USAARL-TECH-FR--2026-33

UNITED STATES ARMY AEROMEDICAL RESEARCH LABORATORY

Whole-Body Vibration Effects on En Route Care Provider Performance – Survey of U.S. Army En Route Care Medical Providers and Potential Mitigation and Training Strategies

Adrienne Madison, Braeden Long, Haley A. Garnett,
Kimberly B. Vasquez, Khalid W. Barazanji, Sandra M. Traxler,
Brandon A. Brown, & Valeta Carol Chancey

Notice

Qualified Requesters

Qualified requesters may obtain copies from the Defense Technical Information Center (DTIC), Fort Belvoir, Virginia 22060. Orders will be expedited if placed through the librarian or other person designated to request documents from DTIC.

Change of Address

Organizations receiving reports from the U.S. Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about laboratory reports.

Disposition

Destroy this document when it is no longer needed. Do not return it to the originator.

Disclaimer

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

Human Subjects Use Statement

The U.S. Army Aeromedical Research Laboratory Exempt Determination Official (EDO) reviewed the protocol and objectives prior to execution. The USAARL EDO determined that this activity is exempt human subjects research since “the information obtained is recorded by the investigator in such a manner that the identity of the human subjects cannot readily be ascertained, directly or through identifiers linked to the subjects, and the investigator will not attempt to re-identify the subjects.” [32 CFR 219.104(d)(2i)]

USAARL Study Determination and Number

This study, USAARL 2025-014, was approved by the U.S. Army Aeromedical Research Laboratory (USAARL) Exempt Determination Officer (EDO) in accordance with USAARL Policy on 08 September 2025.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
17-08-2026	Final Report	01/15/2025 - 4/13/2026

4. TITLE AND SUBTITLE

Whole-Body Vibration Effects on En Route Care Provider Performance – Survey of U.S. Army En Route Care Medical Providers and Potential Mitigation and Training Strategies

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

0602787A

6. AUTHOR(S)

Madison, A. M.[1], Long, B.[1,2], Garnett, H. A.[1,3], Vasquez, K. B.[1], Barazanji, K. W.[1,2], Traxler, S. M.[1,2], Brown, B. A.[1,2], & Chancey, V. C.[1]

5d. PROJECT NUMBER

MM4

5e. TASK NUMBER

CC04

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Aeromedical Research Laboratory
P.O. Box 620577
Fort Rucker, AL 36362

8. PERFORMING ORGANIZATION REPORT NUMBER

USAARL-TECH-FR--2026-33

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army Medical Research and Development Command
504 Scott Street
Fort Detrick, MD 21702-5012

10. SPONSOR/MONITOR'S ACRONYM(S)

USAMRDC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

DISTRIBUTION STATEMENT A. Approved for public release: distribution is unlimited.

13. SUPPLEMENTARY NOTES

[1]U.S. Army Aeromedical Research Laboratory, [2]Chenega Services & Federal Solutions, LLC, [3]Oak Ridge Institute of Science and Education

14. ABSTRACT

Daily operations for military en route care medical providers during casualty evacuation (CASEVAC) and medical evacuation (MEDEVAC) missions include performing lifesaving medical care interventions in tight spaces and awkward positions during dynamic vehicle motion (e.g., vibration, and jolt). This report leveraged an anonymous, comprehensive survey assessment approach to examine the impacts of dynamic vehicle motion on U.S. Army en route care medical providers during air and ground CASEVAC and MEDEVAC missions. The survey consisted of 76 quantitative and qualitative-based questions, of which 29 questions were analyzed to validate earlier findings on the effects of WBV on performance and potential WBV mitigation strategies. Standardized survey questions included a task analysis (2024 U.S. Army Aeromedical Evacuation SMOG task list) to assess susceptibility to WBV, the potential detriment to the patient if delayed, and the difficulty in performing within a WBV environment. Forty-seven experienced U.S. Army (current or prior) en route care medical providers completed the survey. Airway and respiratory management tasks and shock and circulation tasks are most challenging to perform and most susceptible to WBV and include those with the greatest detriment to the patient if delayed.

15. SUBJECT TERMS

MEDEVAC, CASEVAC, whole-body vibration, WBV, WBV mitigation strategies

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Amanda Hayes, MS
					19b. TELEPHONE NUMBER *(Include area code)*
UNCLAS	UNCLAS	UNCLAS	SAR	38	334-255-6067

REPORT DOCUMENTATION PAGE (SF298)
(Continuation Sheet)

14. Abstract (continued)

The most common mitigation strategies used to combat WBV were stabilization techniques, creating pre-made task kits, completing tasks before vehicle/aircraft movement (if possible), and maintaining effective communication with the crew. The survey validated and provided additional mitigation and training strategies to previous USAARL foundational work that explored challenges related to completing en route care tasks in dynamic vehicle motion settings. Survey respondents stated that current training can be improved and optimized to include (1) environmental training exposure (e.g., dynamic vehicle motion); (2) access to live tissue and human or human surrogate (e.g., manikin or cadaver) during training; and (3) stress and composure management techniques. Study outcomes should help inform future medical care practices, trainings, policies, as well as future designs for equipment (i.e., medical, helmets, body armor, etc.) and military vehicles.

Executive Summary

Daily operations for military en route care medical providers during casualty evacuation (CASEVAC) and medical evacuation (MEDEVAC) missions include performing lifesaving medical care interventions in tight spaces and awkward positions during dynamic vehicle motion (e.g., vibration, and jolt). These environments impose unique physical and operational challenges that can potentially hinder task performance and/or increase the risk of musculoskeletal injuries. Interview outcomes from an earlier subject matter expert (SME) panel has shown that exposure to whole-body vibration (WBV) or personal protective equipment (e.g., helmets, body armor, etc.) can affect en route care medical provider performance and musculoskeletal health (French Krahn et al., 2025).

This report leveraged an anonymous, comprehensive survey assessment approach to examine the impacts of dynamic vehicle motion on U.S. Army en route care medical providers during air and ground CASEVAC and MEDEVAC missions. The survey consisted of seventy-six (76) quantitative and qualitative-based questions. Twenty-nine (29) questions, relevant to understanding the effects of WBV on en route care provider performance and potential WBV mitigation strategies, were analyzed to validate findings from the SME interview study reported by French Krahn et al. (2025). Standardized survey questions included an analysis of tasks extracted from the U.S. Army Aeromedical Evacuation standard medical operating guidelines (SMOG) (Department of Aviation Medicine, 2024). The analysis evaluated the susceptibility of the task to WBV, the potential detriment to the patient if that task was delayed, and the difficulty in performing a task within a WBV environment. In addition, the task analysis assessed recommended mitigation strategies, identified by the SME panel, per task. Forty-seven U.S. Army Service Members, with current or previous en route care medical provider experience during CASEVAC and MEDEVAC missions, responded and completed the survey. Their responses were used to determine whether previously identified SMOG task challenges and mitigation suggestions align with the larger en route care medical provider population experience.

Both the standardized SME interview and survey outcomes show that en route care airway and respiratory tasks and shock and circulation management tasks requiring high levels of fine motor control are most challenging to perform and most susceptible to vehicle motion, vibration, and jolt. Similar to the SME interview outcomes, the survey medical tasks most susceptible to WBV were not necessarily those that had the greatest detriment to the patient if delayed, and vice versa. Tasks that had the greatest detriment to the patient if delayed included airway and respiratory management tasks and shock and circulation management tasks. The most common mitigation strategies used to combat WBV were stabilization techniques (maintaining a low center of gravity or bracing against the aircraft or vehicle for balance), creating pre-made task kits, completing tasks before vehicle/aircraft movement (if possible), and maintaining effective communication with the crew. The survey validated and provided additional mitigation and training strategies to previous USAARL foundational work that explored challenges related to completing en route care tasks in dynamic vehicle motion settings. Survey respondents stated that current training can be improved and optimized to include (1) environmental training exposure (e.g., dynamic vehicle motion); (2) access to live tissue and human or human surrogate (e.g., manikin or cadaver) during training; and (3) stress and composure management techniques. Study outcomes should help inform future medical care practices, trainings, policies, as well as future designs for equipment (i.e., medical, helmets, body armor, etc.) and military vehicles.

This page is intentionally blank.

Acknowledgements

This research was supported in part by an appointment to the Research Participation Program at the U.S. Army Aeromedical Research Laboratory administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and the U.S. Army Medical Research and Development Command. The authors would like to thank Lieutenant Colonel Sarah Snyder for her expertise and support throughout the completion of this work.

This page is intentionally blank.

Table of Contents

List of Figures

Table of Contents (continued)

List of Figures (continued)

List of Tables

Introduction

Current military environments are unique and complex, resulting in a majority of Service Members (SMs) operating under mentally and physically demanding conditions. Daily operations for military medical en route care providers (ERCPs) during casualty evacuation (CASEVAC) and medical evacuation (MEDEVAC) missions include performing lifesaving medical care interventions in tight spaces and awkward positions such as kneeling, squatting, or sitting in rear- or side-facing conditions. These interventions and their associated tasks are often conducted during exposure to dynamic air or ground vehicle motion (e.g., whole-body vibration [WBV]) for extended periods of time—all while wearing personal protective equipment (PPE) such as helmets and body armor. Vehicle motion exposures can also be compounded by random jolts or impacts produced by driving over rough terrain, flying through rough air, or making evasive maneuvers. As a result, military medical ERCPs often experience challenges in performing medical tasks in their work environment (French Krahn et al., 2025). Additionally, prolonged and/or repetitive exposures to these dynamic environments could contribute to an increased risk of musculoskeletal injuries and disorders (MSKIs). There is a need to document how the unique and complex dynamic motion exposures in military CASEVAC and MEDEVAC mission environments can affect medical ERCP performance, response, and health.

Previous U.S. Army Aeromedical Research Laboratory (USAARL) research has examined the CASEVAC and MEDEVAC ergonomic environments and their contributions to performance decrement and MSKI risks in medical ERCPs. The confined spaces where care providers normally conduct their tasks during air and ground transport add considerable constraints on head, neck, and back posture, movements, and/or range of motion. Barazanji et al. (2015) found that the space available in HH-60M and UH-60 helicopters with medical interiors is inadequate to perform certain medical tasks across multiple patient configurations. A minimum vertical litter spacing of 26 inches (in.), with a patient in a lower litter position at about 3 inches above floor, is needed to adequately conduct most required medical tasks (Barazanji et al., 2015). A follow up study was conducted at USAARL to evaluate whether space available inside a ground ambulance is adequate for a ground medic to perform medical tasks (Conti et al., 2020). Vertical space limitations were found to be a major factor in completing medical tasks at the standard litter height of 19.5 in. for the top litter and 18.5 in. for the bottom litter. Up to 95.7% of participants failed standard medical operating guidelines (SMOG) medical tasks in the confined space and many participants commented that they hit their helmet on the upper litter or ceiling and had to assume awkward postures to complete many of the tasks (Conti et al., 2020).

