualitative user feedback | N=15 rescue service personal, emergency physicians and medical students | Participants triaged 60 patient cards at different locations, i.e. the location of incident, the treatment area and before release of the patient | - 150 triages were made<br>- more than 90% of the app users and 100% of the dashboard users stated that they would like to use such a system in real disaster |
| **Training 2** | Use prototype in an evacuation training (earthquake) and finish the evacuation within 90 minutes | N=50 medical students as first responder teams, supervised by experienced | Participants triaged 18 patients (played by actors) | - 48 triages were made<br>- scenario could be finished in time<br>- 2 patients were triaged in the wrong category |

| | | | | |
|---|---|---|---|---|
| | | emergency physicians | | - average time of a triage: 42s |
| **Training 3** | Use prototype in an evacuation training (flood warning + gas explosion) and finish the evacuation within 75 minutes | N=50<br>rescue service personal and emergency physicians | Participants triaged 23 patients (played by actors) | - 50 triages were made<br>- all patients were triaged in the correct category<br>- average time of a triage: 37s |

## 1.4. Research Objective

The study aimed to design and evaluate the KatApp as a triage tool for emergency and disaster medicine. The objective was to determine if the KatApp is superior to paper-based triage tools in terms of speed, accuracy, and user experience among emergency medicine experts. We hypothesized that the KatApp would be at least as accurate as the paper-based tool, but faster and more user-friendly.

# 2. Methods

## 2.1. Ethics Approval

The Ethics Committee of the Faculty of Medicine at Tübingen University Hospital approved the study (260/2024BO2). All methods were implemented in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants.

## 2.2. Study Design and Setting

The study was conceived as a within-subjects experimental design, with the triage tool as within-subjects factor (paper-based tool vs. KatApp). The order of the triage tools was counterbalanced to compensate for carry-over effects.

The study was conducted on the premises of the German Red Cross in Kirchentellinsfurt on behalf of the University Hospital Tübingen together with Reutlingen University in June 2024. The study participation was voluntary.

## 2.3. Recruitment

The invitation to the triage training course and the call for participation in the study were sent to a mailing list of the Tübingen District Association of the German Red Cross which comprises approximately 500 different e-mail-addresses of rescue service personal, physicians and medical students.

To determine the sample size for the study, a statistical power analysis was conducted using G*Power (version 3.1 for MacOS) [20], which resulted in a required sample size of 45 participants with an effect size of Cohen's d=0.5, a statistical power of .95, and a level of significance of .05. It should be noted that due to the limited number of similar publications, the statistical power analysis was based on general considerations of the trade-offs between the ability to detect at least medium-size effects and the feasibility to obtain a sufficiently large sample. In case of no-shows and dropouts, we decided to recruit additional 10 participants, summing up to 55.

## 2.4. Study Procedures

After participants registered for the triage training course and study, they were provided with instructions on how to install the app and information regarding the study procedure one week prior to the course.

To familiarize the participants with the mSTART algorithm using both the paper-based tool as well as the KatApp, they were given an introduction at the beginning of the course. They were then asked to complete two triage sessions in the context of a simulated mass casualty incident, which would be caused by a terrorist driving into the Fan Zone of a public screening of the UEFA European Football Championship 2024. In one session, they were using the KatApp, and in the respective other session the conventional paper-based tool. The tool order was randomized. Each session comprised 30 patient cards which had to be classified to one of the four triage categories. The 30 patient cards were distributed along a course of exactly 96.32m for each triage tool. The two sessions were conducted simultaneously, with the next participants starting their sessions every 5 minutes (see *Figure 3* for a sketch of the experimental setup, *Multimedia Appendix 1* for a drone picture and *Multimedia Appendix 2* for and drone film of the setting).

