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Evaluation of Patient-Specific Medical Device Alarms During Multi-Patient Medical Evacuation Scenarios

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14. ABSTRACT
The objective of this work was to evaluate three-dimensional (3D) audio alarms that may contribute to enhanced medical awareness of patients for care providers in the military medical evacuation environment. The specific effect examined was the alarm response time. Qualitative end-user feedback was also collected to evaluate the efficacy of the alarm configurations. Each subject participated in four 60-minute patient care scenarios, two scenarios with monaural alarms broadcasted over a simulated ICS and two scenarios with 3D audio alarms broadcasted over the simulated ICS. Each alarm type was used with two- and three-patient configurations. Although statistical significance was not achieved, trends in the reaction time data indicate that the implementation of 3D audio alarms may be beneficial in high workload environments. Average reaction times were reduced between 1-4 seconds in the configurations with the 3D audio alarms compared to the monaural alarms. Subject feedback indicated that 3D audio was well received and had a positive impact on reducing reaction time and directing attention to the necessary patient.

15. SUBJECT TERMS
saliency, salient signal, integrated alarms, intercommunication set, ICS, communication ear plugs (CEP), CEPs, three-dimensional audio, spatial audio, helicopter, HH-60, medical evacuation, MEDEVAC, patient care, task saturation, alarm fatigue, patient load, medical device, monitor, vital signs, simulator, alarms, time delegation, response time, decompensation, flight medic

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Summary

Purpose: The goal of this study was to evaluate the effects of using three-dimensional (3D) audio alarms to quickly notify critical care flight paramedics (CCFP) which patient monitoring device was alarming and to compare those effects with the effects of integrated monaural alarms. Additionally, this study examined the effects of those integration conditions as patient load increased. The specific effect examined was the alarm response time.

Subject population: The subject population for this study included six active-duty CCFP certified members of the United States (U.S.) Army, Reserves, and National Guard. All subjects were trained or refreshed on the use of the medical devices that alarmed through the intercommunication set (ICS).

Procedures: This was a 2 x 2 repeated measures experimental design evaluating the differences in response time between monaural (standard) versus 3D audio alarms broadcasted over the aircraft ICS. Each subject participated in four 60-minute patient care scenarios. Two scenarios were completed with monaural alarms broadcasted over a simulated ICS, and two scenarios with 3D audio alarms broadcasted over the simulated ICS. Each audio configuration was completed with two and three patients. Average reaction time to planned decompensation events were calculated by averaging the reaction times to only the planned alarms of each scenario. This excludes the reaction time to unprogrammed alarms and silenced alarms that re-sounded. A mixed-effects linear regression model was used to analyze the data. Additionally, qualitative data were collected from the subjects on the benefits and limitations of using the system, as well as Likert ratings related to patient care and workload.

Results: The mixed-effects linear regression model analysis showed that audio configuration, patient number, and the interaction effect were not statistically significant. Although no statistical significance was found, trends observed in the data suggest that audio configuration and patient number may impact CCFP response time. Specifically, increasing from two to three patients increased mean response time by 1.4 seconds in the 3D audio configurations, and 4.2 seconds in the standard audio configurations. Additionally, moving from the standard to the 3D audio two-patient configuration increased mean response time by 1.2 seconds, and 4.0 seconds from the standard to the 3D audio three-patient configuration.

In the two-patient configurations, more alarms were initially ignored during the 3D audio than in the standard audio scenarios. During the three-patient configurations, a total of six patient alarms were initially ignored during the standard audio and only one alarm was initially ignored during the 3D audio. Moreover, the post-test questionnaire provided key insights into how the 3D audio was perceived by the subjects. The Likert ratings did not reveal any clear trends between configurations, except for signal clarity where the 3D audio configuration was scored better. The open-ended questions received positive feedback toward both audio configurations; however, the most reported issue with the standard audio was its inability to indicate which specific device was alarming, highlighting the advantage of the 3D audio.

Discussion: The reaction time in the three-patient configurations was reduced during the 3D audio alarms for every subject, compared to the standard alarms, indicating that the 3D audio may be beneficial during a high workload environment. Although statistical significance was not achieved, some interesting trends were observed in the response time data. Response time

increased when the number of patients was increased within an audio configuration, as well as when moving from the standard to the 3D audio configuration for both two- and three-patient scenarios. These differences were not large in nature, between 1-5 seconds, depending on configuration. More information regarding patient morbidity and mortality will need to be gathered to confirm if these differences significantly affect patient outcomes or provider awareness.

Both audio configurations received positive feedback; many of the subjects expressed favorable feedback toward the 3D audio, citing its ability to quickly direct attention to the alarming monitor or patient. The results of the Likert question relating to signal clarity further supported this conclusion. However, some subjects had trouble distinguishing between patient two and three during the three-patient 3D audio configuration.

Conclusion: Although the analysis of response times did not reach statistical significance, the results provided critical insights into the potential efficacy of 3D audio alarms. The reaction time data indicates that the implementation of 3D audio alarms may be beneficial during high workload environments. These results, supported by subject feedback, suggest that the 3D spatial audio was well received and has a positive impact on reducing reaction time, by anywhere between 1-5 seconds depending on configuration, and directing attention to the necessary patient. Further studies will be required to determine if these differences in response time have a significant impact on patient morbidity and mortality.

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Introduction

One of the many challenges for care providers in rotary-wing aircraft is the inability to detect auditory alarms in the high-noise, high-distraction flight environment (Di Lamb, 2010). Reliance on visual alerts in the flight environment with uncertain lighting conditions and hidden medical devices during black-out operations can adversely affect response times (Fromm et al., 1995; Conti, McLean, et al., 2019). Testing for carry-on medical device airworthiness consistently identifies that "inability to hear the auditory alarms" was worthy of a note of caution on the airworthiness release (U.S. Army Aeromedical Research Laboratory [USAARL], 2012) and the deficit was usually noted on the Aeromedical Certification Memorandum for the medical devices (Department of the Army, 2018) indicating it could impact patient care during flight. A study completed by USAARL showed that a single critical care flight paramedic (CCFP) working alone can only give care to one urgent patient and successfully meet all the standard medical operating guidelines (Barazanji et al., 2018; Conti, Lloyd, et al., 2019). Part of this limitation may involve an excess of clinically insignificant and/or conflicting data inputs that the CCFP receives throughout the continuum of en route care.

The Multiple Resource Model, based on Christopher Wickens' Multiple Resource Theory, elucidates the mechanisms that contribute to sensory overload. The theory postulates that when an individual is engaged in two or more tasks at one time, performance on the tasks is dependent upon the extent to which the tasks consume different resources across four dimensions (for an in-depth review see Wickens [1981], Wickens [2002], and Wickens [2008]). These dimensions include the "stages of processing," "codes of processing," "perceptual modalities," and "visual channels." The model asserts that performance is dictated by the amount of overlap of resources nested within these dimensions. Tasks with little overlap will yield little to no harmful effects on performance, but tasks with greater overlap will have greater decrements in performance. To increase performance, it may be beneficial to introduce information from a separate dimension that aids performance, without overlapping other dimensions too greatly.

The need to detect and respond to evacuated patient needs will become more exigent given that future medical evacuation (MEDEVAC) operations will require the clearing and care of multiple patients directly from a multi-domain operations (MDO) battlefield (TRADOC Pamphlets 525-3-1 and 525-3-8, 2018). Using the conflict in Ukraine as an indicator, a significant increase in the number of patients being treated and an increase in injury severity can be expected (Epstein et al., 2023). Additionally, Ukrainian forces have faced ongoing challenges in the evacuation of casualties, both through ground and air transport. This has resulted in delayed evacuation times, requiring forward medical teams to provide extended periods of prolonged field care. These predicted challenges in patient transport may necessitate the simultaneous evacuation of a large number of casualties. Given limited numbers of CCFPs, it is imperative that their clinical bandwidth be increased so that they can efficiently care for more than a single urgent patient. Auditory cues to patient deterioration are critically important to maintaining situational awareness, especially given low light conditions and multiple patients.

A possible mitigation strategy to improve patient awareness is to transmit auditory signals over the intercommunication set (ICS) to alert the care provider of potential problems with the patient or medical devices. The ICS permits internal communication between flight crew, medical personnel, and pilots aboard the aircraft (Department of the Army, 2020). The

inclusion of alarms into the ICS using monoaural sound display was previously investigated at USAARL (Kroening et al., 2022). The participating medics generally had positive responses to the integration of alarms, and the trends in the data indicated possible improvements to patient care, though some drawbacks and necessary improvements to the system were noted in the medics' feedback. Feedback from the subjects indicated that the sounds alone may not be enough to significantly improve patient awareness. The medical alarms may be obscured or masked by competing sounds. Competing sounds include those from aircraft alarms, pilot and aircrew chatter over the ICS, and ambient aircraft noise. CCFPs may spend several seconds or minutes discerning the specific patient in need of care, resulting in lost critical treatment time as well as time diverted away from caring for an additional casualty during the en route care mission. To further refine the usefulness of the auditory medical alarms, one of the suggested improvements was to add saliency to the alarms for ease of differentiation in multi-device scenarios.

A salient signal is achieved with a striking or unique feature that is easier to detect and is more likely to attract one's attention (Kayser et al., 2005). CCFPs are frequently exposed to an overabundance of sensory events, which cannot be simultaneously processed (Kayser et al., 2005). Neural mechanisms exist for selecting which stimuli are relevant, as attention is selective and capacity limited (Kayser et al., 2005; Wrigley & Brown, 2004). The bottom-up stimulus attention model, also known as the saliency model, postulates that attention shifts to the most significant or important item in the space (Zink et al., 2003; Sawaki & Luck, 2010). Audio saliency has been assessed by manipulating frequencies, timbre, loudness, and locations. (Zlantintsi et al., 2012; Evangelopoulos et al., 2013). With such a mechanism in place, care providers would not only gain the ability to distinguish the medical device alarms from the ambient noise in the aircraft but would be able to identify which patient and device to switch their attention to expeditiously.

One method of achieving saliency is to create an auditory display that spatially separates and places the sounds in a three-dimensional (3D) auditory space. Spatial auditory displays improve intelligibility of messages, even amidst multiple competing talkers or other sound sources through a phenomenon known as spatial release from masking (Drullman & Bronkhorst, 2000; McAnally & Martin, 2007). The creation of 3D audio in sound emitting speakers within a pilot's communication system, similar to those present in standard flight helmets worn by military flight crew, is proven technology. For example, Begault and colleagues conducted a series of experiments using the traffic alert and collision avoidance system used by aircrews that provided a heads-up visual display of surrounding aircraft and spatialized auditory cues for warnings and crash avoidance instructions (Begault et al., 2010). The series of experiments demonstrated that despite spatialized auditory cues maintaining congruency only in the horizontal plane, search time on the display was significantly decreased (Begault, 1993; Begault & Pittman, 1996). Moreover, McAnally and Martin (2008) demonstrated that even in a dynamic environment with visual indications of change in motion, listeners can preserve the ability to localize 3D sound, supporting the appropriateness of use in the aviation environment. As such, during a multi-patient transport scenario, 3D sound-rendering versus a monaural mixed auditory sound display, may aid in more rapidly identifying the patients in need of attention.

The objective of this work was to evaluate 3D audio alarms that may contribute to enhanced medical awareness of patients for care providers in the military medical evacuation environment. The goal of this work was to convey critical patient alarms in the medical

evacuation environment without compromising medical provider administration of en route critical care tasks. Additionally, this work will determine how the number of patients influences the efficacy of care when 3D medical device alarms are present.

Military Relevance

This research addresses the Capability Needs Analysis Gap 203554 – "Army Medical Units lack the ability to provide an advanced level of critical care to treat a range of complex poly-trauma patients during ground and/or air evacuation following emergent life-saving interventions to achieve a 100% survival rate of potentially survivable wounds," as defined in the strategic plan for En Route Critical Care (U.S. Army Medical Research and Development Command, 2021, p. 8). Within the same strategic plan, the project falls under Technical Objective P18.2.2.1 "Research products characterizing & mitigating physical limitations of en route care providers & remote medical system operators" (U.S. Army Medical Research and Development Command, 2021, p. 19). The physical limitation of the en route care provider was the inability to hear medical device alarms during rotary-wing medical evacuation, leading to decreased patient awareness. In multi-patient scenarios with longer medical evacuation times anticipated during large-scale combat operations (LSCO), increased patient awareness should lead to decreased morbidity and mortality during transport. The long-term outcome of this project is more effective patient care during and after point of injury transport in MDO and LSCO environments.

Specific Aims/Hypotheses

The specific aims and hypotheses of this project are as follows:

Specific Aim 1: Determine the efficacy of incorporating spatially separated medical device alarms in the ICS for the CCFP.

> *Hypothesis 1.1:* Response times will be shorter when using spatially separated medical device alarms compared to those in the mixed monaural audio signal condition across all participants.

Specific Aim 2: Determine the effect the number of patients requiring treatment has on the efficacy of en route care when spatially separated medical device alarms are present.

> *Hypothesis 2.1:* Average response times will be equal when more patients requiring care are present using spatially separated medical device alarms.

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Methods

Research Procedures

This study incorporated both monaural (standard) and 3D audio alarms into the simulated aircraft ICS. The design was a 2 x 2 repeated measures experimental design. Differences between the scenarios with standard alarms were analyzed against the scenarios with 3D audio alarms for each medic. The study employed multi-patient configurations of either two or three simulated patients during data collection. In total, each subject completed four runs of data collection, standard audio two-patients, 3D audio two-patients, standard audio three-patients, and 3D audio three-patients.

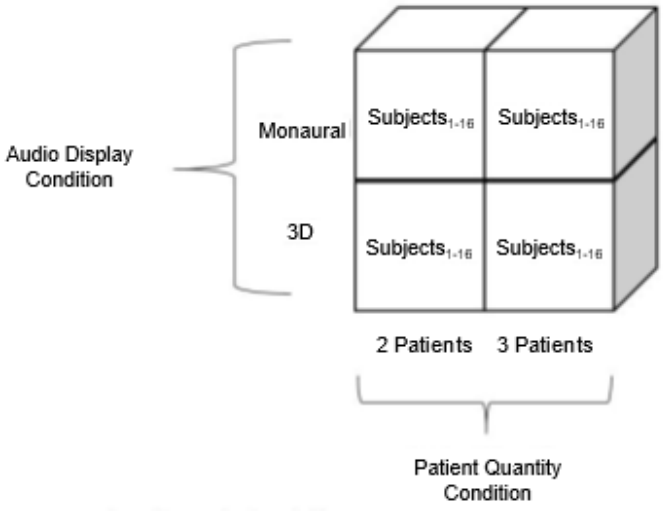

Figure 1. Data collection configurations.

The subject population included six active-duty critical care flight paramedic (CCFP) certified members of the U.S. Army, Reserves, and National Guard, henceforth referred to as CCFPs or "medics," since all active-duty U.S. Army flight medics have been trained in the CCFP course. To participate in this study, subjects were required to be at least 18 years of age or older. Subjects were CCFPs in good health and able to perform their job duties, who have at least normal hearing, verified by an audiogram. A qualified technician administered the subject's otoscopic inspection and hearing test, ensuring they met the standard taken from Army Regulation (AR) 40-501 (Department of the Army, 2019). Individuals were excluded if they had medical conditions that may be adversely affected by performing their roles in the study. Subjects that failed to pass the hearing exam or otoscopic inspection were excluded from the study. Additionally, the subjects agreed to pictures, video, and sound recordings. The collection of reference video was critical to documenting the data collection process, so subjects who did not consent to the collection of video, pictures and sound were excluded.

Prior to data collection, each subject's basic anthropometric measurements were taken. Additionally, a member of the study team familiarized the subjects with the Laerdal SimMan3G patient simulator manikins to ensure they understood what procedures and treatments could be performed. To further simulate the realism of the scenarios, subjects wore the gear that they

would be required to wear in a combat aeromedical environment. This includes their Army Aircrew Combat Uniform (A2CU), approved flame-resistant boots, Head Gear Unit-56/Personal (HGU-56/P) helmet, Communication Ear Plugs (CEP), a plate carrier with plates, and an Air Warrior personal survival gear carrier.

During data collection, patient vitals and medical alarms were simulated using Laerdal's LLEAP software, which operates the SimMan3G manikins. The Zoll Propaq MD is the patient monitor in the current U.S. Army air ambulance medical equipment set (MES) and has audible alarms, and so was chosen as the patient monitor for this study. The manikins were connected to the Propaq MD patient monitors via the VitalsBridge, which served as an interfacing device. Additionally, the VitalsBridge was employed to increase manikin response fidelity to the treatments being performed. The manikins were placed on standard U.S. Army decontaminable litters. During data collection these litters were positioned on the litter pans within USAARL's H-60 aircraft medical interior simulator (see Figure 2). The litter arrangement was determined by the study team to reflect common medical care scenarios. During data collection, the patient monitors were fixed on the back wall of the simulated aircraft (see Figure 2). This position was chosen to enable the subjects to have a full view of the monitors while treating patients and provide an intuitive location for taking the 3D audio into account. Each subject was given time before the start of data collection to situate themselves and the MES supplies as they normally would within the aircraft to ensure that they were familiar with the location of their supplies.

Immediately before the beginning of data collection, the subjects were given Tactical Combat Casualty Care (TCCC) cards to review for the patients they would be treating. TCCC cards for each patient scenario can be found in Appendix B. During data collection the subjects were tasked with providing care for the simulated patients and to respond to the patient alarms as they occurred. Patient decompensation scenarios were devised whereby the CCFPs were required to respond to alerts from the medical devices and perform a medical task or attend to the medical device. One alarm configuration presented standard audio alarms into the ICS and the other configuration presented 3D audio alarms into the ICS. USAARL generated a proof-of-concept technology that consolidated the alerts received from the medical devices through microphones and generated the audio signals that were displayed spatially separated in the ICS. The alert sounds were the same as the alarms on the medical devices. Each of the four data collection scenarios lasted 60 minutes. The manikins and patient monitors are shown below within the simulated medical aircraft (Figure 2).

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Figure 2. Three-patient configuration patient layout used during data collection (Patient one is on the left, patient two is on the top right, and patient three is on the bottom right).

During data collection, an experienced medical provider (such as an experienced CCFP or flight surgeon) was on the ICS communication line with the subject and were monitoring their performance remotely. This medical expert was referred to as the medical validator. The medical validator was a member of the study team that was available to provide insight as to the patient's condition that the subject could not deduce from looking at the patient simulators (such as the temperature of the skin, or amount of bleeding from a wound), as well as to remind the participants to vocalize their procedures. The alert detection time measurement was standardized as the time from the alarm onset to the time the subjects responded to the alarm, either verbally or through touching the alarming device. The alert detection time for each alarm was noted post-data collection by the medical validator, who reviewed each subject's video data. Additionally, during data collection, each manikin was controlled by a member of the research team using Laerdal's LLEAP software. During data collection the operators were able to view the test subject and were responsible for annotating what treatments were being performed on their assigned manikin.

Twelve different patient scenarios were used during data collection: P1-P12. These patient scenarios were all 'priority' level patients (patients whose wounds would necessitate evacuation within 4 hours of injury). The patient scenarios were developed by a team of experienced medics and were derived from actual Operation Iraqi Freedom or Operation Enduring Freedom MEDEVAC cases identified through the Joint Trauma System (JTS) database, as well as reviewing lessons learned via the Combat Casualty Care Weekly teleconference managed by JTS. The patient scenarios were customized to the needs of the study and then programmed into the SimMan3G LLEAP software. Table 1 shows the patient configuration scheme. This scheme was used to ensure that the alarm configurations and number

of patients were counterbalanced; the patients were varied such that the 3D audio and standard alarms were not biased by patient, and that each subject never saw the same patient twice.

Table 1. Patient and Alarm Configurations

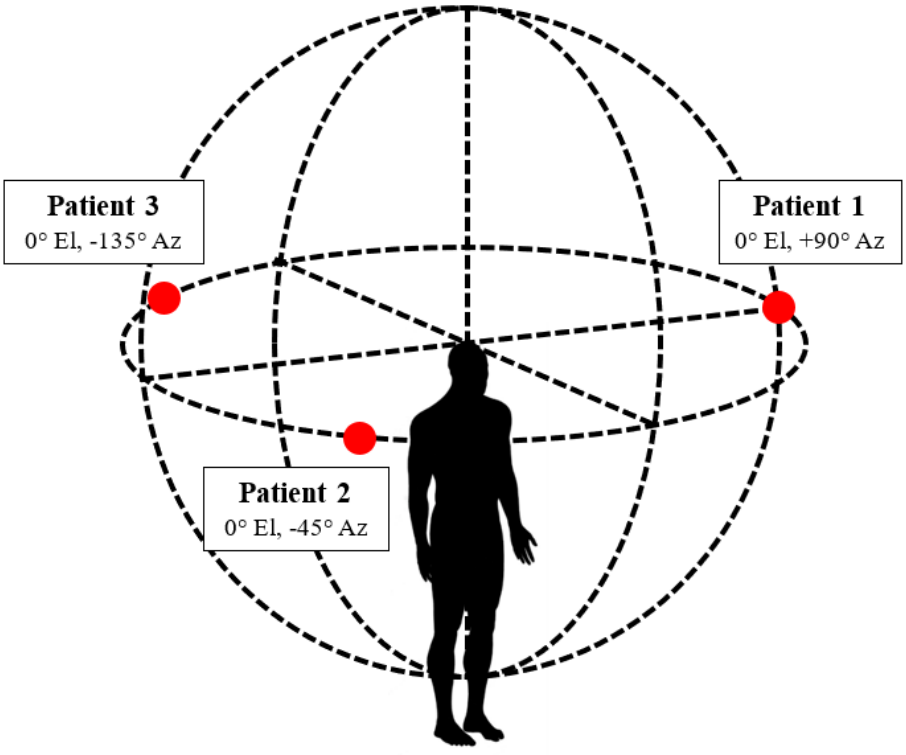
Overall Configuration #	Used for Subject (S)#	Alarm Configuration - # of Patients (PT)	First Patient (P)	Second Patient	Third Patient
Configuration 1	S1, S5	Standard – 2PT	P1	P3	-
		3D Audio – 2PT	P6	P10	-
		3D Audio – 3PT	P2	P4	P9
		Standard – 3PT	P12	P5	P7
Configuration 2	S2, S6	3D Audio – 3PT	P1	P6	P8
		Standard – 3PT	P3	P10	P11
		Standard – 2PT	P7	P9	-
		3D Audio – 2PT	P4	P12	-
Configuration 3	S3	3D Audio – 2PT	P1	P3	-
		Standard – 2PT	P6	P10	-
		Standard – 3PT	P2	P4	P9
		3D Audio – 3PT	P12	P5	P7
Configuration 4	S4	Standard – 3PT	P1	P6	P8
		3D Audio – 3PT	P3	P10	P11
		3D Audio – 2PT	P7	P9	-
		Standard – 2PT	P4	P12	-

[*]*Note.* More subjects were initially anticipated to be tested; additional subjects would have continued to follow the same pattern in configuration assignments to ensure the alarm configuration and number of patients remained counterbalanced.

Patient alarm times were varied so that they occurred at unpredictable intervals, but their start times did not overlap. Alarms were not scheduled to occur in the first minute or last two minutes of data collection, to prevent reaction time data being skewed by proximity to the start or end of a scenario. Each patient was scheduled to alarm four times for one 60-minute scenario. During the two-patient configurations a total of 8 alarms were scheduled, and during the three-patient configurations a total of 12 alarms were scheduled to occur. The order and interval between alarms was varied during each configuration to prevent the subject from potentially guessing which patient may alarm or when an alarm may occur. All patient alarm times can be seen in Figure B1, located in Appendix B.

The 3D audio alarms were created using a real-time virtual environment rendering system originally developed in the Spatial Auditory Displays Lab at the NASA Ames Research Center called slab3d (Miller & Wenzel, 2002). Slab3d performs spatial 3D-sound processing, allowing the deliberate placement of sound sources in auditory space. These sounds were not fixed in the global space as the CCFP moved about the cabin, as head tracking was not used. These sounds were presented to the subjects in the 3D audio display using modified hardware incorporated into the HGU-56/P flight helmet. The 3D audio alarms sounded in the approximate areas corresponding to patient placement within the aircraft, with the assumption that the subject was

sitting in the rear cabin seat facing toward the front of the aircraft, and the patients were in litter berths in front of them. The subjects were given a familiarization session on the 3D audio alarms and a chance to practice responding to them prior to each run that utilized 3D audio. Once the alert sounded, the subject verbalized the associated patient location and physically indicated the associated litter position to ensure understanding and solidify the connection between the alert location and associated patient. A diagram detailing the location of each patient alarm in space is shown below in Figure 3.



Patient #	Elevation (El)	Azimuth (Az)
1	0°	+90°
2	0°	-45°
3	0°	-135°

Figure 3. Location of alarms corresponding to patients, red dot represents where the corresponding patient alarm is heard in space.