Awkward postures in military vehicle cabin and compartment ergonomics in combination with PPE wear have been identified as major contributors to lower back pain in medical ERCPs and interference with completion of mission tasks (Conti et al., 2019; Conti et al., 2021; Lloyd et al., 2023). A previous survey conducted at USAARL gathered responses from 60 U.S. Army medical providers in air-based en route care; the highest number of reported injuries was to the lower back (Conti et al., 2019; Conti et al., 2021). Eighty-seven percent of respondents reported lower back injuries caused by awkward positions/bending, lifting patients, weight of flight gear/body armor, and aircraft conditions (Conti et al., 2019; Conti et al., 2021). Additionally, 62% of respondents reported that PPE negatively impacted their military missions, especially the unequal distribution of body armor weight and weight of the helmet with accessories (Conti et al., 2019; Conti et al., 2021). Another USAARL study, which conducted a laboratory-based kinematic characterization of medic postures, included 17 military medical providers (Lloyd et al., 2023). The study reported overall subject discomfort for bending (83%), squatting (65%), and kneeling (53%). The study showed that 77% of subjects reported lower back discomfort, and 56% reported knee discomfort on a simulated MEDEVAC platform while loading and unloading casualties (Lloyd et al., 2023). However, these studies did not directly investigate or incorporate the contributions and effects of WBV in ground and air environments or its interference with completion of specific medical tasks during dynamic vehicle motion.

CASEVAC and MEDEVAC medical intervention tasks involve the use of medical equipment, tools, or techniques that are challenging to operate or administer on the patient during exposure to dynamic air or ground vehicle motion. Future battlefield scenarios, such as large-scale combat operations (LSCO) are predicted to encompass extended mission duration lengths over varied terrains as well as an increased number of casualties that will have to be evacuated over longer distances. As a result, there is a need to optimize the capability to perform advanced critical care tasks while en route. Early investigations into WBV effects on task performance have primarily focused on vehicle operators and those in mobile command and control platforms (Lewis et al., 1978; Schipani et al., 1998; Hill et al., 2005; Nakashima et al., 2006). Performance assessments were conducted on tasks such as manual tracking, visual acuity, visual display use, cognitive performance, workload, and team performance. A comprehensive review of study outcomes found that WBV has the largest effect on tasks requiring extensive levels of visual perception and fine motor control (Conway et al., 2007). The review also identified differences in how WBV affects speed- and precision-centric task performance. However, the tasks evaluated do not fully encompass the breadth, specificity, and precision of tasks medical ERCPs must perform as part of patient assessment and treatment during WBV exposure.

Recent research approaches at USAARL have aimed at investigating the effects of WBV on military medical personnel while performing critical care tasks en route from point of injury (POI) to the hospital or higher levels of care. French Krahn et al. (2025) conducted a semi-structured interview with medical ERCP subject matter experts (SMEs) using a 10-question survey to collect qualitative data to identify: (1) specific tasks that are highly affected by WBV and (2) learned mitigation strategies that help to mitigate the effects of WBV and jolt. The survey was combined with an analysis of tasks extracted from the U.S. Army Aeromedical Evacuation SMOG (Department of Aviation Medicine, 2024). The task analysis collected ratings on the susceptibility of the task to WBV and the potential detriment to the patient if that task was delayed. In addition, the task analysis collected recommended mitigation strategies per task.

Outcomes from the French Krahn et al. (2025) study showed that dynamic vehicle motion in the medical ERCP environment may affect the ability of the provider to deliver high quality medical care during patient transport. Consistent with the general findings in Conway et al. (2007), French Krahn et al. (2025) found that medical ERCP tasks requiring high levels of visual perception (i.e., vital sign measurement and medical equipment monitoring) and fine motor control (i.e., intravenous [IV] access and airway management techniques) were greatly affected by dynamic vehicle motion. However, SMEs provided insight on a variety of techniques they have used to help mitigate difficulties encountered while performing medical ERCP tasks identified in the U.S. Army Aeromedical Evacuation SMOG during dynamic vehicle motion. These include, but are not limited to, leveraging the use of stabilization methods (e.g., using bracing points and available restraints) or dampening mechanisms (e.g., blankets under patient litter) to reduce the effects of vehicle vibration as well as identifying strategies to optimize or improve the ability to conduct existing techniques under WBV conditions (e.g., stretching skin while inserting an IV) (French Krahn et al., 2025). If those methods were unsuccessful, some SMEs reported that they often chose to complete certain tasks that required precision before medical platform movement or asking the vehicle operator to keep the vehicle steady with less motion (French Krahn et al., 2025).

The work by French Krahn et al. (2025) provided valuable, foundational insight into the demands and challenges medical ERCPs experience conducting CASEVAC and MEDEVAC medical tasks during dynamic vehicle motion. While each SME was asked the same questions, the semi-structured interview format resulted in a wide variability of subjective responses based on individual experience and training. Standardized responses and quantitative data are needed to validate initial SME findings as well as provide streamlined and definitive responses to help identify potential patterns and trends representative of the larger medical ERCP population experience. Additionally, the contributions of PPE, awkward postures, and potential musculoskeletal injury effects were not investigated in the SME interview study. Understanding these collective influences are critical for maintaining and optimizing short- and long-term medical ERCP health and performance as well as improving delivery of medical interventions during transport.

To address remaining research gaps, USAARL conducted a comprehensive survey assessment to examine the impacts of dynamic vehicle motion (e.g., WBV and jolt) on U.S. Army medical ERCPs during air and ground CASEVAC and/or MEDEVAC missions. The survey assessment focused on the providers' performance and health during CASEVAC and MEDEVAC missions, gathering qualitative and quantitative data on medical ERCP tasks, challenges faced in the operational environment, and health risks associated with working in these mission settings. Survey questions were constructed to address six research aims. This report will address the first aim, to validate findings from French Krahn et al. (2025) by using standardized survey questions based on the findings of the SME interview study to determine whether previously identified SMOG task challenges and mitigation suggestions align with the larger medical ERCP population experience. All 37 medical tasks from the SME interview study were included in the current analysis. Seven additional medical tasks from previous USAARL research were included in the survey (Barazanji et al., 2015; Conti et al., 2019). Additionally, this report will include the survey questions aimed at gathering additional insights and feedback directly from military medical ERCPs regarding challenges, training, and mitigation techniques during dynamic vehicle motion to identify unresolved research gaps and inform future investigations to support optimizing performance and improving patient outcomes in CASEVAC and MEDEVAC mission environments. Data outcomes will be used to support the development of new and/or expand existing recommendations, guidance, and thresholds for the following: medical ERCP training, policies, and procedures; WBV exposure recommendations to minimize risks of adverse health effects; as well as next generation PPE, seating, vehicle platform, and medical ERCP equipment for materiel developers.

Methods

An anonymous comprehensive survey assessment was conducted under an exempt human subjects research protocol approved by the USAARL Exempt Determination Official (EDO). U.S. Army Service Members (i.e., Active Duty, Reserve, or National Guard) between 18 and 60 years old with current or previous medical ERCP experience during CASEVAC and MEDEVAC missions were recruited as prospective respondents via flyers, word of mouth, email listservs, and social media posts. This population included all U.S. Army flight and ground medics, certified critical care flight medics, flight surgeons, physicians, flight nurses, etc. By completing the survey, prospective respondents were self-reporting that they met the inclusion criteria listed on the first page of the survey while also agreeing to the use of their data in survey analyses and reporting. Participation in the survey assessment was completely voluntary; respondents could discontinue participation at any time by closing the survey window. Using the statistical analysis of Bartlett et al. (2001) and Conti et al. (2019), a sample size of 43 survey respondents was needed to meet a confidence level of 95 percent (alpha = 0.05).

The survey consisted of 76 quantitative and qualitative-based questions. The 29 questions relevant to understanding the effects of WBV on en route care provider performance and potential WBV mitigation strategies are included in Appendix B. The SelectSurvey.NET (v4 .154.010; ClassApps LLC, Apollo Beach, FL) software was used to electronically administer the survey and collect responses. Selecting "Yes" for Questions 1 and 2 confirmed respondent eligibility, consent to use data, and medical ERCP experience in CASEVAC and MEDEVAC missions. If a respondent selected "No" to Questions 1 or 2, they were not allowed to proceed with completion of the survey. Respondents were asked to answer questions related to their role as a medical ERCP in dynamic motion environments. Topics covered in the survey included: level of medical ERCP training and experience; overall health; factors that may negatively affect mission performance or require/result in awkward postures, as well as cause musculoskeletal discomfort, pain, and/or injury; PPE wear and duration in CASEVAC and MEDEVAC mission environments; amount of time spent in medical ERCP dynamic motion environments (air and ground); type and severity of musculoskeletal discomfort, pain, and/or injury; SMOG task completion difficulty in dynamic motion environments; and training and mitigation feedback.

The raw survey response data were output from SelectSurvey.NET as a single, large, iterative .csv file. The file also classified surveys as complete or incomplete. A survey response was considered complete if it met one of two conditions: (1) the respondent selected "No" to Questions 1 or 2 indicating they did not consent for their data to be used or had no medical ERCP experience during CASEVAC and MEDEVAC missions or (2) all required survey questions were answered. Custom MATLAB (The MathWorks, Natick, MA) scripts were developed to process, parse, and prepare the raw data for analyses. The first task was to remove all incomplete survey responses as well as completed responses that selected "No" to Questions 1 or 2. The code then converted data from questions requiring manual entries for year and month into a single standard unit. Descriptive headers were added to each column (question) and questions with multiple responses or free text entries were formatted and grouped for improved readability and processing during final analyses.

Furthermore, the MATLAB script parsed through the data and flagged responses to specific questions for visual review and confirmation prior to inclusion in final analyses. This step allowed verification that all completed surveys met inclusion criteria as well as review of responses for validity and identification of potential errors or outliers. For example, survey responses were reviewed for potential duplications (one respondent completing survey multiple times with identical responses). The code flagged all other questions with a manual numerical entry of zero (e.g., years of experience, number of deployments, etc.). Each respondent's age was also reviewed to ensure they were between the ages of 18-60; all entries with numerical values less than 18 and greater than 60 were flagged for additional review. If a respondent entered 0 years and 0 months of experience as a medical ERCP, research personnel would review responses to other survey questions to determine whether the entry was an error or if the respondent failed to meet the inclusion criteria.

For this report, demographic data (e.g., years in service, number of deployments, and civilian experience) were analyzed. Fifteen survey questions related to SMOG tasks were analyzed to determine which tasks may be susceptible to WBV and jolt, which tasks were detrimental to the patient if not performed (i.e., critical to complete for patient care), and task difficulty (i.e., how challenging to complete while en route). Tasks were ranked by the participants' rating. Additionally, five survey questions (three structured questions/responses and two questions/free text responses) were analyzed to identify mitigation strategies and training to manage WBV and jolt while en route. Common free text responses from the survey were aggregated using keywords and repeated phrases, then the results were evaluated to identify trends and specific lessons learned from the provider community. These results were also compared to those from the SME interview study (French Krahn et al., 2025).

Results

A total of 139 survey responses were received; of those, 52 surveys were considered complete. Four completed surveys were removed because they either did not consent to the use of their data (Question 1) or had no medical ERCP experience during CASEVAC or MEDEVAC missions (Question 2). Another completed survey was removed because the selected age was greater than 60. As a result, a total of 47 complete surveys were analyzed, exceeding the target goal of 43.

The remaining 47 respondents included 38 males and 9 females with 4 to 35 years of combined military experience. All respondents had experience providing critical care in the military, and 35 also had experience as civilian emergency medical technicians (EMTs), nurses, physicians, or civil search and rescue. Of the 47 respondents, 19 had air and ground evacuation experience, 26 had air experience only, and 2 had ground experience only. Years served in the military ranged from 4.3 to 35.3 years with an average of 16.0 ± 6.6 years served (Figure 1). The 47 respondents reported a total of 80 deployments ranging from zero deployments to 4 deployments per participant (Figure 2).

