



UNITED STATES ARMY AEROMEDICAL RESEARCH LABORATORY

Effects of Altitude During Rotary-Wing Transport in a Large Animal Polytrauma Model

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14. ABSTRACT This study evaluates how different rotary-wing flight profiles during aeromedical evacuation (AE) affect physiological recovery in patients suffering from combined traumatic brain injury and hemorrhagic shock. Using a validated 24-hour swine model, researchers compared the environmental and physiological impacts of three experimental conditions: standard evacuation flight (SEF), tactical evacuation flight (TEF), or mock AE flight. Full datasets were obtained for 20 animals (TEF [N = 7], SEF [N = 7], and mock [N = 6]). Environmental data analysis was completed on the Global Positioning System, altitude, temperature, sound level, and acceleration and rotation data. The mean arterial pressure and intracranial pressure values were calculated for key points in the data collection process, and compared to the environmental data for correlation. This study identified the transportation stresses of a polytrauma swine model in different AE configurations. In summary, though there were differences in rotary-wing transport flight profiles, the study did not determine significant statistical differences in physiological data between the different flight configurations.					
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Summary

Injuries resulting in hemorrhagic shock (HS) and traumatic brain injury (TBI) are leading causes of mortality and morbidity for combat trauma. Treatments consist of hemorrhage control, rapid fluid infusion, and evacuation to a medical treatment facility. Recent scientific publications suggest that aeromedical evacuation (AE) may compound brain and organ damage in TBI/HS patients by increasing hemorrhage, decreasing cerebral blood flow, and further reducing the amount of oxygen reaching vital organs. The objective of this study was to evaluate the effects of varying flight profiles on survival, neurological function, and vital organ function.

The study was completed at the Lovelace Biomedical Research Institute (LBRI) using a validated swine polytrauma model (TBI/HS). It was a 24-hour survival study with 24 swine randomized to one of three experimental conditions: standard evacuation flight (SEF), tactical evacuation flight (TEF), or mock AE flight. Animals were exposed to a rapid rotational acceleration/deceleration force which caused a closed head TBI. After TBI, animals underwent a controlled blood loss of 40% blood volume. AE was initiated 90 minutes post-blood loss with standard interventions (blood reinfusion, ventilation, and warming). After a 60-minute flight aboard a U.S. Army HH-60M medical evacuation helicopter, the animals were monitored for 24 hours. Sensors that measured acceleration, altitude, temperature, and noise were placed in the aircraft and on the animal. Invasive intracranial pressure (ICP), invasive blood pressure, and standard vital signs (VS) were also recorded during flight.

Full datasets were obtained for 20 animals (TEF [$N = 7$], SEF [$N = 7$], and mock [$N = 6$]). Environmental data analysis was completed on the Global Positioning System (GPS), altitude, temperature, sound level, and acceleration and rotation data. Based on the GPS and altitude data the animals in the standard and tactical cohorts experienced similar ride profiles within the cohort. There were no statistical differences between the standard and tactical cohorts for temperatures or sound level. For the acceleration data root mean square (RMS), there were only significant differences in acceleration in the medical backboard x-axis between the SEF and TEF cohorts. When looking at the resultant RMS values, the TEF acceleration values were on average 5.9% higher than the SEF acceleration values and the TEF rotational values were on average 13.5% higher than the SEF rotational.

The Fast Fourier Transform (FFT), power spectral density (PSD) and transmissibility calculations were characterized by peaks around 17.2 Hertz (Hz), which was likely linked to the resonance frequency of the helicopter blades. The fundamental frequency of the Black Hawk main rotor is 4.3 Hz, which is multiplied by the number of blades (four) to create the approximate 17.2 Hz frequency. The most notable feature of the transmissibility was that almost all of the values were above 1, meaning the input acceleration or rotation from the aircraft was being exacerbated to all body segments on the animal.

The mean arterial pressure (MAP) and ICP values were calculated for key points in the data collection process. The MAP saw an average decrease of 44.0 millimeters of mercury (mmHg) after the injury model was completed, while ICP saw an average decrease of 2.3 mmHg. By the end of the study, the MAP and ICP were slightly above the baseline measurements, 4.6% increase for MAP and 13.7% increase for ICP. Cerebral perfusion pressure (CPP) was calculated across three flight profiles by subtracting ICP from MAP to evaluate cerebral oxygen delivery during TBI and hemodynamic instability. Analysis revealed that CPP

trends closely mirrored MAP, characterized by a sharp decline immediately following the TBI event, followed by a post-injury recovery where the tactical flight profile consistently yielded the highest perfusion pressures.

This study identified the transportation stresses of a polytrauma swine model in different AE configurations. In summary, though there were differences in rotary-wing transport flight profiles, the study did not determine significant statistical differences in physiological data between the different flight configurations.

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Introduction

Severe blood loss resulting in hemorrhagic shock (HS) and traumatic brain injury (TBI) are leading causes of mortality and morbidity worldwide but are especially relevant for military trauma (Eastridge et al., 2012; Mazuchowski et al., 2020). TBI has been referred to by physicians and neuroscientists studying the phenomenon as the signature injury of Operation Iraqi Freedom and Operation Enduring Freedom. Blast has been implicated in upwards of 70% of all traumas, with rapid accelerative and decelerative force from tertiary blast injury often resulting in TBI. Similarly, approximately 90% of all preventable mortalities involve HS (Mayer, 2019). After receiving the injury, the ideal care regimen for TBI and HS includes hemorrhage control, rapid fluid resuscitation with blood products, and rapid evacuation to a hospital (Butler et al., 2018; Mazuchowski et al., 2020). However, in austere environments or in theater, resuscitative fluid protocols are more commonly completed during aeromedical evacuation (Department of Defense Center of Excellence for Trauma, 2018; Fisher et al., 2018).

The overall objective of this paper is to characterize the environmental data collected during the transport of the injured swine model, and to examine the physiological data collected during the entire study. This technical report provides results from analyses of the environment and physiological data collected under the Defense Health Program Prolonged Field Care Research Award #W81XWH-21-DMRDP-ERCA, “Effects of Altitude During Rotary-Wing Transport in a Large Animal Polytrauma Model.” Additional results and analyses will be available in related technical reports and forthcoming peer-reviewed journal submissions.

The purpose of this study was to examine the effects of aeromedical evacuation flight configurations on a simulated patient with TBI and HS. Head trauma and severe blood loss are common trauma modalities (e.g., sports injuries, motor vehicle accidents, falls) worldwide. The information gathered from this study may have tremendous potential to aid not only military healthcare providers, but the civilian medical community as well.

Materials and Methods

To examine this issue, a collaboration between the U.S. Army Aeromedical Research Laboratory (USAARL), Mind Research Network, and Lovelace Biomedical Research Institute (LBRI) was formed. USAARL flew their HH-60 Black Hawk helicopter to the LBRI campus in Albuquerque, NM located on the Kirtland Air Force Base (KAFB). While there, they flew different flight profiles with a polytrauma TBI and HS injured animal model. USAARL was responsible for the transportation of the animals, which included securing the animal on the litter and instrumentation of the animal, monitoring while onboard, and standard interventions while en route.

The data collection for this study was conducted on the LBRI campus on KAFB from October 13, 2023 to November 2, 2023. For this study, USAARL’s role was to provide the HH-60M medical evacuation (MEDEVAC) helicopter, provide subject matter expertise on how best to secure the animal to the litter, collect the environmental and physiological data during aeromedical transport, and provide standard care while en route.

The full methods for the injury model are discussed in detail in a separate publication (Mayer, Wick, et al., 2026), but the TBI was initiated via a pneumatic device, HYGE™, (Cullen et al., 2016). For the TBI exposure, all animals were placed in ventral recumbency (sternal) position with the animal laying on their stomach with their back facing upward. The animals' heads were secured with metal straps to the linkage assembly of the HYGE device through a custom-made bite bar that converts linear to angular (rotational) motion. The targeted angular peak velocity was 250 radians/second (s) in the coronal plane. Following the TBI exposure, animals were placed in lateral recumbency and subjected to arterial hemorrhage via controlled removal of approximately 40% of estimated total blood volume to induce HS (Mayer et al., 2019; Mayer et al., 2020).

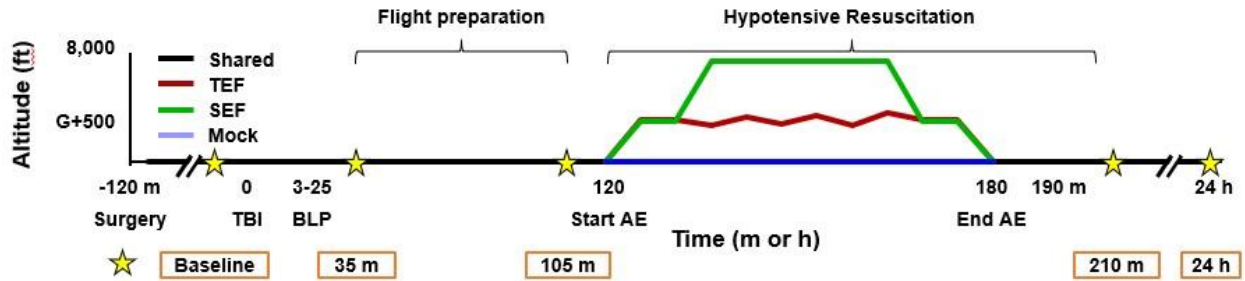
To examine the effects of the aeromedical transport, three flight profiles were examined: tactical evacuation flight, standard flight, and mock (sham) flight profile. The transport conditions were defined as:

- Standard Evacuation Flight (SEF) – Maximum (max) altitude of 8500 feet (ft) above mean sea level, straight and level flight path, smooth ascent and descent to landing pad.
- Tactical Evacuation Flight (TEF) – Max altitude of 500 ft above ground level, tactical maneuvers like sharp banking and cyclic climb, and high velocity speeds.
- Mock – Animal was loaded but aircraft remained stationary with engine off.

The base ground altitude at the test site is approximately 5500 feet above mean sea level. The animals tested in the study had acclimatized to the base altitude for a minimum of two weeks prior to testing. For the TEF flights, the aircraft followed a “nap-of-the-earth” approach following the general terrain of the land at 500 ft above ground level. When following the terrain of nearby canyons during the TEF flights, the aircraft’s altitude in the flight profile could go lower than the starting altitude.

In Figure 1, the animals underwent the same procedures shown on the black line, which include the TBI and blood loss procedures before the aeromedical evacuation (AE) began. The different flight profiles are represented by the colored lines: SEF = red, TEF = green, and mock = purple. During each flight profile, the animals were given half of the shed blood taken in the blood loss procedure, returning approximately 20% of their total blood volume, during the beginning of the flight. Each flight profile lasted for 60 minutes.

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Note. TEF – Tactical Evacuation Flight, SEF – Standard Evacuation Flight, TBI – Traumatic Brain Injury, BLP – Blood Loss Procedure, AE – Aeromedical Evacuation

Figure 1. Flight configuration experimental design.

To transport the animals, USAARL’s HH-60M was flown to Albuquerque, NM from Fort Rucker, AL (Figure 2). Another HH-60M aircraft from the 11th Aviation Support Facility at Fort Carson, CO was also used during the first week of testing while some repairs were completed on USAARL’s aircraft. After being repaired, the USAARL aircraft was used for the final two weeks of testing. Both aircraft have the basic medical interior litter pan system, which can carry up to six patients.



Figure 2. USAARL HH-60M aircraft.

Figure 3 shows the personnel and equipment layout inside of the aircraft during testing. The animal was on the top left litter pan. Across from the animal, two USAARL data collectors and a veterinarian from LBRI sat in the ambulatory patient seats, which fold down from the ceiling and secure to the top litter pan. A critical care flight paramedic (CCFP) sat in the left rear seat and oversaw the operation of the ventilator, the patient monitor, and the reinfusion of the shed blood. All treatments were given based on the U.S. Army Aeromedical Evacuation Standard Medical Operating Guidelines (SMOG) (Department of Aviation Medicine, 2023). A crew chief sat in the right back seat; they assisted the pilots during flight by helping to look for obstacles and making sure all passengers and equipment were secure.