During data collection, a recording of typical cabin sounds (such as rotor blade noise) was played in the ICS to simulate ambient audio stimuli. All volume levels were measured and kept within safety standards. Prior to each data collection event, the ambient noise, alarms, and speaking volume of the subject and medical validator were measured with a sound level meter and a GRAS hearing-protector test fixture type 45CA to ensure the noise levels were within safe ranges. A diagram detailing the setup of the audio system can be found in Figure D1, located in Appendix D.

Statistical Analysis

Statistical analyses for reaction times were performed using R Statistical Software (v4.4.0; R Core Team, 2024). Mixed-effects linear regression models were generated using the lmerTest R package (v3.1.3; Kuznetsova et al., 2017). Regression model marginal means and pairwise comparisons were generated using the emmeans R package (v1.11.0; Lenth, 2025). All statistical tests were evaluated at a significance level of 0.05.

Reaction times to planned decompensation events were averaged for each subject and experimental configuration. A mixed-effects linear regression was chosen to analyze mean reaction times because of the repeated-measures study design. The mixed-effects regression model consisted of fixed effects for patient count (categorical: two patients, three patients), signal (categorical: standard, 3D audio), and the interaction between patient and signal, and a random intercept for each subject. Assumptions of the regression model were validated by checking the normality and homoscedasticity of residuals, as well as checking the normality of the mean reaction times for each experimental configuration. Overall significance of the regression parameters was tested using a Type-III analysis of variance (ANOVA) applied to the regression model. Pairwise comparisons were made between configurations if the interaction effect was statistically significant. Pairwise t-test p-values were adjusted using the Benjamini-Hochberg method to control the false discovery rate and balance controlling for Type-1 and Type-2 errors. If the assumptions of the linear regression model were violated, pairwise Wilxocon Signed-Rank tests were also run to confirm the regression results. Pairwise p-values from Wilcoxon Signed-Rank tests were also adjusted using the Benjamini-Hochberg method.

Additionally, qualitative feedback regarding each test configuration was gathered via post-test questionnaires. The ratings were characterized via descriptive statistics and compared using Friedman two-way analysis of variance by ranks. Basic frequency analyses were performed on the questionnaire answers to quantify the qualitative answers.

Results

Test Data Analysis

After data collection was complete, the video data was examined by a team of active-duty and retired medics. Excel spreadsheets were created with time stamps marking the beginning and end of each action taken by the subjects during testing, category of action (alarm, assessment, medical, treatment, or device), if and when an alarm occurred, as well as the corresponding patient(s). Due to overall project time constraints, the research team was unable to completely process the large amount of video data collected. Out of the twenty-four total one-hour scenarios, twelve video files were completely analyzed. The remaining twelve scenarios were minimally assessed to collect the information regarding the subject’s reaction times to the decompensation events. The potential differences in treatment time, medical, and device time were unable to be fully evaluated.

Time Delegation Comparison

Average reaction time to decompensation events (Figure 4) was the average of the reaction times to the planned alarms of each scenario. This calculation excluded the reaction times to unprogrammed alarms and alarms that were silenced and re-sounded. Subjects were asked to verbalize their acknowledgment of alarms; however, during testing, task saturation sometimes caused subjects to forget to verbalize their acknowledgement. In this situation, there were other signals that indicated acknowledgment of the alarms (e.g., looking at the alarming monitor, commenting on the patient condition, beginning to treat the alarming patient) that enabled the research team to determine their reaction time. During the two-patient configurations, a total of eight alarms were scheduled, and during the three-patient configurations, a total of 12 alarms were scheduled to occur. However, the number of alarms in each configuration varied, primarily due to technical issues. Therefore, the number of alarms that occurred in each configuration is labeled above the corresponding bar in Figure 4. In the two-patient configuration, the average reaction time was greater with the standard audio in subjects 1 and 5, the same in subject 6, and less for the standard audio in subjects 2, 3 and 4. In the three-patient configurations, the reaction time was greater during the standard audio for all subjects.

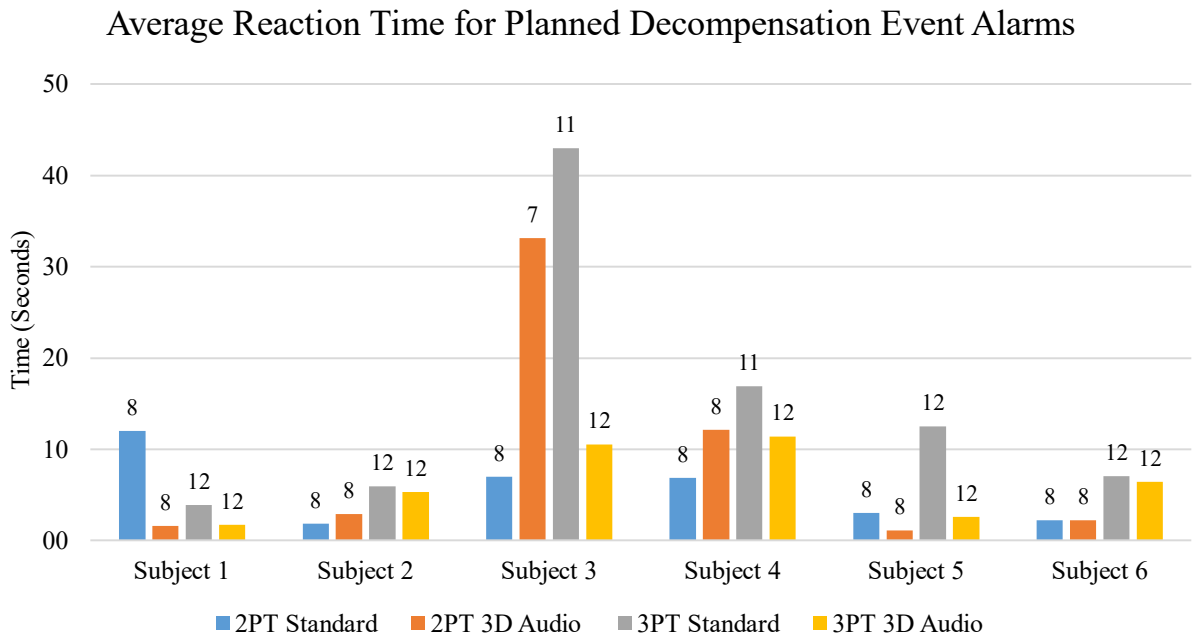


Figure 4. Comparison of the average reaction time for planned decompensation event alarms between configurations and subjects.
**Note.* The number of alarms that occurred during each scenario is depicted by the number above each bar in the Figure.

Statistical Analysis of Reaction Time Data

Six subjects participated in the study and completed all four experimental configurations. Mean reaction times to planned decompensation events are shown in Figure 5. Mean reaction times ranged from 1-43 seconds. However, subject 3 had two mean reaction times (33 and 43 seconds) that were noticeably larger than the mean reaction times for other subjects. The other five subjects (excluding subject 3) had mean reaction times that ranged from 1-17 seconds. There was no clear explanation for the discrepancy of the two large reaction times from subject 3.

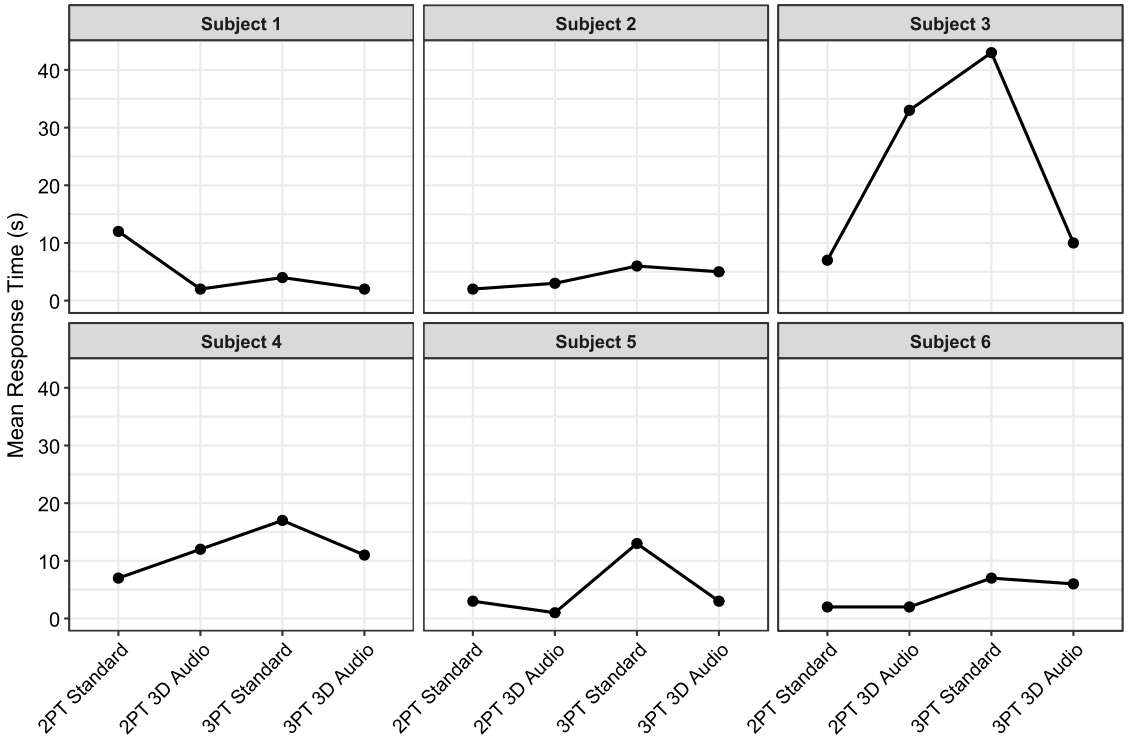


Figure 5. Mean alarm reaction times for each subject.

The mixed-effects linear regression model (described above under Methods) was evaluated using data from all six subjects. Regression model residuals were close to normally distributed, as evidenced by a statistically significant Shapiro-Wilk test ($p = 0.024$) and visual examination using a QQ-plot. Residual values showed unequal variance across the range of mean reaction times, with higher variance being observed as mean reaction time increased. These results indicated that the regression model did not meet the necessary statistical assumptions. To determine if any data points were causing undue influence on the regression model, Cook's Distance was calculated and visualized (data not shown). Two data points exhibited much larger Cook's Distance values compared to the rest of the data, indicating that these two data points were having a larger influence on the regression model compared to the other data. The two influential data points were from subject 3, two-patient 3D audio configuration, and subject 3, three-patient standard audio configuration, the same data points noted previously as being much larger than any others in the study. Taken together, these results led us to remove subject 3 from all statistical analysis of mean reaction times detailed below.

The mixed-effects linear regression model was re-evaluated with subject 3 removed. Residuals from the updated regression model were closer to normally distributed (Shapiro-Wilk; $p = 0.058$) and showed more equal variance (visual inspection; data not shown) compared to the previous model that included subject 3. The updated regression model was not ideal, but the necessary assumptions were successfully met. Results from the ANOVA showed that the interaction effect was not statistically significant ($F(1, 12) = 0.76$, $p = 0.40$). The main effects for signal ($F(1, 12) = 2.62$, $p = 0.13$) and patient ($F(1, 12) = 3.04$, $p = 0.11$) were also not significant. Estimated marginal means and 95% confidence intervals from the updated regression model are shown in Figure 6. Note that the confidence intervals for marginal means indicate the variability of the mean response times between subjects; the confidence intervals do not provide information regarding statistical significance of comparisons between experimental configurations.

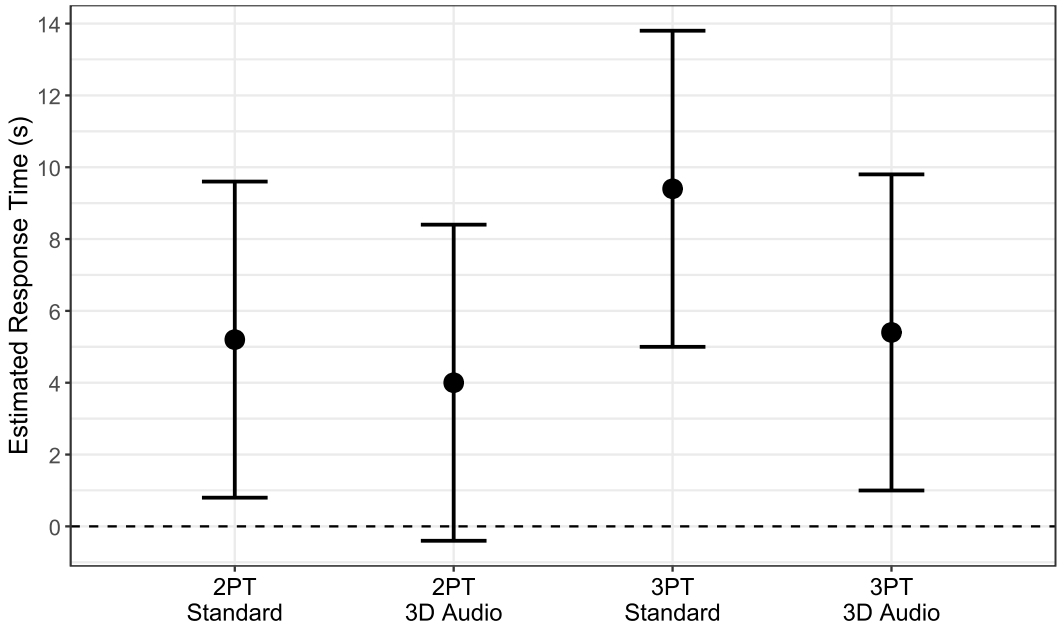


Figure 6. Regression model predictions: estimated marginal means and 95% confidence intervals for mean reaction time to planned decompensation events.

The updated regression model (without subject 3) met the necessary assumptions of a linear regression model. However, the normality and homoscedasticity of the residuals were not ideal, which was likely because of the small sample size and inherent variability between subjects. For these reasons, we chose to evaluate mean reaction times using a non-parametric approach in addition to the parametric regression model. Pairwise Wilcoxon Signed-Rank tests were evaluated, but none showed statistical significance ($p >= 0.23$). These results align with the regression model, indicating that we do not have sufficient evidence to conclude that there are any statistically significant differences in mean reaction times between experimental configurations.

The conclusion that we do not have enough evidence to show statistically significant differences in mean reaction times may be due to the small sample size of the study and not necessarily because there are no true differences between the experimental configurations. The mean reaction times are shown above in Figure 5. Summary statistics for mean reaction time by experimental configuration are shown in Table 2. From the summary statistics, we see that overall mean reaction time increased as configuration changed from 3D audio to standard, as well as when the number of patients increased from two to three.

Table 2. Summary Statistics for Mean Reaction Times

Configuration	N	Minimum	Maximum	Mean	Standard Deviation (SD)
Standard, 2 Patient	5	2	12	5.20	4.32
3D Audio, 2 Patient	5	1	12	4.00	4.53
Standard, 3 Patient	5	4	17	9.40	5.41
3D Audio, 3 Patient	5	2	11	5.40	3.51

To further explore differences in mean reaction times, the differences in mean reaction times between experimental configurations for each subject were calculated (further referred to as delta values). Delta values are the main outcome of interest because the team was interested in how mean reaction times change between configurations. All delta values are shown in Figure 7, along with the overall mean of all delta values illustrated by a red diamond. Summary statistics for delta values are shown in Table 3. The *y*-axis of Figure 7 and the contrast column of Table 3 show how the delta values were calculated. For example, the contrast "3PT 3D Audio - 2PT 3D Audio" indicates that the delta values were calculated by subtracting the two-patient 3D audio mean reaction times from the three-patient 3D audio mean reaction times.

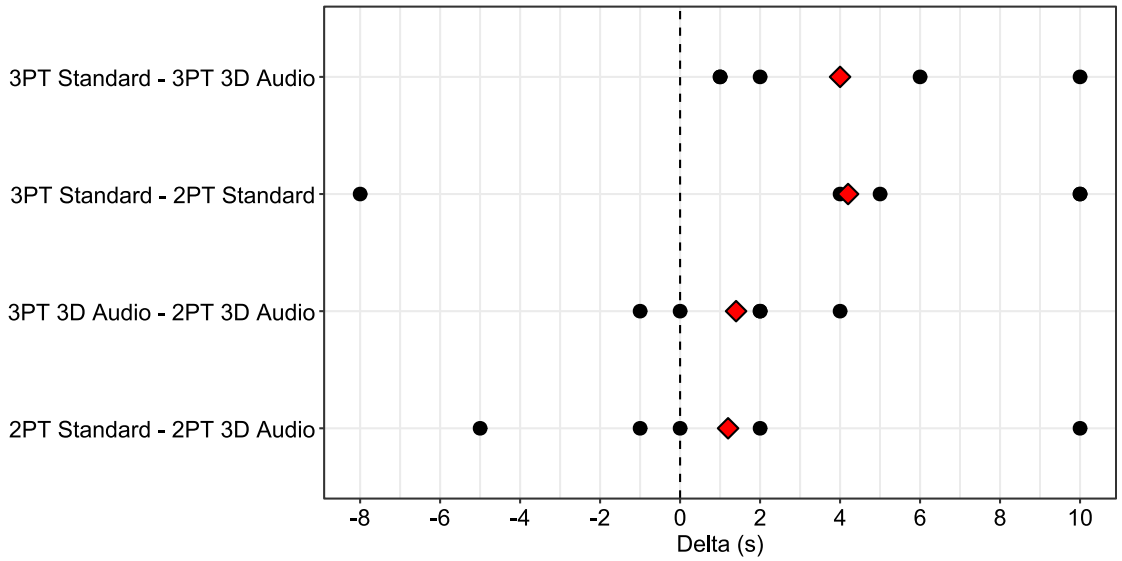


Figure 7. Mean reaction time delta values between configurations. Red diamonds indicate overall mean for each contrast.

Table 3. Summary Statistics for Mean Reaction Time Delta Values

Contrast	N	Minimum	Maximum	Mean	SD
3PT 3D Audio – 2PT 3D Audio	5	-1	4	1.40	1.95
2PT Standard – 2PT 3D Audio	5	-5	10	1.20	5.54
3PT Standard – 3PT 3D Audio	5	1	10	4.00	3.94
3PT Standard – 2PT Standard	5	-8	10	4.20	7.36

Trends in the delta values showed results that aligned with our hypothesis (Table 3). Overall mean delta values increased as patient count increased (1.40 and 4.20 seconds). Overall, mean delta values also increased moving from 3D to standard configurations (1.20 and 4.00 seconds). These results match the hypothesis that reaction times will increase as patient count increases, and that 3D audio will reduce reaction times compared to standard audio. However, it should be noted that not all subjects exhibited delta values that aligned with our hypothesis (see Figure 7). The most convincing results can be seen in the comparison between the 3D audio and standard configurations with three patients. All five subjects had reduced mean reaction times in the 3D audio configuration compared to the standard configuration, with an overall mean delta value of 4.00 seconds. The other three contrasts showed mixed results, with both positive and negative delta values.

Alarm Response Analysis

During data collection, there were three ways in which subjects may have responded to an alarm, acknowledge it, ignore it, or silence it. The subject's initial response to alarms was considered their first response within 45 seconds of the alarm start time. The initial response for all subjects is shown below in Table 4. A total of eight alarms were scheduled to occur during the two-patient configurations, and a total of twelve alarms were scheduled to occur during the three-patient configurations. However, the number of alarms that occurred in each configuration varied, primarily due to technical issues. This is the reason some runs had fewer alarms than expected occur.

Table 4. Subject's Initial Response to Planned Decompensation Event Alarms, by Configuration

Configuration	Alarm Response	Subject (S) Number						Total Count
		S1	S2	S3	S4	S5	S6	
Standard – 2 Patient	Acknowledged	8	8	8	8	8	8	48
	Ignored	0	0	0	0	0	0	0
	Silenced	0	0	0	0	0	0	0
3D Audio – 2 Patient	Acknowledged	8	8	4	8	8	8	44
	Ignored	0	0	3	0	0	0	3
	Silenced	0	0	0	0	0	0	0
Standard – 3 Patient	Acknowledged	12	12	8	10	11	12	65
	Ignored	0	0	4	1	1	0	6
	Silenced	0	0	0	0	0	0	0
3D Audio – 3 Patient	Acknowledged	12	12	11	12	12	12	71
	Ignored	0	0	1	0	0	0	1
	Silenced	0	0	0	0	0	0	0

Questionnaire Data – Likert Scale Ratings

Configuration-specific questionnaires were provided after each of their respective configurations were complete. A questionnaire was provided after both two-patient and three-patient configurations were complete. Lastly, one was provided after all configurations were complete. Each of the questionnaires can be found in Appendix C. Likert scale responses from the post-test questionnaires are shown in Figures 8-16. The "X" within each column represents the mean Likert score of that configuration.

Usability was scored well for both standard audio and 3D audio two-patient configurations, with the mean score for these remaining below a 2 on a scale from 0 (best) to 10 (worst). A much wider score range was observed in the 3D audio three-patient configuration. The usability ratings can be visualized below in Figure 8.

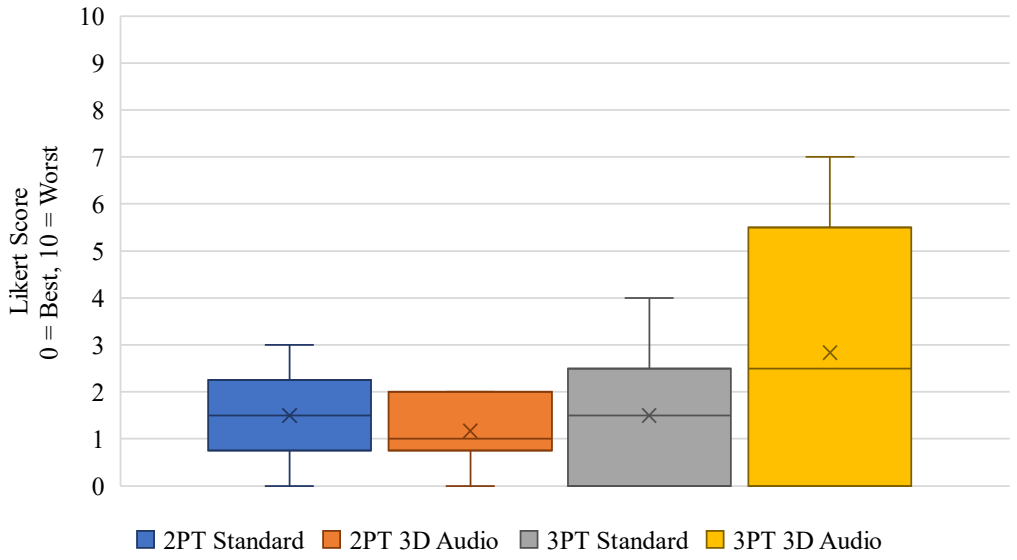


Figure 8. Distribution of usability ratings of each configuration.

Signal clarity explored whether the audio signals the subjects were hearing clearly distinguished which patient was alarming. A score of zero represented no trouble distinguishing which patient was alarming, while a score of ten meant that the subject could not distinguish from which patient the alarm was sounding. The results of the Friedman analysis found the p-value of the signal clarity scores to be the closest to approaching significance, with a value of 0.051. Both 3D audio configurations scored better than the standard audio configurations. The 3D audio two-patient configuration had a mean score of 0.5. The box plot of the signal clarity ratings is shown below in Figure 9. The yellow dot above the 3D audio three-patient box is an outlier in the data. Outliers are data points beyond the first quartile (Q1) + 1.5 * interquartile range (IQR), or third quartile (Q3) + 1.5 * IQR.

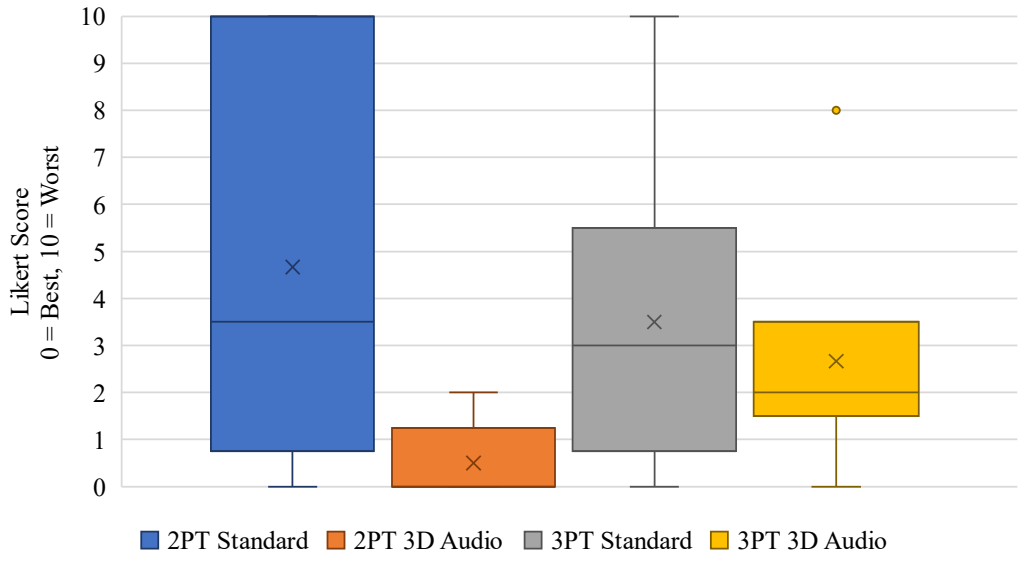


Figure 9. Distribution of signal clarity ratings of each configuration.
**Note.* The yellow dot represents a data outlier.