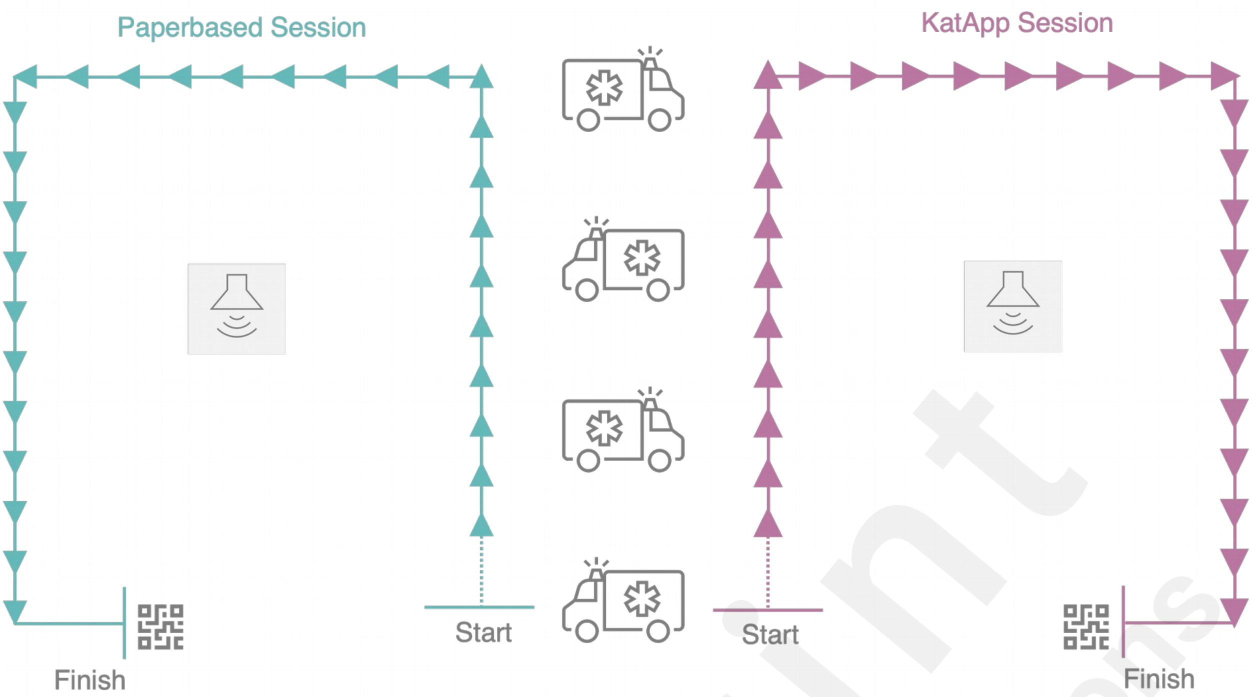


*Figure 3. Sketch of the experimental setup. Each Session consisted of 30 patient cards (marked as triangular in this sketch) that were distributed along a course of 96.32m. Emergency vehicles and a fog machine blocked the view between the two courses. In addition, simulated sounds of a mass casualty incident were played via connected sound boxes that were placed in the middle of each course. Immediately after the sessions, the participants were asked to scan a QR code to complete the follow-up questionnaire.*

After each session, the participants completed a web-based questionnaire using the online questionnaire tool SurveyMonkey (SurveyMonkey Inc., San Mateo, California, USA), and then started the second session with the respective other triage tool after a recovery period of approximately 30 minutes.

## 2.5. Patient Cards

The patient cards were initially designed using a previously designed artificial patient database [21, 22] and then further adapted by the study team. They contained a pictogram to represent the injury pattern and information on the injury severity (Abbreviated Injury Scale, AIS), vital parameters (i.e. Glasgow Coma Scale [GCS], respiratory rate, systolic blood pressure, radial pulse, re-capillarization time, walking ability, age), as well as a short storyboard with additional information on the course of the accident (*Multimedia Appendix 3*). In order to keep the two sessions comparable, the number of patient cards per triage category was identical (red: 20% [6/30], yellow: 43.3% [13/30], green: 30% [9/30], black: 6.7% [2/30]), while the categorization was based on empirical data on mass casualty incidents [23]. In addition, we matched pairs of patient cards in terms of overall injury severity (AIS) and injury pattern to minimize the impact of differences in patient cards on outcome variables between the triage tools. The order of patient cards in each course was randomized using the online randomization tool RANDOM.ORG (Randomness and Integrity Services Limited, Dublin, 2024), but equal for each participant.

## 2.6. Triage Tools

### 2.6.1. Paper-based Tool

When using the conventional paper-based tool, participants had to fill out a casualty card (*Multimedia Appendix 4*) that also required them to fold the triage category manually and attach the card to the patient card. In addition, the participants had to record the triage category on a documentation sheet. To facilitate the triage, the participants were given an mSTART checklist [6].

### 2.6.2. KatApp

When using the KatApp, participants had to scan a QR code for each patient and conduct the triage process as described above (*Figure 1*) and displayed in *Multimedia Appendix 5*. Participants used their mobile smartphones which were connected to the mobile network. The triage results were immediately forwarded to a central dashboard.

## 2.7. Measuring and Outcomes

### 2.7.1. Duration and Quality of Triages

The study staff recorded the time at the beginning and end of each parcours as soon as the participants crossed the start and finish lines. In addition, the number of correct triages per session was assessed by analyzing participants' documentation sheets of the paper-based tool, and the data that was collected by the KatApp.

### 2.7.2. Subjective Ratings

The participants had to rate both triage tools as a school grade of the German grading system from 1 (excellent) to 6 (insufficient). They were also asked about their preference with a forced-choice item.

### 2.7.3. User Experience Questionnaire

We used the German version of the User Experience Questionnaire (UEQ) [24] to assess the participants' experience after each triage tool. The UEQ consists of 26 items that are grouped into six scales (Attractiveness, Perspicuity, Efficiency, Dependability, Stimulation, Novelty), while each item displays a semantic differential that must be rated on a 7-point Likert scale, which are in turn coded from -3 to +3 (*Multimedia Appendix 6*). *Attractiveness* refers to the overall impression of the product (Do user like or dislike the product?), whereas *Perspicuity* assesses the ease to get familiar with the product and to learn how to use it. In addition, *Efficiency* displays whether users can solve their tasks without unnecessary efforts, and *Dependability* refers to the feeling of control of the interaction, security and predictability. *Stimulation* measures how exciting and motivating it is to use the product, and *Novelty* presents whether the product is creative and catches the interest of users. *Figure 4* illustrates the overall experimental design.