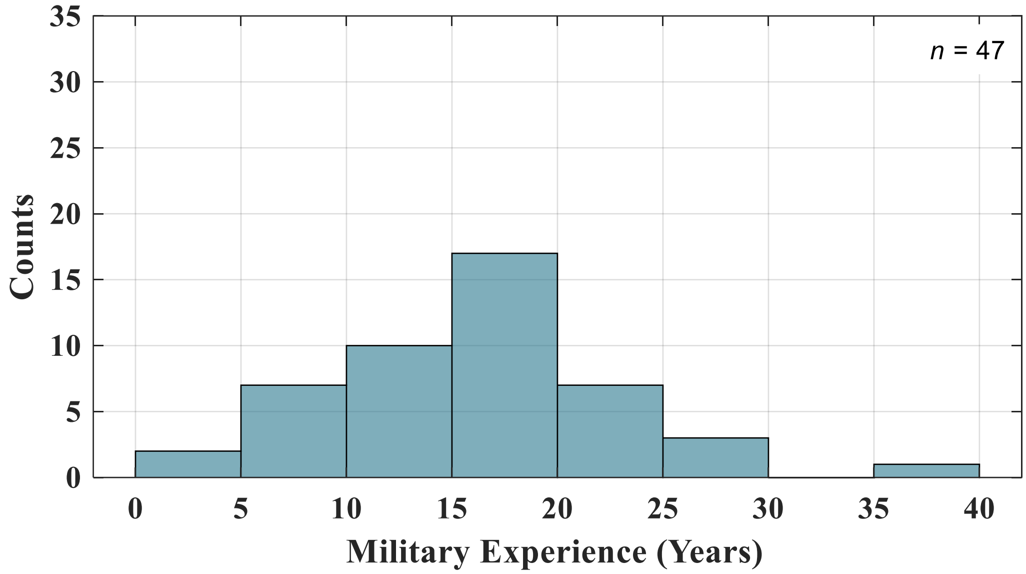


Figure 1. Time served in the military is listed for each survey respondent. The average time served was 16.0 ± 6.6 years with a range of 4.3 to 35.3 years.

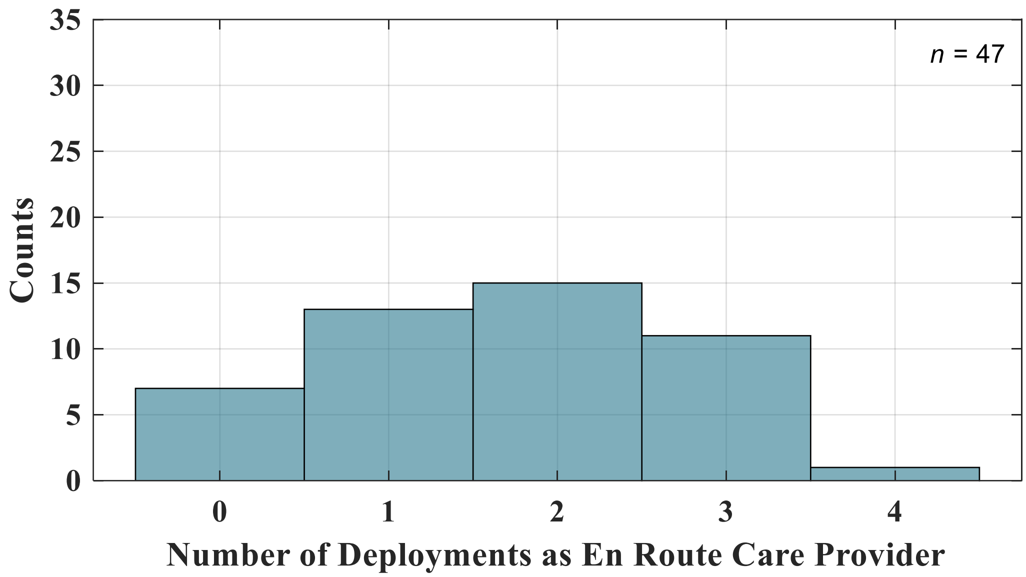


Figure 2. Number of deployments is listed for each survey respondent. The average number of deployments was 1.7 ± 1.1 with a range of 0 to 4 deployments across the 47 respondents.

SMOG Task Analysis

The top ten tasks with the highest susceptibility to WBV in the SMOG task table included: cricothyroidotomy (CRIC), endotracheal intubation, rapid sequence intubation (RSI), vascular access via external jugular vein cannulation, needle CRIC, vascular access via central catheter, vascular access (intravenous), 12-lead electrocardiogram (EKG), simple finger and tube thoracostomy, and nasotracheal intubation (Figure 3 blue bars). Figure 3 (orange bars) also shows the percentage of respondents that determined if the task is delayed due to vibration, then the outcome will be detrimental to patients. Note that the figure is ranked by tasks to be affected by WBV and were not necessarily in the same order of tasks that are considered detrimental to patients if delayed.

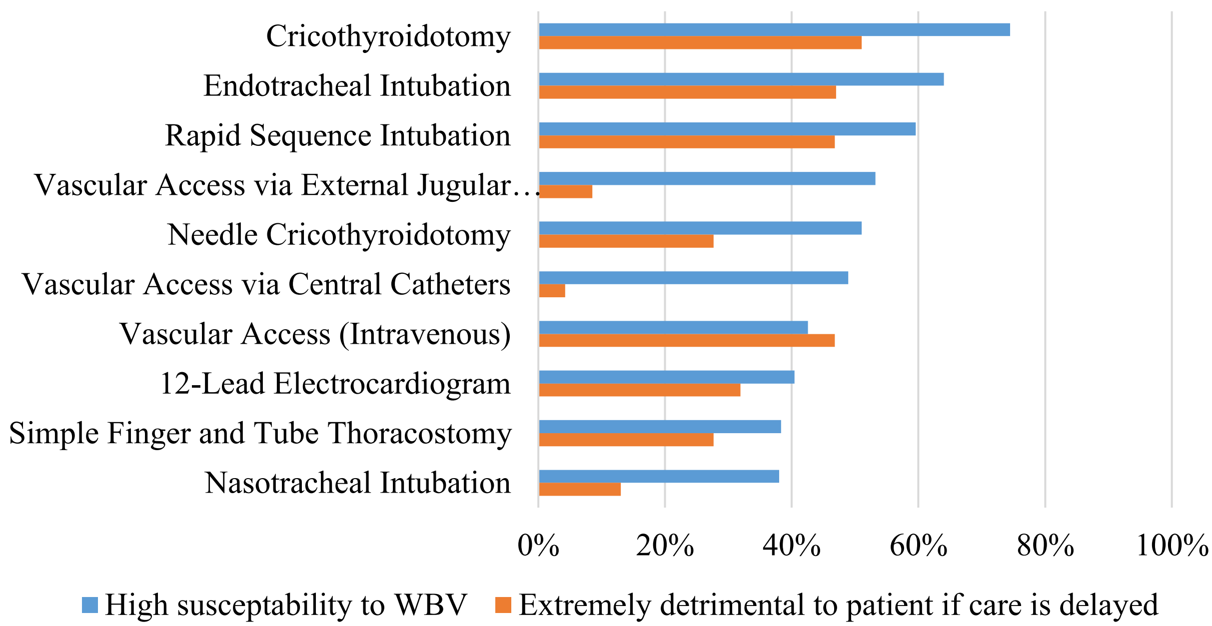


Figure 3. Bar chart shows the top 10 SMOG tasks based on the proportion of respondents rating the task as highly susceptible to WBV and the associated proportion of responses rated as extremely detrimental to the patient if the task is delayed.

The full SMOG task table ratings were summarized (Figures 4-6). Tasks with the highest response rate and highest susceptibility to WBV or jolt included airway tasks (CRIC, endotracheal intubation, RSI, needle CRIC) or gaining intravenous access (vascular access via external jugular vein cannulation and vascular access [intravenous]) (Figure 4). Tasks with the highest response rate and extremely detrimental to patient care included tourniquet application, bag valve mask (BVM) ventilation, cardiac defibrillation, blood component/fresh whole blood use, and hypothermia prevention and management (Figure 5). Overall, tasks received low ratings (1, 2, or 3) on the level of difficulty of providing en route care due to vehicle motion and vibration. Tasks that were rated at higher ratings (4 and 5) on the level of difficulty included the airway and respiratory management tasks (RSI, CRIC, endotracheal intubation, nasotracheal intubation) and cardiac monitoring (12-lead EKG) (Figure 6).

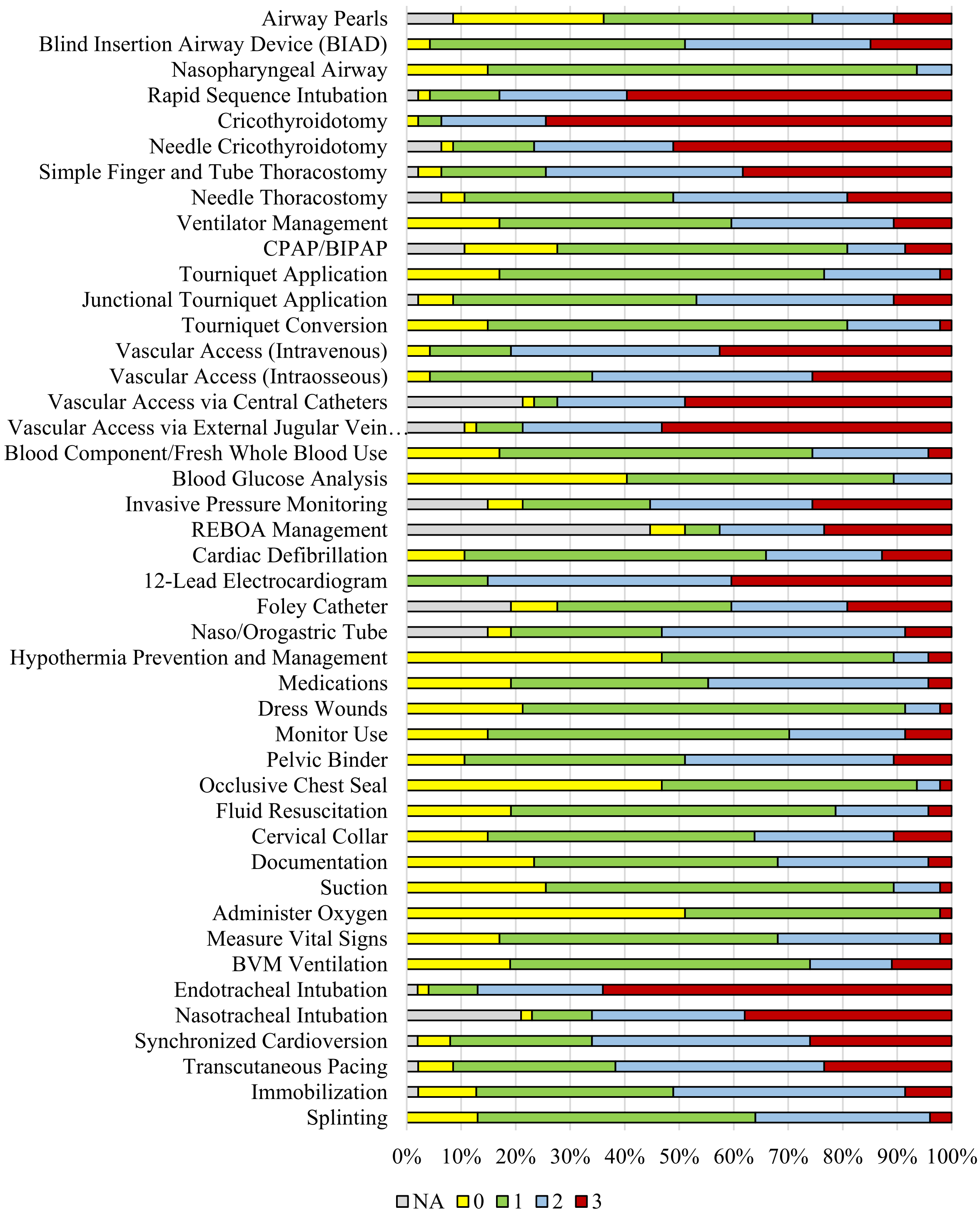


Figure 4. Bar chart showing rating responses of 0 through 3 (i.e., 0 – not susceptible, 1 – low susceptibility, 2 – medium susceptibility, and 3 – high susceptibility) for how susceptible each SMOG task is to WBV.