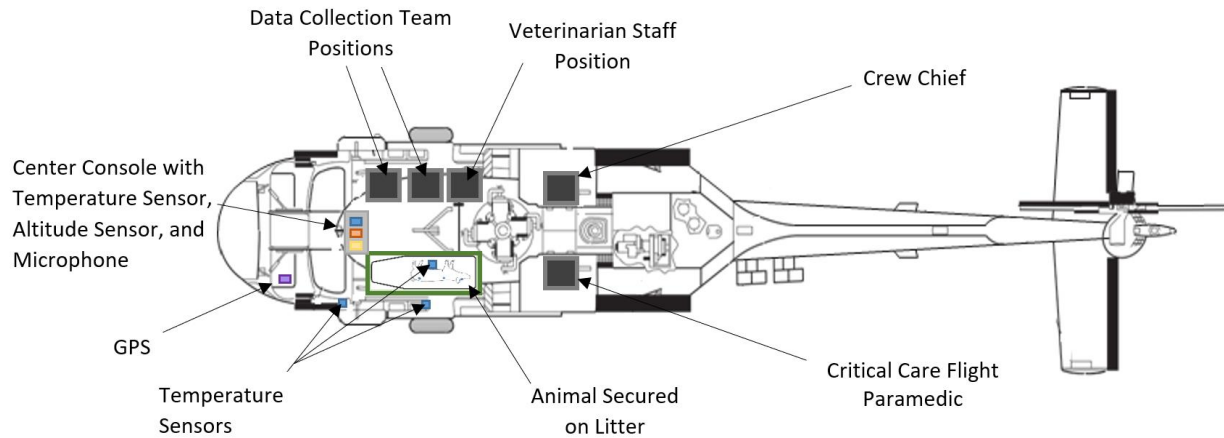


Figure 3. Test layout for HH-60M aircraft.

Environmental Data Acquisition

The data acquisition system used for measuring flight parameters during transport was the Environmental Factors Data Acquisition System (EFDAS). This system was built in-house at USAARL and uses the Heim XMA Core 8 Data Acquisition System (Safran, Arlington, VA) as the signal conditioner and recorder. The system is capable of powering and conditioning 40 analog channels of data. It is contained within a rugged storage case with LEMO connectors along the sides to allow the sensors to be connected without opening the case. A rechargeable battery is mounted inside the case and can power the EFDAS for up to four hours. There is a switch mounted to the front of the case that allows the system to be placed in record mode. During testing, the system was secured in the lower litter pan of the aircraft underneath the subject. The EFDAS can be seen in Figure 4 with sensors connected to the LEMO connections on the side. During this study, the EFDAS was used to collect the following data: acceleration, rotation, temperature, atmospheric pressure, microphone, and Global Positioning System (GPS) data.

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Figure 4. Environmental Factors Data Acquisition System.

The EFDAS has been approved for flight. The EFDAS is modular to allow for collection of different data types, but the configuration used for this data collection effort is specified in Table 1 and the test layout can be seen in Figure 3. During testing, live data from the EFDAS was monitored using a laptop by test personnel to help identify anomalies in the data.

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Table 1. EFDAS Sensor Information

Sensor Type	Sensor Location	Channel	Senor Information
Six Degree of freedom (6DOF) (Combined linear accelerometers and gyroscopes)	Aircraft litter pan, spine board, and subject's head, scapula, and pelvis	3-0 through 6-5 (30 channels total)	Dytran 6DOF Sensors Model Number: 7556A2 Range: ± 6 g
Ambient pressure	Center console	6-6	Endevco Miniature Piezoresistive MEMS Pressure Sensors Model Number: 8530C Range: 0-15 psia
Temperature	Between animal and blanket	7-0	Omega Insulated Thermocouples Model Number: 5LRTC-GG-KI-24-2M Range: -200
	Above litter pan	7-1	
	Center console	7-2	
	Above left pilot	7-3	
Microphone	Center console	7-4	PCB Piezotronics Low-Profile Surface Pressure Microphone Model Number: 130B40 Range: 150 dB re 20 μ Pa
GPS	Above left pilot	Not applicable	Safran Defense & Space, Inc. HEIM XMA GPS Card Model Number: SM01051053B Antena Specifications Frequency: 1575.42 MHz Voltage: 3.0-5.0 V Gain: 30 ± 3 dB

Note. dB re 20 μ Pa – decibels referenced to standard pressure of 20 microPascals, dB – decibels, MHz – Megahertz, V – volts

Five 6DOF sensors were used during testing. Three were secured on the animal, one was fastened underneath the backboard, and one was secured on the litter berth. Figure 5 shows the sensor placement on the animal. The sensors on the backboard and litter berth were placed approximately underneath the animal's center of gravity (Figure 6). In Figure 6, the sensors' locations are indicated by the red circles. The sensor information was recorded using the EFDAS.

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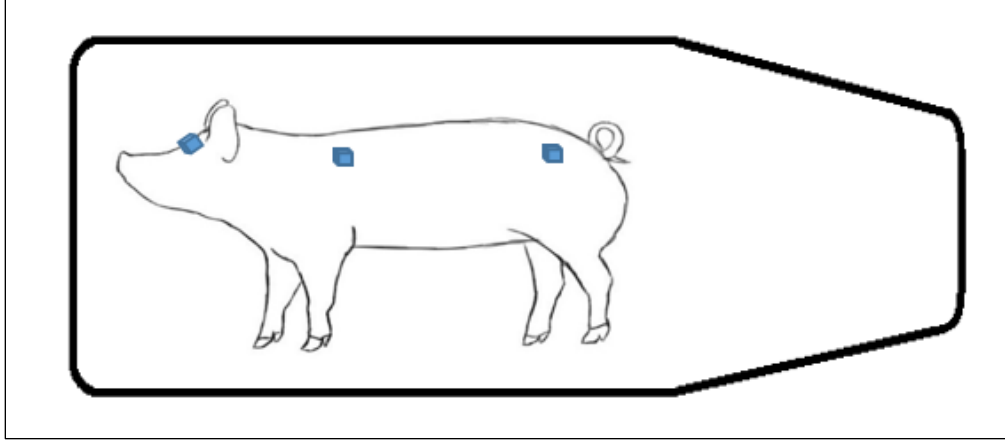


Figure 5. Animal 6DOF sensor locations.



Figure 6. Spine board 6DOF sensor location (left), and litter pan sensor location (right).

On days where multiple animals were tested, two sensor configurations were used, either ‘A Board’ or ‘B Board.’ Due to periods of monitoring where the subjects could not be touched, there were separate sets of 6DOF sensors used for the animal and the spine board during testing. The sensor connections for ‘A Board’ and ‘B Board’ configurations can be seen in Appendix B in Tables B1 and B2, respectively. The sensors placed on the vehicle, backboard, and animal subject measured vibration acceleration in three main axes (x -axis, vehicle front-to-back; y -axis, vehicle side-to-side; and z -axis, ground-to-sky) and can be seen defined in Figure 7.

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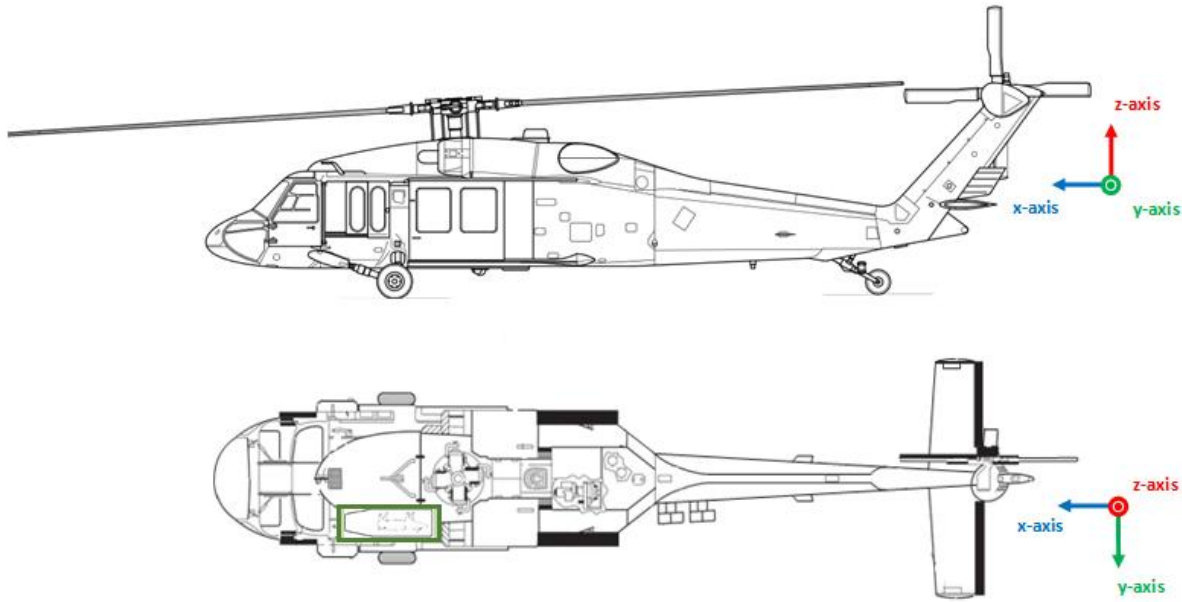


Figure 7. Coordinate system for 6DOF sensors.

Four temperature sensors were used during the flight profiles. The temperature sensors were placed in different locations in the aircraft. The first was packaged with the animal between the animal's skin and the blanket. The second was placed on the wall above the litter pan with the packaged animal. The third was placed on the center console, co-located with some of the other environmental sensors. The fourth temperature sensor was located above the left pilot seat.

On the center console of the aircraft, a microphone and ambient pressure sensor were also placed next to the temperature sensor, seen in Figure 8. The microphone was a PCB Piezotronics low-profile surface pressure microphone (Model 130B40) and was used to monitor the ambient sound levels in the cabin of the aircraft during testing. The ambient pressure sensor was used to verify the altitude readings from the GPS.

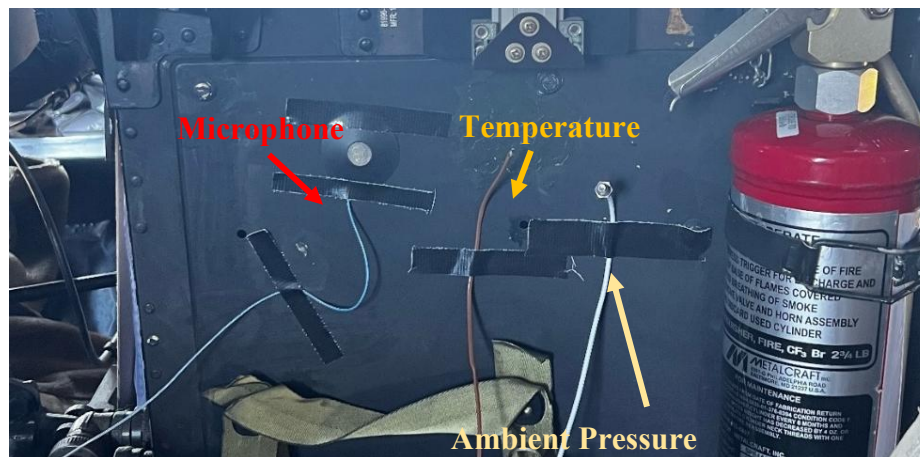


Figure 8. Sensors mounted on aircraft center console.

Above the left pilot seat, a GPS unit was mounted in the window so that it could receive signal from satellites. The GPS needed to be able to connect to at least three satellites to know where the aircraft was located. This became an issue during sharp turns and the GPS unit lost signal multiple times.

Subject Securing

Before transport, the animal was secured to a standard NATO litter with a North American Rescue (NAR) Spine Board on top of the litter. Figure 9 shows the NATO litter, National Stock Number (NSN) # 6530-01-380-7309, and Figure 10 shows the NAR Spine Board NSN # 6530-01-490-2487.



Figure 9. NATO Litter.



Figure 10. NAR Spine Board.

To provide cushion and warmth, rolled U.S. Army wool blankets (NSN# 7210-00-715-7985) were used to bolster the animal on either side. Another wool blanket was used to cover the animal during flight. To secure the animal to the litter with the backboard, National Industries for the Blind Canvas Webbing Patient Securing Cargo Straps (litter straps) and the Spider Strap XL, NSN # 6530-01-593-0010, were used (Figure 11). To stabilize the head during transport, the Morrison Medical Head Immobilizer, NSN# 6530-01-619-1777, was attached to the backboard.



Figure 11. Spider Strap XL (left) and Morrison Medical Head Immobilizer (right).

Medical Devices

Several medical devices were used during testing. This section defines the devices used during the study including before, during, and after transport.

Zoll Propaq MD.

The patient monitor used for this study was the Zoll Propaq MD (Figure 12) (Zoll Medical Corporation, New York, NY). The Zoll Propaq MD is the patient monitor used for patient care during U.S. Army air MEDEVAC, as it is part of the U.S. Army Air Ambulance Medical Equipment Set (MES). The equipment in the MES are updated periodically, but the Zoll Propaq MD is a part of the current 257C version of the MES (U.S. Army Medical Materiel Agency, 2015).