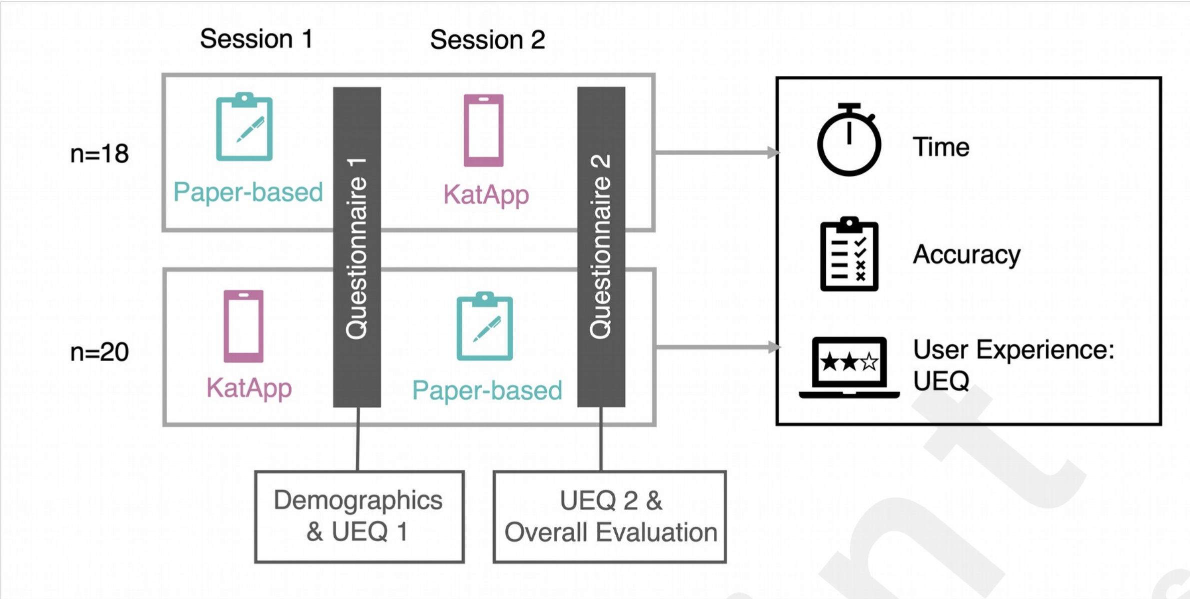


*Figure 4. Within-subjects experimental design that was used for the evaluation of the KatApp compared to the conventional paper-based tool. Each participant conducted two sessions in which they had to triage 30 patient cards. The tool order was counterbalanced to compensate for possible carry-over effects.*

## 2.8. Statistical Analysis

The Statistical Package for the Social Sciences (SPSS, IBM Corp., Version 29 for MacOS) was used for data management and statistical analyses.

To analyze differences between the conventional paper-based tool and the KatApp, we calculated a mixed multivariate analysis of variance (MANOVA) with triage tool as within-subjects factor (paper-based tool vs. KatApp). To account for possible interactions between triage tool and tool order, we added the tool order (KatApp used in the first vs. in the second session) as between-subjects factor. As dependent variables, we added the overall time to complete the respective triage session, the number of correct triages, the participants' subjective ratings of the triage tools as a German school grade, as well as the results of the six scales of the UEQ.

In another repeated-measures MANOVA, we used measurement timepoint (first vs. second session) as within-subjects factor for the same nine dependent variables to assess differences between the measurement timepoints.

We reported Pillai's trace as F-statistic in our models, and post-hoc univariate ANOVAs were conducted for each dependent variable.

Despite the violation of the normal distribution assumptions for some of the outcome variables, we calculated MANOVAs, as this method is relatively robust against such violations [25]. We preferred to conduct MANOVAs instead of multiple ANOVAs, as MANOVAs account for the complex structure between the dependent variables, have greater statistical power and are advantageous compared to multiple testing regarding alpha error accumulation.

As an exploratory analysis, we calculated non-parametric correlations (Kendal's tau) between age and the outcome variables to test the requirements for including age as a covariate in our model. However, no statistically significant correlations were found, which is why we decided to not conduct multivariate analyses of covariance (MANCOVAs), as this would have been associated with a reduction in statistical power. We set the significance level at $\alpha$=.05 in our analyses.

We created raincloud plots in R using the packages raincloud plots [26], as this approach visualizes differences between the two triage tools as well as raw data, probability density and key summary statistics in a transparent format.

# 3. Results

## 3.1. Sample Size and Exclusions

In total, 55 people initially registered for the course, while N=48 participants finally showed up and attended the course which displays a no-show rate of 12.7% (7/55). From those who attended the course, n=6 participants had to be excluded from further statistical analyses due to an incomplete documentation of the triages (n=3 with the paper-based tool, n=2 within the KatApp, n=1 within both tools), another n=2 participants did not complete questionnaire 1, and n=2 participants did not complete questionnaire 2. Hence, the final sample size consisted of N=38 participants for further statistical analyses.