Note. REBOA = resuscitative endovascular balloon occlusion of the aorta; CPAP = continuous positive airway pressure; BiPAP = bilevel positive airway pressure

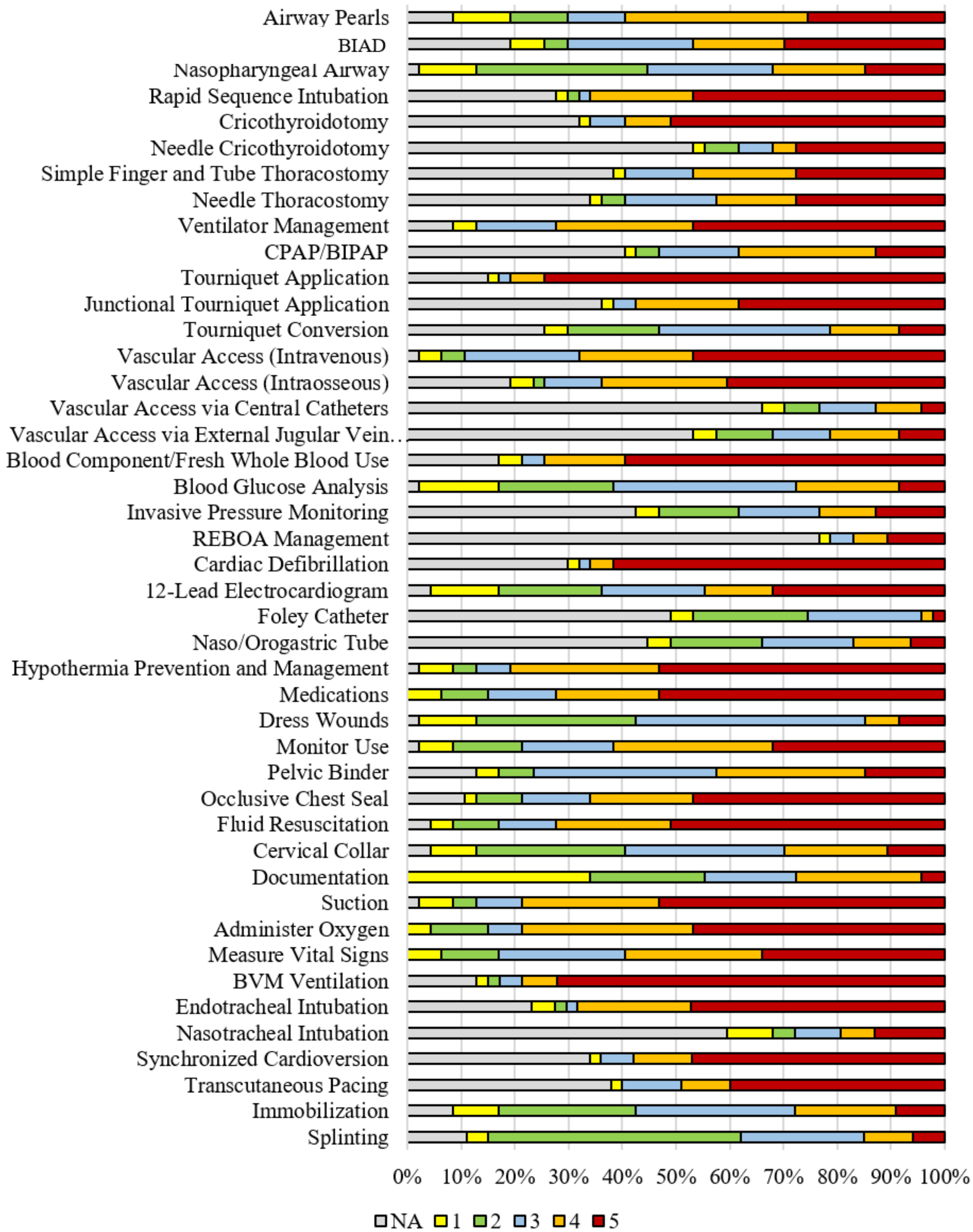


Figure 5. Bar chart showing rating responses of 1 through 5 (i.e., 1 – not detrimental, 2 – slightly detrimental, 3 – moderately detrimental, 4 – very detrimental, and 5 – extremely detrimental) for detriment to patient if care is delayed for each SMOG task.

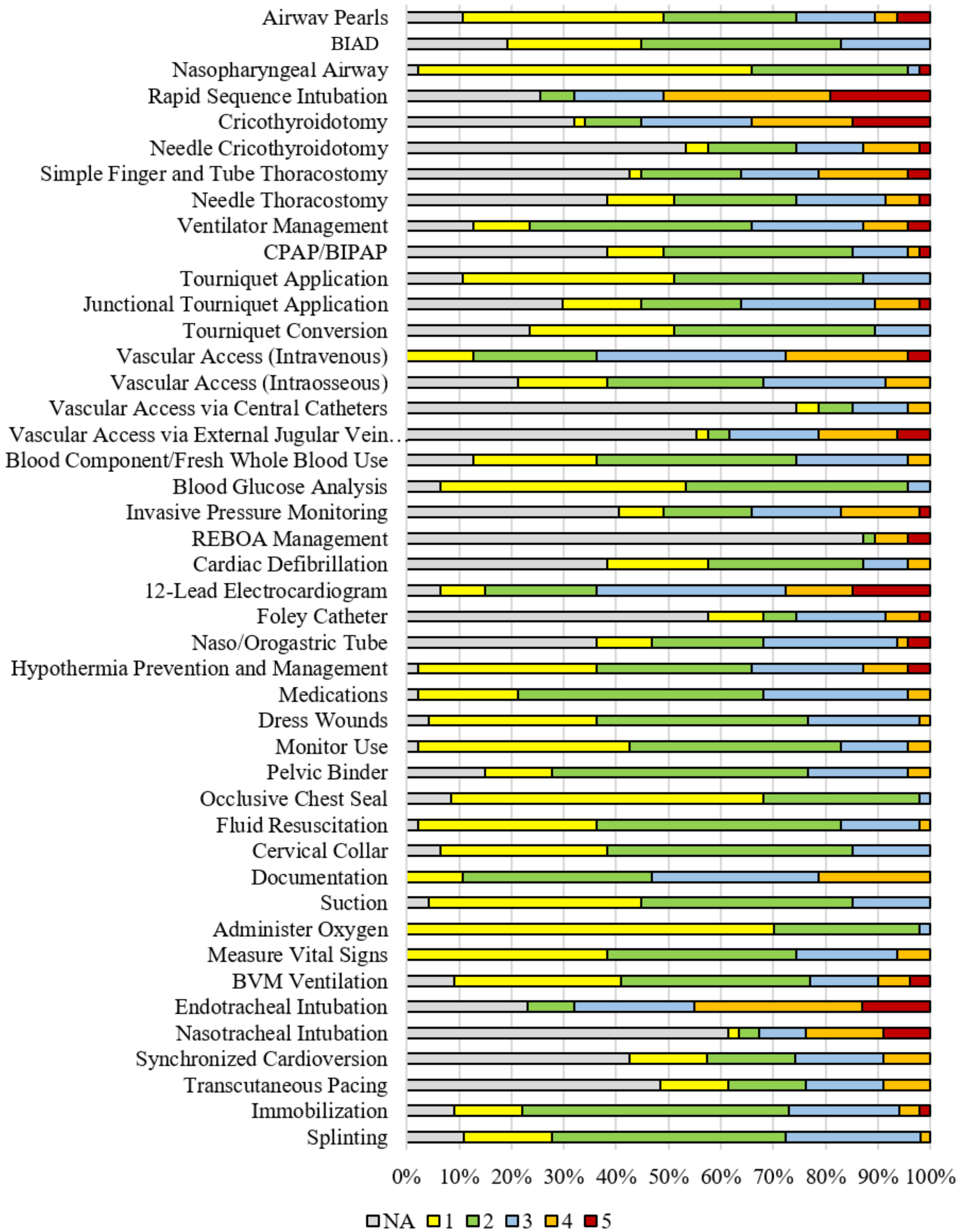


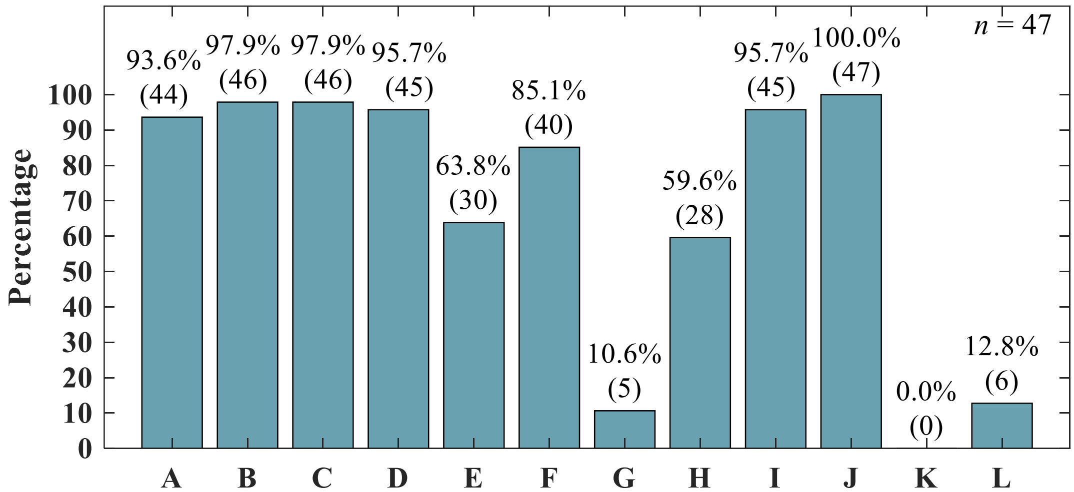
Figure 6. Bar chart showing rating responses of 1 through 5 (i.e., 1 – not challenging, 2 – slightly challenging, 3 – moderately challenging, 4 – very challenging, and 5 – extremely challenging) for the difficulty of performing each SMOG task.

Mitigation Strategies and Training

Based on the previous SME panel interview, five survey questions were included to determine strategies, techniques, and training to mitigate the risks associated with WBV or jolt while performing critical care tasks. Three of the survey questions listed structured responses, but the respondent could choose more than one response. The last two questions of the survey allowed for free text. The free text responses were organized into like topics (Appendix C).