Efficacy ratings referred to how successful the participant thought the audio alarms were at directing attention to the alarming patient. The average score for the standard audio configurations was 6.67 and for the 3D audio configurations, the average score was 7.83. Box plots of the efficacy Likert ratings are shown below in Figure 10.

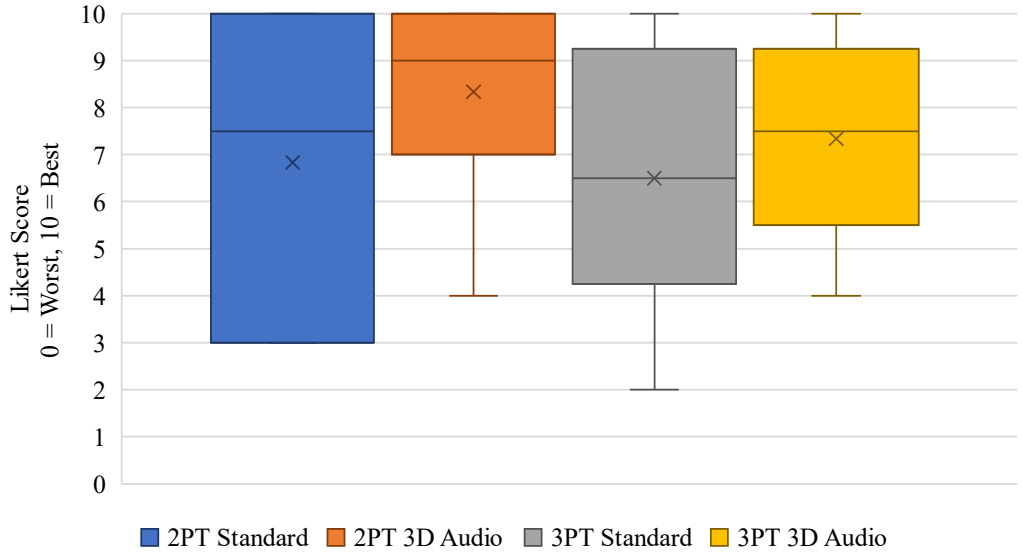


Figure 10. Distribution of efficacy ratings of each configuration.

As a whole, subjects scored their trust in the auditory signals relatively equal between all four configurations. There was one outlier in the 3D audio two-patient configuration represented by the orange dot in Figure 11.

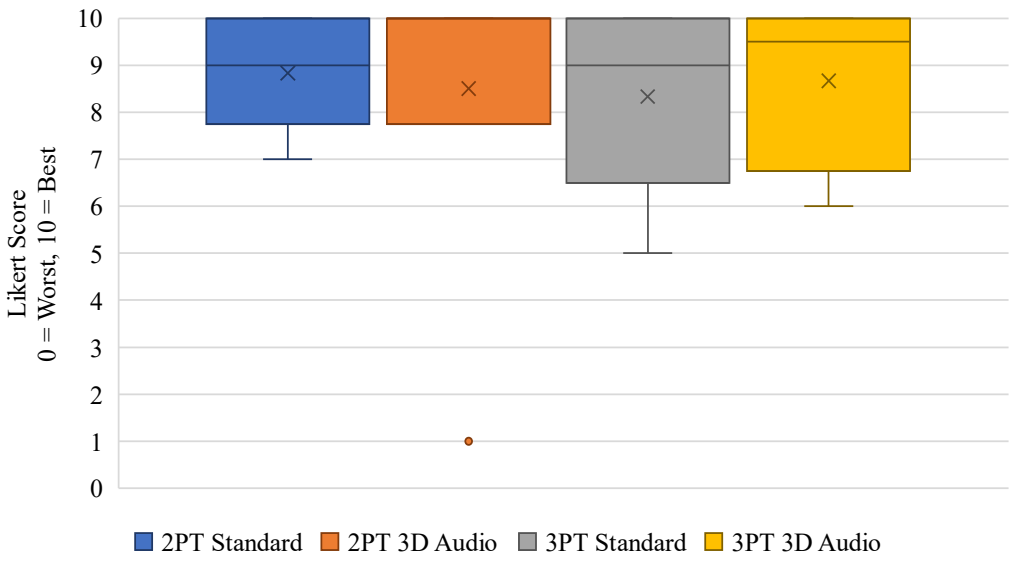


Figure 11. Distribution of trust in auditory signal ratings of each configuration.
**Note.* The orange dot represents a data outlier.

The mean workload ratings were similar for the standard audio two- and three-patient configurations as well as the 3D audio two-patient configuration, which were 6, 5.83, and 6.17, respectively. The 3D audio three-patient configuration mean score was slightly higher at 7.17. Box plots of the workload ratings are shown below in Figure 12.

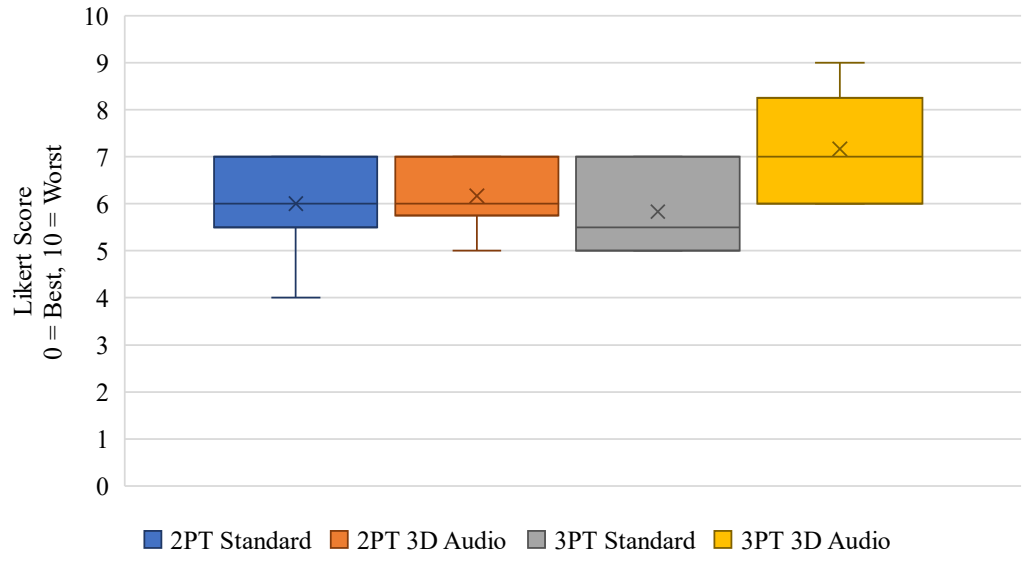


Figure 12. Distribution of workload ratings of each configuration.

Ease of patient care ratings were used by the subjects to describe whether they were able to keep up with all the treatments for the patients. The ratings indicated that subjects felt they were able to most successfully keep up with the treatments in the 3D audio two-patient

configuration, with a mean score of 1.5. Box plots to visualize this data are shown below in Figure 13.

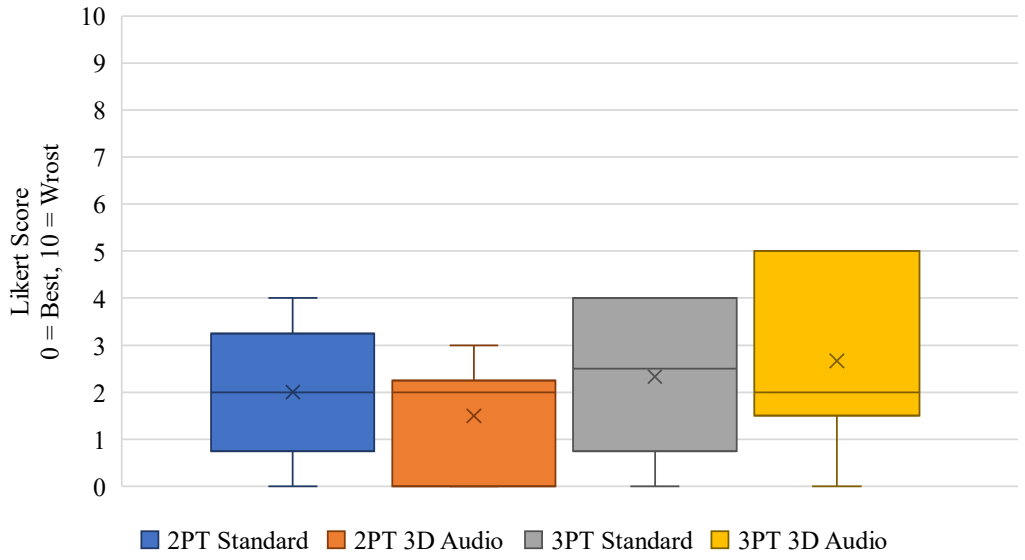


Figure 13. Distribution of ease of patient care ratings of each configuration.

The mean time delegation scores were similar between the two-patient and three-patient configurations. The mean scores for the standard and 3D audio two-patient configurations were 1.17 and 1.33, respectively. The mean score was 2.5 for both the standard and 3D audio three-patient configurations. Box plots to visualize this data are below in Figure 14.

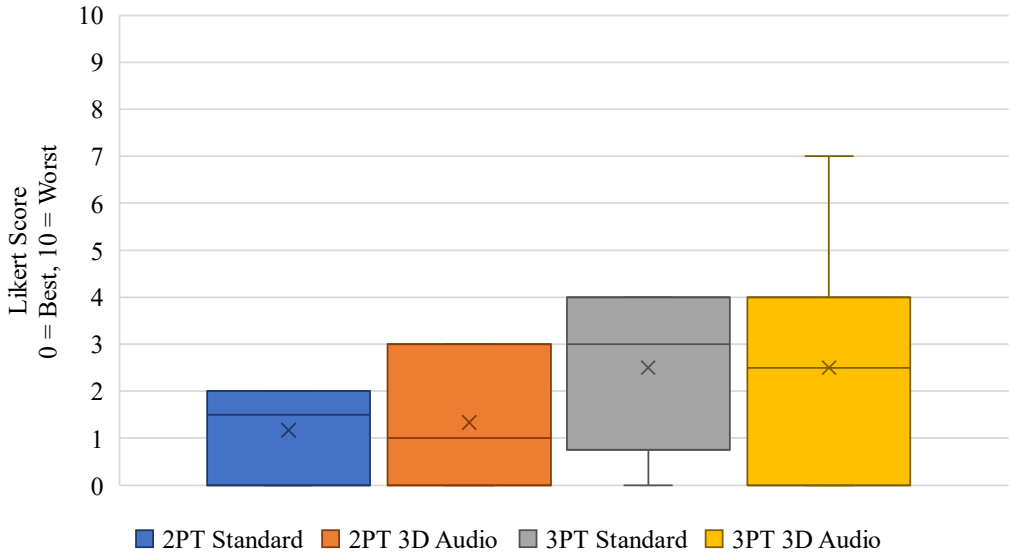


Figure 14. Distribution of time delegation ratings of each configuration.

The subjects' ratings for distraction level were similar across the four configurations. The standard audio configurations scored slightly higher than the 3D audio configurations. The mean scores for the standard and 3D audio two-patient configurations were 2.17 and 1.67, respectively. This pattern remained in the three-patient configurations, with the mean scores for the standard and 3D audio being 3.17 and 2.33, respectively. Figure 15 shows distraction level box plots.

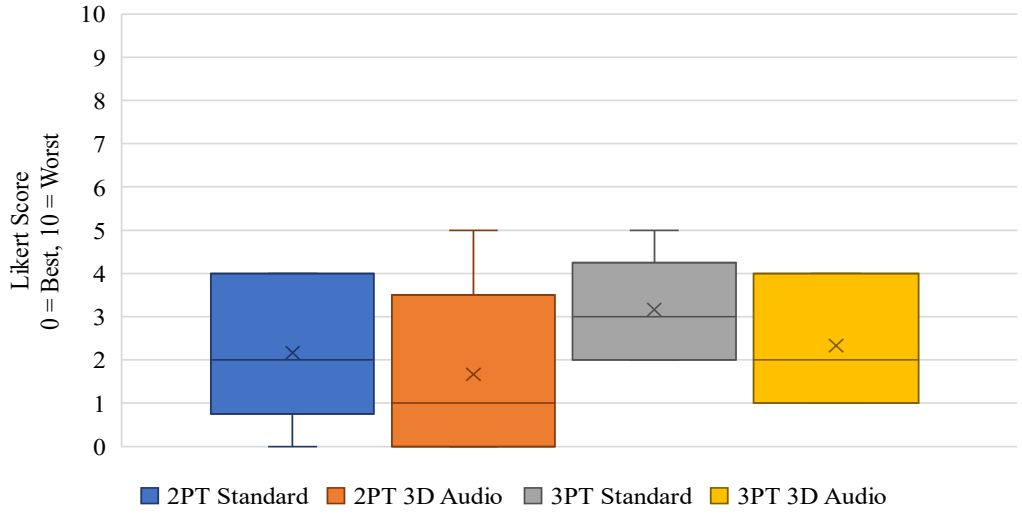


Figure 15. Distribution of distraction level ratings of each configuration.

The 3D audio two-patient configuration was scored the best with a mean rating of 1.33, meaning the subjects felt that they were able to mentally keep track of everything occurring with each patient most successfully during this configuration. The box plots are shown below in Figure 16; the gray dot represents an outlier in the data.

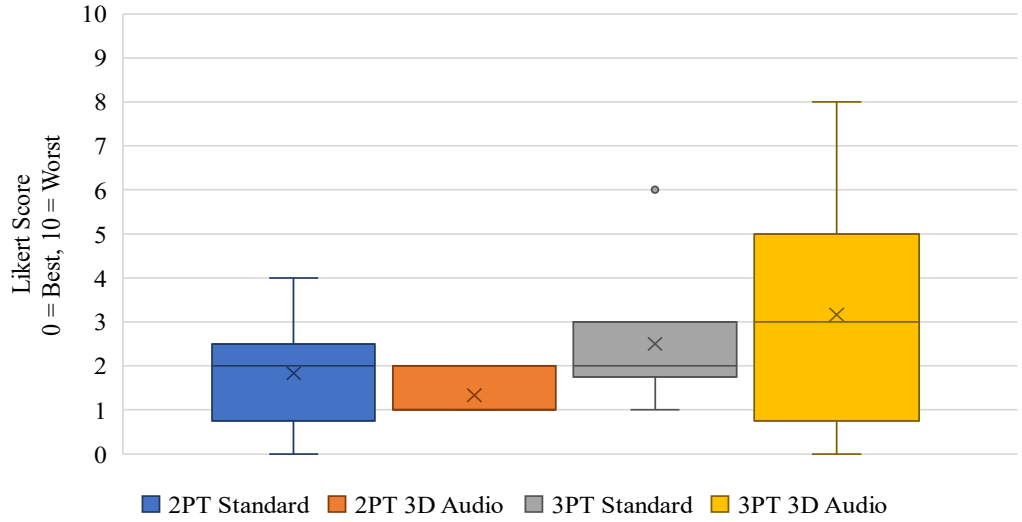


Figure 16. Distribution of mental burden ratings of each configuration.
**Note.* The gray dot represents a data outlier.

A Friedman two-way analysis was completed on the results of the Likert ratings; the findings are below in Table 5. The analysis yielded no significant results.

Table 5. Friedman Two-Way Analysis Results of Likert Ratings

Likert Category	Degrees of Freedom (df)	Chi-squared	p-value
Usability	3	1.415	0.702
Signal Clarity	3	7.789	0.051
Efficacy	3	2.712	0.438
Trust in Auditory Signal	3	2.512	0.473
Workload	3	4.468	0.215
Ease of Patient Care	3	3.900	0.273
Time Delegation	3	6.848	0.077
Distraction Level	3	2.712	0.438
Mental Burden	3	3.551	0.314

Questionnaire Data – Open-Ended Feedback

Along with the Likert rating questions, subjects were asked to answer open-ended questions after each configuration, after completing both two-patient configurations, after completing both three-patient configurations, and finally after all configurations were complete. The questions are listed below.

3D Audio Alarms/2-Patient and 3-Patient Configuration Post-Test Questions:

1. Are there any benefits of using 3D audio that you noticed?
2. Are there any drawbacks of using 3D audio that you noticed?
3. Were you initially alerted to an alarm by any medical device lights instead of the audio alarms during this scenario?
4. Do you have any feedback that wasn't captured in your answers above?

Regular (Standard) Alarms/2-Patient and 3-Patient Configuration Post-Test Questions:

1. Are there any benefits of using regular audio that you noticed?
2. Are there any drawbacks of using regular audio that you noticed?
3. Were you initially alerted to an alarm by any medical device lights during this scenario?
4. Do you have any feedback that wasn't captured in your answers above?

Both Alarm Configurations/2-Patient Configuration Post-Test Questions:

1. How did the 3D audio compare to the regular audio in the 2-patient configuration?
2. Do you have any feedback that wasn't captured in your answers above?

Both Alarm Configurations/3-Patient Configuration Post-Test Questions:

1. How did the 3D audio compare to the regular audio in the 3-patient configuration?
2. Do you have any feedback that wasn't captured in your answers above?

All Four Configurations Post-Test Questions:

1. How did the 3D audio compare to the regular audio overall for all of the configurations?
2. Were there any differences in using the 3D alarms or the regular alarms between the two patient versus the 3-patient scenarios?

3. Do you have any final feedback that wasn't captured in your answers?

The questionnaire responses were open-ended, and often, different questions produced answers with overlapping themes. This data was analyzed by grouping similar responses and/or topics to provide an overall picture of the content of the responses and the end-users' opinions on the audio configurations. The answers were evaluated for recurring ideas relating to the benefits, drawbacks, and possible improvements of 3D audio alarm integration. The groups for similar responses about the benefits, drawbacks, and improvements of the 3D audio and standard audio are displayed in Figures 17 and 18. In addition to these Figures, a sunburst chart detailing the response breakdown can be found in Figure E1, located in Appendix E. The corresponding section names, sub-section names, and response totals are in Tables E1, E2, and E3 located in Appendix E.

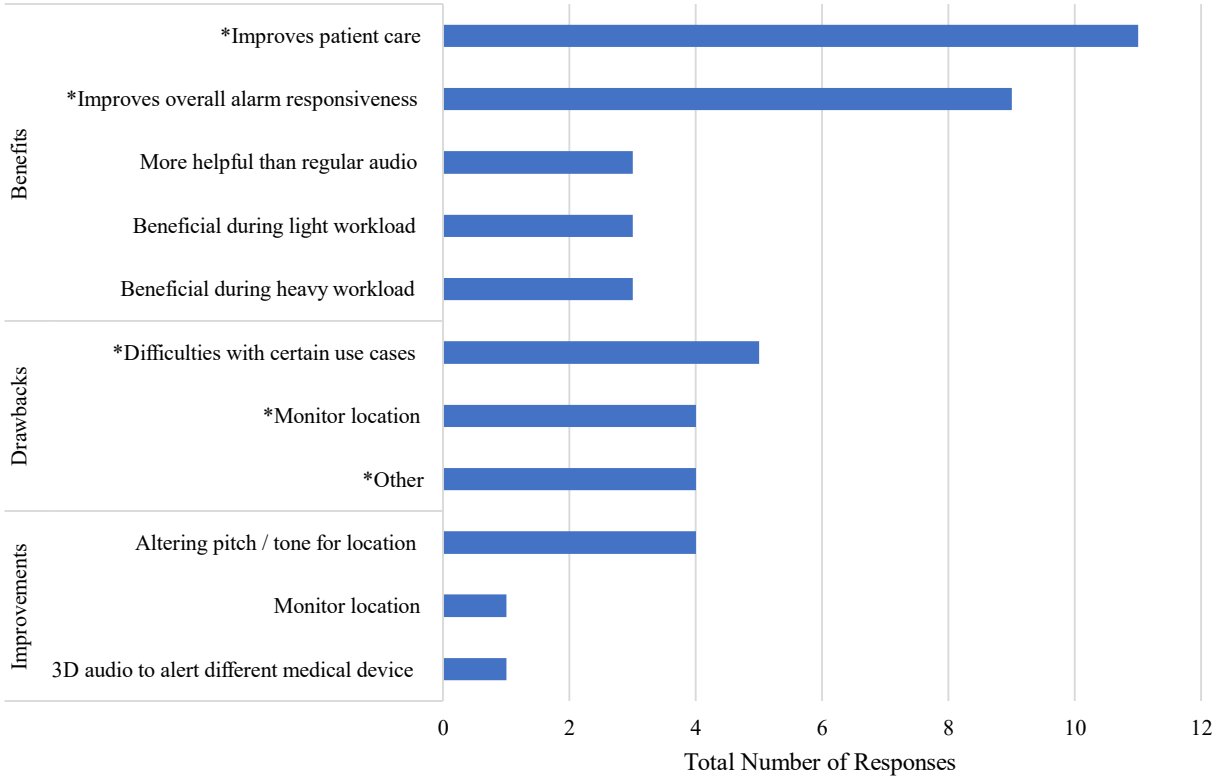


Figure 17. 3D audio – major groups of benefits, drawbacks, and improvements.
**Note.* Starred groups are broken down into sub-groups, detailed in Figure E1 and Tables E1, E2, and E3 located in Appendix E.

Select responses from the sub-group with the highest total responses within each group (benefits, drawbacks, improvements) are shown below in Table 6.

Table 6. Select Responses from Sub-Group with Highest Total Responses within Benefits, Drawbacks, and Improvements of 3D Audio

Sub-Group	Subject Responses
Benefits: improves patient care	• "Benefits provided direction on which monitor to look at on the wall." • "Great for directional identification of the monitor alarming." • "3D audio made it much easier to narrow down which monitor to look at." • "It easily directed attention to the patient needing assistance." • "I prefer the 3D audio. I had a better idea of which patient required my attention, even before looking at the monitors." • "I felt more confident in not having to focus on the devices as often."
Drawbacks: difficulties with certain use cases	• "The audio is very helpful, but the 3D directional aspect was difficult to use." • "The 3D audio for 2 & 3 was difficult to differentiate. They sounded the same, as opposed to the familiarization. 3D audio is vastly superior to the regular when dealing with more than 2 patients." • "Extreme difficulty distinguishing between 2 and 3. Felt I only got it right about 50% of the time." • "Effectiveness decreased under heavier workload." • "3D more effective until workload is increased." • "No difference during periods of increased workload."
Improvements: altering pitch /tone for location	• "Instead of totally directional audio, what about left ear cup for all left side, right ear cup for all right side? Then use a high/medium/low pitch to distinguish top/middle/bottom patient." • "A more significant shift in tones when differentiating patients on the same side would vastly improve the system in my opinion."

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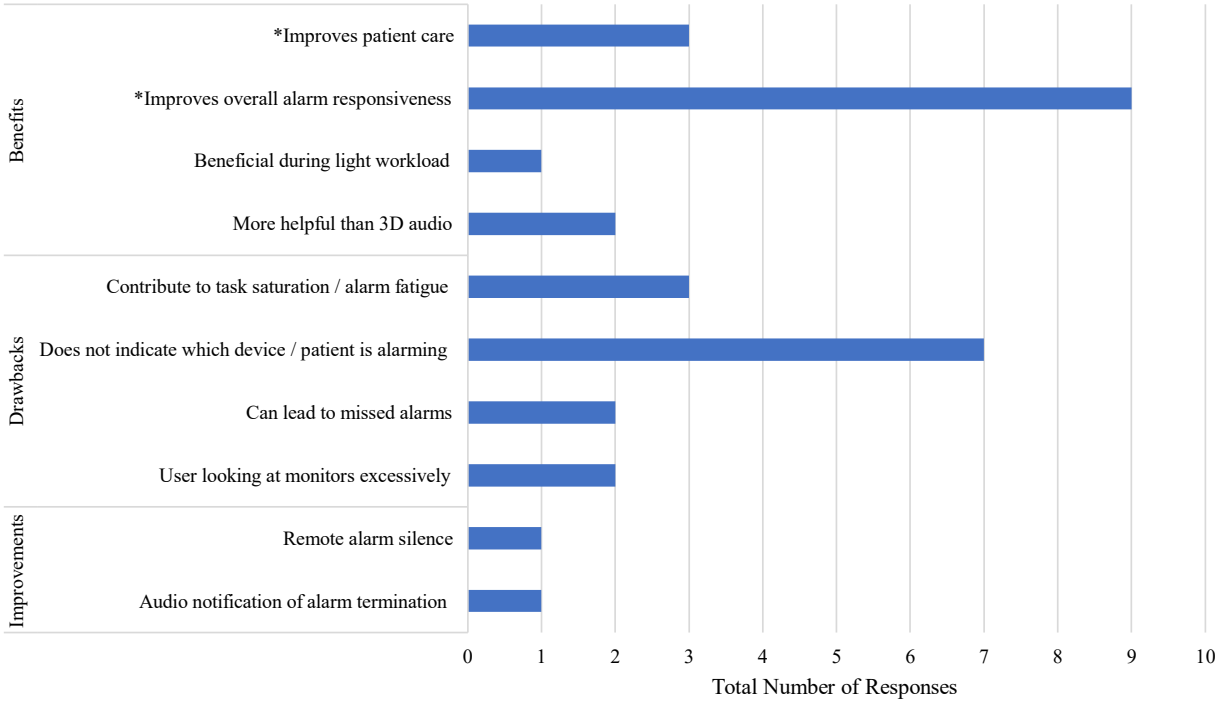

Figure 18. Standard audio – major groups of benefits, drawbacks, and improvements.
**Note.* Starred groups are broken down into sub-groups, detailed in Figure E1 and Tables E1, E2, and E3 located in Appendix E.