## 3.2. Sample Characteristics

Demographic characteristics of the sample are presented in *Table 2*. The average age of the sample was 32.5 years (SD 9.2), with 63.2% (24/38) being male. In total, 39.5% (15/38) reported to have previous experience with triaging. Regarding their occupation, 36.8% (14/38) of the participants were physicians, 44.7% (17/38) worked as rescue service personal, 10.5% (4/38) were medical students and 7.9% (3/38) reported to belong to another group (e.g. standby service or honorary position).

*Table 2. Demographic characteristics of the sample.*

| | Value |
|---|---|
| Age (years), mean (SD) | 32.5 (9.2) |
| **Gender, n (%)** | |
| Female | 14/38 (36.8) |
| Male | 24/38 (63.2) |
| **Previous Experience, n (%)** | |
| Yes | 15/38 (39.5) |
| No | 23/38 (60.5) |
| **Occupation, n (%)** | |
| Physician | 14/38 (36.8) |
| Rescue Service Personal | 17/38 (44.7) |
| Medical Students | 4/38 (10.5) |
| Other | 3/38 (7.9) |
| **Specialization (Physicians)** | |
| Anesthesiology | 10/14 (71.4) |
| Surgery | 2/14 (14.3) |
| Neurology | 1/14 (7.1) |
| Pediatrics | 1/14 (7.1) |
| **Additional Qualification in Emergency Medicine (Physicians)** | |
| Yes | 11/14 (78.6) |
| No | 3/14 (21.4) |
| **Highest Qualification (Rescue Service Personal)** | |
| EMT-Basic | 12/17 (70.6) |
| EMT-Intermediate | 1/17 (5.9) |
| Paramedic | 4/17 (23.5) |

## 3.3. Evaluation Results

### 3.3.1. Overall

Findings of the 2 (triage tool) x 2 (tool order) mixed MANOVA revealed a significant main effect for the within-subjects factor triage tool ($F_{9,28}$=70.585, $P$<.001, $\eta^2_p$ =.958) and a significant interaction between the triage tool and the tool order ($F_{9,28}$=4.432, $P$=.001, $\eta^2_p$=.588), but no significant main effect for the between-subjects factor tool order ($F_{9,28}$=1.382, $P$=.243, $\eta^2_p$ = .308).

### 3.3.2. Duration

The results of the post-hoc univariate ANOVA showed that the participants were significantly faster using the KatApp than the paper-based tool ($F_{1,36}$=229.769, $P$<.001, $\eta^2_p$ =.865). The mean difference is illustrated in *Figure 5A*. In addition, a significant interaction was found between triage tool and tool order $F_{1,36}$=15.052, $P$<.001, $\eta^2_p$=.295), indicating that the time taken for each tool was lower when it was used in the second session, but always being less for the KatApp.

### 3.3.3. Accuracy

Simultaneously, the post-hoc univariate ANOVA revealed that the participants significantly assigned more patient cards to the correct category with the KatApp than with the paper-based tool ($F_{1,36}$=8.979, $P$=.005, $\eta^2_p$ =.2), which is illustrated in *Figure 5B*. Again, a significant interaction was found between triage tool and tool order for triage quality ($F_{1,36}$=4.731, $P$=.036, $\eta^2_p$=.116), suggesting that the number of correct triages for each tool was higher when it was used in the second session, but always higher when using the KatApp.

### 3.3.4. Subjective Ratings

When participants were asked to rate the triage tools within the German school grading system, the post-hoc univariate ANOVA showed significant better ratings for the KatApp (excellent) than for the paper-based tool (satisfactory; $F_{1,36}$=116.281, $P$<.001, $\eta^2_p$=.764), with no interaction between triage tool and tool order ($F_{1,36}$=0.007, $P$=.932, $\eta^2_p$=.000). The mean difference is illustrated in *Figure 5C*.