The survey data collected highlighted mitigation techniques to aid in achieving tasks that are susceptible to WBV. Among the mitigations listed (Figure 7), the most frequently selected response was to maintain a low center of gravity, reported by 100.0% of respondents. This was followed closely by completing tasks before aircraft or vehicle movement and creating pre-made task kits, both reported by 97.9% of respondents. Less frequently selected mitigations included using available restraints to prevent sudden movements (59.6%) and using ultrasound to improve IV access and fluid assessment (10.6%). Other suggested responses (12.8%) included: practice, high risk interventions before flight, assistance from the crew chief, mitigating vibration into the monitors, ultrasound, and straddling patients.

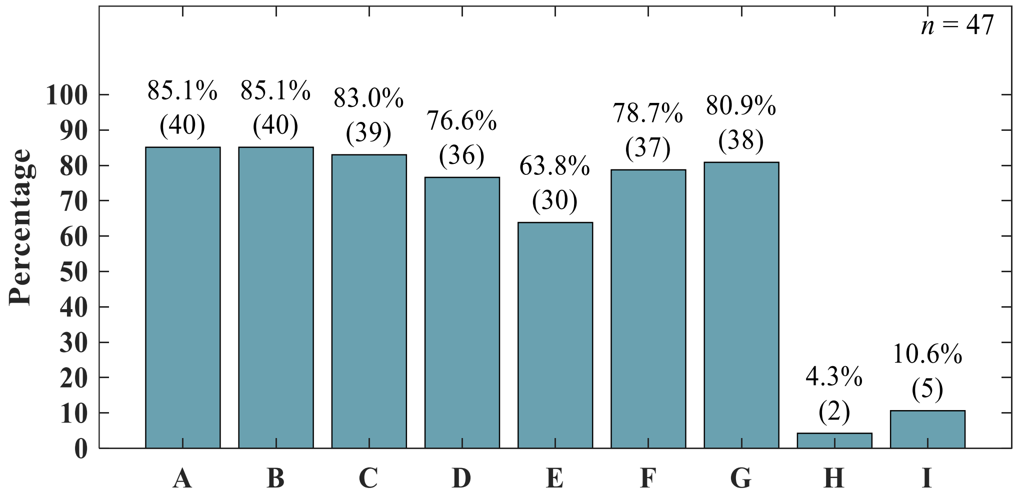
This space is intentionally blank.



Respondents were allowed to select multiple responses. The available responses were given as follows: (A) Pulling/pinching the skin taut at the IV access location for easier insertion, (B) Completing tasks before aircraft or vehicle movement (if possible), (C) Creating pre-made task kits (i.e., IV kits, blood transfusions), (D) Communicating effectively with the flight crew or driver to limit unexpected movements, (E) Propping patient extremities on blankets to lessen vibrations, (F) Finding anchor points on the patient's body to stabilize the movement needed (e.g., using the pinky finger as an anchor point to stabilize the hand during IV access), (G) Using ultrasound to improve landmark location during IV insertion and assessing body cavities for fluids, (H) Using available restraints to prevent sudden movements (e.g., ratchet straps, monkey tails, etc.), (I) Bracing against the aircraft or vehicle for balance (e.g., pushing helmet into aircraft ceiling or leaning a shoulder against the vehicle door), (J) Maintaining a low center of gravity (e.g., sitting on the aircraft or vehicle floor), (K) None of these, (L) Other.

Figure 7. The percentage of participants (n = 47) that selected a response for: "When conducting en route care in a high vibration environment, have you used any of the following strategies or techniques to mitigate the risks associated with WBV or jolt while performing critical care tasks?"

The survey data collected also highlighted which mitigation techniques would be easier to perform under WBV if lessons or training materials were provided on the listed tasks. Among the mitigation techniques listed (Figure 8), completing tasks before aircraft or vehicle movement and communicating with crew to limit unexpected movements were both reported by 85.1% of respondents. Additionally, propping patient extremities on blankets to lessen vibrations was chosen by 76.6% of respondents. A small percentage (4.3%) indicated that none of the listed mitigations were applicable. Other suggested responses (10.6%) included: practice, low visibility training, training assistant crew members and crew chiefs, and training in more realistic environment scenarios (i.e., on a moving aircraft with a person, etc.). One respondent documented that experience is the only way.

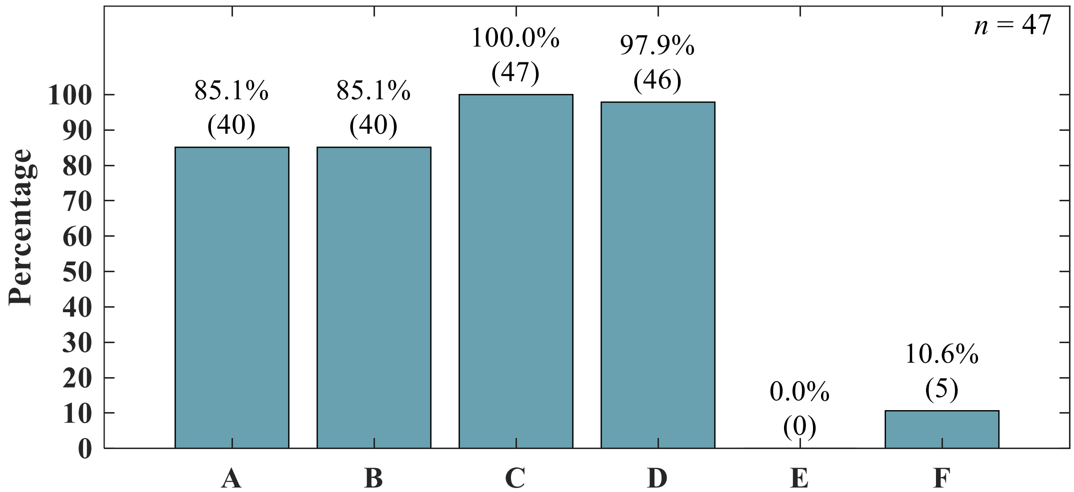


Respondents were allowed to select multiple responses. The available responses were given as follows: (A) Completing tasks before aircraft or vehicle movement (if possible), (B) Communicating effectively with the flight crew or driver to limit unexpected movements, (C) Finding anchor points on the patient's body to stabilize the movement needed (e.g., using the pinky finger as an anchor point to stabilize the hand during IV access), (D) Propping patient extremities on blankets to lessen vibrations, (E) Using available restraints to prevent sudden movements (e.g., ratchet straps, monkey tails, etc.), (F) Bracing against the aircraft or vehicle for balance (e.g., pushing helmet into aircraft ceiling or leaning a shoulder against the vehicle door), (G) Maintaining a low center of gravity (e.g., sitting on the aircraft or vehicle floor), (H) None of these, (I) Other.

Figure 8. The percentage of respondents (n = 47) that selected a response for: "Would lessons or training materials on the following make these tasks easier for care providers while the vehicle or aircraft is in motion?"

Data on the most frequently reported lessons and training that could improve abilities to perform en route care tasks during WBV were also collected. Among the lessons and training (Figure 9), realistic vibration/jolt simulations to improve readiness (100.0%) and training medical tasks in motion/vibration/jolt simulations (97.9%) were the highest reported responses. Furthermore, live tissue labs and challenging and repetitive field training were each reported by 85.1% of respondents. Other suggested responses (10.6%) included: working in the field taking care of patients, training crew chiefs basic life support, train as you fight, consistency in training more than once or twice a year, and training with various manikins (particularly pumps for tourniquet training) to gain confidence.

This space is intentionally blank.



Respondents were allowed to select multiple responses. The available responses were given as follows: (A) Live tissue labs, (B) Challenging and repetitive field training, (C) Realistic simulations (in a vibration/jolt environment) to improve readiness for challenges while providing care, (D) Training on medical tasks in a simulated environment with motion, jolts, vibration, (E) None of these, (F) Other.

Figure 9. The percentage of respondents (n = 47) that selected a response for: "Would any of the following lessons improve a care provider's ability to complete tasks in a high vibration/jolt environment if the lessons are included in training courses or material for mitigating the vibration effects?"

Respondents had the opportunity to list any additional strategies used to combat the challenges of providing en route care that were not taught in training. Several strategies respondents repeatedly reported include the following: training in platform where care will be delivered, training in low light conditions, and stabilizing patients prior to transport. Additionally, the survey collected respondent recommendations for improving training for en route care medical providers. The most common recommendations received were allowing all providers- not only physicians, physician assistants, and nurses- to rotate through civilian healthcare systems, providing training on stress management techniques and maintaining composure in high stress environments, and increasing access to cadavers and live tissue training. A full list of these strategies can be found in Appendix C.

Discussion

The present work aimed to validate the previous SME panel interview (French Krahn et al., 2025). Specifically, the objectives were to (1) identify critical care tasks that could be affected by WBV or jolt associated with en route care platforms (both rotary-wing and ground vehicle platforms) and (2) identify learned mitigation strategies to address the critical care tasks that could be affected by WBV or jolt. Qualitative data were collected using a survey to rate tasks identified on the SMOG list. The task analysis collected ratings on the susceptibility of the task to WBV, the potential detriment to the patient if that task was delayed, and difficulty performing those tasks under WBV. In addition, questions with structured responses and with free text responses were collected to recommend mitigation strategies, techniques, and training.

Airway and respiratory management findings indicate that advanced airway procedures such as CRIC and RSI are perceived as highly susceptible to WBV (Figure 4), aligning with prior work by demonstrating that precision for high acuity tasks declines in high WBV environments (French Krahn et al., 2025). Within shock and circulation management tasks, external jugular cannulation was identified as the most susceptible task. This is consistent with the SME interview responses which identified use of sharps as highly susceptible to WBV. Cardiac monitoring tasks (e.g., 12-lead EKG, cardiac defibrillation) were rated highly susceptible in both the current and previous work. Furthermore, the cardiac monitoring domain was consistently impacted across all ratings, suggesting both technical limitations of monitoring equipment and fine motor control required for these tasks. Interestingly, medical assessment tasks were rarely rated as susceptible yet still demonstrated high rates of performance across both air and ground platforms. This may suggest these tasks are less susceptible to the environmental stressors associated with en route care. However, medication administration, monitor use, and documentation regularly appeared as the top three tasks within its task domain, mirroring responses from the semi-structured SME interviews with medication administration and monitor use receiving high WBV susceptibility ratings and documentation having high likelihood of being affected by WBV.

The SMOG task analysis for perceived detriment to a patient if care is delayed due to WBV was rated from 1 (not detrimental) to 5 (extremely detrimental) (Figure 5). Overall, cardiac monitoring tasks, such as 12-lead EKG and cardiac defibrillation had the highest number of extremely detrimental ratings. This is corroborated by the SME panel interview results, which rated cardiac defibrillation as being extremely detrimental and 12-lead EKG has having medium to high likelihood of being detrimental to the patient if care is delayed. Conversely, stabilization (e.g., pelvic binder, immobilization) tasks showed the lowest overall perceived detriment if the task was delayed. Despite their importance in preventing secondary injury, these tasks may be less prioritized in a life-threatening scenario

The SMOG task analysis identified that task difficulty was rated from 1 (not challenging) to 3 (moderately challenging) for most of the tasks (Figure 6). However, 36 of the 44 tasks had at least a 4 (very challenging) or 5 (extremely challenging) rating. The more invasive airway tasks such as nasotracheal intubation, endotracheal intubation, RSI, CRIC, and simple finger and tube thoracostomy had ratings of 4 and 5. Shock and circulation management tasks such as IV access, IV via external jugular vein cannulation, and invasive pressure monitoring, as well as the 12-lead EKG all had ratings of 4 and 5. These study findings align with the previous SME panel interview results, where SMEs stated that some tasks would not be attempted because of their invasive nature or may not have as much familiarity with conducting those tasks (French Krahn et al., 2025). Interestingly, documentation had higher than anticipated difficulty ratings of 2 (slightly challenging), 3 (moderately challenging), and 4 (very challenging). This finding was also in the previous study.