Figure 12. Zoll Medical Propaq MD patient monitor

The vital signs monitored and recorded by the Propaq MD for this study are listed in Table 2 (Zoll Medical Corporation, 2011). This data was saved to the internal storage of the device and was copied off the device at the end of each data collection event. Also, the Propaq MD is configurable to display up to four waveforms, which were recorded for later export.

Table 2. Propaq MD Vital Sign Value Recording Specifications

Parameter	Specification	Range	Frequency
ICP	± 2 mmHg or 2% of reading, whichever is greater, plus transducer error	-30 to 300 mmHg	2 samples/minute (min)
Partial pressure of brain tissue oxygen (PbrO ₂)	± 2 mmHg or 2% of reading, whichever is greater, plus transducer error	-30 to 300 mmHg	2 samples/min
Invasive blood pressure mean arterial pressure (MAP)	± 2 mmHg or 2% of reading, whichever is greater, plus transducer error	-30 to 300 mmHg	2 samples/min
Capnography (CO ₂)	CO ₂ Partial Pressure*: Accuracy** 0-38 mmHg: ± 2 mmHg 39-99 mmHg: ± (5% of reading + 0.08% for every 1 mmHg above 38 mmHg) 100-150 mmHg: ± (5% of reading + 0.08% for every 1 mmHg above 38 mmHg)	0 to 150 mmHg	2 samples/min
Oxygen saturation	70-100%: ± 3% 0-70%: unspecified	0 to 100%	2 samples/min
Systolic blood pressure	± 2 mmHg or 2% of reading, whichever is greater, plus transducer error	-30 to 300 mmHg	2 samples/min
Diastolic blood pressure	± 2 mmHg or 2% of reading, whichever is greater, plus transducer error	-30 to 300 mmHg	2 samples/min
Respiration rate	0 to 70 beats per minute (bpm): ±1 bpm 71 to 120 bpm: ± 2 bpm 121 to 150 bpm: ± 3 bpm	0 to 150 Breaths/min (BrPM)	2 samples/min
Heart rate		30 to 300 bpm	2 samples/min
Temperature	± 0.1° C from 10° C to 50° C ± 0.2° C from 0° C to 10° C	0°-50° C	2 samples/min

Note. * At sea level.

**Accuracy applies for breath rates of up to 80 bpm. For breath rates above 80 bpm, accuracy is 4 mmHg or ± 12% of reading whichever is greater, for EtCO₂ (End tidal CO₂) values exceeding 18 mmHg. This is tested according to and is compliant with International Organization for Standardization (ISO) 21647. To achieve the specified accuracies for breath rates above 60 BrPM, the Microstream FilterLine H Set for infant/neonatal must be used. Above 40° C, ± 1 mmHg or ± 2.5% (whichever is greater) has to be added to the tolerance of the accuracy specifications.

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Raumedic.

The Raumedic Neurovent (Raumedic AG, Helmbrechts, Germany) device was used by the LBRI team to collect data during the study. The physiological sensors for ICP and PbrO₂ plugged into the Raumedic before plugging into the Zoll Propaq MD. The Raumedic Neurovent is a device that measures and logs the ICP. During the transport, the Raumedic NPS2 (Raumedic AG, Helmbrechts, Germany) was used to measure the ICP. The Raumedic devices were swapped during the packaging of the subject to the back board and litter. The Raumedic NPS2 device also connected to the physiological sensors for ICP and PbrO₂, but its smaller size made it more portable for transport. After transport was completed, the Raumedic Neurovent NPS2 was swapped back to the Raumedic Neurovent. Both devices can be seen in Figure 13.



Figure 13. Raumedic Neurovent (left), and Raumedic NPS2 (right).

Hamilton-T1 Ventilator.

The Hamilton-T1 Ventilator (Hamilton Medical, Inc., Reno, NV) is the current ventilator used in patient care in U.S. Army air MEDEVAC, as it is part of the U.S. Army Air Ambulance MES (Figure 14). Similar to the Zoll Propaq MD, the Hamilton-T1 (Hamilton Medical, 2020) is currently a part of the 257C version of the MES (Medical Equipment Set Air Ambulance, 2024). This device was used for ventilation of the subjects, but only during the aeromedical evacuation of the animal in the aircraft. The required ventilation settings specific to the animal species were determined by the physicians on the LBRI team, but USAARL's CCFP operated the device in flight.

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Figure 14. Hamilton-T1 ventilator.

Belmont Medical Buddy Lite.

The Buddy Lite (Figure 15) (Belmont Medical Technologies, Billerica, MA) is a blood warmer that was used to warm the shed blood reinfused to the animal during aeromedical evacuation. It is a part of the 257C version of the MES (Medical Equipment Set Air Ambulance, 2024). The system works by funneling the blood through a single use cartage that is secured into a heating unit of the device. The output temperature of the device is $38^{\circ}\text{C} \pm 2^{\circ}\text{C}$ (Belmont Medical Technologies, n.d.).



Figure 15. Buddy Lite Blood Warmer.

Physiological Data Preparation

Several types of physiological data were collected during this study. For this data analysis, arterial blood pressure (ABP) and ICP are discussed. Both vitals were collected from the baseline period before the injury model was applied until the end of the continuous monitoring phase, which was shortly after the blood draw at 210 minutes. The data was collected as continuous waveform data sampled at 125 Hz, and as discrete values by the Zoll Propaq every 30 seconds. When analyzing the data, seven points of interest, or epochs, were determined. For each of these epochs, a 10-minute window was analyzed and, when possible, the cleanest 5

minutes of data was used for analysis. This was defined as the 5-minute window with the least number of artifacts. The ABP and ICP data were time-synced when the data was selected. The seven epochs were defined as:

- Baseline (BL)
 - Data taken before the TBI and HS procedures were performed, but after the surgery to place the femoral catheters and ICP probes.
- TBI + 10 minutes (TBI)
 - Data taken ten minutes after the TBI injury was performed; the ten minutes allowed the equipment to be re-attached to the animal and recalibrated. TBI is considered time zero for rest of the data collection times.
- Blood Draw at 105 minutes (BD105)
 - Data taken before the blood draw conducted at 105 minutes after TBI; during this time the animal was not being touched to reduce motion artifacts.
- Start Aeromedical Evacuation (Start AE)
 - Data taken after aeromedical evacuation had started, which was around 125 minutes after TBI.
- Mid Aeromedical Evacuation (Mid AE)
 - Data taken in the middle of the aeromedical evacuation (155 minutes after TBI).
- End Aeromedical Evacuation (End AE)
 - Data taken at the end of the aeromedical evacuation (185 minutes after TBI).
- Blood Draw at 210 minutes (BD210)
 - Data taken before the 210-minute blood draw; during this time the animal was not being touched to reduce motion artifacts.

ABP.

The ABP waveform was captured at 125 Hz on the Zoll Propaq. The MAP data was calculated from the ABP waveform that was collected. To prepare the ABP data for analysis, a finite impulse response low-pass filter was used to remove signal noise. The filter's passband cutoff frequency was 20 Hz, and the stopband cutoff frequency was 25 Hz. Then, a moving mean filter was applied in MATLAB to smooth the data with a window of 5 data points.

ICP.

ICP is a measurement of the pressure of cerebrospinal fluid in the subarachnoid space or the space between the skull and the brain. ICP is used in monitoring TBI injuries because an increase in ICP values can be caused by swelling of the brain or edema, which is common in TBI injuries (Pinto et al., 2023).

The ICP data analysis was performed in MATLAB R2023b and Microsoft Excel. To process the ICP waveform data, the motion artifacts were first removed. The pre-processing performed within the Zoll is unknown, and could not be provided by the manufacturer, as it is

proprietary information. Per the Zoll Propaq MD Operator's Guide (Zoll Medical Corporation, 2011), the monitor adheres to MIL-STD 810G, Method 514.6, which tests if the device can operate in the vibration profiles for the UH-1, UH-60, and CH-47 rotary-wing aircraft.

To process the data, this analysis utilized the methodology proposed by Feng et al. (2011) and Dai et al. (2020) to remove non-vibration motion artifacts from the ICP data. First, a finite impulse response low-pass filter was used to remove signal noise, which was generated by MATLAB(R) 23.2 and Signal Processing Toolbox 23.2 FIRPM function. The sampling rate was 100 Hz. The filter's passband cutoff frequency was 20 Hz, and the stopband cutoff frequency was 25 Hz. Second, empirical mode decomposition was performed using the MATLAB emd() function to reduce signal into its component intrinsic mode functions. Third, the Hampel identifier, a variation of the 3σ filter, was used to identify the artifact sites in the data stream using mean-absolute deviation. The MATLAB hampel() function was used for this. Fourth, an auto-regressive moving average function was created in MATLAB and used to replace the artifacts identified by the 3σ filter.

After the non-vibration motion artifacts were removed, the data for each epoch was selected for each animal when available. The data was filtered with a lowpass filter with a passband of 20 Hz to remove high frequency vibration noise, and then a moving mean filter with a window of 5 data points was used to smooth the data.

Cerebral perfusion pressure (CPP).

The CPP was calculated by subtracting the ICP from the MAP data. CPP describes the pressure gradient that facilitates the delivery of oxygen to cerebral tissue (Mount & Das, 2023). CPP is one component of cerebral blood flow, which is the volume of blood passing through a unit of brain tissue at a given time (Fantini et al., 2016). Clinically, CPP is used when managing patients with intracranial pathology, such as a TBI, and hemodynamic instability or shock (Mount & Das, 2023). Injuries involving intracranial pathology influence the ICP, typically resulting in a pressure increase. This increase in ICP will result in a decrease of the CPP value. In cases involving hemodynamic instability, a decrease in the MAP value may be observed, leading to a decrease in CPP. This calculation was completed with the filtered ICP and MAP data, then the average of the results were taken and can be seen below for the different configurations.

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Subjects

For the study, a total of 25 animals were tested and are shown in Table 3. Four did not survive to transport and one tactical animal (SID 3629) was transported but was removed from the study population. This animal likely experienced respiratory arrest during the blood loss phase and exhibited misleading vital signs prior to transport. This left the three transport conditions with the following number of subjects, Standard: $N = 7$, Tactical: $N = 7$, and Mock: $N = 6$.

Table 3. Cohort Animal List

Date	Animal ID	Transport Condition	Sensor Configuration
10/17/2023	3631	Mock	A board
10/17/2023	3677	Mock/did not transport*	B board
10/18/2023	3630	Tactical/did not transport*	A board
10/18/2023	3667	Standard	B board
10/19/2023	3620	Tactical	A board
10/19/2023	3614	Tactical/did not transport*	B board
10/20/2023	3642	Tactical	A board
10/20/2023	3629	Tactical*	B board
10/23/2023	3638	Standard	A board
10/23/2023	3679	Standard	B board
10/24/2023	3663	Standard	A board
10/24/2023	3676	Standard	B board
10/25/2023	3641	Mock	A board
10/25/2023	3665	Tactical	B board
10/26/2023	3720	Mock	A board
10/26/2023	3716	Tactical	B board
10/30/2023	3637	Standard	A board
10/30/2023	3711	Mock	B board
10/31/2023	3656	Standard/did not transport*	A board
10/31/2023	3724	Mock	B board
10/31/2023	3719	Tactical	A board
11/1/2023	3709	Tactical	A board
11/1/2023	3640	Standard	B board
11/2/2023	3728	Mock	A board
11/2/2023	3635	Tactical	B board

Note. *Not usable for transport data analysis.

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Results

The data analyses for this project were performed in MATLAB R2024, R Studio Version 4.4.0 software and Microsoft Excel. There were two types of data that were examined in this report, environmental data and physiological data. The environmental data was only collected during the aeromedical transport of the subject, whereas the physiological data was collected from the Zoll Propaq that was attached to the animal during the entire study.

Environmental Data Analysis

The environmental data analyzed in this study includes GPS, altitude, temperature, sound level, acceleration, and rotation.

GPS data.

GPS data was collected for the flight profiles; the system needed to be in line with three satellites to keep accurate positioning. Figure 16 shows an example of the standard flight profile in two dimensions (2D). The aircraft took off and went in a straight path forward with minimal turns and turned around halfway into the flight to return to the landing site. Figure 17 shows the altitude changes during the flight in three dimensions (3D).