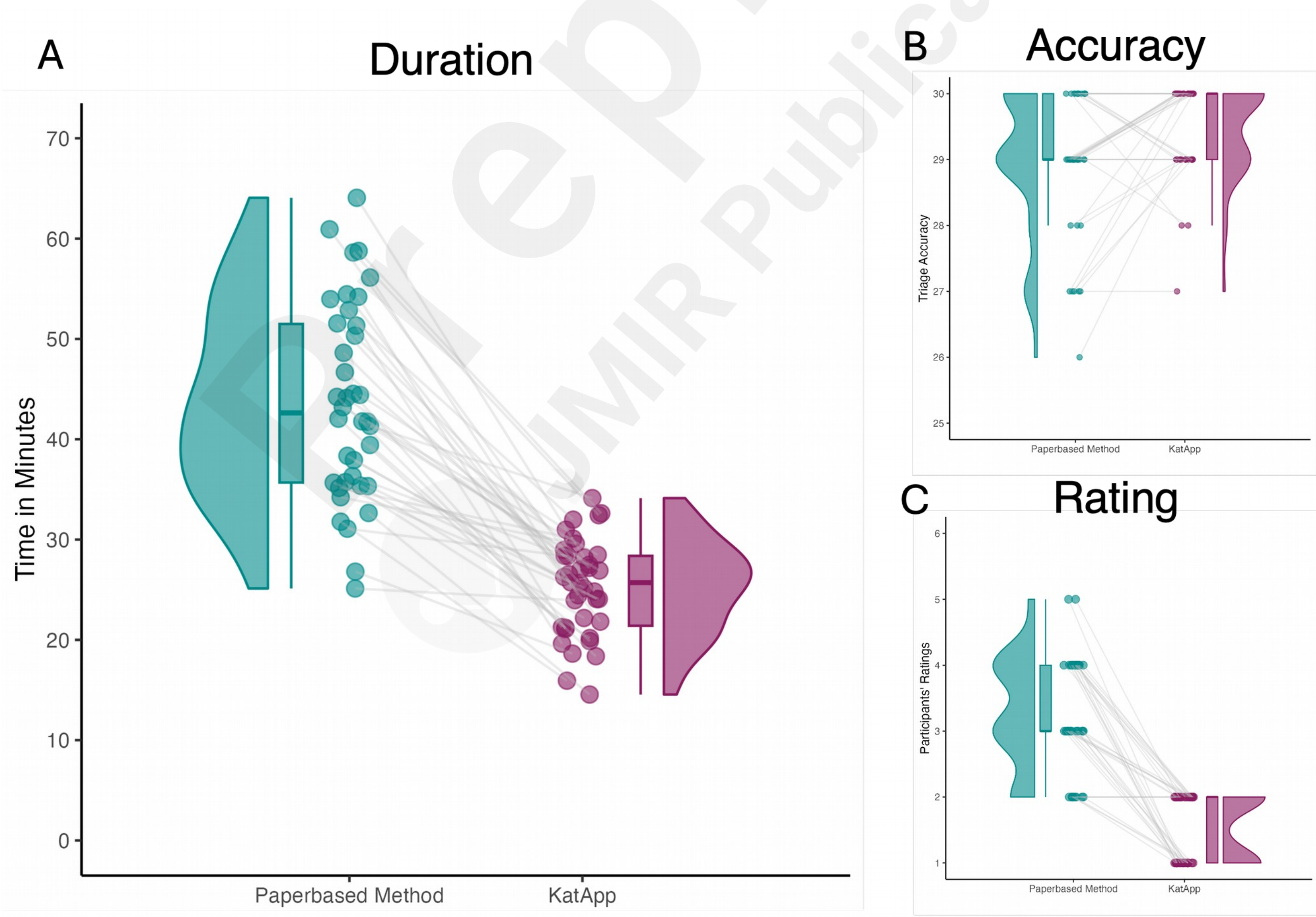


*Figure 5. Comparison of the conventional paper-based tool with the KatApp regarding duration to complete each session in minutes (A), triage accuracy as number of correct triages out of 30 (B),*

*and the participants' subjective ratings as German school grades (C) from 1 (excellent) to 6 (insufficient).*

### 3.3.5. User Experience Questionnaire

Regarding the six scales of the UEQ, post-hoc univariate ANOVAs indicated significant better ratings for the KatApp than for the paper-based tool in each scale (Attractiveness: $F_{1,36}$=128.812, $P$<.001, $\eta^2_p$=.782; Efficiency: $F_{1,36}$=105.542, $P$<.001, $\eta^2_p$=.744; Perspicuity: $F_{1,36}$=26.390, $P$<.001, $\eta^2_p$=.423; Dependability: $F_{1,36}$=61.693, $P$<.001, $\eta^2_p$=.631; Stimulation: $F_{1,36}$=58.422, $P$<.001, $\eta^2_p$=.619; Novelty: $F_{1,36}$=132.687, $P$<.001, $\eta^2_p$=.787). There was no significant interaction between triage tool and tool order in any of the scales (Attractiveness: $F_{1,36}$=0.214, $P$=.647, $\eta^2_p$=.006; Efficiency: $F_{1,36}$=0.006, $P$=.937, $\eta^2_p$=.000; Perspicuity: $F_{1,36}$=0.636, $P$=.430, $\eta^2_p$=.017; Dependability: $F_{1,36}$=1.762, $P$=.193, $\eta^2_p$=.047; Stimulation: $F_{1,36}$=0.434, $P$=.514, $\eta^2_p$=.012; Novelty: $F_{1,36}$=2.361, $P$=.133, $\eta^2_p$=.062). *Figure 6* illustrates the differences between the tools regarding the six scales of the UEQ.

The mean values and corresponding statistics for the outcome measures between the two triage tools are reported in *Table 3*.