Analysis of medical ERCP challenges, training, and mitigation strategies employed during vehicle motion were identified using mitigation suggestions from French Krahn et al. (2025). The survey identified a 100.0% consensus on maintaining a low center of gravity along with 95.7% of respondents selecting bracing against the platform frame indicates that physical stabilization is the primary mitigation strategy used to combat WBV (Figure 7). Furthermore, nearly all respondents preferring to complete tasks prior to vehicle movement identifies a gap in training standards by relying on pre-movement care (Figure 8).

Regarding training, the results indicate a need for an increase in realistic simulations (in a vibration/jolt environment) and additional training on medical tasks in a simulated environment with motion, jolt, and vibration (Figure 9). Medical ERCP responses also indicate a desire for more live tissue labs and repetitive field training. Furthermore, respondent recommendations repeatedly expressed the importance of training in specific aircraft and/or ground vehicles where the care will be delivered, as well as the need for low-light and high-stress training techniques that can be employed in real-life scenarios. Additionally, there were multiple recommendations to expand training into the civilian healthcare system for all provider levels to further optimize medical ERCP readiness and increase multi-echelon exposure (Appendix C).

Conclusion

A standardized survey was conducted to validate en route care provider SME interview responses regarding task challenges due to WBV exposure during dynamic vehicle motion. Both the interview and survey outcomes show that en route care airway and respiratory management tasks and shock and circulation management tasks requiring high levels of fine motor control are most challenging to perform and are most susceptible to vehicle motion, vibration, and jolt. Similar to the interview outcomes, the tasks most susceptible to WBV were not necessarily those that had the greatest detriment to the patient if delayed, and vice versa. Tasks that had the greatest detriment to the patient if delayed included airway and respiratory management tasks and shock and circulation management tasks. The most common mitigation strategies used to combat WBV were stabilization techniques (maintaining a low center of gravity or bracing against the aircraft or vehicle for balance), creating pre-made task kits, completing tasks before vehicle/aircraft movement (if possible), and maintaining effective communication with the crew.

The findings presented in this work related to medical ERCP task difficulty, susceptibility, and potential detriment during dynamic vehicle motion reiterate the need for realistic training and validated mitigation strategies. Understanding these collective influences are critical for maintaining and optimizing short-term and long-term en route care medical provider health and performance as well as improving delivery of medical interventions during transport. Future discussions and research should examine how current training can be improved and optimized to include considerations including, but not limited to, incorporating: (1) environmental training exposure (e.g., dynamic vehicle motion); (2) access to live tissue and human or human surrogate (e.g., manikin or cadaver) during training; and (3) stress and composure management techniques.

Work is also ongoing to analyze survey findings to examine potential relationships between operational exposures such as cabin ergonomics, posture, PPE, and other factors that may increase the risk of musculoskeletal discomfort, pain, or injury pathologies in U.S. Army medical ERCPs. Survey outcomes can be used to inform U.S. Army recommendations, policies, and strategies to minimize negative effects of medical ERCP operational exposures on Soldier health, wellness, and performance.

References

Barazanji, K., Eslinger, A., Brown, D., Hildebrandt, G., Squire, C., Eddins, J., Oldorf, L., Bowers, B., Wilson, R., & Warren, J. (2015). *Aeromedical evacuation enroute critical care validation study* (Report No. 2015-07). U.S. Army Aeromedical Research Laboratory.

Bartlett, J. E., Kotrlik, J. W., & Higgins, C. C. (2001). Organizational research: Determining appropriate sample size in survey research. *Information Technology, Learning and Performance Journal, 19*(1), 43–50.

Conti, S., Kroening, L., Kinsler, R., Lloyd, A, & Molles, J. (2019). *Optimal physical space for en route care: Medic posture and injury survey results* (Report No. 2019-18). U.S. Army Aeromedical Research Laboratory.

Conti, S., Kroening, L., Lloyd, A, Kinsler, R., & Molles, J. (2020). *U.S. Army ground evacuation enroute critical care validation study* (Report No. 2020-05). U.S. Army Aeromedical Research Laboratory.

Conti, S. M., Kroening, L. R., Molles, J. J., Davenport, M. L., Kinsler, R. E., & Lloyd, A. L. (2021). Optimal physical space for en route care: Medic posture and injury survey. *Military Medicine, 186*, S1, 305.

Conway, G. E., Szalma, J. L., & Hancock, P. A. (2007). A quantitative meta-analytic examination of whole-body vibration effects on human performance. *Ergonomics, 50*(2), 228–245.

Department of Aviation Medicine. (2024). *U.S. Army aeromedical evacuation standard medical operating guidelines (SMOG) (CY24 Version).* Department of Aviation Medicine.

French Krahn, H. A., Stewart, A. S., Barazanji, K. W., Wagner, C. E., Crowley, J. S., Chancey, V. C., & Rooks, T. F. (2025). *Whole body vibration effects on en route care medical provider performance-Subject matter expert review of potential mitigation strategies* (Report No. USAARL-TECH-FR--2025-02). U.S. Army Aeromedical Research Laboratory. https://doi.org/10.3357/AMHP.4027.2015

Hill, S. G., & Tauson, R. A. (2005). *Soldier performance issues in C2 'On the move'* [Oral presentation]. 10th International Command Control Research Technology Symposium, McLean, VA.

Lewis, C. H., & Griffin, M. J. (1978). A review of the effects of vibration on visual acuity and continuous manual control, part II: Continuous manual control. *Journal of Sound and Vibration, 56*(3), 415–457.

Lloyd, A., Kinsler, R., Caruso, K., Kroening, L., & Molles, J. (2023). Im*pact of transport forces and immobilization practices on patient physiology: Evaluate effect of strapping tension* (Report No. USAARL-TECH-TR--2023-17). U.S. Army Aeromedical Research Laboratory.

Nakashima, A., & Cheung, B. (2006). *The effects of vibration frequencies on physical, perceptual and cognitive performance* (Report No. 2006-218). Defence Research and Development Canada.

Schipani, S. P., Bruno, R. S., Lattin, M. A., King, B. M., & Patton, D. J. (1998). *Quantification of cognitive process degradation while mobile, attributable to the environmental stressors endurance, vibration, and noise* (Report No. ARL-TR-1603). U. S. Army Research Laboratory.

Appendix A. Acronyms and Abbreviations

BIAD	Blind Insertion Airway Device
BiPAP	Bilevel Positive Airway Pressure
CPAP	Continuous Positive Airway Pressure
CPR	Cardiopulmonary Resuscitation
CRIC	Cricothyrotomy
C2	Command and Control
EKG	Electrocardiogram
EMT	Emergency Medical Technician
IO	Intraosseous
IV	Intravenous
LSCO	Large Scale Combat Operations
MEDEVAC	Medical Evacuation
O_2	Oxygen
REBOA	Resuscitative Endovascular Balloon Occlusion of the Aorta
RSI	Rapid Sequence Intubation
SME	Subject Matter Expert
SMOG	Standard Medical Operating Guidelines
VA	Vascular Access
WBV	Whole-Body Vibration
USAARL	U.S. Army Aeromedical Research Laboratory

Appendix B. Survey Questions

1. Do you agree to participate in the survey?
    a. Yes
    b. No

2. During your time in the military, have you gained experience, other than training, as an en route care provider (ground medic, flight paramedic, flight surgeon, etc.) during MEDEVAC or CASEVAC missions?
    a. Yes
    b. No

- What is your current rank?

E1	E5	E9	W4	O3	O7
E2	E6	W1	W5	O4	O8
E3	E7	W2	O1	O5	O9
E4	E8	W3	O2	O6	O10

- How many years and months have you served in the military in any role?

- How many years of experience do you have as an en route care provider for the U.S. Army, Reserves, or National Guard?

- What is/was your job/position in the military when you were an en route care provider?
    a. Ground Medic
    b. Flight Paramedic
    c. Critical Care Flight Paramedic
    d. Nurse
    e. Flight Nurse
    f. Physician
    g. Surgeon
    h. Flight Surgeon
    i. Other

- Do you have additional en route care experience outside of the military (e.g., civilian en route care experience, credentials, certifications, etc.)?
    a. I do not have additional en route care experience
    b. Civilian EMT/Medic (With En Route Care Experience)
    c. Civilian Nurse (With En Route Care Experience)
    d. Civilian Physician (With En Route Care Experience)
    e. Civil Search & Rescue (With En Route Care Experience)
    f. Other

- How many times have you been deployed as an en route care provider while serving in the U.S. Army, Reserves, or National Guard?

- What was the average time of your deployments as an en route care provider?
    a. 0-6 Months
    b. 7-12 Months
    c. 12+ Months
    d. I have not been deployed as an en route care provider

- Rate the following airway and respiratory tasks from 1 to 5 based on the level of difficulty of providing en route care due to vehicle motion and vibration. Please choose one answer per line.

    1 – Not challenging
    2 – Slightly challenging
    3 – Moderately challenging
    4 – Very challenging
    5 – Extremely challenging

	1	2	3	4	5	Have not completed and cannot rate this task
Airway Pearls	☐	☐	☐	☐	☐	☐
Blind Insertion Airway Device (BIAD)	☐	☐	☐	☐	☐	☐
Nasopharyngeal Airway	☐	☐	☐	☐	☐	☐
Naso/Orogastric Tube	☐	☐	☐	☐	☐	☐
Nasotracheal Intubation	☐	☐	☐	☐	☐	☐
Endotracheal Intubation	☐	☐	☐	☐	☐	☐
Rapid Sequence Intubation	☐	☐	☐	☐	☐	☐
Cricothyroidotomy	☐	☐	☐	☐	☐	☐
Needle Cricothyroidotomy	☐	☐	☐	☐	☐	☐
Simple Finger and Tube Thoracostomy	☐	☐	☐	☐	☐	☐
Needle Thoracostomy	☐	☐	☐	☐	☐	☐
BVM Ventilation	☐	☐	☐	☐	☐	☐
Ventilator Management	☐	☐	☐	☐	☐	☐
CPAP/BIPAP	☐	☐	☐	☐	☐	☐
Occlusive Chest Seal	☐	☐	☐	☐	☐	☐
Suction	☐	☐	☐	☐	☐	☐
Administer Oxygen	☐	☐	☐	☐	☐	☐

- Rate the following shock and circulation management tasks from 1 to 5 based on the level of difficulty of providing en route care due to vehicle motion and vibration. Please choose one answer per line.

  1 – Not challenging
  2 – Slightly challenging
  3 – Moderately challenging
  4 – Very challenging
  5 – Extremely challenging

	1	2	3	4	5	Have not completed and cannot rate this task
Tourniquet Application	☐	☐	☐	☐	☐	☐
Junctional Tourniquet Application	☐	☐	☐	☐	☐	☐
Tourniquet Conversion	☐	☐	☐	☐	☐	☐
Dress Wounds	☐	☐	☐	☐	☐	☐
Vascular Access (Intravenous)	☐	☐	☐	☐	☐	☐
Vascular Access (Intraosseous)	☐	☐	☐	☐	☐	☐
Vascular Access via Central Catheters	☐	☐	☐	☐	☐	☐
Vascular Access via External Jugular Vein Cannulation	☐	☐	☐	☐	☐	☐
Blood Component/Fresh Whole Blood Use	☐	☐	☐	☐	☐	☐
Fluid Resuscitation	☐	☐	☐	☐	☐	☐
Hypothermia Prevention and Management	☐	☐	☐	☐	☐	☐
Foley Catheter	☐	☐	☐	☐	☐	☐
REBOA Management	☐	☐	☐	☐	☐	☐
Invasive Pressure Monitoring	☐	☐	☐	☐	☐	☐

This space is intentionally blank.