Select responses from the sub-group with the highest total responses within each group (benefits, drawbacks, improvements) are shown below in Table 7.

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Table 7. Select Responses from Sub-Group with Highest Total Responses within Benefits, Drawbacks, and Improvements of Standard Audio

Sub-Group	Subject Responses
Benefits: improves overall alarm responsiveness	• "Good primary alert for alarms." • "Yes, just having the audio to direct attention made me pay close attention to the monitors and address issues faster." • "Alarm alertness during flight is highly beneficial." • "Yes, having the ability to hear medical device alarms through the CEPs is a plus." • "Definitely got my attention immediately." • "I was able to immediately identify an alarm, even if I was not looking at the monitors."
Drawbacks: does not indicate which device/patient is alarming	• "I was not able to distinguish which monitor was alarming. I used the indication lights to know." • "Every time an alarm sounded, I had to stop what I was doing and scan each device to figure out which one was alarming. This took more time away from treatments." • "I felt I spent additional time scanning the devices for the alarm with the regular audio." • "With regular audio I had to confirm each time which PT had alarms."
Improvements: remote alarm silence and audio notification of alarm termination	• "Remote alarm silence." • "Repetition/frequency of alarm may be distracting. > Primary alarm w/audio followed by visual alerts. > Consider audio notification for alarm termination."

[*]*Note.* For improvements, both sub-groups had only one response, therefore both responses are displayed in the table.

Discussion

Reaction Time Data

The reaction time in the two-patient configuration did not show any clear trends. Three subjects had a lower reaction time with the standard audio, two had a greater reaction time, and one subject had an equal reaction time with the 3D audio. However, in the three-patient configurations, the reaction time was lower in every 3D audio scenario. This indicates that the 3D audio may be beneficial in a high workload environment.

Reaction Time Analysis

Analysis of mean reaction times showed no statistically significant differences between experimental configurations. This result was shown initially with a mixed-effects linear regression model and confirmed using pairwise Wilcoxon Signed-Rank tests. However, the lack of statistical significance is likely due to the small sample size of the study and does not necessarily reflect true differences between the configurations. Mean reaction times and delta values both showed trends that aligned with our research hypotheses. Overall mean delta values increased by 1.40-4.20 seconds as patient count increased from two to three, and overall mean delta values decreased by 1.20-4.00 seconds as listening configuration changed from standard to 3D audio.

Although the overall mean delta values aligned with the team's hypothesized changes in reaction time, not all subjects showed the same pattern. Two subjects had relatively large delta values that were the opposite of our hypothesized change. Subject 1 showed an 8 second decrease in mean reaction time going from two patients to three patients in the standard configuration, and subject 4 showed a 5 second increase going from the standard to 3D audio configurations with two subjects.

As previously mentioned, the analysis did not reach statistical significance, likely due to the small sample size. However, one important consideration is that a larger sample size may not result in mean changes in the reaction time. If the mean reaction time remains unchanged, it will be important to find the practical significance in reducing reaction time by 1-4 seconds. Further discussion with subject matter experts as well as more in-depth studies looking at patient mortality and morbidity may provide the significance of a 1-4 second reduction in reaction time. One of the team's subject matter experts, an experienced flight medic, provided his opinion that the small changes in reaction time, such as reacting to an alarm 4 seconds faster, is unlikely to affect the outcome of a single patient. However, in a multi-patient scenario, the 3D audio may increase overall patient awareness, especially if the flight medic becomes task saturated.

Alarm Response Analysis

In the two-patient configurations, more alarms were initially ignored during the 3D audio than in the standard audio scenarios. During the standard audio scenarios, every subject acknowledged every pre-set alarm that was presented to them. This pattern was not true for the three-patient configurations. During the standard audio scenarios, a total of six patient alarms were initially ignored, while during the 3D audio scenarios only one alarm was initially ignored across all subjects.

Questionnaire Discussion

Overall, the Likert ratings did not reveal any clear trends between the configurations. The Friedman rank sum test on the Likert ratings yielded no significant results. However, the 3D audio configurations clearly scored better on signal clarity. A zero represented 'no trouble distinguishing which patient was alarming,' and a ten represented 'there was no distinguishing which patient was alarming.' The two-patient and three-patient standard audio configurations had a mean subject score of 4.67 and 3.5, respectively, compared to the 3D audio configurations,

which had a mean subject score of 0.5 and 2.67, respectively. The Friedman two-way analysis produced a p-value of 0.051.

Altogether, the incorporation of the audio alarms into the ICS was well received by the users, through both audio configurations. Many of the subjects expressed positive feedback toward the 3D audio, citing its ability to quickly direct attention to the alarming monitor or patient, although the difference was stated to be relatively small. This may be attributed to the proximity of the patient monitors to each other during testing, as mentioned by subjects in the survey responses. To enhance the effect of the 3D audio, one subject suggested repositioning the patient monitors in various locations through the aircraft cabin, with the goal of making the 3D audio more discernable. The standard audio configurations also received positive feedback, primarily due to its effectiveness in alerting users to alarms. However, there were some notable drawbacks, with the most reported issue being its inability to indicate which specific device was alarming.

There was mixed feedback regarding whether the 3D audio was more advantageous during the two- or three-patient configurations, suggesting the perceived benefits of the 3D audio are contingent upon the specific use case. Moreover, some subjects experienced difficulty distinguishing between patient two and three during the three-patient 3D audio configurations. To address this issue, subjects suggested adjusting the tone or pitch of the alarm to correlate with patient location (e.g., high tones for upper litter pans; low tones for lower litter pans). Expanding on this, one subject suggested using 3D audio to indicate alarms from different devices, such as intravenous (IV) pumps, ventilators, and patient monitors. Throughout both audio configurations, concerns were also raised that the embedded audio may contribute to task saturation and alarm fatigue. This highlights the need for careful consideration of audio design, to minimize potential drawbacks and maximize the overall benefit of the integrated alarms. Addressing these concerns is critical to ensuring the safe and effective operation of integrated ICS alarms.

Limitations

One of the most substantial limitations of this study was the small number of subjects. Due to recruitment difficulties and personnel turnover, the number of subjects fell well below the recruitment goal of 16 total subjects. The decision was made to proceed with the existing subject population and complete the project due to time and funding constraints.

Additional data was collected that is not presented in this report. Along with alarm reaction time data, data regarding treatment and device time may be collected from the video recordings. The “treatment” category may include administering treatments to patients, while the “device” category would describe any time the subject spent interacting with or viewing the patient monitoring device. These time variables may be analyzed and presented in future reports. Additionally, binary treatment success of critical medical tasks performed by the subjects may be analyzed and presented in future studies.

The manikins used in this study were used to simulate patients in a test environment, and do not fully imitate an actual patient in real life. The subjects’ responses may not be the same with these manikins as they would be with real trauma patients.

Only the patient monitor was selected out of the devices in the current MES kit that produce audible alarms. Items such as the Hamilton T1 ventilator and the Alaris Medsystem III infusion pump were intentionally excluded, as they were deemed not practical for this study. These items are not as frequently utilized as the patient monitors. By only using the patient monitors, the research team was more able to ensure that each subject was exposed to the same number of alarms. Incorporating these other devices would have required them to be set up and connected to the ICS system, limiting the ways in which the subjects could employ them. However, several subjects mentioned that these devices, ventilators in particular, are often the source of alarms that are not clinically significant. The addition of these devices may contribute to overall task saturation and alarm fatigue, possibly impacting the realism of the scenarios.

To further ensure that all subjects were exposed to the same number of alarms, within the LLEAP program, the scenarios were created such that only the specified vital sign could alarm in each time range. All other vitals could vary; however, they had to remain in the non-alarming range. As a result, this study cannot evaluate the effect of incorporating spatially identifiable alarms on patient clinical outcomes.

During this study, head-tracking was not implemented alongside the 3D audio. Due in part to the limited space inside the simulated aircraft and the number of cables present, the use of a head tracking device on the helmet was deemed a non-necessary risk. Additionally, a head-tracking device may introduce additional weight to the helmet, increasing the subject's risk of muscle fatigue. This study was intended to investigate the use of spatially identifiable alarms, and not the execution of the three-dimensional audio itself. Moreover, the research team was unable to customize the spatial locations of the alarms for each subject. To establish a level of consistency in the results, the location in space in which the alarms sounded for each patient was consistent across subjects. Every subject was provided an opportunity to familiarize themselves with the 3D audio alarms prior to start of data collection.

The location of the patient monitors may have negatively impacted the effect of the 3D audio. There were multiple mentions of this topic in the subjects' open-ended feedback. The monitors were near each other, making visually scanning all the monitors rather undemanding. Placing the monitors in different locations around the simulated cabin may have produced a more detectable impact of the spatially separated audio. The current setup does not enable the patient monitors to be placed around the cabin. To operate the LLEAP software, the monitors must be hardwired to the VitalsBridge.

Conclusion

The reaction time in the three-patient configurations was faster for every subject during the 3D audio alarms compared to the standard alarms. This may indicate that the implementation of 3D audio alarms would be beneficial during high workload environments. Moreover, the post-test questionnaire provided key insights into how the 3D audio was perceived by the end-users. Both the standard audio and 3D audio received positive feedback from the subjects. Overall, the Likert ratings did not reveal any clear trends between the configurations. However, the 3D audio configurations clearly scored better on signal clarity. In the open-ended questions, the most reported issue with the standard audio was its inability to indicate which specific device was alarming, highlighting the advantage of the 3D audio providing more directional information.

Despite not achieving statistical significance, the results emphasize that patient care is unique and complex in nature and there may be other factors besides reaction time that are influenced by the implementation of 3D audio. The results of this work support future studies to further develop and examine the effects of an integrated alarm system. A follow-up study is currently being worked on by USAARL to investigate the efficacy of prioritized verbal alarms in assisting medics.

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Appendix A. Acronyms and Abbreviations

3D	Three-Dimensional
A2CU	Army Aircrew Combat Uniform
ANOVA	Analyses of Variance
AR	Army Regulation
BAS	Battalion Aid Station
BLE	Bilateral Lower Extremities
BP	Blood Pressure
BPM	Beats Per Minute
BrPM	Breaths Per Minute
CCFP	Critical Care Flight Paramedic
CEP	Communication Ear Plugs
cm	Centimeters
DBP	Diastolic Blood Pressure
df	Degrees of Freedom
DoD	Department of Defense
ECG	Enroute Care Group
$EtCO_2$	End-Tidal Carbon Dioxide
FX	Fracture
G	Gauge
g	Gram
GSW	Gun Shot Wound
gtt	Gutta
H_2O	Water
HGU-56/P	Head Gear Unit-56/Personal
HR	Heart Rate
IBP	Invasive Blood Pressure
ICP	Intracranial Pressure
ICS	Intercommunication Set
IED	Improvised Explosive Device
IM	Intramuscular
IO	Intraosseous
IQR	Interquartile range
IV	Intravenous
JTS	Joint Trauma System
L	Left
LLE	Left Lower Extremity
LPM	Liters Per Minute
LSCO	Large Scale Combat Operations
LT	Laryngeal Lube
LUE	Left Upper Extremity
MANOVA	Multivariate Analysis of Variance
Max	Maximum
MDO	Multi-Domain Operations

MEDEVAC	Medical Evacuation
MES	Medical Equipment Set
mg	Milligram
mL	Milliliter
mmHG	Millimeters of Mercury
NA	Not Applicable
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NCD	Needle Chest Decompression
NRB	Non-Rebreather Mask
NS	Normal Saline
O_2	Oxygen
P	Patient
PEEP	Positive End-Expiratory Pressure
Pg.	Page
PRBC	Packed Red Blood Cells
PT	Patients
Q1	First Quartile
Q3	Third Quartile
R	Right
RLE	Right Lower Extremity
RR	Respiration Rate
RXN	Reaction
r/o	Rule Out
S	Subject
SBP	Systolic Blood Pressure
SD	Standard Deviation
SMOG	Standard Medical Operating Guidelines
SpO_2	Oxygen Saturation
TBI	Traumatic Brain Injury
TBSA	Total Body Surface Area
TCCC	Tactical Combat Casualty Card
TD	Tetanus and Diphtheria
TDaP	Tetanus, Diphtheria, and Pertussis
Temp	Temperature
TQ	Tourniquet
TXA	Tranexamic Acid
USAARL	United States Army Aeromedical Research Laboratory
U.S.	United States
WB	Whole Blood
^oF	Degrees Fahrenheit

Appendix B. Patient Summaries

Table B1. Patient Alarm Schedule

Patient #	Time	Alarm Type	Value	Cause of Alarm
1	01:30	HR high	135 BPM, no limit	Pain
	27:06	BP low	75/45 mmHG	Fluid loss
	38:00	RR low	5 BrPM, max 14	Lack of perfusion/shock
	45:30	SpO_2 low	84%	Shock
2	09:27	BP low	80/50 mmHG	Blood loss
	16:30	HR low	47 BPM, max 60	Decompensation from wounds/fluid loss
	41:48	RR low	4 BrPM, max 15	Shock/decompensation
	55:30	BP low	83/52 mmHG	Blood loss
3	13:12	BP high	190/110 mmHG	Compensation for internal bleeding
	21:00	RR low	5 BrPM	ICP
	33:00	HR low	45 BPM, can't fix. Max of 60	TBI/ICP
	50:06	BP low	76/54 mmHG	Internal bleeding
4	04:30	RR high	34 BrPM	Hyperventilation
	28:30	BP low	85/55 mmHG	Internal bleeding
	36:30	RR low	5 BrPM	Collapsed lung
	44:30	SpO_2 low	85%	Lack of perfusion/shock
5	07:39	BP low	100/50 mmHG	Hypotension
	19:30	SpO_2 low	86%	Blunt head injury (i.e., post-traumatic hypoxia)
	39:48	RR low	5 BrPM	Blunt head injury (i.e., post-traumatic hypoxia/bradycapnea)
	56:30	HR high	123 BPM	Seizure
6	14:30	HR high	130 BPM	Pain
	22:00	BP low	87/57 mmHG	Hypotension due to burn injury
	32:00	Temp high	101.5 ºF	Infection/fever or medication RXN (r/o)
	49:30	BP high	186/110 mmHG	Pain
7	02:48	BP high	188/113 mmHG	Pain
	25:30	RR high	25 BrPM	Anxiety/hyperventilation
	37:30	HR high	130 BPM	Anxiety
	47:30	HR low	47 BPM	Overmedication (i.e., anti-pain/anxiety)
8	06:45	BP low	87/56 mmHG	Blood loss/hypotension
	18:30	SpO_2 low	86%	Hypoxic hypoxia (circulatory hypoxia 2/2 blood loss)
	41:06	HR high	125 BPM	Pain/anxiety
	57:30	Temp low	95 ºF	Hypothermia
9	11:12	BP low	86/55 mmHG	Blood loss/hypotension
	24:00	SpO_2 low	86%	Hypoxic hypoxia (circulatory hypoxia 2/2

				blood loss)
	31:00	HR high	135 BPM	Pain/anxiety/hypotension
	51:30	Temp high	103 ºF	Blood transfusion RXN/infection or medication RXN (r/o)
10	05:24	BP low	83/60 mmHG	Blood loss/hypotension
	26:18	Temp high	102 ºF	Blood transfusion RXN/infection or medication RXN (r/o)
	35:00	SpO_2 low	85%	Pneumothorax (r/o); hypoxic hypoxia (circulatory hypoxia 2/2 blood loss)
	46:30	HR high	131 BPM	Pain/anxiety
11	08:33	BP low	86/52 mmHG	Blood loss/hypotension
	17:30	HR high	123 BPM	Nausea/vomiting
	43:00	SpO_2 low	85%	Hypoxic hypoxia (circulatory hypoxia 2/2 blood loss)
	54:00	RR high	30 BrPM	Anxiety
12	12:30	BP low	84/59 mmHG	Blood loss/hypotension
	23:00	Temp high	102 ºF	Blood transfusion RXN/infection or medication RXN (r/o)
	30:00	SpO_2 low	86%	Hypoxic hypoxia (circulatory hypoxia 2/2 blood loss)
	52:18	HR high	126 BPM	Pain/anxiety or nausea with vomiting

[*]*Note.* Heart rate (HR), respiration rate (RR), blood pressure (BP), oxygen saturation (SpO_2), temperature (Temp), beats per minute (BPM), breaths per minute (BrPM), maximum (Max), millimeters of mercury (mmHG), degrees Fahrenheit (ºF), reaction (RXN), systolic blood pressure (SBP), diastolic blood pressure (DBP), rule out (r/o), traumatic brain injury (TBI), intracranial pressure (ICP)

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Table B2. Propaq MD Monitor Alarm Limits

Parameter	**Alarm Lower Limit**	**Alarm Upper Limit**	**SMOG Reference Page Number (pg.)**
Heart rate	50 BPM	120 BPM	Both: Pg. 252, post-operative and interfacility transfer
Respiration rate	8 BrPM	21 BrPM (for programming error)	Lower: Pg. 17, multiple trauma Upper: Pg. 41, sepsis
SpO_2	90%	100%	Lower: Pg. 37–38, respiratory distress; pg. 48, chest pain Upper: No limit
Temperature	96.8 ºF	100.4 ºF	Both: Pg. 41, sepsis
P1 systolic	90 mmHG	185 mmHG	Lower: Pg. 23, pg. 57, shock/ hypotension Upper: Pg. 58, hypertensive crisis
P1 diastolic	60 mmHG	110 mmHG	Lower: General practice (Mayo Clinic, 2024) Upper: Pg. 42, stroke/TIA; pg. 58, hypertension

[*]*Note.* SMOG; Department of Aviation Medicine (2023)

Table B3. Ranges to Ensure Alarm or Ensure no Alarm using SMOG Limits and VitalsBridge Errors

Parameter	**Ensure Alarm**	**Ensure No Alarm**	**VitalsBridge Error**
Heart rate	0-47 BPM 123+ BPM	53-117 BPM	± 3 BPM for normal conditions from 40–200 BPM
Respiration rate	0-6 BrPM 23+ BrPM	10-19 BrPM	± 1 BrPM within range of 4–15 BrPM ± 2 BrPM outside range
SpO_2	0-86%	94-100%	± 4% for range 80–100% with HR 60–110 BPM ± 7% for < 80%
Temperature	1-95.9 ºF 101.3 ºF +	97.7-99.5 ºF	± 0.9 ºF
IBP systolic	0-85 mmHG 197+ mmHG	95-173 mmHG	± 5 for range (80/40–150/110 mmHG for HR 60–110) and ± 12 mmHG for outside range
IBP diastolic	0-55 mmHG 122+ mmHG	65-105 mmHG	

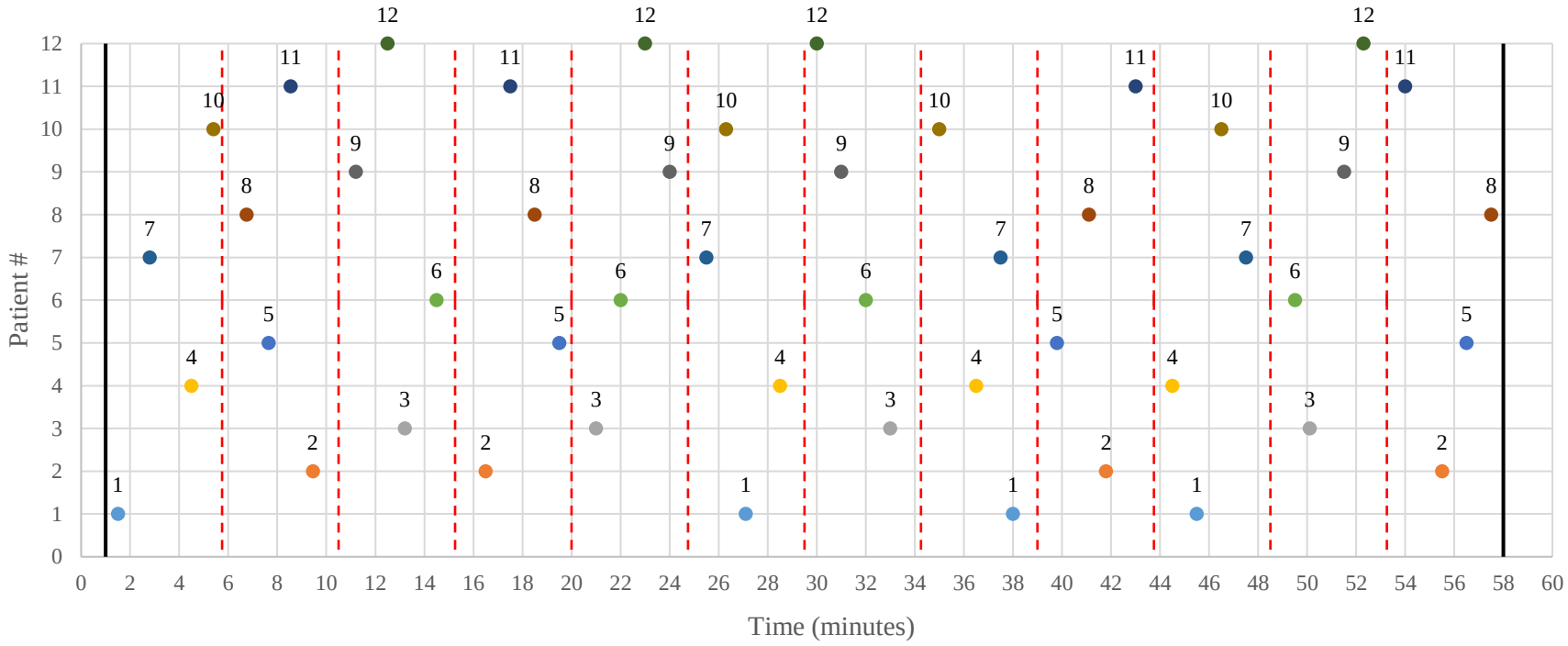

Figure B1. All patient alarm times.