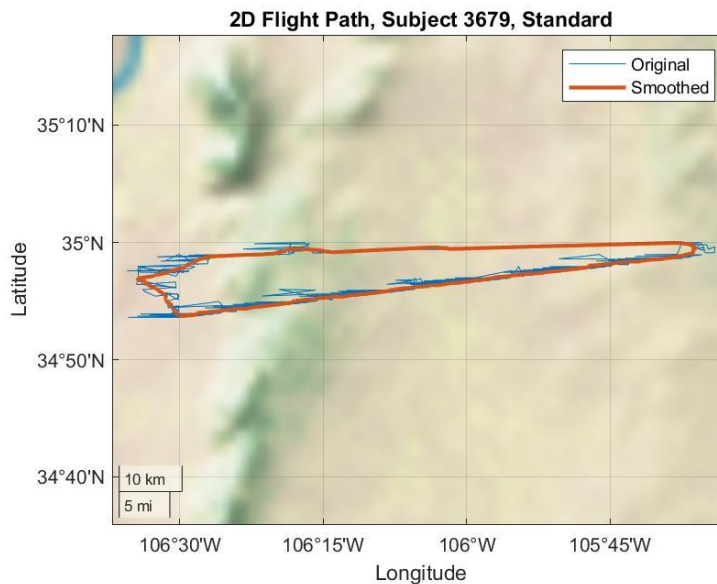


Figure 16. Standard flight profile 2D flight path example.

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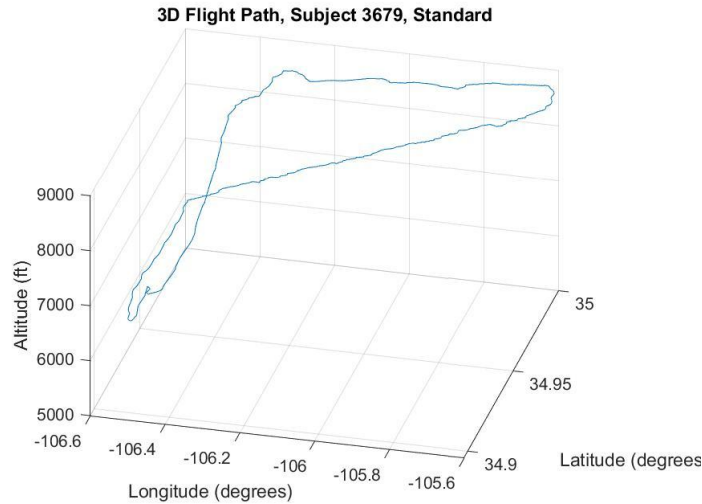


Figure 17. Standard flight profile 3D flight path example.

Figure 18 shows a tactical flight profile in 2D. The flight started with a straight flight path at high speeds, then nap-of-the-earth maneuvers were performed, and the profile ended with another straight flight path at high speeds. For this flight profile, there was some variability in the presentation of the tactical maneuvers, but the pilots tried to keep the same general flight path. Figure 19 shows the tactical flight profile in 3D showing the altitude changes.

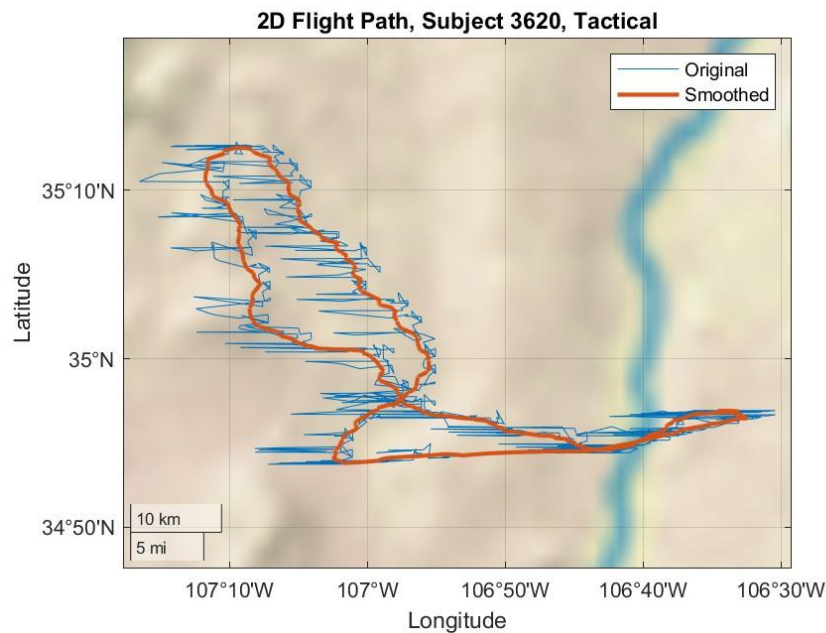


Figure 18. Tactical flight profile 2D flight path example.

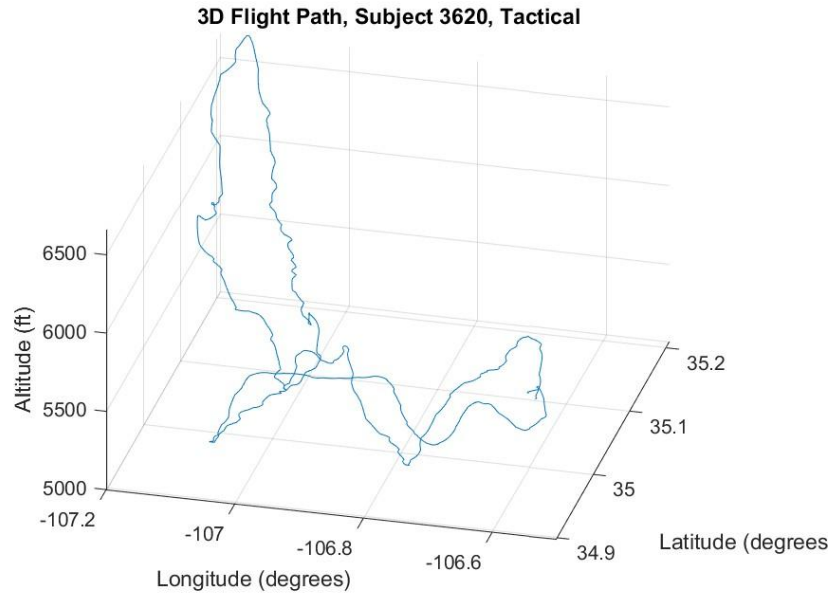


Figure 19. Tactical flight profile 3D flight path example.

Altitude.

Figure 20 shows the altitudes for the standard and tactical cohorts. In the legend of the graph, the animals' subject IDs have either an (S) or (T), which indicates either standard or tactical flight profile, respectively. The starting altitude of all flights from the landing zone was 5780 ft above sea level. For the standard flight animals, it can be seen on the graph that the aircraft rose to the max altitude of around 8500 ft until descending around 55 minutes into the flight. For animal 3638 (S), the max altitude recorded by the GPS unit is around 7800 ft, which is lower than the rest of the standard cohort.

For the tactical flight cohort, the GPS data shows maneuvers with rapid decreases and increases in altitude, which was part of the study design. The tactical profile started and ended with a low altitude approach to some canyons near the landing zone. At the canyons the aircraft followed a “nap-of-the-earth” approach following the general terrain of the land at 500 ft above ground level, this is also why some of the altitudes are lower than the starting altitude.

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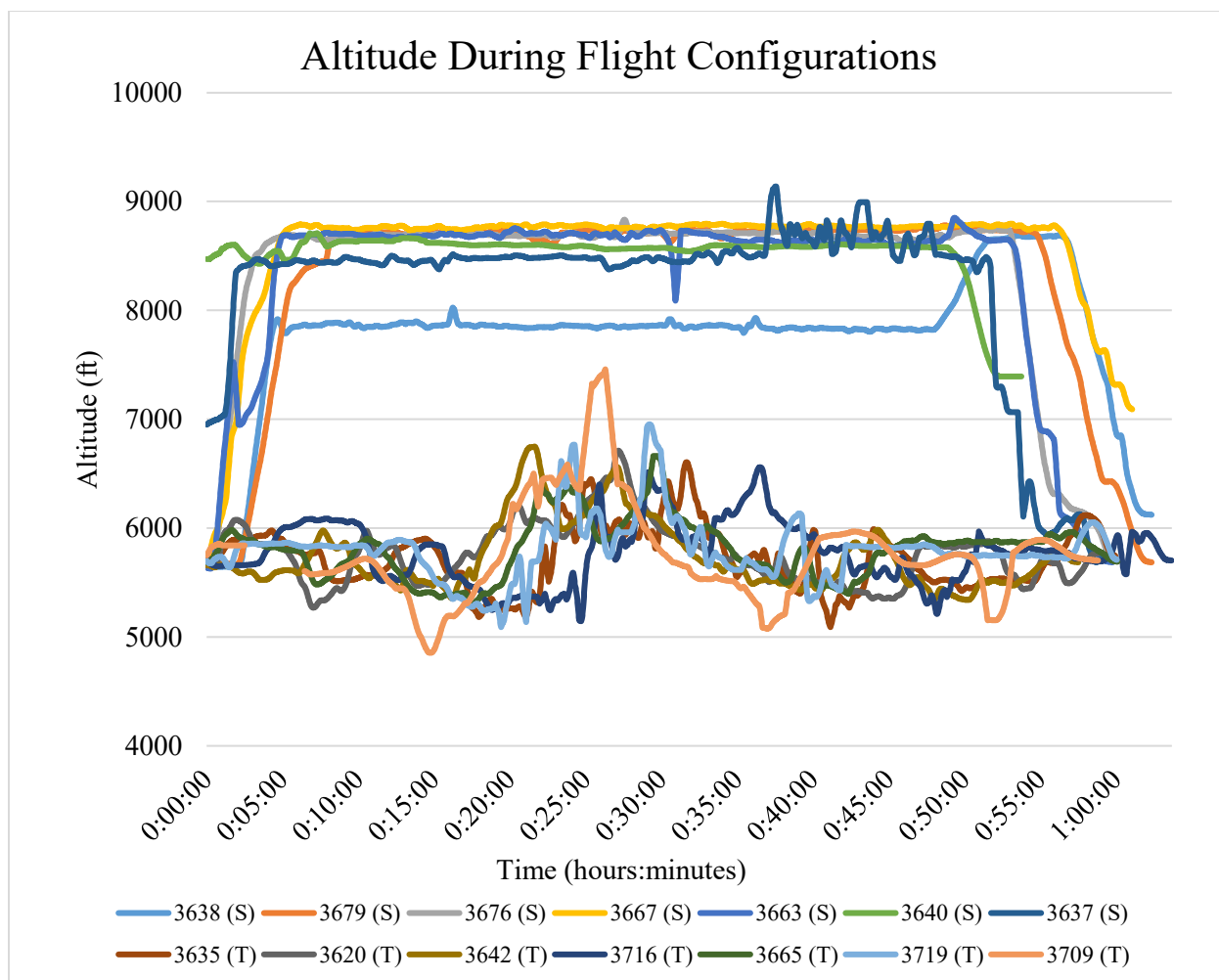


Figure 20. Altitude comparison for standard and tactical flight configurations.

Temperature.

Four temperature probes were connected to the EFDAS during the flights. There was a sensor placed in the following locations: between the blanket and the subject, on the wall of the aircraft above the litter pan, on the center console of the aircraft, and on the wall above the left pilot. The flight testing was completed in October in Albuquerque, NM, where the average daily temperature based off the National Weather Service data was 16.4° C. Figure 21 shows the average temperatures for the sensors during the entire transport of the standard transport animals. The blue line represents the temperature sensor placed between the blankets of the subject, which had an average temperature of 35° C. This temperature was likely influenced by the hypothermia prevention used, which included standard Army wool blankets and Ready Heat thermal blankets. The other sensors, exposed to the ambient environment in the aircraft, showed colder temperatures.