- Rate the following cardiac monitoring tasks from 1 to 5 based on the level of difficulty of providing en route care due to vehicle motion and vibration. Please choose one answer per line.

  1 – Not challenging
  2 – Slightly challenging
  3 – Moderately challenging
  4 – Very challenging
  5 – Extremely challenging

	1	2	3	4	5	Have not completed and cannot rate this task
Cardiac Defibrillation	☐	☐	☐	☐	☐	☐
Synchronized Cardioversion	☐	☐	☐	☐	☐	☐
12-Lead Electrocardiogram	☐	☐	☐	☐	☐	☐
Transcutaneous Pacing	☐	☐	☐	☐	☐	☐

- Rate the following medical assessment tasks from 1 to 5 based on the level of difficulty of providing en route care due to vehicle motion and vibration. Please choose one answer per line.

  1 – Not challenging
  2 – Slightly challenging
  3 – Moderately challenging
  4 – Very challenging
  5 – Extremely challenging

	1	2	3	4	5	Have not completed and cannot rate this task
Blood Glucose Analysis	☐	☐	☐	☐	☐	☐
Documentation	☐	☐	☐	☐	☐	☐
Measure Vital Signs	☐	☐	☐	☐	☐	☐
Medications	☐	☐	☐	☐	☐	☐
Monitor Use	☐	☐	☐	☐	☐	☐

- Rate the following stabilization tasks from 1 to 5 based on the level of difficulty of providing en route care due to vehicle motion and vibration. Please choose one answer per line.

  1 – Not challenging
  2 – Slightly challenging
  3 – Moderately challenging
  4 – Very challenging
  5 – Extremely challenging

	1	2	3	4	5	Have not completed and cannot rate this task
Splinting	☐	☐	☐	☐	☐	☐
Cervical Collar	☐	☐	☐	☐	☐	☐
Immobilization	☐	☐	☐	☐	☐	☐
Pelvic Binder	☐	☐	☐	☐	☐	☐

This space is intentionally blank.

- Using the scale below, how detrimental would each airway and respiratory management task be to the patient if delayed or if you were unable to perform the task during en route care?

    1 – Not detrimental. It could not cause harm to the patient.
    2 – Slightly detrimental. There is a low risk of causing any harm to patient; impact on physical, mental, or social function is expected to be resolved in days (contusion, nausea, stress, strain).
    3 – Moderately detrimental. Impact on physical, mental, or social function is expected to be resolved in a month or longer (severe sprain, large non-life-threatening wounds, etc.).
    4 – Very detrimental. Would/could cause harm to the patient; impact on physical, mental, or social function may never be resolved and may cause secondary issues (serious trauma, infection).
    5 – Extremely detrimental. Would/could cause serious harm to the patient, including death (pulmonary embolism, brain damage, heart attack, stroke, severe allergic reaction, etc.)

	1	2	3	4	5	Have not completed and cannot rate this task
Airway Pearls	☐	☐	☐	☐	☐	☐
Blind Insertion Airway Device (BIAD)	☐	☐	☐	☐	☐	☐
Nasopharyngeal Airway	☐	☐	☐	☐	☐	☐
Naso/Orogastric Tube	☐	☐	☐	☐	☐	☐
Nasotracheal Intubation	☐	☐	☐	☐	☐	☐
Endotracheal Intubation	☐	☐	☐	☐	☐	☐
Rapid Sequence Intubation	☐	☐	☐	☐	☐	☐
Cricothyroidotomy	☐	☐	☐	☐	☐	☐
Needle Cricothyroidotomy	☐	☐	☐	☐	☐	☐
Simple Finger and Tube Thoracostomy	☐	☐	☐	☐	☐	☐
Needle Thoracostomy	☐	☐	☐	☐	☐	☐
BVM Ventilation	☐	☐	☐	☐	☐	☐
Ventilator Management	☐	☐	☐	☐	☐	☐
CPAP/BIPAP	☐	☐	☐	☐	☐	☐
Occlusive Chest Seal	☐	☐	☐	☐	☐	☐
Suction	☐	☐	☐	☐	☐	☐
Administer Oxygen	☐	☐	☐	☐	☐	☐

- Using the scale below, how detrimental would each shock and circulation management task be to the patient if delayed or if you were unable to perform the task during en route care?

  1 – Not detrimental. It could not cause harm to the patient.
  2 – Slightly detrimental. There is a low risk of causing any harm to patient; impact on physical, mental, or social function is expected to be resolved in days (contusion, nausea, stress, strain).
  3 – Moderately detrimental. Impact on physical, mental, or social function is expected to be resolved in a month or longer (severe sprain, large non-life-threatening wounds, etc.).
  4 – Very detrimental. Would/could cause harm to the patient; impact on physical, mental, or social function may never be resolved and may cause secondary issues (serious trauma, infection).
  5 – Extremely detrimental. Would/could cause serious harm to the patient, including death (pulmonary embolism, brain damage, heart attack, stroke, severe allergic reaction, etc.)

	1	2	3	4	5	Have not completed and cannot rate this task
Tourniquet Application	☐	☐	☐	☐	☐	☐
Junctional Tourniquet Application	☐	☐	☐	☐	☐	☐
Tourniquet Conversion	☐	☐	☐	☐	☐	☐
Dress Wounds	☐	☐	☐	☐	☐	☐
Vascular Access (Intravenous)	☐	☐	☐	☐	☐	☐
Vascular Access (Intraosseous)	☐	☐	☐	☐	☐	☐
Vascular Access via Central Catheters	☐	☐	☐	☐	☐	☐
Vascular Access via External Jugular Vein Cannulation	☐	☐	☐	☐	☐	☐
Blood Component/Fresh Whole Blood Use	☐	☐	☐	☐	☐	☐
Fluid Resuscitation	☐	☐	☐	☐	☐	☐
Hypothermia Prevention and Management	☐	☐	☐	☐	☐	☐
Foley Catheter	☐	☐	☐	☐	☐	☐
REBOA Management	☐	☐	☐	☐	☐	☐
Invasive Pressure Monitoring	☐	☐	☐	☐	☐	☐

- Using the scale below, how detrimental would each cardiac monitoring task be to the patient if delayed or if you were unable to perform the task during en route care?

  1 – Not detrimental. It could not cause harm to the patient.
  2 – Slightly detrimental. There is a low risk of causing any harm to patient; impact on physical, mental, or social function is expected to be resolved in days (contusion, nausea, stress, strain).
  3 – Moderately detrimental. Impact on physical, mental, or social function is expected to be resolved in a month or longer (severe sprain, large non-life-threatening wounds, etc.).
  4 – Very detrimental. Would/could cause harm to the patient; impact on physical, mental, or social function may never be resolved and may cause secondary issues (serious trauma, infection).
  5 – Extremely detrimental. Would/could cause serious harm to the patient, including death (pulmonary embolism, brain damage, heart attack, stroke, severe allergic reaction, etc.)

	1	2	3	4	5	Have not completed and cannot rate this task
Cardiac Defibrillation	☐	☐	☐	☐	☐	☐
Synchronized Cardioversion	☐	☐	☐	☐	☐	☐
12-Lead Electrocardiogram	☐	☐	☐	☐	☐	☐
Transcutaneous Pacing	☐	☐	☐	☐	☐	☐

This space is intentionally blank.

- Using the scale below, how detrimental would each medical assessment task be to the patient if delayed or if you were unable to perform the task during en route care?

  1 – Not detrimental. It could not cause harm to the patient.
  2 – Slightly detrimental. There is a low risk of causing any harm to patient; impact on physical, mental, or social function is expected to be resolved in days (contusion, nausea, stress, strain).
  3 – Moderately detrimental. Impact on physical, mental, or social function is expected to be resolved in a month or longer (severe sprain, large non-life-threatening wounds, etc.).
  4 – Very detrimental. Would/could cause harm to the patient; impact on physical, mental, or social function may never be resolved and may cause secondary issues (serious trauma, infection).
  5 – Extremely detrimental. Would/could cause serious harm to the patient, including death (pulmonary embolism, brain damage, heart attack, stroke, severe allergic reaction, etc.)

	1	2	3	4	5	Have not completed and cannot rate this task
Blood Glucose Analysis	☐	☐	☐	☐	☐	☐
Documentation	☐	☐	☐	☐	☐	☐
Measure Vital Signs	☐	☐	☐	☐	☐	☐
Medications	☐	☐	☐	☐	☐	☐
Monitor Use	☐	☐	☐	☐	☐	☐

This space is intentionally blank.

- Using the scale below, how detrimental would each stabilization task be to the patient if delayed or if you were unable to perform the task during en route care?

  1 – Not detrimental. It could not cause harm to the patient.
  2 – Slightly detrimental. There is a low risk of causing any harm to patient; impact on physical, mental, or social function is expected to be resolved in days (contusion, nausea, stress, strain).
  3 – Moderately detrimental. Impact on physical, mental, or social function is expected to be resolved in a month or longer (severe sprain, large non-life-threatening wounds, etc.).
  4 – Very detrimental. Would/could cause harm to the patient; impact on physical, mental, or social function may never be resolved and may cause secondary issues (serious trauma, infection).
  5 – Extremely detrimental. Would/could cause serious harm to the patient, including death (pulmonary embolism, brain damage, heart attack, stroke, severe allergic reaction, etc.)

	1	2	3	4	5	Have not completed and cannot rate this task
Splinting	☐	☐	☐	☐	☐	☐
Cervical Collar	☐	☐	☐	☐	☐	☐
Immobilization	☐	☐	☐	☐	☐	☐
Pelvic Binder	☐	☐	☐	☐	☐	☐

This space is intentionally blank.

- Which of the following airway and respiratory management tasks are the most susceptible to vehicle motion, vibration, or jolt? Please rate each task using a rating of 0 through 3.

  0 – Not susceptible
  1 – Low susceptibility
  2 – Medium susceptibility
  3 – High susceptibility

	0	1	2	3	I am not sure
Airway Pearls	☐	☐	☐	☐	☐
Blind Insertion Airway Device (BIAD)	☐	☐	☐	☐	☐
Nasopharyngeal Airway	☐	☐	☐	☐	☐
Naso/Orogastric Tube	☐	☐	☐	☐	☐
Nasotracheal Intubation	☐	☐	☐	☐	☐
Endotracheal Intubation	☐	☐	☐	☐	☐
Rapid Sequence Intubation	☐	☐	☐	☐	☐
Cricothyroidotomy	☐	☐	☐	☐	☐
Needle Cricothyroidotomy	☐	☐	☐	☐	☐
Simple Finger and Tube Thoracostomy	☐	☐	☐	☐	☐
Needle Thoracostomy	☐	☐	☐	☐	☐
BVM Ventilation	☐	☐	☐	☐	☐
Ventilator Management	☐	☐	☐	☐	☐
CPAP/BIPAP	☐	☐	☐	☐	☐
Occlusive Chest Seal	☐	☐	☐	☐	☐
Suction	☐	☐	☐	☐	☐
Administer Oxygen	☐	☐	☐	☐	☐

This space is intentionally blank.