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Table B4. Patient Injuries, Starting Vitals, Treatments, and Medications

Patient #	Patient Status	Starting Vitals	Injury Descriptions	Treatments and Medications	Medications
1	Priority	IBP: 90/70 Temp: 97.9 HR: 87 RR: 14 SpO_2: 96	• Degloving injury LUE • Open ulnar and 4/5 metacarpal FX • Shrapnel to bilateral posterior	• TQ on L arm • 18 G IV	• 100 mg Ketamine
2	Priority	IBP: 90/70 Temp: 99 HR: 110 RR: 19 SpO_2: 96	• GSW L lateral thigh • GSW L lower leg • GSW R lower leg • Laceration bilateral hands • FX in L hand • FX R tibia and fibula • Open FX L tibia	• TQ on L leg • TQ on R leg • 18G IV • Dressings on L leg	• 50 mg Ketamine
3	Priority	IBP: 142/97 Temp: 99 HR: 112 RR: 16 SpO_2: 96	• Multiple lacerations to face • Hematoma to neck • Shrapnel wounds to bilateral hands and forearm	• Dressing on neck • Ready heat	NA
4	Priority	IBP: 95/80 Temp: 99 HR: 113 RR: 16 SpO_2: 94	• GSW to R back and mid sternum	• Chest Seal R upper back • NCD R side • Tibial IO L leg • Ready heat • King LT	• 40 mg IO Ketamine
5	Priority	IBP: 160/71 Temp: 97.7 HR: 55 RR: 19	• R occipital laceration with blood to right ear	• NRB with O_2 % supplementation • 2 large bore 18 G peripheral IVs placed	NA

		SpO_2: 94		• Laceration covered with dry sterile dressing	
6	Priority	IBP: 94/60 Temp: 98 HR: 53 RR: 12 SpO_2: 99	• Fourth degree chemical burn noted to R forearm (approximately 1% TBSA) • Second degree burns to R forearm (approximately 2% TBSA) and L index finger (palmar) (approximately 1 % TBSA)	• Removed rings, bracelets, or other constricting items • Removed burning/charred clothing and cool with sterile saline/gel pad the areas burned • Burned areas covered with dry sheet/gauze/dry sterile dressings • 18 G IV LUE	• 500 mL fluid bolus given of lactated ringers • 400 mg IV Moxifloxacin administered x1
7	Priority	IBP: 122/72 Temp: 98.2 HR: 59 RR: 18 SpO_2: 99	• Laceration to L eye	• L eye irrigated with normal saline • L eye covered and bandaged, but lightly bleeding • Two 18 G IVs placed in the antecubital fossa	• 1-2 gtt(s) tetracaine 0.5% solution, L eye • 250 mg IM Ketamine • 400 mg IV Moxifloxacin x 1
8	Priority	IBP: 150/89 Temp: 98.9 HR: 86 RR: 16 SpO_2: 98	• IED/shrapnel injury: Deformities to BLE	• 2 large bore 18 G peripheral IVs placed • BLE splints • Shrapnel wounds irrigated with normal saline and BLE field dressings placed	• 1 g IV Ertapenem x 1 • Tetanus immunization (TD) shot x 1 given • Fentanyl lollipops x 2 given prior to loading on MEDEVAC
9	Priority	IBP: 121/71 Temp: 98.2 HR: 68 RR 19 SpO_2: 100	• Crush injury: Open fracture and degloving soft-tissue injuries to the LLE. Continued LLE bleeding, despite two thigh torniquets previously applied	• Thigh TQ x 2 and compressive dressings LLE (improperly applied, don't add in LLEAP) • Wounds irrigated with normal saline before	• Tetanus immunization (TDaP) shot x 1 given at the role 1/BAS

				compressive dressing applied in the field	
10	Priority	IBP: 96/63 Temp: 99 HR: 110 RR: 18 SpO_2: 94	• GSW with visible penetrating injury to right lower chest and left upper chest	• Chest seals applied x 2 • 2 large bore 18 G peripheral IVs placed • Placed on the ventilator (AC tidal volume: 450, flow rate: 50 cm H_20, RR: 14 , PEEP 5 cm H_20, $EtCO_2$ 36) • Foley catheter placed	• 2 g IV Ancef x 1 • 2 g IV TXA x 1 • 3 g IV calcium x 1 • 8 units WB, 1 PRBC + 4 liters crystalloid given • 50 mg IV Ketamine
11	Priority	IBP: 85/65 Temp: 99 HR: 110 RR: 12 SpO_2: 98	• BLE amputations	• BLE TQs • L humerus IO placed • Cervical collar placed	• 2 g IV Ancef x 1 • 2 g IV TXA x 1 • 50 mg IO Ketamine
12	Priority	IBP: 154/101 Temp: 98.8 HR: 117 RR: 18 SpO_2: 95	• GSW to RLE x 2 and LLE x 1 • RLE open fracture (tib/fib) • R hand injury with a laceration to the fourth digit & open FXs on the right middle and ring finger	• TQ below R knee • TQ below L knee • 2 large bore 18 G peripheral IVs placed • Cervical collar placed • Foley placed • Placed on O_2 via NRB at 15 LPM	• 2 g IV Ancef x 1 • TXA 100 mL NS over 10 minutes administered. • 50 mg IV Ketamine • TD shot x 1 given Role 1/BAS

[*]*Note.* Invasive blood pressure (IBP), left upper extremity (LUE), fracture (FX), tourniquet (TQ), gauge (G), intravenous (IV), milligram (mg), gunshot wound (GSW), left (L), right (R), needle chest decompression (NCD), intraosseous (IO), laryngeal tube (LT), non-rebreather mask (NRB), oxygen (O_2), milliliters (mL), gutta (gtt), intramuscular (IM), improvised explosive device (IED), bilateral lower extremities (BLE), gram (g), tetanus and diphtheria (TD), left lower extremity (LLE), right lower extremity (RLE), tetanus, diphtheria, and pertussis (TDaP), centimeters (cm), water (H_2O), positive end-expiratory pressure (PEEP), end-tidal carbon dioxide ($EtCO_2$), tranexamic acid (TXA), whole blood (WB), packed red blood cells (PRBC), right left extremity (RLE), liters per minute (LPM), normal saline (NS), not applicable (NA), total body surface area (TBSA), battalion aid station (BAS), assist control (AC)

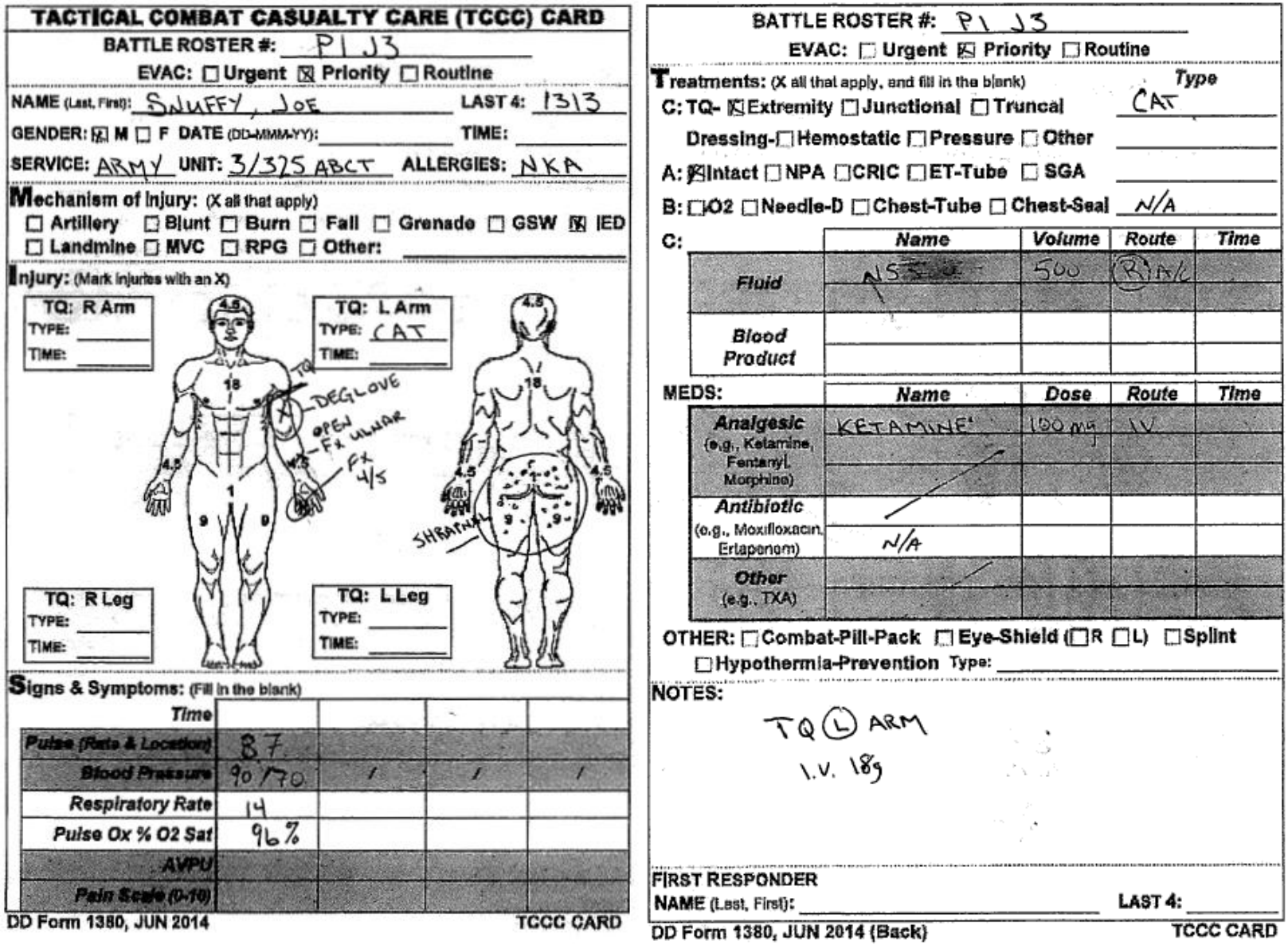
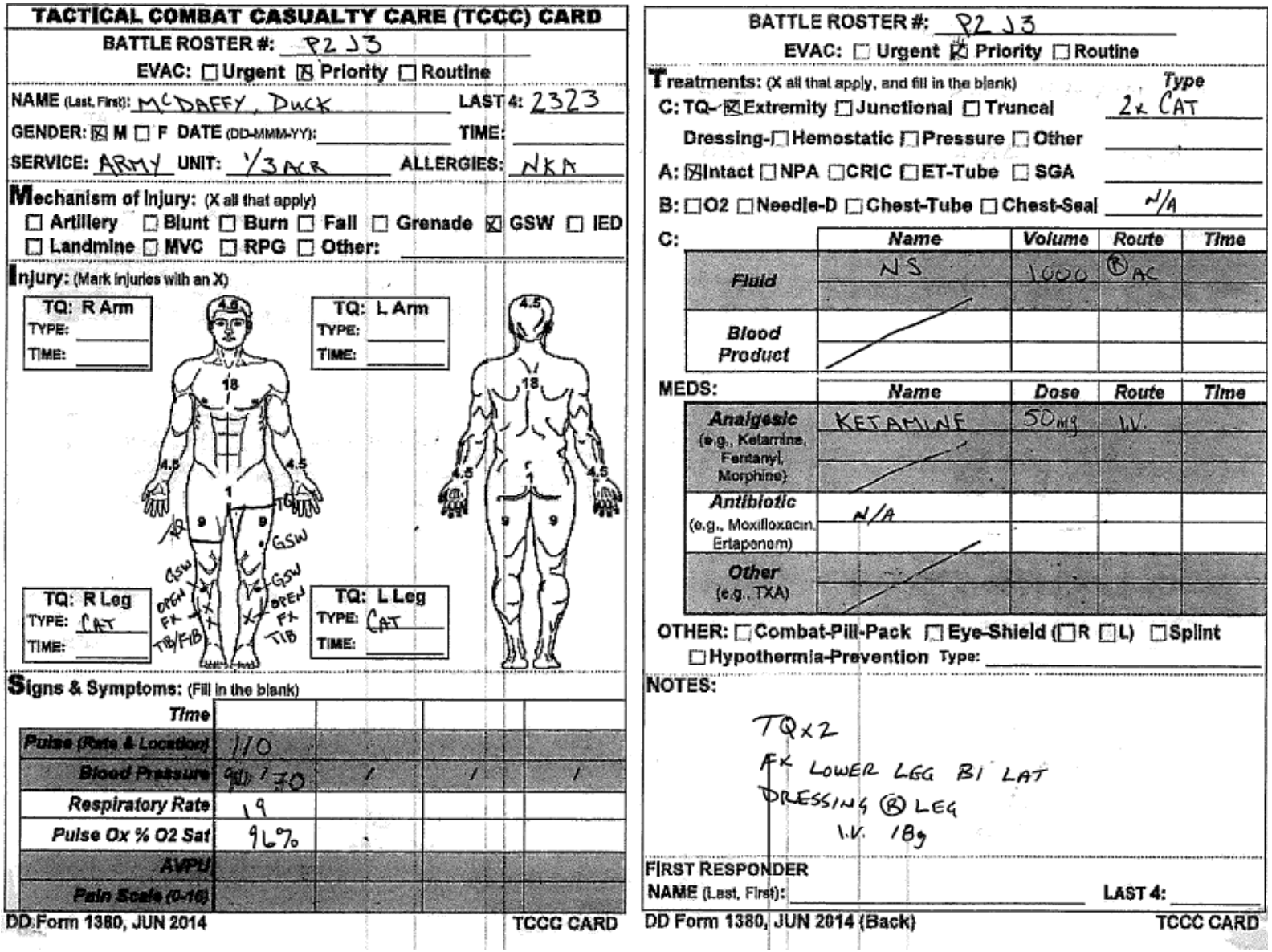


Figure B2. Patient 1 TCCC card, front and back.



TACTICAL COMBAT CASUALTY CARE (TCCC) CARD

BATTLE ROSTER #: P2 J3

EVAC: ☐ Urgent ☒ Priority ☐ Routine

NAME (Last, First): MCDAFFY, DUCK LAST 4: 2323

GENDER: ☒ M ☐ F DATE (DD-MMM-YY): TIME:

SERVICE: ARMY UNIT: 1/3 ACR ALLERGIES: NKA

Mechanism of Injury: (X all that apply)

☐ Artillery ☐ Blunt ☐ Burn ☐ Fall ☐ Grenade ☒ GSW ☐ IED

☐ Landmine ☐ MVC ☐ RPG ☐ Other:

Injury: (Mark injuries with an X)

TQ: R Arm TYPE: TIME:

TQ: L Arm TYPE: TIME:

TQ: R Leg TYPE: CAT TIME:

TQ: L Leg TYPE: CAT TIME:

GSW, OPEN FX TIB/FIB

Signs & Symptoms: (Fill in the blank)

Time				
Pulse (Rate & Location)	110			
Blood Pressure	90/70	/	/	/
Respiratory Rate	19			
Pulse Ox % O2 Sat	96%			
AVPU				
Pain Scale (0-10)				

DD Form 1380, JUN 2014 TCCC CARD

BATTLE ROSTER #: P2 J3

EVAC: ☐ Urgent ☒ Priority ☐ Routine

Treatments: (X all that apply, and fill in the blank)

C: TQ- ☒ Extremity ☐ Junctional ☐ Truncal Type: 2x CAT

Dressing- ☐ Hemostatic ☐ Pressure ☐ Other

A: ☒ Intact ☐ NPA ☐ CRIC ☐ ET-Tube ☐ SGA

B: ☐ O2 ☐ Needle-D ☐ Chest-Tube ☐ Chest-Seal N/A

C:

	Name	Volume	Route	Time
Fluid	NS	1000	® AC	
Blood Product				

MEDS:

	Name	Dose	Route	Time
Analgesic (e.g., Ketamine, Fentanyl, Morphine)	KETAMINE	50 mg	I.V.	
Antibiotic (e.g., Moxifloxacin, Ertapenem)	N/A			
Other (e.g., TXA)				

OTHER: ☐ Combat-Pill-Pack ☐ Eye-Shield (☐ R ☐ L) ☐ Splint

☐ Hypothermia-Prevention Type:

NOTES:

TQx2

FX LOWER LEG BI LAT

DRESSING ® LEG

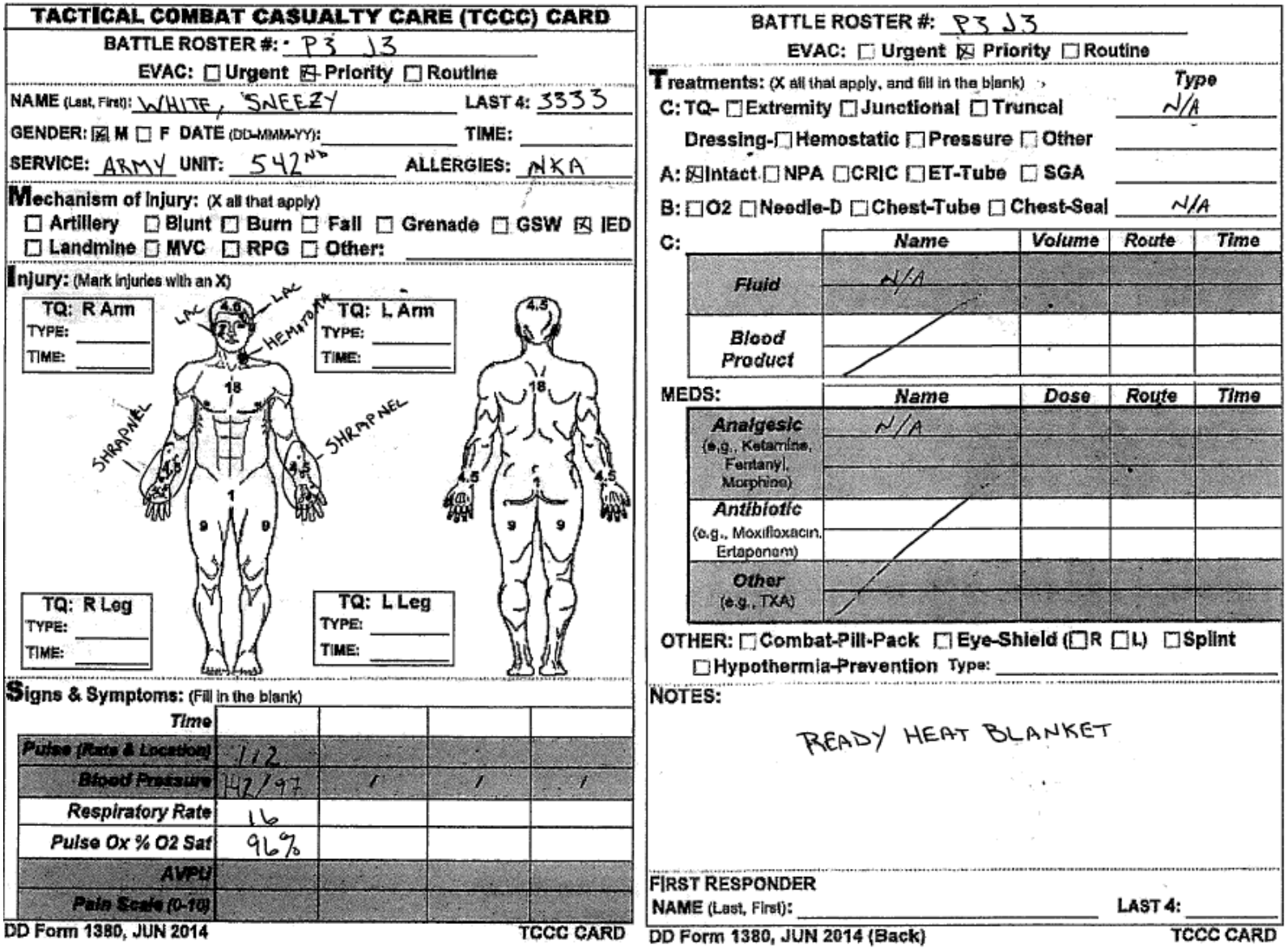
I.V. 1Bg

FIRST RESPONDER

NAME (Last, First): LAST 4:

DD Form 1380, JUN 2014 (Back) TCCC CARD

Figure B3. Patient 2 TCCC card, front and back.



TACTICAL COMBAT CASUALTY CARE (TCCC) CARD

BATTLE ROSTER #: P3 J3

EVAC: ☐ Urgent ☒ Priority ☐ Routine

NAME (Last, First): WHITE, SNEEZY LAST 4: 3333

GENDER: ☒ M ☐ F DATE (DD-MMM-YY): TIME:

SERVICE: ARMY UNIT: 542ND ALLERGIES: NKA

Mechanism of Injury: (X all that apply)

☐ Artillery ☐ Blunt ☐ Burn ☐ Fall ☐ Grenade ☐ GSW ☒ IED

☐ Landmine ☐ MVC ☐ RPG ☐ Other:

Injury: (Mark injuries with an X)

TQ: R Arm TYPE: TIME:

TQ: L Arm TYPE: TIME:

TQ: R Leg TYPE: TIME:

TQ: L Leg TYPE: TIME:

LAC LAC HEMORRHAGE SHRAPNEL SHRAPNEL

Signs & Symptoms: (Fill in the blank)

	Time			
Pulse (Rate & Location)	112			
Blood Pressure	142/97	/	/	/
Respiratory Rate	16			
Pulse Ox % O2 Sat	96%			
AVPU				
Pain Scale (0-10)				

DD Form 1380, JUN 2014 TCCC CARD

BATTLE ROSTER #: P3 J3

EVAC: ☐ Urgent ☒ Priority ☐ Routine

Treatments: (X all that apply, and fill in the blank) Type

C: TQ- ☐ Extremity ☐ Junctional ☐ Truncal N/A

Dressing- ☐ Hemostatic ☐ Pressure ☐ Other

A: ☒ Intact ☐ NPA ☐ CRIC ☐ ET-Tube ☐ SGA

B: ☐ O2 ☐ Needle-D ☐ Chest-Tube ☐ Chest-Seal N/A

C:	Name	Volume	Route	Time
Fluid	N/A			
Blood Product				

MEDS:	Name	Dose	Route	Time
Analgesic (e.g., Ketamine, Fentanyl, Morphine)	N/A			
Antibiotic (e.g., Moxifloxacin, Ertapenem)				
Other (e.g., TXA)				

OTHER: ☐ Combat-Pill-Pack ☐ Eye-Shield (☐ R ☐ L) ☐ Splint

☐ Hypothermia-Prevention Type:

NOTES:

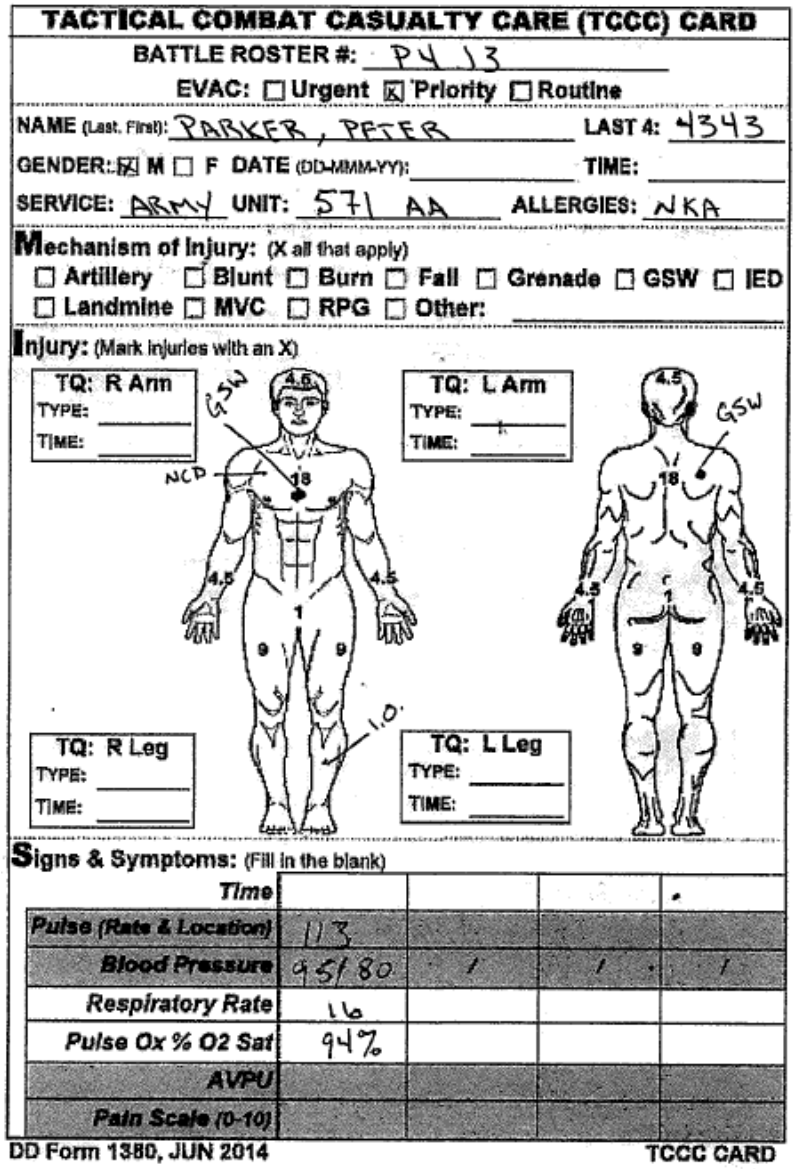
READY HEAT BLANKET

FIRST RESPONDER

NAME (Last, First): LAST 4:

DD Form 1380, JUN 2014 (Back) TCCC CARD

Figure B4. Patient 3 TCCC card, front and back.