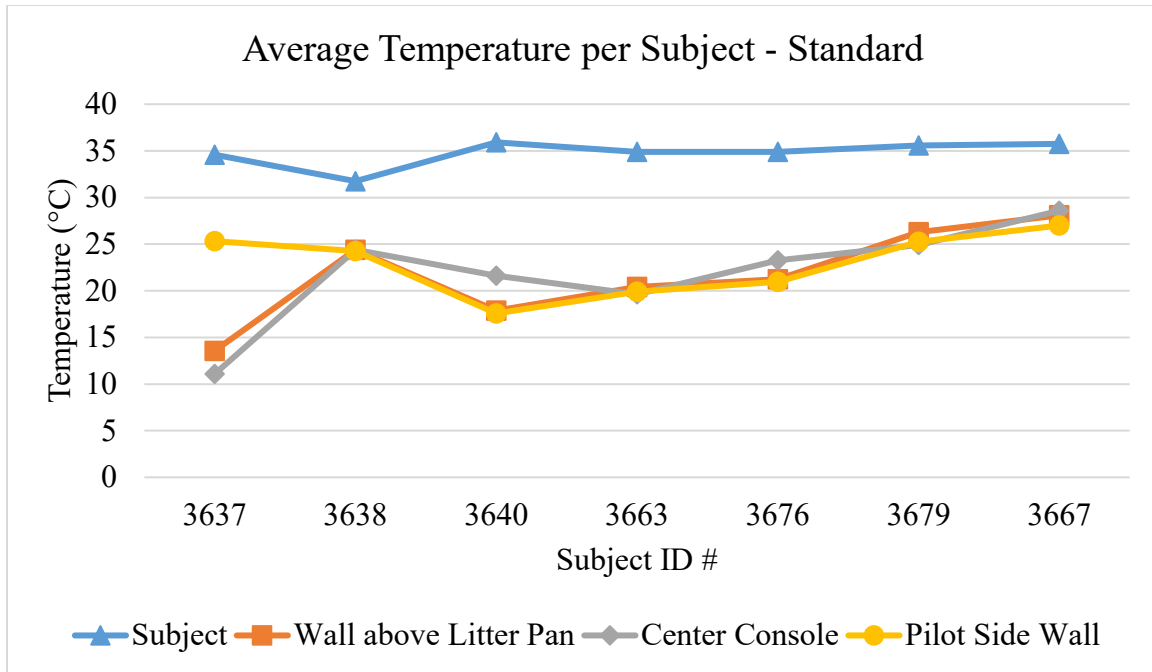


Figure 21. Average temperature by subject ID for standard flight profiles.

Figure 22 shows the average temperature for the tactical subjects for the different sensor locations. Similar to the standard profiles, the temperature sensor placed with the animal recorded the highest temperature of around 35° C. The other sensors were placed in locations where they were exposed to open air, which showed colder temperatures.

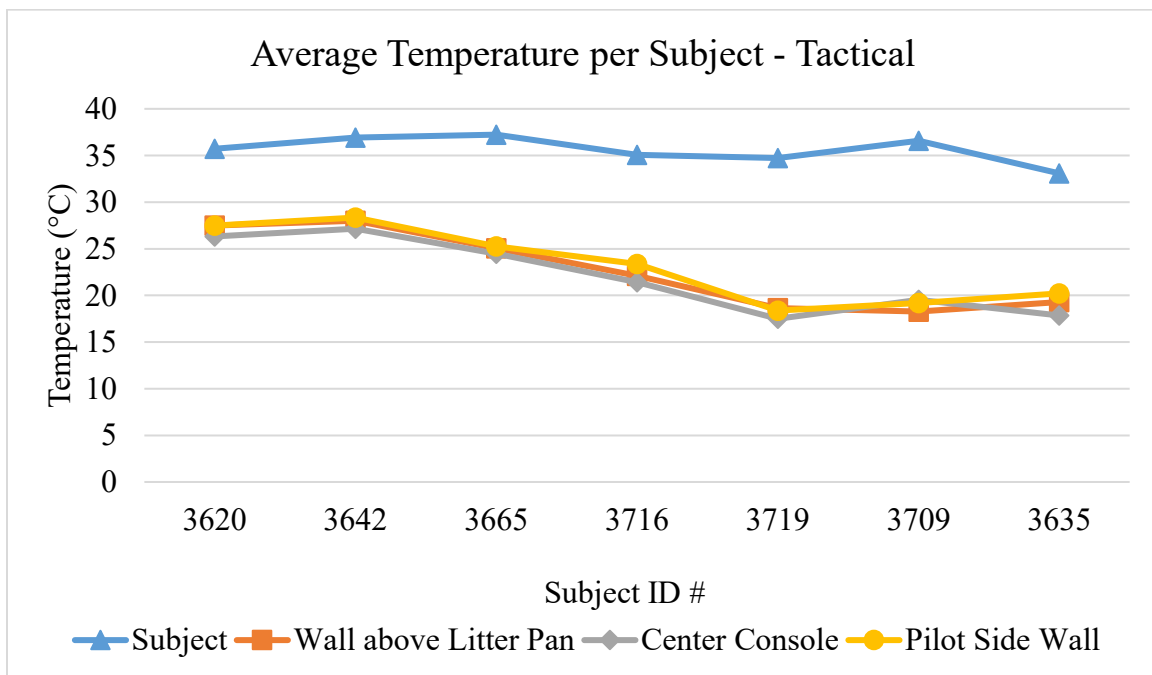


Figure 22. Average temperature by subject ID for tactical flight profiles.

Figure 23 shows the average across the flight profiles by sensor location. The standard flight profiles are shown by the blue bars, and the tactical flight profiles are represented by the orange bars. There was no statistical difference between the profiles, even though the standard profile flights were completed at a higher altitude and exposed to colder temperatures.

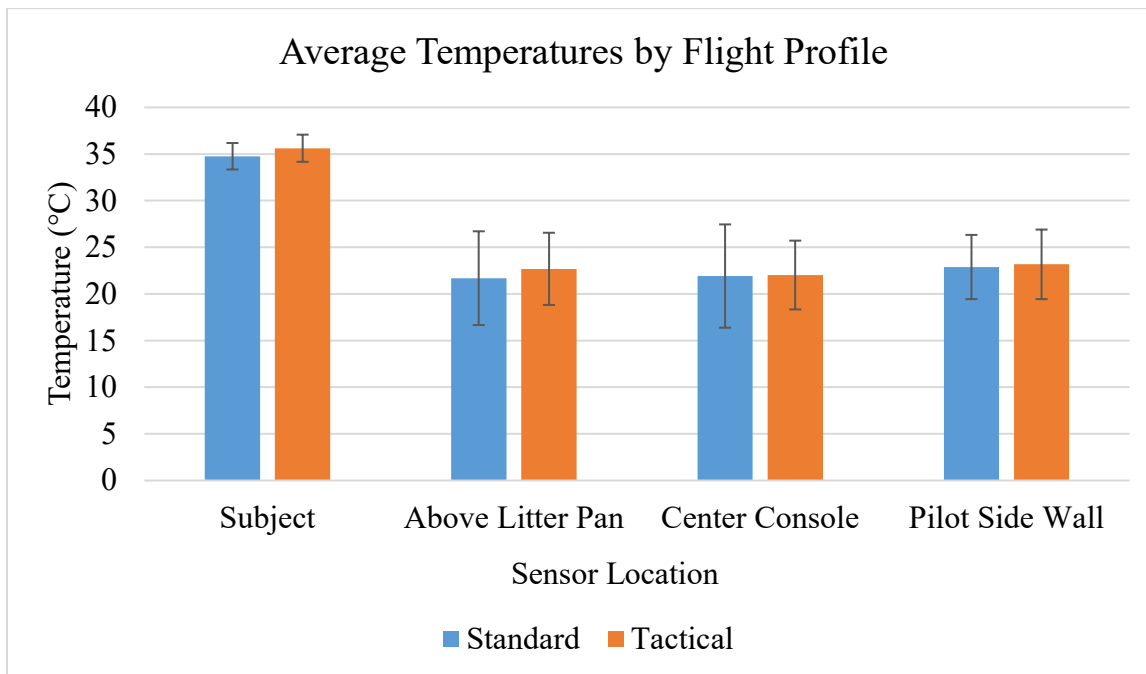


Figure 23. Average of temperature by flight profile.

Decibel level (noise).

A microphone was placed on the center console of the aircraft to capture the sound level of the interior of the cabin during transport. Everyone on board had ear protection, except for the animal subject. The sound levels during the transport profiles can be seen in Figure 24. The blue line is the average sound level across all seven standard profile subjects (110.1 dB, $SD \pm 2.4$ dB). Each standard animal individual sound level is represented by the blue triangles. There was an outlier with animal #4, which was subject 3663, which was removed when calculating the average sound level. The study notes were examined and there was no notable difference in flight profile; it is assumed this reduction in noise is from a study member blocking the microphone during transport or a malfunction in the equipment. The orange line is the average of the tactical animals (109.2 dB, $SD \pm 2.6$ dB), and the individual animals in the tactical profile are represented by the orange squares.

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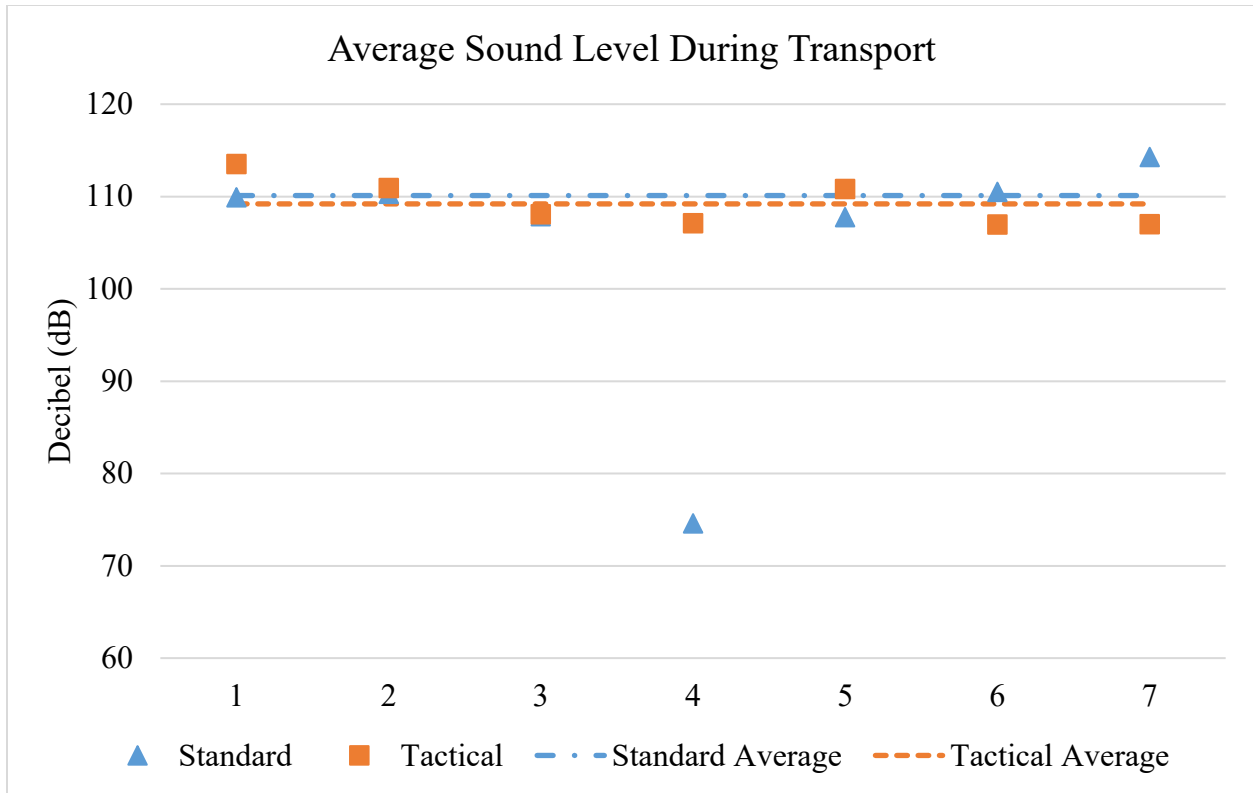


Figure 24. Average decibel level during transport by flight profile.

Acceleration and rotation.

Root mean square (RMS).

One way to determine the amount of vibrational energy present in a signal is to calculate the RMS of the acceleration values over a particular period of time. RMS acceleration is the square root of the sum of each acceleration value squared, divided by the total number of values. This allows the averages of amplitudes to be calculated. If a signed average was calculated the negative values would cancel out the positive values. The equation for this calculation is shown in Figure 25.

$$RMS = \sqrt{\frac{1}{N} \sum_{i=1}^N x(i)^2}$$

Figure 25. RMS equation.

The full acceleration RMS data for each subject can be found in Appendix C in Tables C1-C3. Figure 26 shows the average RMS acceleration values for the standard flights by axes for each 6DOF sensor. The “Helicopter” sensor in the graphs refer to the 6DOF sensor that was mounted on the litter pan that the animal was placed on during transport. The average RMS values for the tactical flights can be seen in Figure 27.