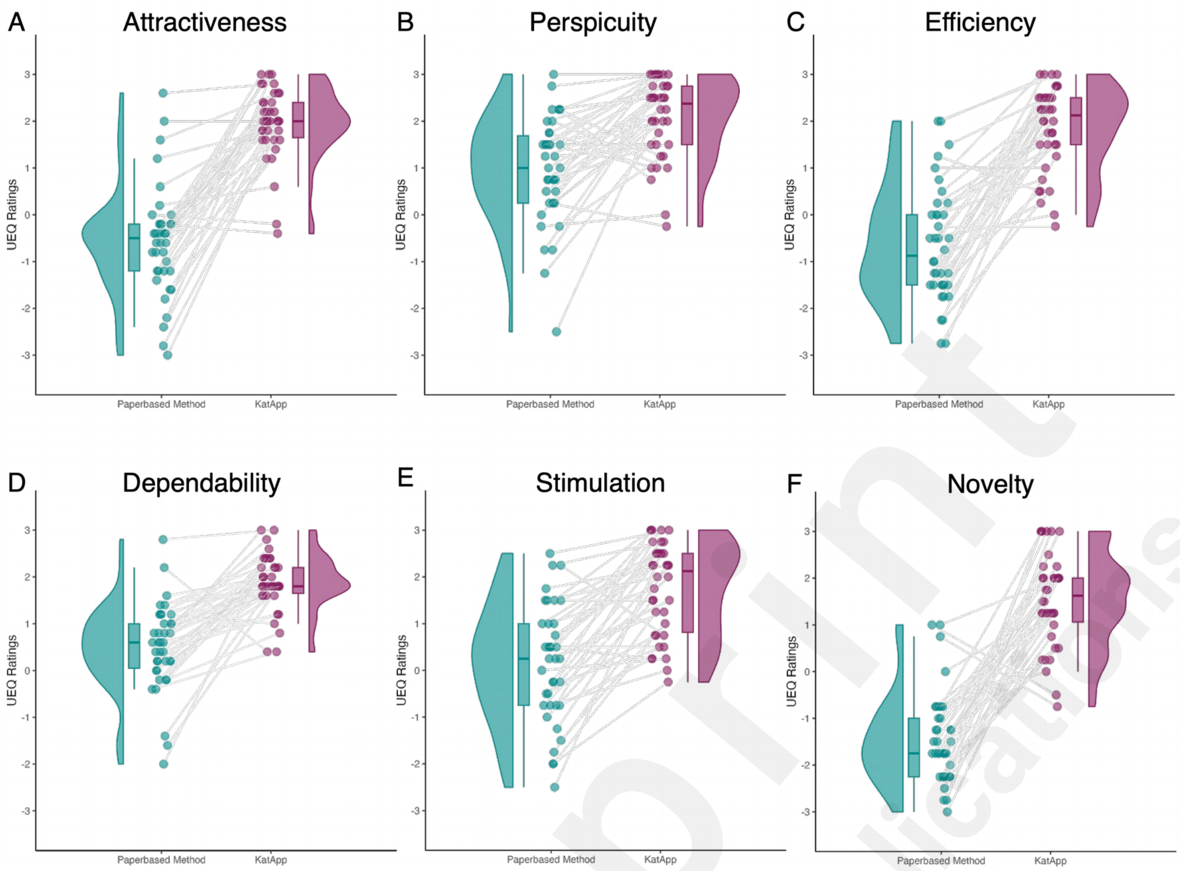


*Figure 6. Results of the User Experience Questionnaire (UEQ) comparing the conventional paper-based tool with the KatApp regarding the six scales Attractiveness (A), Perspicuity (B), Efficiency (C), Dependability (D), Stimulation (E) and Novelty (F).*

*Table 3. Post-hoc univariate ANOVA comparison between the paper-based tool and the KatApp (N=38).*

| Outcome Variable | Paper-based, mean (SD) | KatApp, mean (SD) | $F_{1, 36}$ | *P* | $\eta^2_p$ |
|---|---|---|---|---|---|
| | *Annotations* | *Annotations* | | | |
| **Duration in minutes** | 43.71 (9.816) | 25.22 (4.737) | 229.769 | <.001 | .865 |
| **Triage Accuracy** | 28.92 (1.099) | 29.45 (0.724) | 8.979 | .005 | .200 |
| **Subjective Rating** | 3.26 (0.860) | 1.53 (0.506) | 116.281 | <.001 | .764 |
| | *Satisfactory*[a] | *Excellent*[a] | | | |
| **User Experience Questionnaire** | | | | | |
| Attractiveness | -0.58 (1.175) | 1.96 (0.764) | 128.812 | <.001 | .782 |
| | *Bad*[b] | *Excellent*[b] | | | |
| Efficiency | -0.65 (1.224) | 1.86 (0.900) | 104.542 | <.001 | .744 |
| | *Bad*[b] | *Good*[b] | | | |
| Perspicuity | 0.94 (1.146) | 2.09 (0.861) | 26.390 | <.001 | .423 |
| | *Below average*[b] | *Excellent*[b] | | | |
| Dependability | 0.49 (0.937) | 1.88 (0.600) | 61.693 | <.001 | .631 |
| | *Bad*[b] | *Excellent*[b] | | | |
| Stimulation | 0.14 (1.251) | 1.76 (0.997) | 58.422 | <.001 | .619 |
| | *Bad*[b] | *Excellent*[b] | | | |
| Novelty | -1.45 (0.964) | 1.54 (0.999) | 132.687 | <.001 | .787 |
| | *Bad*[b] | *Good*[b] | | | |

[a] Grading according to the German academic grading system ranging from 1 (excellent) to 6 (insufficient).

[b] Classification according to the general benchmark of the UEQ [27].

### 3.3.6. Preference

When participants were asked to give their preference on a forced-choice item, 94.7% (36/38) opted for the KatApp, and 5.3% (2/38) for the paper-based tool.

## 3.4. Controlling for Order Effects

Results of the 2 (triage tool) x 2 (tool order) mixed MANOVA revealed no significant main effect for the between-subjects factor tool order ($F_{9,28}$=1.382, $P$=.243, $\eta^2_p$ = .308). Upon conducting univariate ANOVAs for the between-subjects effect, no significant differences surfaced in any of the measures despite the UEQ scale novelty ($F_{1,36}$=6.625, $P$=.014, $\eta^2_p$=.155), indicating that when the KatApp was used in the second session, novelty ratings were significantly higher than when it was used first.