TACTICAL COMBAT CASUALTY CARE (TCCC) CARD

BATTLE ROSTER #: P4 J3

EVAC: ☐ Urgent ☒ Priority ☐ Routine

NAME (Last, First): PARKER, PETER LAST 4: 4343

GENDER: ☒ M ☐ F DATE (DD-MMM-YY): TIME:

SERVICE: ARMY UNIT: 571 AA ALLERGIES: NKA

Mechanism of Injury: (X all that apply)

☐ Artillery ☐ Blunt ☐ Burn ☐ Fall ☐ Grenade ☐ GSW ☐ IED

☐ Landmine ☐ MVC ☐ RPG ☐ Other:

Injury: (Mark injuries with an X)

TQ: R Arm TYPE: TIME:

TQ: L Arm TYPE: TIME:

TQ: R Leg TYPE: TIME:

TQ: L Leg TYPE: TIME:

GSW NCD 1.0 GSW

Signs & Symptoms: (Fill in the blank)

	Time			
Pulse (Rate & Location)	113			
Blood Pressure	95/80	/	/	/
Respiratory Rate	16			
Pulse Ox % O2 Sat	94%			
AVPU				
Pain Scale (0-10)				

DD Form 1380, JUN 2014 TCCC CARD

BATTLE ROSTER #: P4 J3

EVAC: ☐ Urgent ☒ Priority ☐ Routine

Treatments: (X all that apply, and fill in the blank)

C: TQ- ☐ Extremity ☐ Junctional ☐ Truncal Type: N/A

Dressing- ☐ Hemostatic ☐ Pressure ☒ Other

A: ☒ Intact ☐ NPA ☐ CRIC ☐ ET-Tube ☐ SGA

B: ☐ O2 ☒ Needle-D ☐ Chest-Tube ☒ Chest-Seal (S) UPPER BACK

C:

	Name	Volume	Route	Time
Fluid				
Blood Product				

MEDS:

	Name	Dose	Route	Time
Analgesic (e.g., Ketamine, Fentanyl, Morphine)	KETAMINE	40mg	I.O.	
Antibiotic (e.g., Moxifloxacin, Ertapenem)	N/A			
Other (e.g., TXA)				

OTHER: ☐ Combat-Pill-Pack ☐ Eye-Shield (☐ R ☐ L) ☐ Splint

☐ Hypothermia-Prevention Type:

NOTES:

NCD (R) SIDE

CHEST SEAL UPPER (R) BACK

I.O. (L) TIB

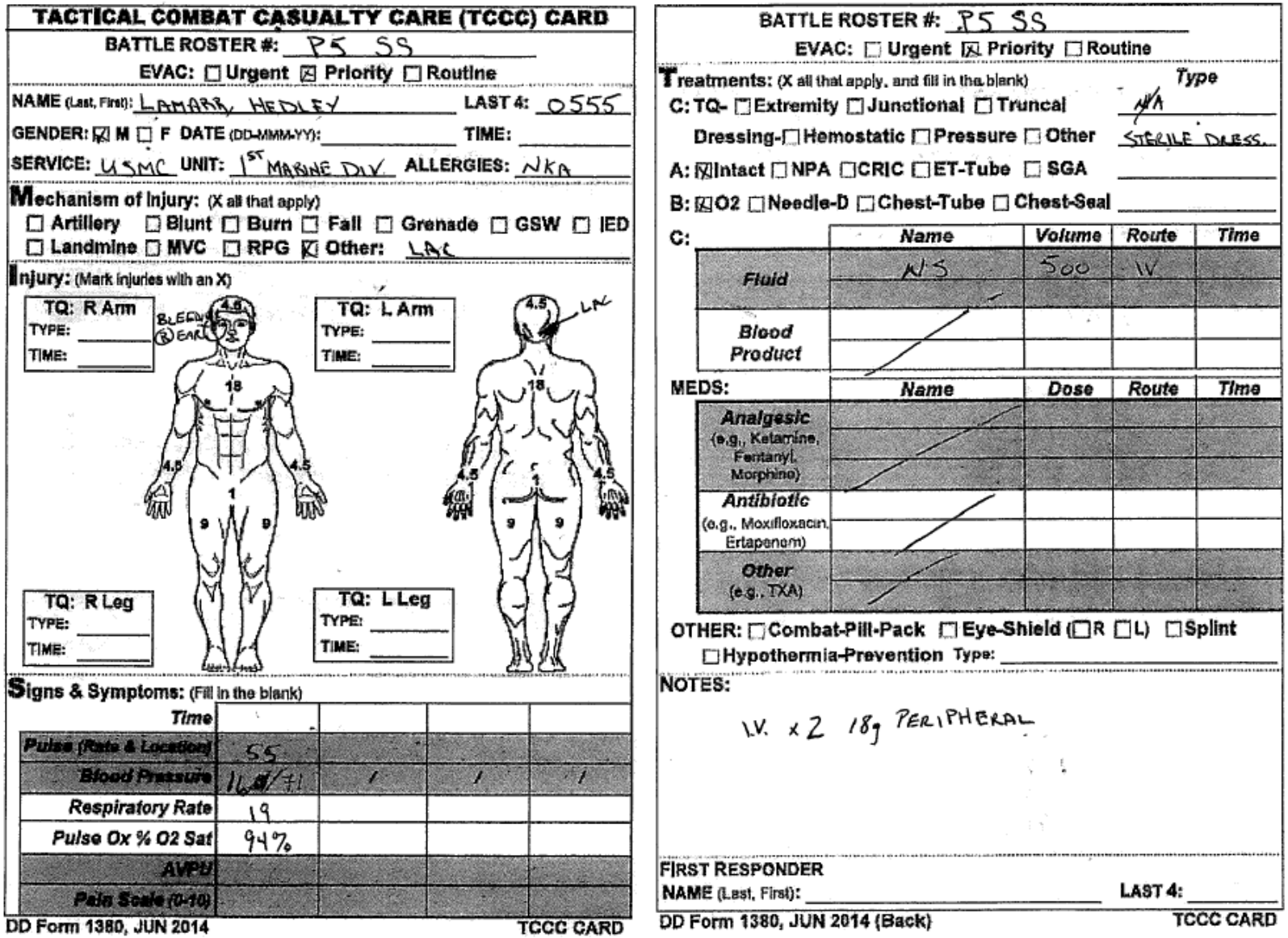
READY HEAT

FIRST RESPONDER

NAME (Last, First): LAST 4:

DD Form 1380, JUN 2014 (Back) TCCC CARD

Figure B5. Patient 4 TCCC card, front and back.



TACTICAL COMBAT CASUALTY CARE (TCCC) CARD

BATTLE ROSTER #: P5 SS

EVAC: ☐ Urgent ☒ Priority ☐ Routine

NAME (Last, First): LAMARR, HEDLEY LAST 4: 0555

GENDER: ☒ M ☐ F DATE (DD-MMM-YY): TIME:

SERVICE: USMC UNIT: 1ST MARINE DIV ALLERGIES: NKA

Mechanism of Injury: (X all that apply)

☐ Artillery ☐ Blunt ☐ Burn ☐ Fall ☐ Grenade ☐ GSW ☐ IED
☐ Landmine ☐ MVC ☐ RPG ☒ Other: LAC

Injury: (Mark injuries with an X)

TQ: R Arm TYPE: TIME:

TQ: L Arm TYPE: TIME:

TQ: R Leg TYPE: TIME:

TQ: L Leg TYPE: TIME:

Signs & Symptoms: (Fill in the blank)

	Time			
Pulse (Rate & Location)	55			
Blood Pressure	168/71	/	/	/
Respiratory Rate	19			
Pulse Ox % O2 Sat	94%			
AVPU				
Pain Scale (0-10)				

DD Form 1380, JUN 2014 TCCC CARD

BATTLE ROSTER #: P5 SS

EVAC: ☐ Urgent ☒ Priority ☐ Routine

Treatments: (X all that apply, and fill in the blank)

C: TQ- ☐ Extremity ☐ Junctional ☐ Truncal Type: N/A

Dressing- ☐ Hemostatic ☐ Pressure ☐ Other STERILE DRESS.

A: ☒ Intact ☐ NPA ☐ CRIC ☐ ET-Tube ☐ SGA

B: ☒ O2 ☐ Needle-D ☐ Chest-Tube ☐ Chest-Seal

C:

	Name	Volume	Route	Time
Fluid	NS	500	IV	
Blood Product				

MEDS:

	Name	Dose	Route	Time
Analgesic (e.g., Ketamine, Fentanyl, Morphine)				
Antibiotic (e.g., Moxifloxacin, Ertapenem)				
Other (e.g., TXA)				

OTHER: ☐ Combat-Pill-Pack ☐ Eye-Shield (☐ R ☐ L) ☐ Splint
☐ Hypothermia-Prevention Type:

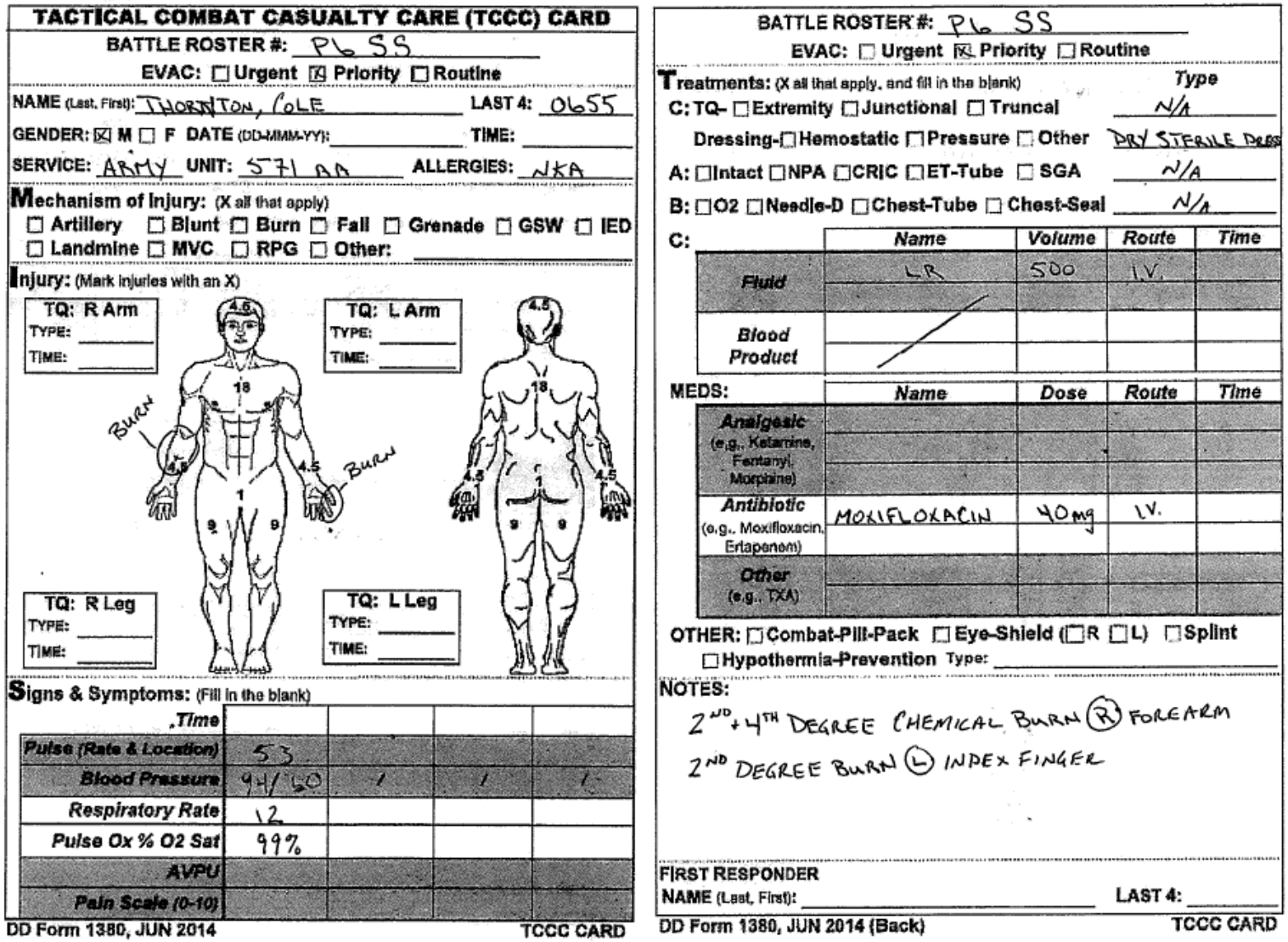
NOTES:

I.V. x2 18g PERIPHERAL

FIRST RESPONDER
NAME (Last, First): LAST 4:

DD Form 1380, JUN 2014 (Back) TCCC CARD

Figure B6. Patient 5 TCCC card, front and back.



TACTICAL COMBAT CASUALTY CARE (TCCC) CARD

BATTLE ROSTER #: P6 SS

EVAC: ☐ Urgent ☒ Priority ☐ Routine

NAME (Last, First): THORNTON, COLE LAST 4: 0655

GENDER: ☒ M ☐ F DATE (DD-MMM-YY): TIME:

SERVICE: ARMY UNIT: 571 BA ALLERGIES: NKA

Mechanism of Injury: (X all that apply)

☐ Artillery ☐ Blunt ☐ Burn ☐ Fall ☐ Grenade ☐ GSW ☐ IED

☐ Landmine ☐ MVC ☐ RPG ☐ Other:

Injury: (Mark injuries with an X)

TQ: R Arm TYPE: TIME:

TQ: L Arm TYPE: TIME:

BURN

BURN

TQ: R Leg TYPE: TIME:

TQ: L Leg TYPE: TIME:

Signs & Symptoms: (Fill in the blank)

Time				
Pulse (Rate & Location)	53			
Blood Pressure	94/60	/	/	/
Respiratory Rate	12			
Pulse Ox % O2 Sat	99%			
AVPU				
Pain Scale (0-10)				

DD Form 1380, JUN 2014 TCCC CARD

BATTLE ROSTER #: P6 SS

EVAC: ☐ Urgent ☒ Priority ☐ Routine

Treatments: (X all that apply, and fill in the blank)

C: TQ- ☐ Extremity ☐ Junctional ☐ Truncal Type: N/A

Dressing- ☐ Hemostatic ☐ Pressure ☐ Other DRY STERILE DRESS

A: ☐ Intact ☐ NPA ☐ CRIC ☐ ET-Tube ☐ SGA N/A

B: ☐ O2 ☐ Needle-D ☐ Chest-Tube ☐ Chest-Seal N/A

C:	Name	Volume	Route	Time
Fluid	LR	500	I.V.	
Blood Product				

MEDS:	Name	Dose	Route	Time
Analgesic (e.g., Ketamine, Fentanyl, Morphine)				
Antibiotic (e.g., Moxifloxacin, Ertapenem)	MOXIFLOXACIN	400mg	I.V.	
Other (e.g., TXA)				

OTHER: ☐ Combat-Pill-Pack ☐ Eye-Shield (☐ R ☐ L) ☐ Splint

☐ Hypothermia-Prevention Type:

NOTES:

2ND + 4TH DEGREE CHEMICAL BURN (R) FOREARM

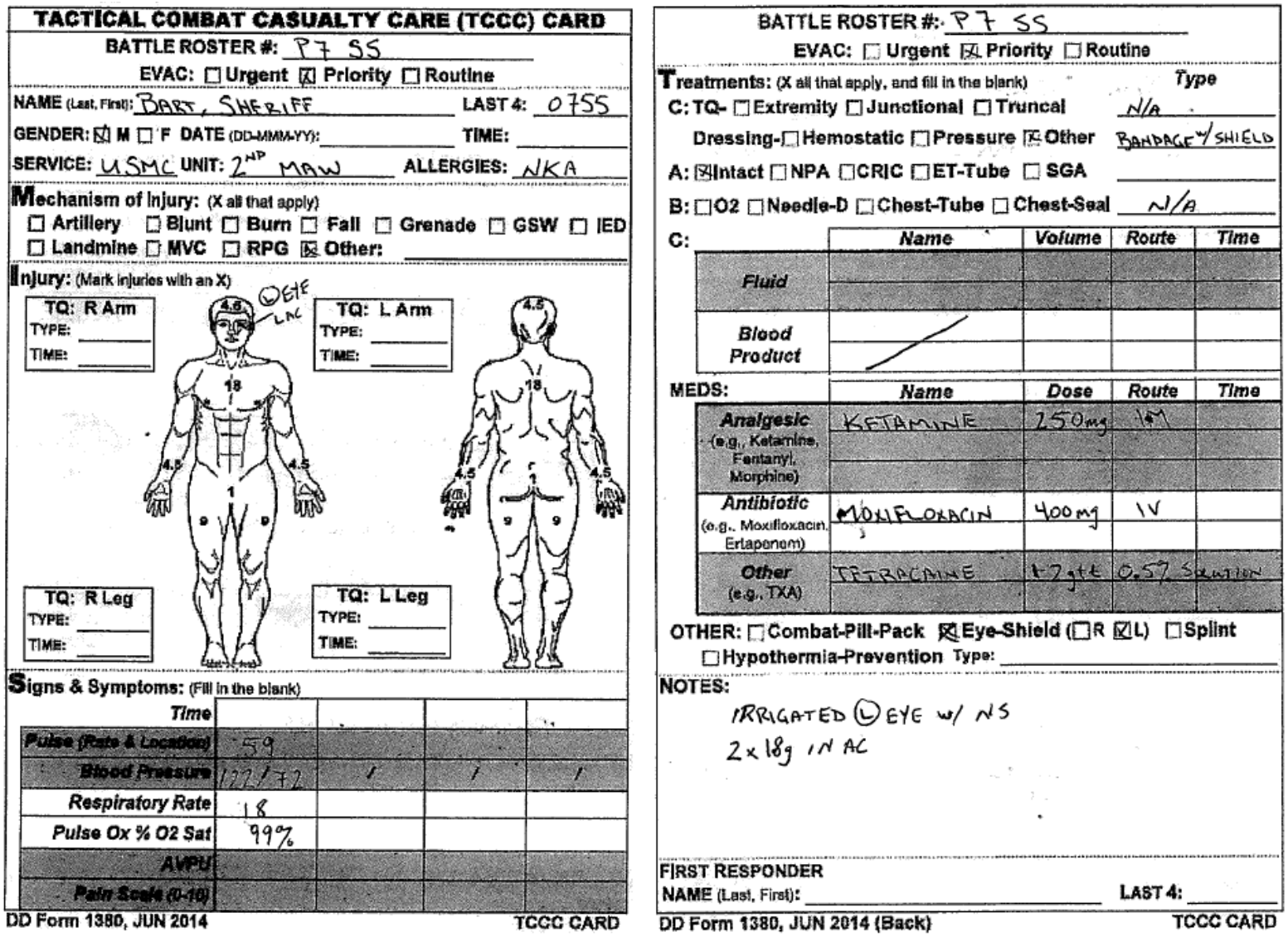
2ND DEGREE BURN (L) INDEX FINGER

FIRST RESPONDER

NAME (Last, First): LAST 4:

DD Form 1380, JUN 2014 (Back) TCCC CARD

Figure B7. Patient 6 TCCC card, front and back.



TACTICAL COMBAT CASUALTY CARE (TCCC) CARD

BATTLE ROSTER #: P7 SS

EVAC: ☐ Urgent ☒ Priority ☐ Routine

NAME (Last, First): BART, SHERIFF LAST 4: 0755

GENDER: ☒ M ☐ F DATE (DD-MMM-YY): TIME:

SERVICE: USMC UNIT: 2ND MAW ALLERGIES: NKA

Mechanism of Injury: (X all that apply)

☐ Artillery ☐ Blunt ☐ Burn ☐ Fall ☐ Grenade ☐ GSW ☐ IED

☐ Landmine ☐ MVC ☐ RPG ☒ Other:

Injury: (Mark injuries with an X)

TQ: R Arm TYPE: TIME:

TQ: L Arm TYPE: TIME:

TQ: R Leg TYPE: TIME:

TQ: L Leg TYPE: TIME:

Signs & Symptoms: (Fill in the blank)

Time				
Pulse (Rate & Location)	59			
Blood Pressure	122/72	/	/	/
Respiratory Rate	18			
Pulse Ox % O2 Sat	99%			
AVPU				
Pain Scale (0-10)				

DD Form 1380, JUN 2014 TCCC CARD

BATTLE ROSTER #: P7 SS

EVAC: ☐ Urgent ☒ Priority ☐ Routine

Treatments: (X all that apply, and fill in the blank)

C: TQ- ☐ Extremity ☐ Junctional ☐ Truncal Type: N/A

Dressing- ☐ Hemostatic ☐ Pressure ☒ Other BANDAGE W/ SHIELD

A: ☒ Intact ☐ NPA ☐ CRIC ☐ ET-Tube ☐ SGA

B: ☐ O2 ☐ Needle-D ☐ Chest-Tube ☐ Chest-Seal N/A

C:	Name	Volume	Route	Time
Fluid				
Blood Product				

MEDS:	Name	Dose	Route	Time
Analgesic (e.g., Ketamine, Fentanyl, Morphine)	KETAMINE	250mg	IM	
Antibiotic (e.g., Moxifloxacin, Ertapenem)	MOXIFLOXACIN	400mg	IV	
Other (e.g., TXA)	TETRACAINE	1 gtt	0.5% SOLUTION	

OTHER: ☐ Combat-Pill-Pack ☒ Eye-Shield (☐ R ☑ L) ☐ Splint

☐ Hypothermia-Prevention Type:

NOTES:

IRRIGATED L EYE W/ NS

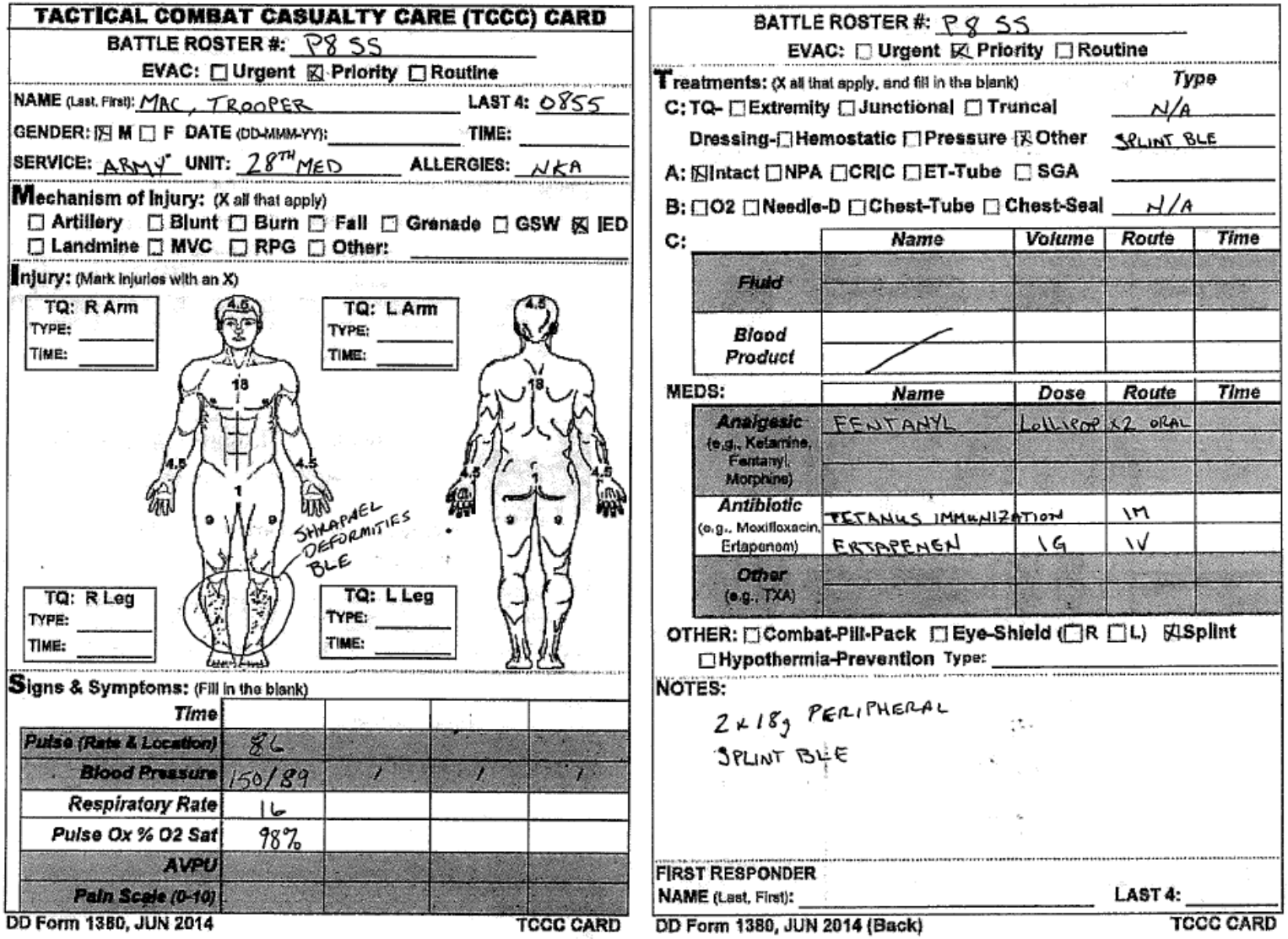
2x 18g IN AC

FIRST RESPONDER

NAME (Last, First): LAST 4:

DD Form 1380, JUN 2014 (Back) TCCC CARD

Figure B8. Patient 7 TCCC card, front and back.