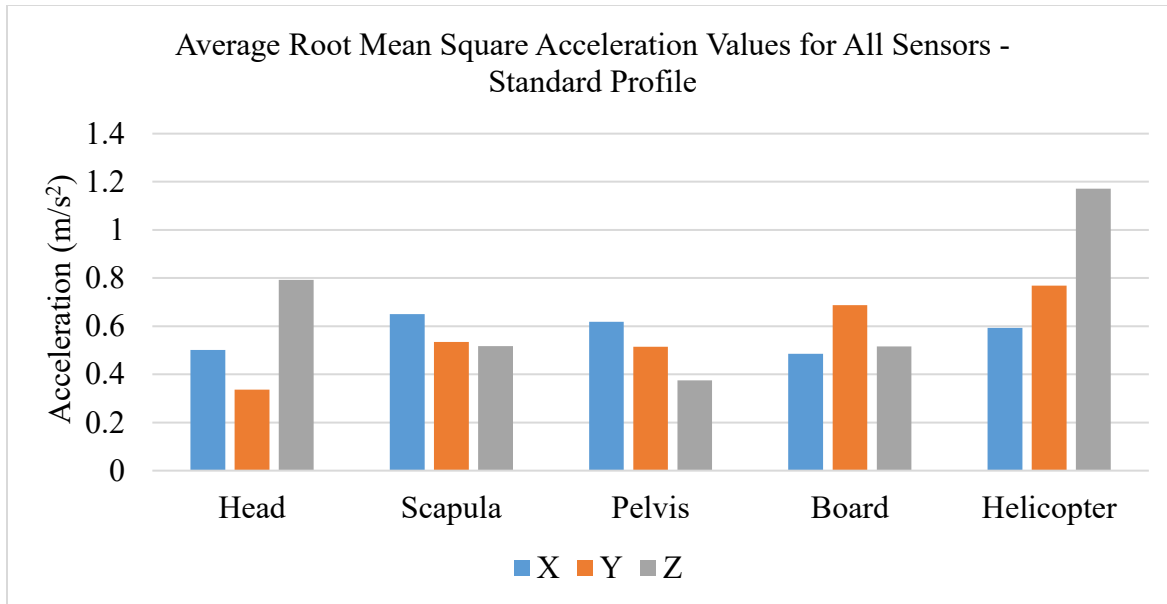


Figure 26. Average RMS acceleration values for the standard profile.

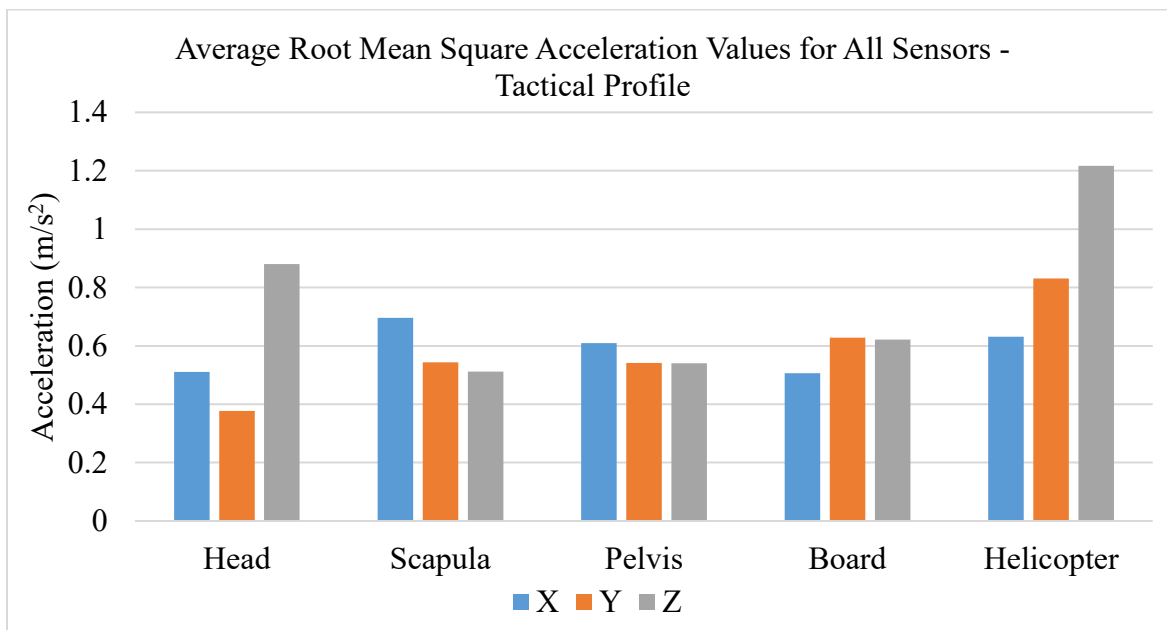


Figure 27. Average RMS acceleration values for the tactical profile.

The acceleration averages for the tactical profile flights are higher in amplitude than the standard profile flight accelerations in all but three of the axes (scapula z -axis, pelvis x -axis, and board y -axis). Table 4 shows the averages of the RMS values and the percent differences of the axes.

Table 4. Average Acceleration RMS Values and Percent Difference

Standard – Average Acceleration RMS Values					
Axis	Head	Scapula	Pelvis	Board	Helicopter
X	0.50 m/s ²	0.65 m/s ²	0.62 m/s ²	0.49 m/s ²	0.59 m/s ²
Y	0.34 m/s ²	0.54 m/s ²	0.51 m/s ²	0.69 m/s ²	0.77 m/s ²
Z	0.79 m/s ²	0.52 m/s ²	0.38 m/s ²	0.52 m/s ²	1.17 m/s ²
Tactical – Average Acceleration RMS Values					
Axis	Head	Scapula	Pelvis	Board	Helicopter
X	0.51 m/s ²	0.70 m/s ²	0.61 m/s ²	0.51 m/s ²	0.63 m/s ²
Y	0.38 m/s ²	0.54 m/s ²	0.54 m/s ²	0.63 m/s ²	0.83 m/s ²
Z	0.88 m/s ²	0.51 m/s ²	0.54 m/s ²	0.62 m/s ²	1.22 m/s ²
Average Acceleration Percent Difference of RMS Values					
Axis	Head	Scapula	Pelvis	Board	Helicopter
X	1.97 %	6.83 %	1.52 %	4.11 %	6.24 %
Y	11.65 %	1.61 %	5.03 %	9.12 %	7.80 %
Z	10.57 %	1.04 %	36.00 %	18.54 %	3.75 %

A statistical analysis using a t-test with a two tailed distribution assuming unequal variance was completed using the full dataset values in Appendix B. Table 5 shows the p-values for the t-test, assuming a significance of 0.05. There was only one statistically significant difference between the RMS for the standard and tactical profiles, which was seen in the board z -axis (bolded in table).

Table 5. t-Test Results for Acceleration RMS Values

Axis	Head	Scapula	Pelvis	Board	Helicopter
X	0.75	0.60	0.86	0.64	0.50
Y	0.23	0.82	0.61	0.61	0.64
Z	0.33	0.94	0.15	0.02	0.76

The RMS for the gyroscope values (rotational velocity) were found using the equation in Figure 24 as well. The rotational velocity values were all squared and divided by the total number of values, then square root was taken. Figure 28 shows the average RMS values for the standard flights by axes for the rotational values. The average rotational RMS values for the tactical flights can be seen in Figure 29. The full rotational RMS data for each subject can be found in Appendix B in Tables B4-B6.

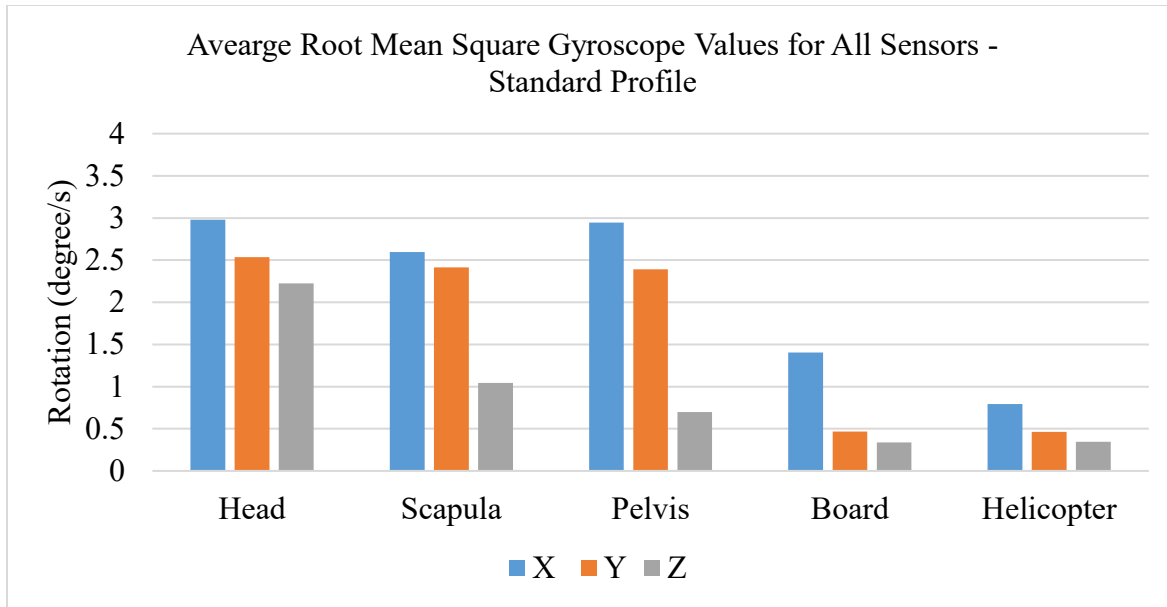


Figure 28. Average RMS rotational velocity values for the standard profile.

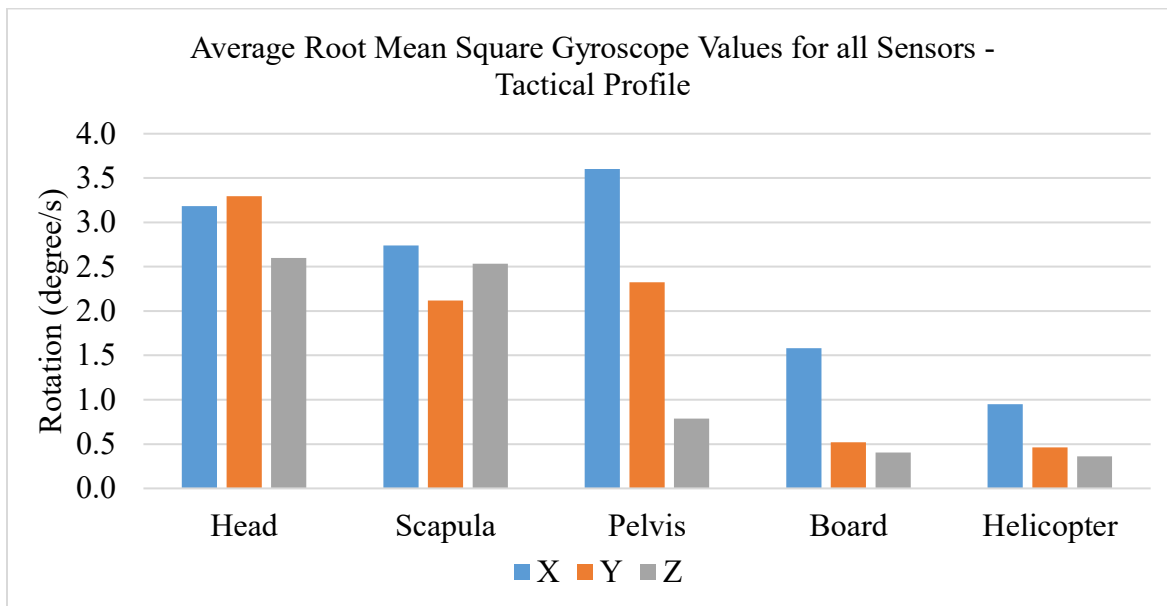


Figure 29. Average RMS rotational velocity values for the tactical profile.

The average rotational RMS for the tactical profile flights were higher in amplitude than the standard profile flight acceleration in all but three of the axes which were all in the y-axis (scapula, pelvis, and helicopter). Table 6 shows the averages of the RMS values and the percent differences of the axes.