- Which of the following shock and circulation management tasks are the most susceptible to vehicle motion, vibration, or jolt? Please rate each task using a rating of 0 through 3.

  0 – Not susceptible
  1 – Low susceptibility
  2 – Medium susceptibility
  3 – High susceptibility

	0	1	2	3	I am not sure
Tourniquet Application	☐	☐	☐	☐	☐
Junctional Tourniquet Application	☐	☐	☐	☐	☐
Tourniquet Conversion	☐	☐	☐	☐	☐
Dress Wounds	☐	☐	☐	☐	☐
Vascular Access (Intravenous)	☐	☐	☐	☐	☐
Vascular Access (Intraosseous)	☐	☐	☐	☐	☐
Vascular Access via Central Catheters	☐	☐	☐	☐	☐
Vascular Access via External Jugular Vein Cannulation	☐	☐	☐	☐	☐
Blood Component/Fresh Whole Blood Use	☐	☐	☐	☐	☐
Fluid Resuscitation	☐	☐	☐	☐	☐
Hypothermia Prevention and Management	☐	☐	☐	☐	☐
Foley Catheter	☐	☐	☐	☐	☐
REBOA Management	☐	☐	☐	☐	☐
Invasive Pressure Monitoring	☐	☐	☐	☐	☐

This space is intentionally blank.

- Which of the following cardiac monitoring tasks are the most susceptible to vehicle motion, vibration, or jolt? Please rate each task using a rating of 0 through 3.

  0 – Not susceptible
  1 – Low susceptibility
  2 – Medium susceptibility
  3 – High susceptibility

	0	1	2	3	I am not sure
Cardiac Defibrillation	☐	☐	☐	☐	☐
Synchronized Cardioversion	☐	☐	☐	☐	☐
12-Lead Electrocardiogram	☐	☐	☐	☐	☐
Transcutaneous Pacing	☐	☐	☐	☐	☐

- Which of the following medical assessment tasks are the most susceptible to vehicle motion, vibration, or jolt? Please rate each task using a rating of 0 through 3.

  0 – Not susceptible
  1 – Low susceptibility
  2 – Medium susceptibility
  3 – High susceptibility

	0	1	2	3	I am not sure
Blood Glucose Analysis	☐	☐	☐	☐	☐
Documentation	☐	☐	☐	☐	☐
Measure Vital Signs	☐	☐	☐	☐	☐
Medications	☐	☐	☐	☐	☐
Monitor Use	☐	☐	☐	☐	☐

- Which of the following stabilization tasks are the most susceptible to vehicle motion, vibration, or jolt? Please rate each task using a rating of 0 through 3.

  0 – Not susceptible
  1 – Low susceptibility
  2 – Medium susceptibility
  3 – High susceptibility

	0	1	2	3	I am not sure
Splinting	☐	☐	☐	☐	☐
Cervical Collar	☐	☐	☐	☐	☐
Immobilization	☐	☐	☐	☐	☐
Pelvic Binder	☐	☐	☐	☐	☐

- When conducting en route care in a high vibration environment, have you used any of the following strategies or techniques to mitigate the risks associated with WBV or jolt while performing critical care tasks?
  a. Pulling/pinching the skin taut at the IV access location for easier insertion
  b. Completing tasks before aircraft or vehicle movement (if possible)
  c. Creating pre-made task kits (i.e., IV kits, blood transfusions)
  d. Communicating effectively with the flight crew or driver to limit unexpected movements
  e. Propping patient extremities on blankets to lessen vibrations
  f. Finding anchor points on the patient's body to stabilize the movement needed (e.g., using the pinky finger as an anchor point to stabilize the hand during IV access)
  g. Using ultrasound to improve landmark location during IV insertion and assessing body cavities for fluids
  h. Using available restraints to prevent sudden movements (e.g., ratchet straps, monkey tails, etc.)
  i. Bracing against the aircraft or vehicle for balance (e.g., pushing helmet into aircraft ceiling or leaning a shoulder against the vehicle door)
  j. Maintaining a low center of gravity (e.g., sitting on the aircraft or vehicle floor)
  k. None of these
  l. Other

- Would lessons or training materials on the following make these tasks easier for care providers while the vehicle or aircraft is in motion?
    a. Completing tasks before aircraft or vehicle movement (if possible)
    b. Communicating effectively with the flight crew or driver to limit unexpected movements
    c. Finding anchor points on the patient's body to stabilize the movement needed (e.g., using the pinky finger as an anchor point to stabilize the hand during IV access)
    d. Propping patient extremities on blankets to lessen vibrations
    e. Using available restraints to prevent sudden movements (e.g., ratchet straps, monkey tails, etc.)
    f. Bracing against the aircraft or vehicle for balance (i.e., pushing helmet into aircraft ceiling or leaning a shoulder against the vehicle door)
    g. Maintaining a low center of gravity (e.g., sitting on the aircraft or vehicle floor)
    h. None of these
    i. Other

- Would any of the following lessons improve a care provider's ability to complete tasks in a high vibration/jolt environment if the lessons are included in training courses or material for mitigating the vibration effects?
    a. Live tissue labs
    b. Challenging and repetitive field training
    c. Realistic simulations (in a vibration/jolt environment) to improve readiness for challenges while providing care en route
    d. Training on medical tasks in a simulated environment with motion, jolts, and vibration
    e. None of these
    f. Other

- Have you learned or identified any additional strategies that were not taught in your training courses to make these medical tasks easier while en route?

- Do you have suggestions for improving training for care providers?

Appendix C. En Route care Training and Mitigation Insights & Feedback

Table C1. Reported Recommendations for Techniques/Strategies to Aid En Route Care Provider Performance

"Have you learned or identified any additional strategies that were not taught in your training courses to make these medical tasks easier while en route?"	
	Recommendation
Realistic Training Environment	Train in platform where care will be delivered
	Practice treating real patients with motion and vibration
	Train in low light conditions, with and without night vision goggles
	Integrate external stressors and high stress scenarios into training
	Include complex and multi-patient scenarios for training
	Train with full mission loads
	Train in realistic cabin configurations
	Practice actual patient movement and transportation procedures
	Train providers to perform invasive tasks under high stress and high workload
	Incorporate breathing exercises and techniques to maintain composure in high stress environments
	Maintain physical conditioning, especially core strength, to improve stability while working in moving environments
	Include arctic and other extreme environment training
Experience and Skill Development	Build high repetition task training to develop muscle memory for critical interventions
	Maintain consistent training for perishable skills
	Incorporate more training with critical care patients, both in hospital and pre-hospital settings
	Train long-term airway and ventilator management
	Regularly test knowledge on vital signs, medications, and intervention protocols
	Develop competency tracking and progression standards
	Utilize live tissue labs or high-fidelity training when appropriate
Critical Care Practices	Stabilize patients prior to transport
	Perform as many interventions as possible prior to takeoff or movement
	Establish priorities of care during transport
	Train stabilization techniques for IV insertion
	Use "to keep open" (TKO) IV fluids with medication through the same line when appropriate
	Utilize pinky to pinky medication drawing technique for stability
	Apply tape and straps to secure lines and monitoring devices to prevent dislodgement
	Use 100 milliliter (mL) bags for pushover time medications

	Use femur traction splints during patient transportation
Cabin/Space Management	Implement purposeful and standardized aircraft configurations
	Practice cabin configuration and management prior to missions
	Maximize available cabin space for treatment
	Plan patient positioning in aircraft based on anticipated complications
	Train how to manage vibration and jolt while en route
	Consider hanging monitors or equipment from platform structure to reduce vibration effects
	Use carabiners, ratchet straps, and cable sleeves for equipment and cable management
	Standardize shorter integrated cable systems (ICS) to prevent entanglement
Equipment and Medical Supply Organization	Use pre-made intervention packages
	Ensure medical supplies remain accessible
	Transition from rigid trauma panels to bag-based equipment set-ups
	Use two light sources (e.g., chest and helmet-mounted)
	Conduct equipment and system checks on the ground before departure
	Issue portable ultrasounds
Team Integration and Communication	Conduct joint training with other medical and operational units (air and ground)
	Practice handoff communication with detailed patient reports
	Work closely with non-medical crew members to maximize capabilities
	Coordinate training across air and ground platforms

Table C2. Reported Recommendations for En Route Care Provider Training Improvements

“Do you have suggestions for improving training for care providers?”	
	Recommendations
Realistic Training Environment	Conduct medical evaluations and clinical training in flight when possible
	Increase use of actual platforms and mobile environments during training
	Train in the same environments providers will operate in
	Include low-light and total darkness procedural training
	Integrate external stressors and unexpected-event scenarios to replicate operational stress
	Conduct complex simulations that combine POI, prolonged casualty care, and en route care
	Train with realistic patient packaging, line management, and long-duration patient care scenarios
	Increase repetitions of critical care tasks and invasive procedures during flight or simulated movement
Experience, Skill, and Performance	Provide regular real-world clinical experience through rotations in civilian hospitals, ambulances, and critical care transport platforms
	Allow all providers- not only physicians, physician assistants, and nurses- to rotate through civilian healthcare systems
	Establish routine partnerships with civilian flight programs and emergency medical systems agencies for ride-alongs and training
	Sustain provider proficiency by integrating civilian healthcare work into routine training requirements
	Train providers to manage unexpected events, take mission control, and make critical decisions under pressure
	Emphasize anticipatory thinking and planning several steps ahead
	Provide training on stress management techniques and maintaining composure in high stress environments
	Enable providers to spend more time training with operational units rather than clinical assignments
Advanced Medical Skills Development	Increase training in critical care management, damage control resuscitation, and duration airway/ventilator management
	Expand instruction in pharmacology, medication administration, and dosing during transport
	Provide greater emphasis on hypothermia training during en route care
	Strengthen foundational anatomy, physiology, and pathophysiology training for entry-level medical personnel
	Provide more hands-on airway management training with focus on prolonged care
	Include specialized training (e.g., K9 casualty en route care)
	Increase access to cadavers and live tissue training

	Provide adequate class VIII medical supplies (e.g., airway manikins, IV trainers, bleed kits, and catheter trainers)
Training Standardization and Pipeline Improvements	Develop standardized en route care training programs and requirements across units
	Establish competency tracking systems for providers
	Implement training standards tied to credentialing or recertification for en route care providers
	Require scenario-based training during unit drills
	Continue En Route Critical Care Nurse program and integrate courses like Joint En Route Care Course JECC and any advanced en route care courses
	Update relevant development courses (e.g., Advanced Leader Course, Senior Leader Course)
	Require en route care training earlier in the pipeline to identify individuals who cannot tolerate flight conditions or perform effectively in that environment
	Increase flight exposure beyond initial qualification training to build experience and proficiency
	Ensure standardization instructors maintain currency through continuing education and advanced training
Access and Funding	Improve funding and administrative pathways for civilian training opportunities
	Allow joint training with civilian EMS and first responder groups without financial barriers
	Simplify processes for establishing local training sites and obtaining site codes
	Provide temporary duty training opportunities
	Allow medical personnel to manage and submit civilian continuing education toward national registry requirements

U.S. ARMY AEROMEDICAL RESEARCH LABORATORY

FORT RUCKER, ALABAMA

Optimizing

HUMAN PROTECTION AND PERFORMANCE

since 1962

U.S. ARMY

FCC

MRDC