TACTICAL COMBAT CASUALTY CARE (TCCC) CARD

BATTLE ROSTER #: P8 SS

EVAC: ☐ Urgent ☒ Priority ☐ Routine

NAME (Last, First): MAC, TROOPER LAST 4: 0855

GENDER: ☒ M ☐ F DATE (DD-MMM-YY): TIME:

SERVICE: ARMY UNIT: 28TH MED ALLERGIES: NKA

Mechanism of Injury: (X all that apply)

☐ Artillery ☐ Blunt ☐ Burn ☐ Fall ☐ Grenade ☐ GSW ☒ IED

☐ Landmine ☐ MVC ☐ RPG ☐ Other:

Injury: (Mark injuries with an X)

TQ: R Arm TYPE: TIME:

TQ: L Arm TYPE: TIME:

SHRAPNEL DEFORMITIES BLE

TQ: R Leg TYPE: TIME:

TQ: L Leg TYPE: TIME:

Signs & Symptoms: (Fill in the blank)

	Time			
Pulse (Rate & Location)	86			
Blood Pressure	150/89	〃	〃	〃
Respiratory Rate	16			
Pulse Ox % O2 Sat	98%			
AVPU				
Pain Scale (0-10)				

DD Form 1380, JUN 2014 TCCC CARD

BATTLE ROSTER #: P8 SS

EVAC: ☐ Urgent ☒ Priority ☐ Routine

Treatments: (X all that apply, and fill in the blank) Type

C: TQ- ☐ Extremity ☐ Junctional ☐ Truncal N/A

Dressing- ☐ Hemostatic ☐ Pressure ☒ Other SPLINT BLE

A: ☒ Intact ☐ NPA ☐ CRIC ☐ ET-Tube ☐ SGA

B: ☐ O2 ☐ Needle-D ☐ Chest-Tube ☐ Chest-Seal N/A

C:	Name	Volume	Route	Time
Fluid				
Blood Product				

MEDS:	Name	Dose	Route	Time
Analgesic (e.g., Ketamine, Fentanyl, Morphine)	FENTANYL	LOLLIPOP X2	ORAL	
Antibiotic (e.g., Moxifloxacin, Ertapenem)	TETANUS IMMUNIZATION		IM	
	ERTAPENEM	1G	IV	
Other (e.g., TXA)				

OTHER: ☐ Combat-Pill-Pack ☐ Eye-Shield (☐ R ☐ L) ☒ Splint

☐ Hypothermia-Prevention Type:

NOTES:

2 x 18g PERIPHERAL

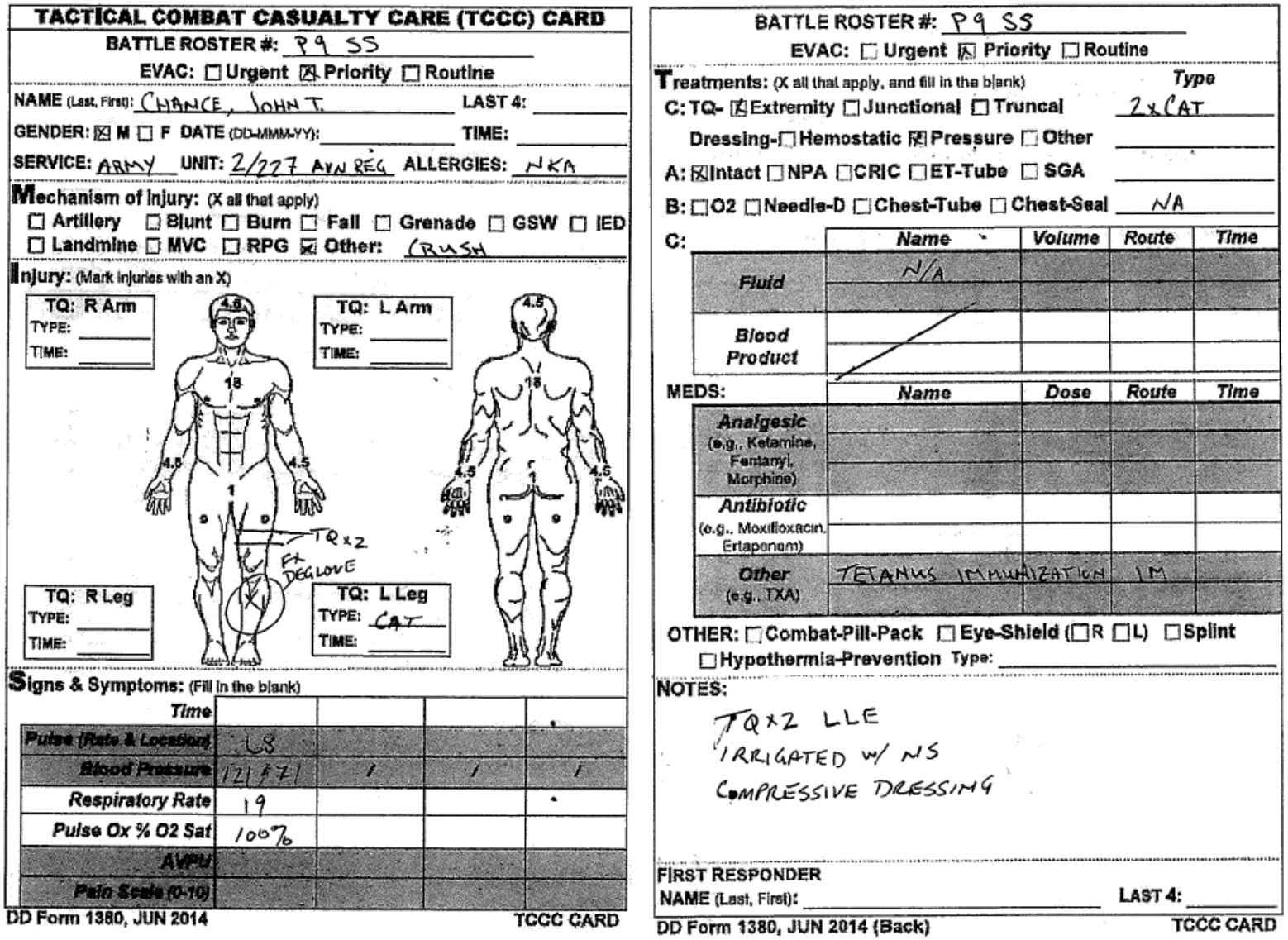
SPLINT BLE

FIRST RESPONDER

NAME (Last, First): LAST 4:

DD Form 1380, JUN 2014 (Back) TCCC CARD

Figure B9. Patient 8 TCCC card, front and back.



TACTICAL COMBAT CASUALTY CARE (TCCC) CARD

BATTLE ROSTER #: P9 SS

EVAC: ☐ Urgent ☒ Priority ☐ Routine

NAME (Last, First): CHANCE, JOHN T. LAST 4: ____

GENDER: ☒ M ☐ F DATE (DD-MMM-YY): ____ TIME: ____

SERVICE: ARMY UNIT: 2/227 AVN REG ALLERGIES: NKA

Mechanism of Injury: (X all that apply)

☐ Artillery ☐ Blunt ☐ Burn ☐ Fall ☐ Grenade ☐ GSW ☐ IED
☐ Landmine ☐ MVC ☐ RPG ☒ Other: CRUSH

Injury: (Mark injuries with an X)

TQ: R Arm — TYPE: ____ TIME: ____

TQ: L Arm — TYPE: ____ TIME: ____

TQ: R Leg — TYPE: ____ TIME: ____

TQ: L Leg — TYPE: CAT TIME: ____

TQ x2

Ft DEGLOVE

Signs & Symptoms: (Fill in the blank)				
Time				
Pulse (Rate & Location)	L8			
Blood Pressure	121/71	/	/	/
Respiratory Rate	19			
Pulse Ox % O2 Sat	100%			
AVPU				
Pain Scale (0-10)				

DD Form 1380, JUN 2014 TCCC CARD

BATTLE ROSTER #: P9 SS

EVAC: ☐ Urgent ☒ Priority ☐ Routine

Treatments: (X all that apply, and fill in the blank) Type

C: TQ- ☒ Extremity ☐ Junctional ☐ Truncal 2x CAT

Dressing- ☐ Hemostatic ☒ Pressure ☐ Other ____

A: ☒ Intact ☐ NPA ☐ CRIC ☐ ET-Tube ☐ SGA ____

B: ☐ O2 ☐ Needle-D ☐ Chest-Tube ☐ Chest-Seal N/A

C:	Name	Volume	Route	Time
Fluid	N/A			
Blood Product				

MEDS:	Name	Dose	Route	Time
Analgesic (e.g., Ketamine, Fentanyl, Morphine)				
Antibiotic (e.g., Moxifloxacin, Ertapenem)				
Other (e.g., TXA)	TETANUS IMMUNIZATION		IM	

OTHER: ☐ Combat-Pill-Pack ☐ Eye-Shield (☐ R ☐ L) ☐ Splint

☐ Hypothermia-Prevention Type: ____

NOTES:

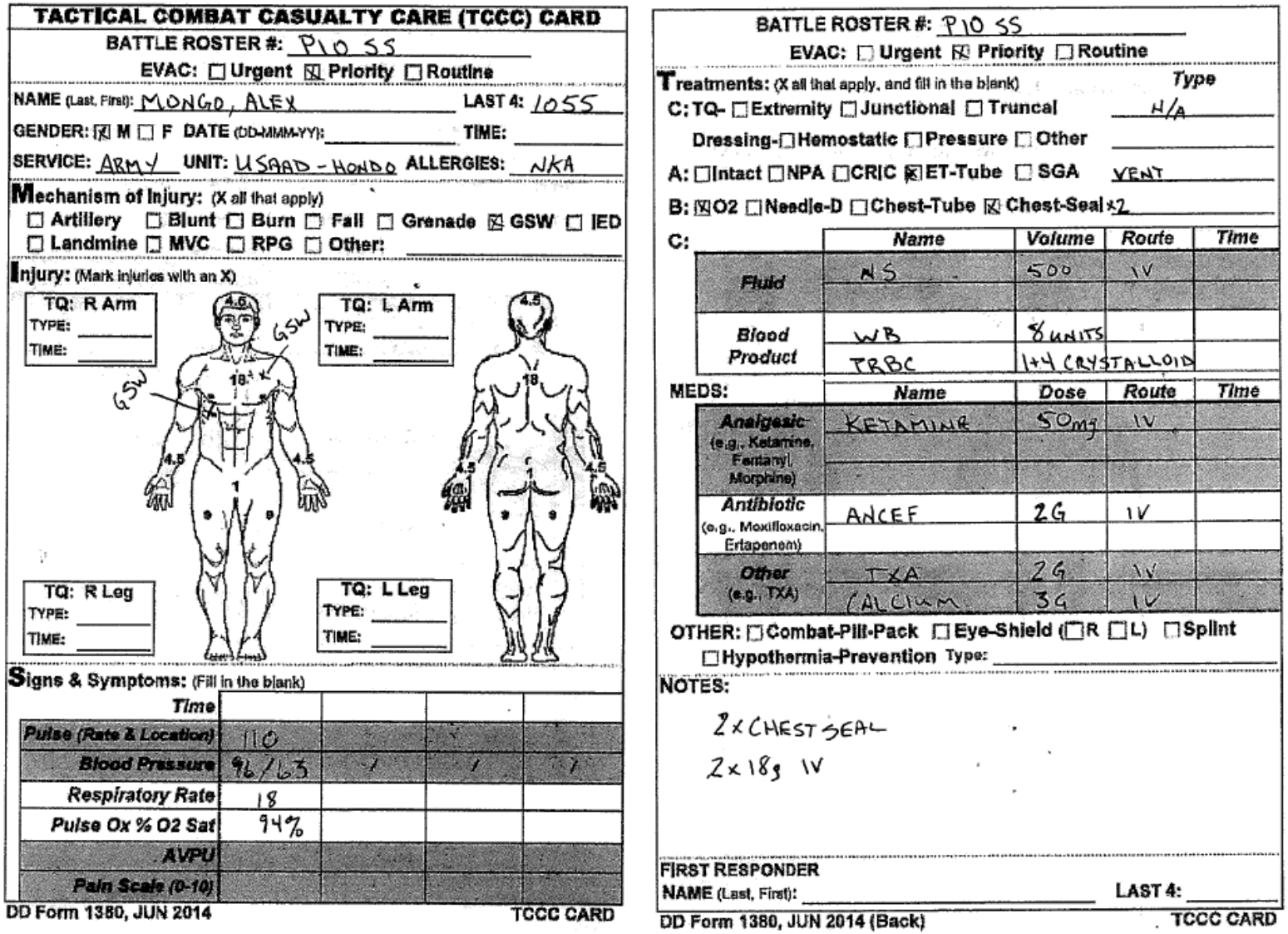
TQ x2 LLE
IRRIGATED W/ NS
COMPRESSIVE DRESSING

FIRST RESPONDER

NAME (Last, First): ____ LAST 4: ____

DD Form 1380, JUN 2014 (Back) TCCC CARD

Figure B10. Patient 9 TCCC card, front and back.



TACTICAL COMBAT CASUALTY CARE (TCCC) CARD

BATTLE ROSTER #: P10 SS

EVAC: ☐ Urgent ☒ Priority ☐ Routine

NAME (Last, First): MONGO, ALEX LAST 4: 1055

GENDER: ☒ M ☐ F DATE (DD-MMM-YY): TIME:

SERVICE: ARMY UNIT: USAAD - HONDO ALLERGIES: NKA

Mechanism of Injury: (X all that apply)

☐ Artillery ☐ Blunt ☐ Burn ☐ Fall ☐ Grenade ☒ GSW ☐ IED

☐ Landmine ☐ MVC ☐ RPG ☐ Other:

Injury: (Mark injuries with an X)

TQ: R Arm TYPE: TIME:

TQ: L Arm TYPE: TIME:

GSW GSW

TQ: R Leg TYPE: TIME:

TQ: L Leg TYPE: TIME:

Signs & Symptoms: (Fill in the blank)

	Time			
Pulse (Rate & Location)	110			
Blood Pressure	96/63	"	"	"
Respiratory Rate	18			
Pulse Ox % O2 Sat	94%			
AVPU				
Pain Scale (0-10)				

DD Form 1380, JUN 2014 TCCC CARD

BATTLE ROSTER #: P10 SS

EVAC: ☐ Urgent ☒ Priority ☐ Routine

Treatments: (X all that apply, and fill in the blank) Type

C: TQ- ☐ Extremity ☐ Junctional ☐ Truncal N/A

Dressing- ☐ Hemostatic ☐ Pressure ☐ Other

A: ☐ Intact ☐ NPA ☐ CRIC ☒ ET-Tube ☐ SGA VENT

B: ☒ O2 ☐ Needle-D ☐ Chest-Tube ☒ Chest-Seal x2

C:

	Name	Volume	Route	Time
Fluid	NS	500	IV	
Blood Product	WB	8 UNITS		
	TRBC	1+4 CRYSTALLOID		

MEDS:

	Name	Dose	Route	Time
Analgesic (e.g., Ketamine, Fentanyl, Morphine)	KETAMINE	50mg	IV	
Antibiotic (e.g., Moxifloxacin, Ertapenem)	ANCEF	2G	IV	
Other (e.g., TXA)	TXA	2G	IV	
	CALCIUM	3G	IV	

OTHER: ☐ Combat-Pill-Pack ☐ Eye-Shield (☐ R ☐ L) ☐ Splint

☐ Hypothermia-Prevention Type:

NOTES:

2 x CHEST SEAL

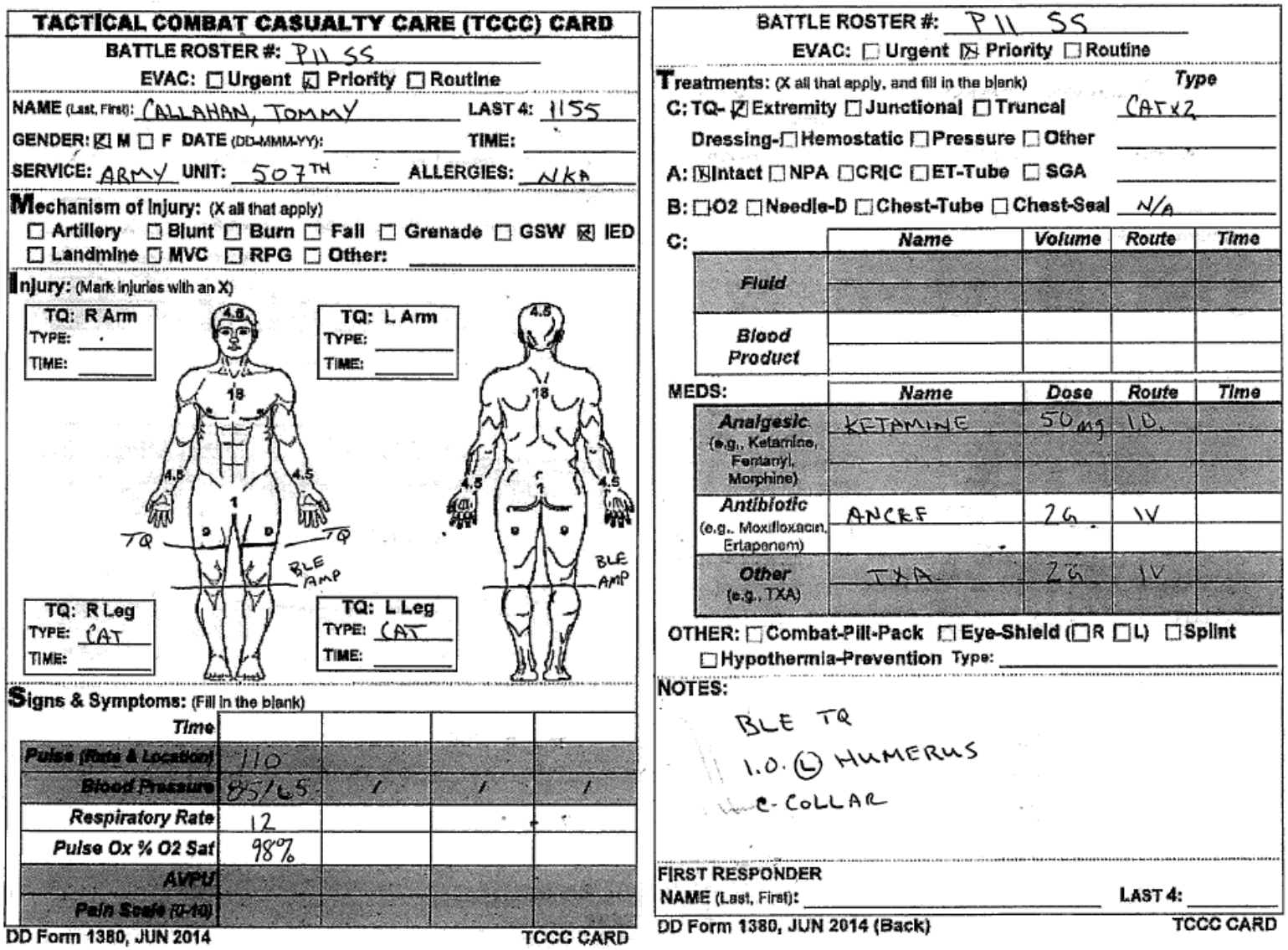
2 x 18g IV

FIRST RESPONDER

NAME (Last, First): LAST 4:

DD Form 1380, JUN 2014 (Back) TCCC CARD

Figure B11. Patient 10 TCCC card, front and back.



TACTICAL COMBAT CASUALTY CARE (TCCC) CARD

BATTLE ROSTER #: P11 SS

EVAC: ☐ Urgent ☒ Priority ☐ Routine

NAME (Last, First): CALLAHAN, TOMMY LAST 4: 1155

GENDER: ☒ M ☐ F DATE (DD-MMM-YY): TIME:

SERVICE: ARMY UNIT: 507TH ALLERGIES: NKA

Mechanism of Injury: (X all that apply)

☐ Artillery ☐ Blunt ☐ Burn ☐ Fall ☐ Grenade ☐ GSW ☒ IED

☐ Landmine ☐ MVC ☐ RPG ☐ Other:

Injury: (Mark injuries with an X)

TQ: R Arm TYPE: TIME:

TQ: L Arm TYPE: TIME:

TQ: R Leg TYPE: CAT TIME:

TQ: L Leg TYPE: CAT TIME:

Signs & Symptoms: (Fill in the blank)

Time				
Pulse (Rate & Location)	110			
Blood Pressure	85/65	/	/	/
Respiratory Rate	12			
Pulse Ox % O2 Sat	98%			
AVPU				
Pain Scale (0-10)				

DD Form 1380, JUN 2014 TCCC CARD

BATTLE ROSTER #: P11 SS

EVAC: ☐ Urgent ☒ Priority ☐ Routine

Treatments: (X all that apply, and fill in the blank) Type

C: TQ- ☑ Extremity ☐ Junctional ☐ Truncal CAT x2

Dressing- ☐ Hemostatic ☐ Pressure ☐ Other

A: ☒ Intact ☐ NPA ☐ CRIC ☐ ET-Tube ☐ SGA

B: ☐ O2 ☐ Needle-D ☐ Chest-Tube ☐ Chest-Seal N/A

C:

	Name	Volume	Route	Time
Fluid				
Blood Product				

MEDS:

	Name	Dose	Route	Time
Analgesic (e.g., Ketamine, Fentanyl, Morphine)	KETAMINE	50 mg	I.O.	
Antibiotic (e.g., Moxifloxacin, Ertapenem)	ANCEF	2G	IV	
Other (e.g., TXA)	TXA	2G	IV	

OTHER: ☐ Combat-Pill-Pack ☐ Eye-Shield (☐ R ☐ L) ☐ Splint

☐ Hypothermia-Prevention Type:

NOTES:

BLE TQ

I.O. (L) HUMERUS

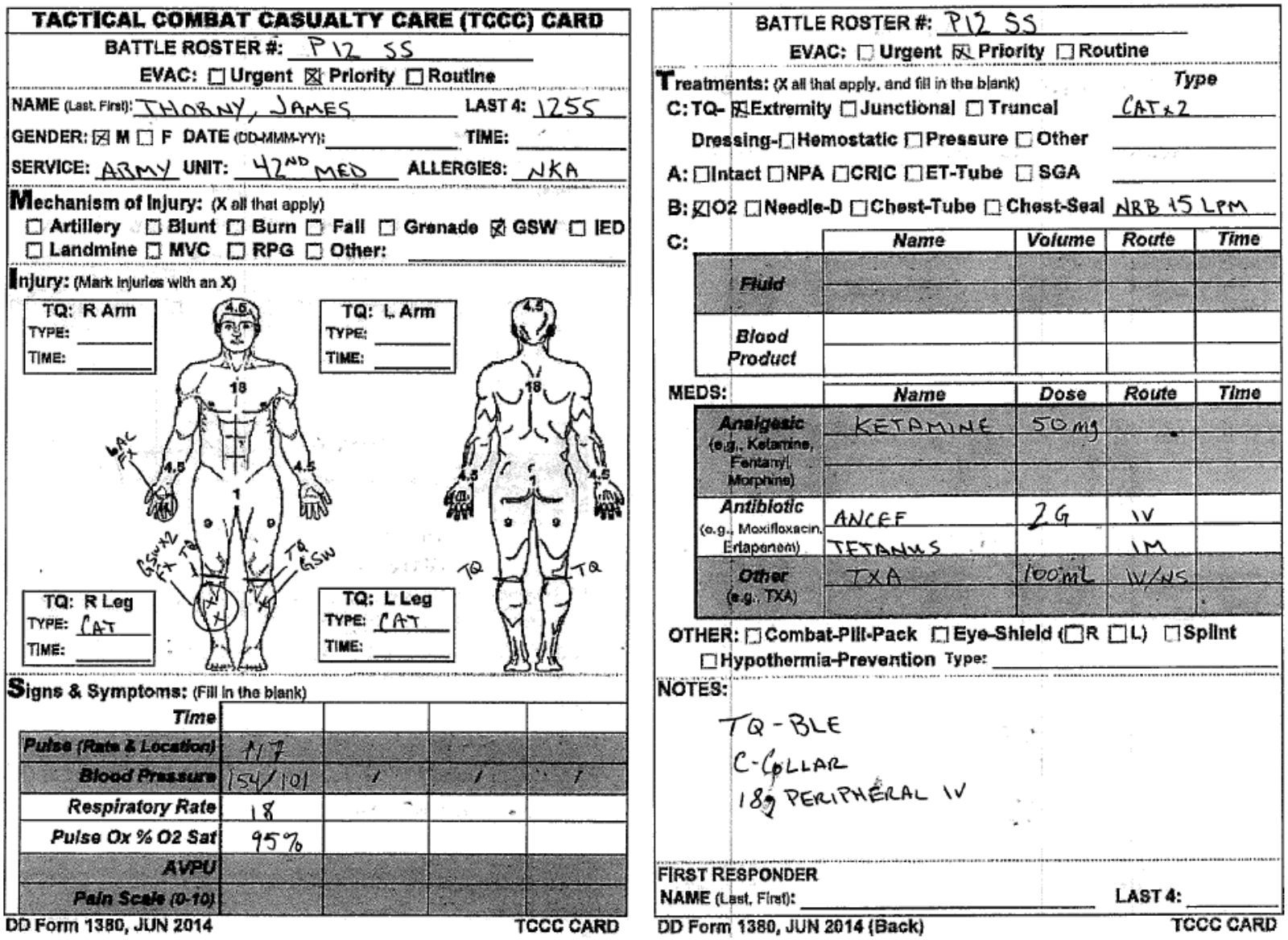
C-COLLAR

FIRST RESPONDER

NAME (Last, First): LAST 4:

DD Form 1380, JUN 2014 (Back) TCCC CARD

Figure B12. Patient 11 TCCC card, front and back.