In addition, the repeated measures MANOVA for outcome measures per measurement timepoint as within-subjects factor did not reveal a significant main effect for session ($F_{9,29}$=2.094, $P$=.064, $\eta^2_p$=.394). None of the post-hoc analyses revealed significant differences between the first and second session on any of the outcome measures (*Table 4*).

*Table 4. Post-hoc univariate MANOVA comparison between the results of the first and the second session.*

| | $F_{1, 37}$ | $P$ | $\eta^2_p$ |
|---|---|---|---|
| | | | |
| **Triage Quality** | 3.357 | .075 | .083 |
| **Time Duration** | 3.357 | .257 | .035 |
| **Subjective Rating** | 0.104 | .749 | .003 |
| **UEQ** | | | |
| Attractiveness | 0.253 | .618 | .007 |
| Efficiency | 0.101 | .753 | .003 |
| Perspicuity | 0.165 | .687 | .004 |
| Dependability | 1.151 | .290 | .030 |
| Stimulation | 0.443 | .510 | .012 |
| Novelty | 0.190 | .665 | .005 |

# 4. Discussion

## 4.1. Principal Results

In this paper, we present an innovative approach for triage that no longer classifies patients with a paper-based but a mobile App-based system into the different triage categories in the context of mass casualty incidents. After prototyping the mobile app, we applied it in several trainings and refined it. The final prototype version was then evaluated compared to the conventional paper-based tool in terms of time duration, triage quality and subjective ratings such as user experience using a within-subjects experimental study. Our results suggest that when using this software system, triages can be made faster, easier, and even more accurate compared to the conventional paper-based tool, overcoming time-consuming and error-prone issues of the current procedures in disaster medicine.

The most important and obvious difference is the time participants needed to complete the two triage sessions which comprised 30 patient cards each: With the KatApp, participants were on average more than 18 minutes faster than with the paper-based tool. Combined with the fact that the command posts receive information in real time, critical decisions could be made earlier, and patients could be treated faster, which in turn could save additional lives. It should be noted that participants didn't even have to transmit their information via radio-communication to the command post in the paper-based session, which would have been even more time-consuming. The fact that they had to fill out the casualty cards manually and complete the documentation sheet could have already account for this difference.

In addition, participants found the KatApp to be more user-friendly than the conventional paper-based tool. In each of the six scales of the UEQ, participants rated the KatApp as an "excellent" or at least "good" tool when using the corresponding benchmarks [27]. In comparison, the paper-based tool scored "bad" or "below average". This pattern is also found when comparing the school grades awarded by the participants: While the KatApp was perceived as "excellent", the paper-based tool received an average school grade of "satisfactory". These results indicate that, in addition to the time advantage, the KatApp was also perceived as easier to use than the paper-based tool. A further indication of how important the digitalization of disaster medicine processes could be is provided by the fact that 94.7% (36/38) of participants would prefer the KatApp if they had to choose between the two triage tools.

Surprisingly, there was also a statistically significant difference in terms of triage accuracy between the two triage tools, indicating that when using the KatApp, participants triaged more patients correctly than when using the paper-based tool. As the effect size for this difference was lower compared to the other effect sizes, this result should not be over-interpreted. It might be that the patient cards slightly differed although being matched in terms of injury severity, injury pattern and triage category. In addition, the number of correctly assigned patient cards was high using both tools. Nevertheless, some participants particularly appreciated the support provided by the app while triaging, which may have led to fewer errors due to the automated application of the mSTART algorithm.

The results of our within-subjects experimental study are therefore consistent with our hypotheses, demonstrating that the KatApp system is at least as useful and reliable as the conventional paper-based tool to perform triages in disasters with mass casualty incidents. The advantages and benefits of a digital triage tool, such as the automatic forwarding of information to a shared data source and central dashboard, the collection of real-time data, the tracking of the patients' geolocations, and the collection of complex data to further optimize rescue operations, are thus brought to bear. Besides our quantitative results, some of these additional advantages could be observed in our study: In the early implementations of the KatApp, as well as in the experimental study, the participants didn't receive a special training in advance to use the KatApp system. They were only given a quick introduction right before the start of the training, which underlines the general usability of the system.

Furthermore, the qualitative feedback from the command posts after the trainings confirmed that the information presented in the dashboard simplified their work dramatically. Especially, the real-time overview of patients with their triage categories and the map with the locations of the patients were highly appreciated.