Table 6. Average Acceleration RMS Values and Percent Difference

Standard – Average Rotational RMS Values					
Axis	Head	Scapula	Pelvis	Board	Helicopter
X	2.98 °/s	2.60 °/s	2.95 °/s	1.40 °/s	0.80 °/s
Y	2.53 °/s	2.41 °/s	2.39 °/s	0.47 °/s	0.46 °/s
Z	2.22 °/s	1.04 °/s	0.70 °/s	0.34 °/s	0.35 °/s
Tactical – Average Rotational RMS Values					
Axis	Head	Scapula	Pelvis	Board	Helicopter
X	3.18 °/s	2.74 °/s	3.60 °/s	1.58 °/s	0.95 °/s
Y	3.29 °/s	2.12 °/s	2.32 °/s	0.52 °/s	0.46 °/s
Z	2.60 °/s	2.53 °/s	0.79 °/s	0.40 °/s	0.36 °/s
Average Rotational Percent Difference of RMS Values					
Axis	Head	Scapula	Pelvis	Board	Helicopter
X	6.60 %	5.36 %	20.00 %	11.99 %	17.71 %
Y	26.07 %	12.98 %	2.91 %	11.24 %	0.08 %
Z	15.60 %	83.43 %	11.66 %	18.41 %	3.70 %

A statistical analysis using a t-test with a two tailed distribution assuming unequal variance was completed using the full dataset values in Appendix B. Table 7 shows the p-values for the t-test, assuming a significance of 0.05. There was only one statistically significant difference between the RMS for the standard and tactical profiles, which was seen in the board z-axis (bolded in table). The board z-axis was also statistically significant when comparing the acceleration values.

Table 7. t-Test Results for Rotational RMS Values

Axis	Head	Scapula	Pelvis	Board	Helicopter
X	0.84	0.80	0.19	0.35	0.32
Y	0.14	0.59	0.87	0.10	0.99
Z	0.45	0.38	0.83	0.02	0.17

The resultant RMS, or average of the three axes (x-, y- and z- axes), was also computed and the equation for this calculation is shown in Figure 30.

$$RMS = \sqrt{\frac{\sum_{i=1}^N x(i)^2 + y(i)^2 + z(i)^2}{N}}$$

Figure 30. Resultant RMS equation.

Figures 31 and 32 show the results of the resultant RMS values. In the graphs the standard values are blue, and the tactical values are orange. The *x*-axis shows the location of the sensor, and the *y*-axis shows the amplitude of the acceleration or rotation.

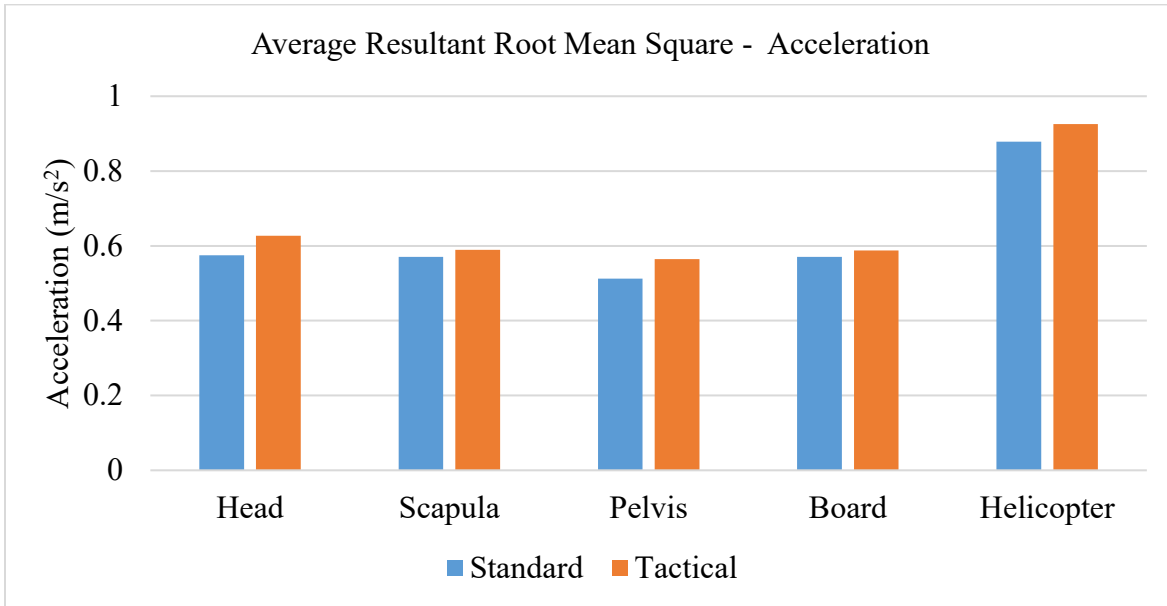


Figure 31. Average resultant RMS acceleration values.

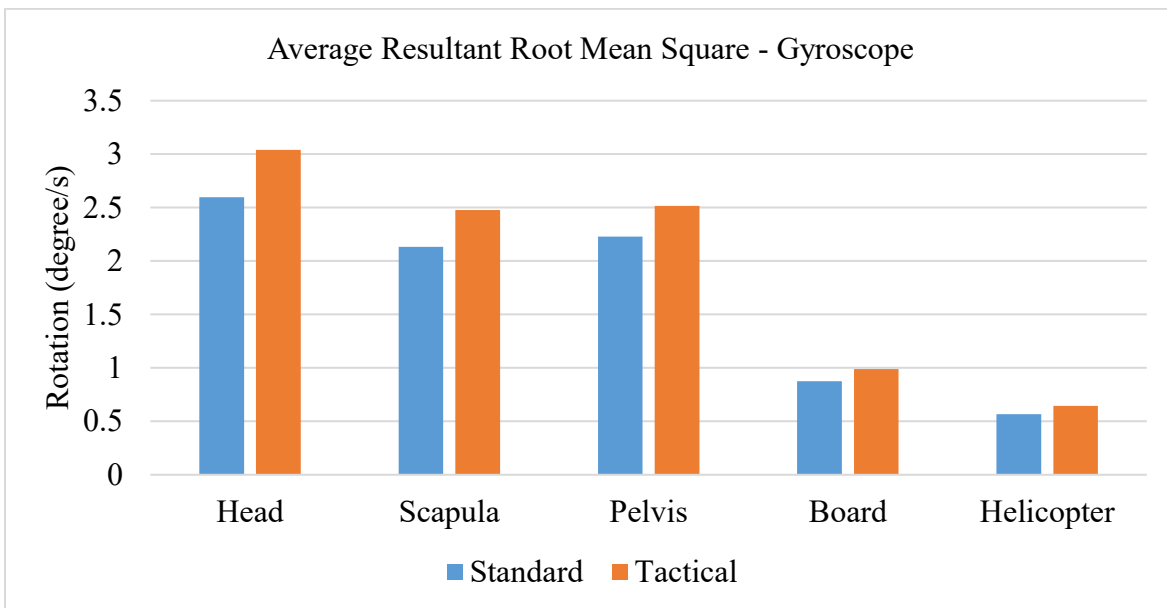


Figure 32. Average resultant RMS rotational values.

The average resultant RMS values for the tactical profile flights are higher in amplitude than the standard profile for both acceleration and rotational velocity for all sensors. Table 8 shows the resultant RMS values and the percent differences of the axes. For the acceleration values, the tactical is on average 5.9 % higher than the standard profile. However, for the

rotational values, the tactical profile is on average 13.5% higher than standard profile.

Table 8. Average Resultant RMS Values and Percent Difference

Standard – Average Resultant RMS Values					
	Head	Scapula	Pelvis	Board	Helicopter
Accel	0.57 m/s ²	0.57 m/s ²	0.51 m/s ²	0.57 m/s ²	0.88 m/s ²
Gyro	2.56 °/s	2.13 °/s	2.23 °/s	0.88 °/s	0.57 °/s
Tactical – Average Resultant RMS Values					
	Head	Scapula	Pelvis	Board	Helicopter
Accel	0.63 m/s ²	0.59 m/s ²	0.56 m/s ²	0.59 m/s ²	0.93 m/s ²
Gyro	3.04 °/s	2.48 °/s	2.52 °/s	0.99 °/s	0.64 °/s
Average Resultant Percent Difference of RMS Values					
	Head	Scapula	Pelvis	Board	Helicopter
Accel	8.66 %	3.26 %	9.63 %	3.04 %	5.19 %
Gyro	15.72 %	14.95 %	12.12 %	12.26 %	12.64 %

Fast Fourier Transforms.

The Fast Fourier Transforms (FFT) of the acceleration and gyroscope data were calculated using the MATLAB[®] SimpleFFT function. An FFT transforms signals from the time domain into the frequency domain, allowing the signal characteristics to be analyzed. Figures 33 and 34 show the average FFT for the standard and tactical flight profile subjects for the head sensor. These graphs were found by taking the individual FFTs of the acceleration data in the three axes during the aeromedical transport of each animal and then averaging them by flight profile. Most of the energy in the graphs can be found around 17.2 hertz (Hz). This is from main rotor blades of the Black Hawk helicopter. The fundamental frequency of the motor (4.3 Hz) multiplied by the number of rotor blades (4) creates the majority of the energy at 17.2 Hz frequency seen in the graphs (McFarland, 1983). Harmonics of the blades can also be seen at 4.3 Hz intervals following the peak at 17.2 Hz. When comparing the graphs for the acceleration FFT for the head sensors, the amplitudes of both flight profiles are similar for axes.

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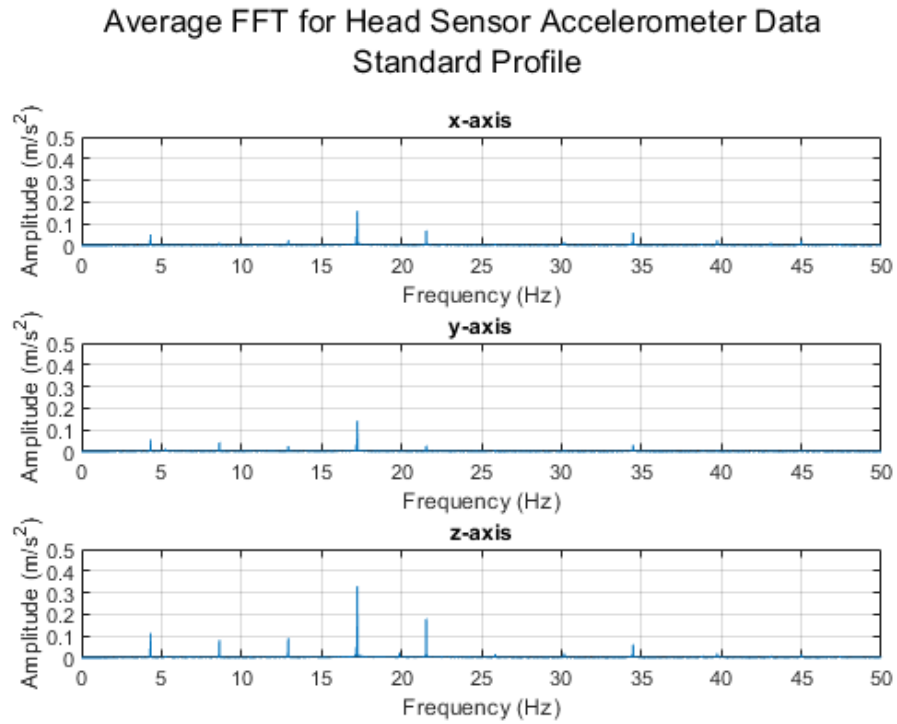


Figure 33. Average FFT for head sensor accelerometer data in the standard profile.

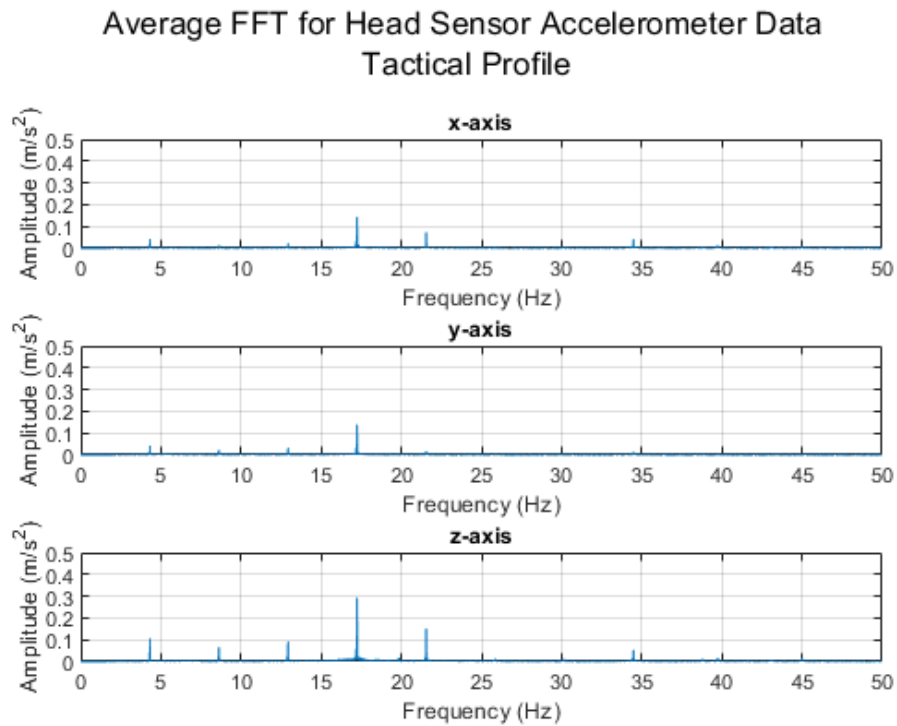


Figure 34. Average FFT for head sensor accelerometer data in the tactical profile.