TACTICAL COMBAT CASUALTY CARE (TCCC) CARD

BATTLE ROSTER #: P12 SS

EVAC: ☐ Urgent ☒ Priority ☐ Routine

NAME (Last, First): THORNY, JAMES LAST 4: 1255

GENDER: ☒ M ☐ F DATE (DD-MMM-YY): TIME:

SERVICE: ARMY UNIT: 42ND MED ALLERGIES: NKA

Mechanism of Injury: (X all that apply)

☐ Artillery ☐ Blunt ☐ Burn ☐ Fall ☐ Grenade ☒ GSW ☐ IED

☐ Landmine ☐ MVC ☐ RPG ☐ Other:

Injury: (Mark injuries with an X)

TQ: R Arm TYPE: TIME:

TQ: L Arm TYPE: TIME:

TQ: R Leg TYPE: CAT TIME:

TQ: L Leg TYPE: CAT TIME:

Signs & Symptoms: (Fill in the blank)

Time				
Pulse (Rate & Location)	117			
Blood Pressure	154/101	/	/	/
Respiratory Rate	18			
Pulse Ox % O2 Sat	95%			
AVPU				
Pain Scale (0-10)				

DD Form 1380, JUN 2014 TCCC CARD

BATTLE ROSTER #: P12 SS

EVAC: ☐ Urgent ☒ Priority ☐ Routine

Treatments: (X all that apply, and fill in the blank) Type

C: TQ- ☒ Extremity ☐ Junctional ☐ Truncal CAT x2

Dressing- ☐ Hemostatic ☐ Pressure ☐ Other

A: ☐ Intact ☐ NPA ☐ CRIC ☐ ET-Tube ☐ SGA

B: ☒ O2 ☐ Needle-D ☐ Chest-Tube ☐ Chest-Seal NRB 15 LPM

C:

	Name	Volume	Route	Time
Fluid				
Blood Product				

MEDS:

	Name	Dose	Route	Time
Analgesic (e.g., Ketamine, Fentanyl, Morphine)	KETAMINE	50 mg		
Antibiotic (e.g., Moxifloxacin, Ertapenem)	ANCEF	2G	IV	
	TETANUS		IM	
Other (e.g., TXA)	TXA	100mL	W/NS	

OTHER: ☐ Combat-Pill-Pack ☐ Eye-Shield (☐ R ☐ L) ☐ Splint

☐ Hypothermia-Prevention Type:

NOTES:

TQ - BLE
C-COLLAR
18g PERIPHERAL IV

FIRST RESPONDER

NAME (Last, First): LAST 4:

DD Form 1380, JUN 2014 (Back) TCCC CARD

Figure B13. Patient 12 TCCC card, front and back.

Appendix C. Post-Test Questionnaires

3D Alarms/2-Patient Configuration Post-Test-Questionnaire

Please rank the following on a scale of 0 to 10. Note the scale definitions written below each line.

Please circle the number that best corresponds to your experience:

Usability

How did you find the usability of the alarm system during this testing configuration?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

The 3D audio system was easy and intuitive to use.

The 3D audio system was moderately difficult and non-intuitive to use.

The 3D audio system was impossibly difficult and non-intuitive to use.

Signal Clarity

How did you find the signal clarity during this testing configuration?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I had no trouble distinguishing which patient the alarms were coming from.

I had moderate difficulty distinguishing which patient the alarms were coming from.

I could not distinguish which patient the alarms were coming from.

Efficacy

How effective did you find the alarms at directing your attention during this testing configuration?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

The alarms were not effective in directing my attention to the alarming patient.

The alarms were moderately effective in directing my attention to the alarming patient.

The alarms were extremely effective in directing my attention to the alarming patient.

Trust in Auditory Signal

How much did you trust that the alarms were alerting correctly within your CEPs?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I did not trust that the alarms in my headset were correct.

I trusted that the alarms in my headset were correct half of the time.

I trusted that the alarms in my headset were correct all of the time.

Workload

How did you find the workload during this testing configuration?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I had no tasks to perform. — I was busy with tasks half the time. — I was overwhelmed with tasks.

Ease of Patient Care

How would you describe how you were able to keep up with the treatments for all patients?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I could easily treat all patients. — I had moderate difficulty keeping up with the treatments for all patients. — I could not keep up with the treatments for all patients.

Time Delegation

How do you feel about the amount of time spent with each patient?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I was able to give each patient the amount of time they needed. — I had moderate difficulty giving each patient the amount of time they needed. — I could not give each patient the amount of time they needed.

Distraction Level

Rate your distraction level due to the alarms during this testing configuration.

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I was not distracted by the alarms at all. — I was moderately distracted by the alarms. — I could not focus on the patients because of the alarms.

Mental Burden

How well were you able to mentally keep track of everything occurring with each patient?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I had no trouble mentally keeping up with patient care. — I had moderate trouble mentally keeping up with patient care. — I could not mentally keep up with patient care.

Q1. Are there any benefits of using 3D audio that you noticed?

Q2. Are there any drawbacks of using 3D audio that you noticed?

Q3. Were you initially alerted to an alarm by any medical device lights instead of the audio alarms this scenario?

Q4. Do you have any feedback that wasn't captured in your answers above?

This space is intentionally blank.

Regular Alarms/2-Patient Configuration Post-Test-Questionnaire

Please rank the following on a scale of 0 to 10. Note the scale definitions written below each line.

Please circle the number that best corresponds to your experience:

Usability

How did you find the usability of the alarm system during this testing configuration?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

The audio system was easy and intuitive to use.

The audio system was moderately difficult and non-intuitive to use.

The audio system was impossibly difficult and non-intuitive to use.

Signal Clarity

How did you find the signal clarity during this testing configuration?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I had no trouble distinguishing which patient the alarms were coming from.

I had moderate difficulty distinguishing which patient the alarms were coming from.

I could not distinguish which patient the alarms were coming from.

Efficacy

How effective did you find the alarms at directing your attention during this testing configuration?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

The alarms were not effective in directing my attention to the alarming patient.

The alarms were moderately effective in directing my attention to the alarming patient.

The alarms were extremely effective in directing my attention to the alarming patient.

Trust in Auditory Signal

How much did you trust that the alarms were alerting correctly within your CEPs?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I did not trust that the alarms in my headset were correct.

I trusted that the alarms in my headset were correct half of the time.

I trusted that the alarms in my headset were correct all of the time.

Workload

How did you find the workload during this testing configuration?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I had no tasks to perform. — I was busy with tasks half the time. — I was overwhelmed with tasks.

Ease of Patient Care

How would you describe how you were able to keep up with the treatments for all patients?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I could easily treat all patients. — I had moderate difficulty keeping up with the treatments for all patients. — I could not keep up with the treatments for all patients.

Time Delegation

How do you feel about the amount of time spent with each patient?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I was able to give each patient the amount of time they needed. — I had moderate difficulty giving each patient the amount of time they needed. — I could not give each patient the amount of time they needed.

Distraction Level

Rate your distraction level due to the alarms during this testing configuration.

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I was not distracted by the alarms at all. — I was moderately distracted by the alarms. — I could not focus on the patients because of the alarms.

Mental Burden

How well were you able to mentally keep track of everything occurring with each patient?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I had no trouble mentally keeping up with patient care. — I had moderate trouble mentally keeping up with patient care. — I could not mentally keep up with patient care.

Q1. Are there any benefits of using regular audio that you noticed?

Q2. Are there any drawbacks of using regular audio that you noticed?

Q3. Were you initially alerted to an alarm by any medical device lights during the scenario?

Q4. Do you have any feedback that wasn't captured in your answers above?

This space is intentionally blank.

3D Alarms/3-Patient Configuration Post-Test-Questionnaire

Please rank the following on a scale of 0 to 10. Note the scale definitions written below each line.

Please circle the number that best corresponds to your experience:

Usability

How did you find the usability of the alarm system during this testing configuration?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

The 3D audio system was easy and intuitive to use.

The 3D audio system was moderately difficult and non-intuitive to use.

The 3D audio system was impossibly difficult and non-intuitive to use.

Signal Clarity

How did you find the signal clarity during this testing configuration?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I had no trouble distinguishing which patient the alarms were coming from.

I had moderate difficulty distinguishing which patient the alarms were coming from.

I could not distinguish which patient the alarms were coming from.

Efficacy

How effective did you find the alarms at directing your attention during this testing configuration?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

The alarms were not effective in directing my attention to the alarming patient.

The alarms were moderately effective in directing my attention to the alarming patient.

The alarms were extremely effective in directing my attention to the alarming patient.

Trust in Auditory Signal

How much did you trust that the alarms were alerting correctly within your CEPs?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I did not trust that the alarms in my headset were correct.

I trusted that the alarms in my headset were correct half of the time.

I trusted that the alarms in my headset were correct all of the time.

Workload

How did you find the workload during this testing configuration?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I had no tasks to perform. — I was busy with tasks half the time. — I was overwhelmed with tasks.

Ease of Patient Care

How would you describe how you were able to keep up with the treatments for all patients?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I could easily treat all patients. — I had moderate difficulty keeping up with the treatments for all patients. — I could not keep up with the treatments for all patients.

Time Delegation

How do you feel about the amount of time spent with each patient?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I was able to give each patient the amount of time they needed. — I had moderate difficulty giving each patient the amount of time they needed. — I could not give each patient the amount of time they needed.

Distraction Level

Rate your distraction level due to the alarms during this testing configuration.

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I was not distracted by the alarms at all. — I was moderately distracted by the alarms. — I could not focus on the patients because of the alarms.

Mental Burden

How well were you able to mentally keep track of everything occurring with each patient?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I had no trouble mentally keeping up with patient care. — I had moderate trouble mentally keeping up with patient care. — I could not mentally keep up with patient care.

Q1. Are there any benefits of using 3D audio that you noticed?

Q2. Are there any drawbacks of using 3D audio that you noticed?

Q3. Were you initially alerted to an alarm by any medical device lights instead of the audio alarms this scenario?

Q4. Do you have any feedback that wasn't captured in your answers above?

This space is intentionally blank.

Regular Alarms/3-Patient Configuration Post-Test-Questionnaire

Please rank the following on a scale of 0 to 10. Note the scale definitions written below each line.

Please circle the number that best corresponds to your experience:

Usability

How did you find the usability of the alarm system during this testing configuration?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

The audio system was easy and intuitive to use.

The audio system was moderately difficult and non-intuitive to use.

The audio system was impossibly difficult and non-intuitive to use.

Signal Clarity

How did you find the signal clarity during this testing configuration?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I had no trouble distinguishing which patient the alarms were coming from.

I had moderate difficulty distinguishing which patient the alarms were coming from.

I could not distinguish which patient the alarms were coming from.

Efficacy

How effective did you find the alarms at directing your attention during this testing configuration?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

The alarms were not effective in directing my attention to the alarming patient.

The alarms were moderately effective in directing my attention to the alarming patient.

The alarms were extremely effective in directing my attention to the alarming patient.

Trust in Auditory Signal

How much did you trust that the alarms were alerting correctly within your CEPs?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I did not trust that the alarms in my headset were correct.

I trusted that the alarms in my headset were correct half of the time.

I trusted that the alarms in my headset were correct all of the time.

Workload

How did you find the workload during this testing configuration?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I had no tasks to perform. — I was busy with tasks half the time. — I was overwhelmed with tasks.

Ease of Patient Care

How would you describe how you were able to keep up with the treatments for all patients?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I could easily treat all patients. — I had moderate difficulty keeping up with the treatments for all patients. — I could not keep up with the treatments for all patients.

Time Delegation

How do you feel about the amount of time spent with each patient?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I was able to give each patient the amount of time they needed. — I had moderate difficulty giving each patient the amount of time they needed. — I could not give each patient the amount of time they needed.

Distraction Level

Rate your distraction level due to the alarms during this testing configuration.

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I was not distracted by the alarms at all. — I was moderately distracted by the alarms. — I could not focus on the patients because of the alarms.

Mental Burden

How well were you able to mentally keep track of everything occurring with each patient?

⓪ ① ② ③ ④ ⑤ ⑥ ⑦ ⑧ ⑨ ⑩

I had no trouble mentally keeping up with patient care. — I had moderate trouble mentally keeping up with patient care. — I could not mentally keep up with patient care.

Q1. Are there any benefits of using regular audio that you noticed?

Q2. Are there any drawbacks of using regular audio that you noticed?

Q3. Were you initially alerted to an alarm by any medical device lights during the scenario?

Q4. Do you have any feedback that wasn't captured in your answers above?

This space is intentionally blank.

Both Alarm Configurations/2-Patient Configuration Post-Test-Questionnaire

Q1. How did the 3D audio compare to the regular audio in the 2-patient configuration?

Q2. Do you have any feedback that wasn't captured in your answers above?

Both Alarm Configurations/3-Patient Configuration Post-Test-Questionnaire

Q1. How did the 3D audio compare to the regular audio in the 3-patient configuration?

Q2. Do you have any feedback that wasn't captured in your answers above?

All Four Configurations Post-Test-Questionnaire

Q1. How did the 3D audio compare to the regular audio overall for all of the configurations?

Q2. Were there any differences in using the 3D alarms or the regular alarms between the two patients versus the three patient scenarios?

Q3. Do you have any final feedback that wasn't captured in your answers?

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Appendix D. Diagrams

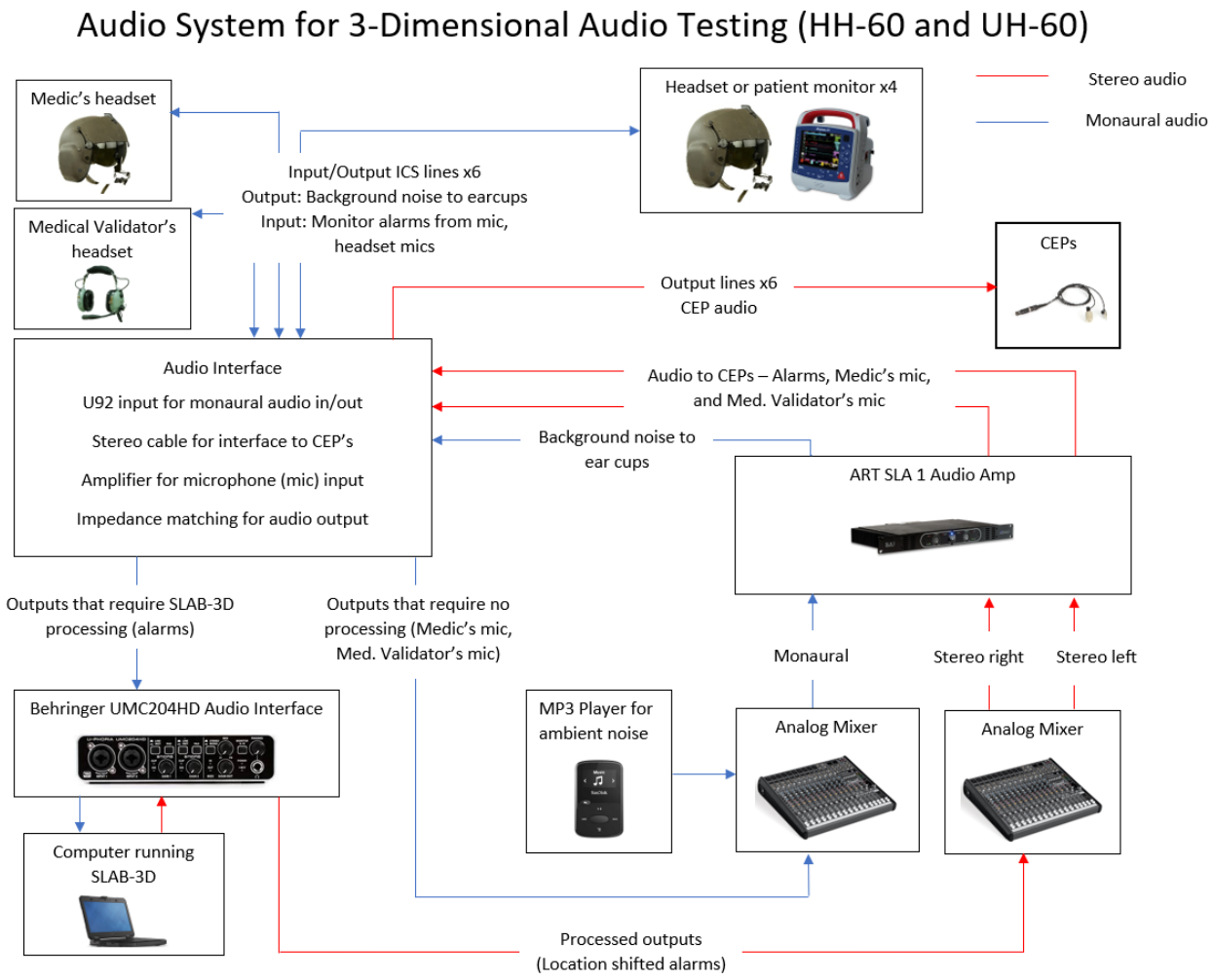

Figure D1. Audio setup used in study.

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Appendix E. Questionnaire Responses

Table E1. Quantified Questionnaire Responses: Benefits

Sub-Category (Chart #)	Second Sub-Category (Chart #)	Third Sub-Category (Chart #)	Total # of Responses	
3D Audio (B.1)	*Improves patient care (B.1.1)	Indicates which monitor to assess (B.1.1.1)	*11	5
		Positive impact on patient care (B.1.1.2)		1
		Indicates the patient alarming (B.1.1.3)		4
		Less focus needed on devices (B.1.1.4)		1
	*Improves overall alarm responsiveness (B.1.2)	Quicker response to alarms (B.1.2.1)	*9	2
		Identifying the device is easier/quicker (B.1.2.2)		3
		Beneficial when not looking at monitors (B.1.2.3)		4
	More helpful than standard audio (B.1.3)	Not applicable (NA)	3	
	Beneficial during light workload (B.1.4)	NA	3	
	Beneficial during heavy workload (B.1.5)	NA	3	
Standard Audio (B.2)	*Improves patient care (B.2.1)	Hearing patient alarms (B.2.1.1)	*3	1
		Alerts to a change in patient status (B.2.1.2)		2
	*Improves overall alarm responsiveness (B.2.2)	Helps grab attention/notify provider of alarm (B.2.2.1)	*9	7
		Beneficial when not looking at monitors (B.2.2.2)		2
	Beneficial during light workload (B.2.3)	NA	1	
	More helpful than 3D audio (B.2.4)	NA	2	

**Note.* Starred values belong to the second sub-category, which breaks down into the third sub-category values on the right side of the same column.

Table E2. Quantified Questionnaire Responses: Drawbacks

Sub-Category (Chart #)	Second Sub-Category (Chart #)	Third Sub-Category (Chart #)	Total # of Responses	
3D Audio (D.1)	*Difficulties with certain use cases (D.1.1)	Difficulty with overall use (D.1.1.1)	*5	1
		Difficult to differentiate between patient 2 and 3 (D.1.1.2)		2
		Not as helpful/difficult to use during heavy workload (D.1.1.3)		2
	*Monitor location (D.1.2)	During testing monitors were close together, easy to scan all (D.1.2.1)	*4	3
		Possible confusion if devices were moved around (D.1.2.2)		1
	*Other (D.1.3)	Spatial audio does not follow body orientation (D.1.3.1)	*4	1
		No remote silence (D.1.3.2)		1
		Time wasted correlating sound with direction (D.1.3.3)		1
		Contribute to task saturation/alarm fatigue (D.1.3.4)		1
Standard Audio (D.2)	Contribute to task saturation/alarm fatigue (D.2.1)	NA	3	
	Does not indicate which device/patient is alarming (D.2.2)	NA	7	
	Can lead to missed alarms (D.2.3)	NA	2	
	User looking at monitors excessively (D.2.4)	NA	2	
No major difference in 3D audio and standard audio (D.3)	NA	NA	2	

Note. Starred values belong to the second sub-category, which breaks down into the third sub-category values on the right side of the same column.

Table E3. Quantified Questionnaire Responses: Improvements

Sub-Category (Chart #)	**Second Sub-Category (Chart #)**	**Total # of Responses**
3D Audio (I.1)	Altering pitch/tone for location (I.1.1)	4
	Monitor location (I.1.2)	1
	3D audio to alert different medical device (I.1.3)	1
Standard Audio (I.2)	Remote alarm silence (I.2.1)	1
	Audio notification of alarm termination (I.2.2)	1

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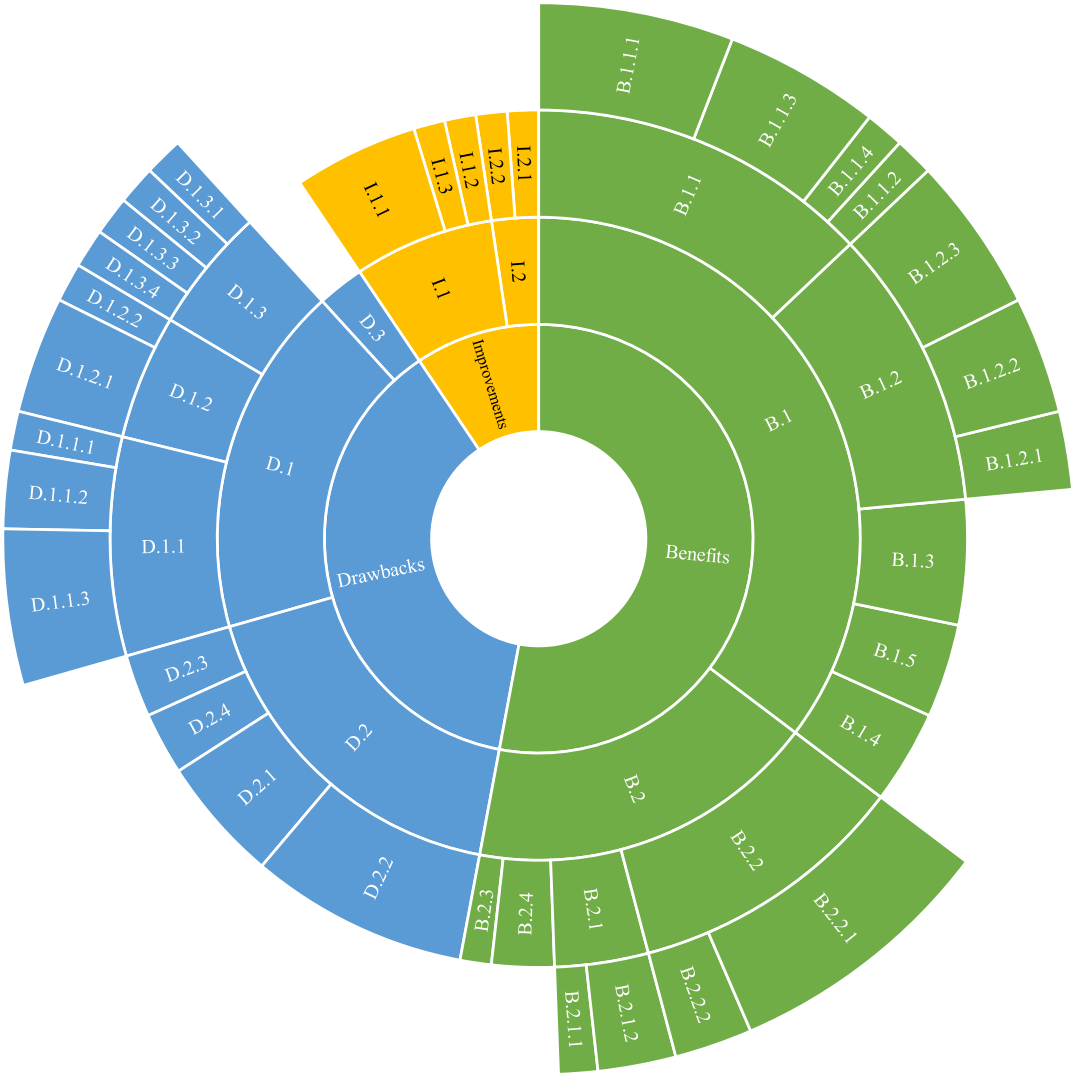

Figure E1. Summary of responses to open-ended survey questions.
**Note*. See Tables E1-E3 above for details in diagram.

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