## 4.2. Limitations

In our study, we used patient cards instead of real patients or actors, which could limit the external validity. Our goal was to compare both triage tools within a standardized procedure and analyze a large number of triages, achieving 2280 triages. Using 60 actors would have been costlier with little additional benefit. The KatApp must still be evaluated in real disaster operations or large-scale simulations. Regarding the within-subjects design, order effects like practice or fatigue cannot be completely ruled out. We counterbalanced the tool order and included it as a between-subjects factor in our MANOVA and conducted a second repeated-measures MANOVA with measurement timepoint as a within-subjects factor. Our analyses showed no significant influence of order on primary outcomes. While practice effects were observed, participants always performed better in terms of time and accuracy with the KatApp. Despite these order effects, a within-subjects design was chosen for its greater statistical power, control over individual differences, and smaller sample size requirement. However, within-subjects designs can make it easier for participants to guess the hypotheses, potentially distorting results due to raised expectations. Finally, some assumptions for our statistical analyses, like the normal distribution of variables, were partially violated, but MANOVA is considered robust to such violations[25]. The overall missing data rate was high at 20.8% (10/48), but we still reported large effect sizes with our results.

## 4.3. Next steps and further adaptions

Next steps will be the improvement of the inter-connectivity between the smartphones when mobile network is not available, inclusion of emergency resources like ambulances, helicopters and hospitals in the back end. After those will be implemented a pilot phase will start in real non-simulation settings with the aim to introduce the live system within the shortest time possible.

## 4.4. Comparison with Prior Work

As to our knowledge, this is the first paper that addresses the issues of current rescue operations in disasters with mass casualties by the development, implementation, and experimental evaluation of a mobile triage app compared an conventional paper-based tool. According to a systematic review of triage apps for health emergencies[28], there have been former attempts to develop such an approach. In 2014 for example, a research group developed a mobile-based system to support triage in mass casualty incidents including a Cox proportional hazard model to present the survival curve of the patients in order to support triage and transportation decisions[29]. Another approach was to use Smart Glasses and a specific Android App to assist triage during mass casualty incidents, which was evaluated within a randomized controlled simulation trial[30]. The TRIAGIST mobile application [31, 32] was developed as a low-cost system that dispatch centers or rescue teams in Thailand could hire for developmental purposes. Nevertheless, none of these approaches have been further implemented for use in disaster medicine so far. Furthermore, a decrease in studies of apps for catastrophe triage has been noted in the past years, and the little number of existing triage apps on the market which are based on a scientific and academic background, lack free access [28]. Following the call to develop an accessible app that provides patient geolocation and assists rescue teams by automatically applying a triage algorithm [28], with our KatApp system, we can contribute to close a gap in science that is of great practical importance.

## 4.5. Conclusions

In this paper, we present research addressing weaknesses and problems of the current triage process in mass casualty incidents with the development, implementation and evaluation of a mobile system called KatApp.

We were able to show that, with the KatApp, we've developed a mobile triage app for use in disaster medicine that cannot only keep up with the conventional paper-based tool, but perhaps even surpass it in terms of efficiency and usability. This could further expand the potential of digitalization to optimize processes in disaster medicine, which in turn could save more lives. Although it is evident that this novel approach reduces time-consuming and error-prone manual tasks, we are not yet able to fully quantify the acceleration in dealing with a real disaster situation by using the KatApp system, as we have only implemented the system in simulated training scenarios so far. For this purpose, further research and refining of this approach is required.

## Authors' contributions

RW, ES and MSc initiated and coordinated the study. RW and JS coordinated the experiment inclusive data collection. JS and RW interpreted the data. MS and JS wrote the initial draft of the manuscript. PR, AM, BB and MSi critically reviewed and substantially improved the manuscript. All authors reviewed and approved the final version of the manuscript before submission. All authors had access to all data and analysis in the study. All authors had final responsibility for the decision to submit for publication.

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## Conflicts of Interest

None declared.

## Funding information

No external funding was used.

## Abbreviations

AIS: Abbreviated Injury Scale

AWS: Amazon Web Services

EMT: Emergency Medical Technician

GCS: Glasgow Coma Scale

MANOVA: Multivariate Analysis of Variance

mSTART: modified Simple Triage and Rapid Treatment

START: Simple Triage and Rapid Treatment

UEQ: User Experience Questionnaire

## Multimedia Appendix 1

Drone Picture of the Experiment Setting.

## Multimedia Appendix 2

Drone Film of the Experiment Setting.

## Multimedia Appendix 3

Example of a patient card used in the experimental study.

## Multimedia Appendix 4

Casualty cards used as paper-based tool in the experimental study.

## Multimedia Appendix 5

Mock-up of the KatApp.

## Multimedia Appendix 6

German Version of the UEQ with an English translation of the items.

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# Supplementary Files

# Multimedia Appendixes

Experiment overview picture.
URL: http://asset.jmir.pub/assets/929e1b00dd72e2d872a1515adaf7a4e9.png

Experiment overview film.
URL: http://asset.jmir.pub/assets/eb29200398bc66538d280463b562e071.mov

Patient Cards.
URL: http://asset.jmir.pub/assets/85a6424c58e78ff7fd3cb97f939607de.pdf

Paper-based casualty cards.
URL: http://asset.jmir.pub/assets/ce0ab79141b3d2a5128c2c1e79e27e1b.pdf

KatApp mock-ups.
URL: http://asset.jmir.pub/assets/6c7f375d67f4b2974a31193518ba1103.pdf

German Version of the User Experience Questionnaire as used in our study with English translations.
URL: http://asset.jmir.pub/assets/7e1b1fd6fd9c1469e6f2e145fd0e3dcc.docx

# TOC/Feature image for homepages

SmartApp-based system in use.