Figures 35 and 36 show the average FFT for the gyroscope or rotational data for the head sensor for the standard and tactical ride profiles, respectively. The tactical profile has a slight increase in amplitude than the standard profile at the peaks. The peaks for the rotational data also appear to be at the 4.3 Hz intervals caused by the helicopter blades.

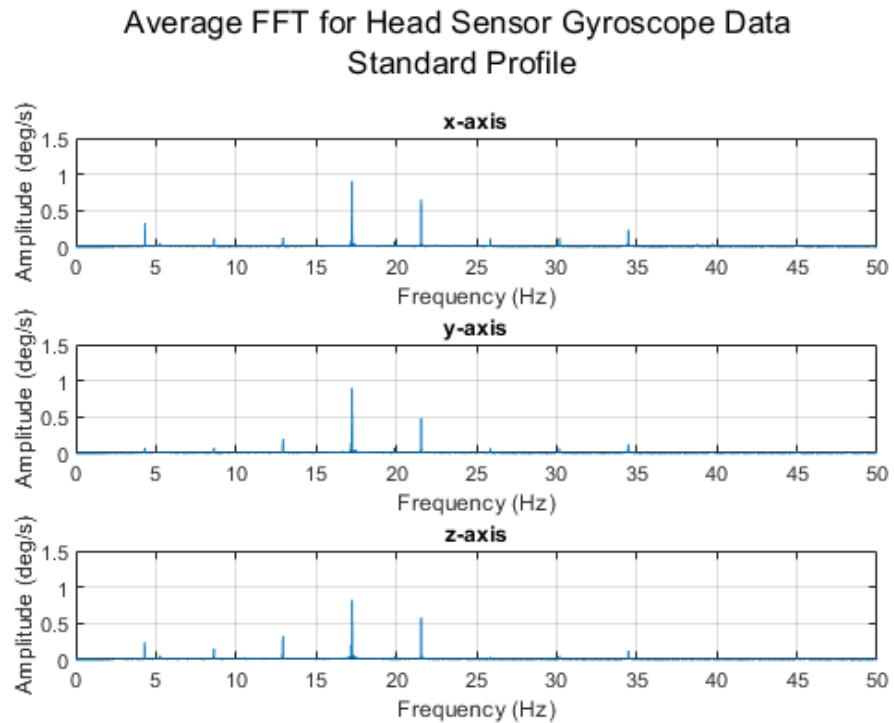


Figure 35. Average FFT for head sensor gyroscope data in the standard profile.

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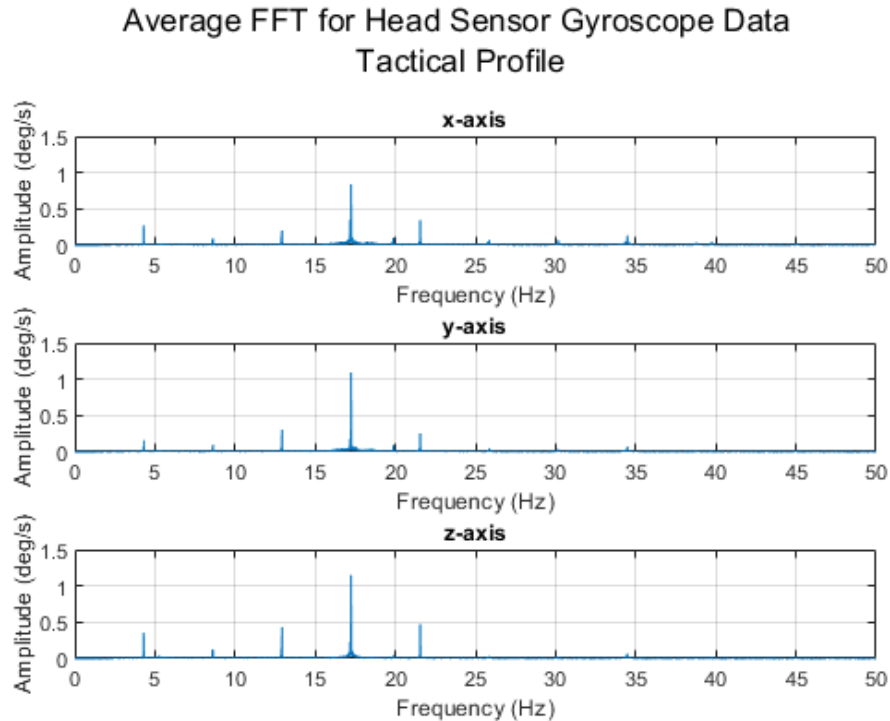


Figure 36. Average FFT for head sensor gyroscope data in the tactical profile.

PSD.

The PSD functions were also calculated from the dataset using MATLAB®. When plotted across specific frequency bands, PSD describes the frequencies at which energy is present and at what levels. This is of particular interest when higher levels of energy are present in frequency bands that are known to have possible health effects on humans during whole-body vibration. The average PSD graphs for the head sensor of the standard and tactical ride profiles can be seen in Figures 36 and 37. For both graphs, most of the energy is present at 17.2 Hz, which is the dominant frequency output of the Black Hawk helicopter blades. The amplitudes for both graphs are similar for the *x* and *y* axes. However, the amplitude for the *z*-axis (the bottom graph in Figures 37 and 38) shows a 33% increase in amplitude between the two flight profiles. The peak for the tactical profile is around 40 Hz, and the peak for the standard profile is around 30 Hz.

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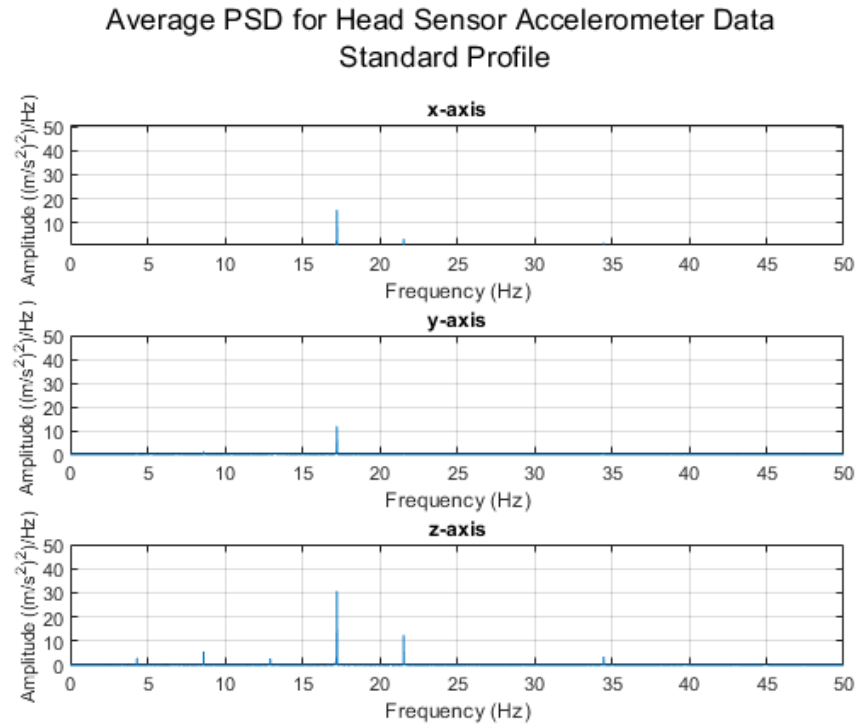


Figure 37. Average PSD for head sensor accelerometer data for the standard profile.

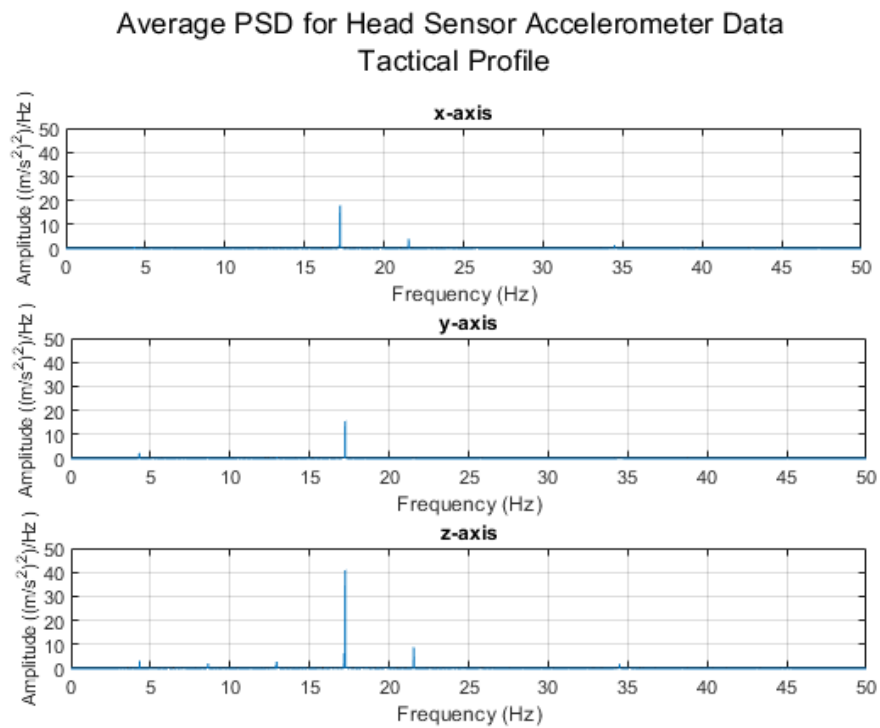


Figure 38. Average PSD for head sensor accelerometer data for the tactical profile.

Transmissibility.

Transmissibility is the ratio of the output vibration divided by the input vibration. If the ratio is above 1.0 then there is amplification in the system. A transmissibility below 1.0 indicates that the output signal was attenuated, and if the ratio is equal to 1.0 then the output signal is equal to the input. Transmissibility has been used to characterize the human system as a single-output/single-input function or as a multiple-output/multiple-input function (Paddan & Griffin, 1998; DeShaw & Rahmatalla, 2014; Hinz et al., 2010). For this analysis, the input acceleration was from the sensor placed on the litter berth of the helicopter. The output acceleration was the acceleration at each body segment of the subject (head, scapula, and pelvis). To find the transmissibility, the FFT of each segment was used to find the cross covariance, demonstrated in Table 9, which calculates the transmissibility in 3D space. While using the FFT of the input signals removes some of the risk of motion artifact and the data being out of phase, caution must be exercised when examining this analysis given the possibility for compounding errors in a narrow frequency band.

Table 9. Transmissibility Cross-Covariance Combinations

		Output Signal		
		Fore-Aft Output (X)	Lateral Output (Y)	Vertical Output (Z)
Input Signal	Fore-Aft Input (X)	Fore-aft output ÷ fore-aft input (X/X)	Lateral output ÷ fore-aft input (Y/X)	Vertical output ÷ fore-aft input (Z/X)
	Lateral Input (Y)	Fore-aft output ÷ lateral input (X/Y)	Lateral output ÷ lateral input (Y/Y)	Vertical output ÷ lateral input (Z/Y)
	Vertical Input (Z)	Fore-aft output ÷ vertical input (X/Z)	Lateral output ÷ vertical input (Y/Z)	Vertical output ÷ vertical input (Z/Z)

Note. / = divided by

Figures 38 through 41 show the average transmissibility cross-covariance for accelerometer and gyroscope data for the standard and tactical cohorts. On the graphs, the *x*-axis shows the frequencies, and the *y*-axis shows transmissibility ratio. In all of the graphs, the head versus helicopter is represented by the blue line, the scapula versus helicopter is represented by the orange line, and the pelvis versus the helicopter is represented by the yellow line.

Figure 39 shows the average transmissibility of the acceleration data for the standard profile animals during transport. The highest transmissibility is seen in the vertical output versus the lateral input (Z/Y) graph, with maximum for the scapula reaching 13.7 at 7.1 Hz. The peaks in transmissibility can be seen over the range of 0 to 20 Hz for all graphs, with a majority of the energy under 10 Hz. There is very little transmissibility in the vertical input graphs (X/Z, Y/Z, and Z/Z).

Average Transmissibility of Accelerometer Data FFT - Standard Profile

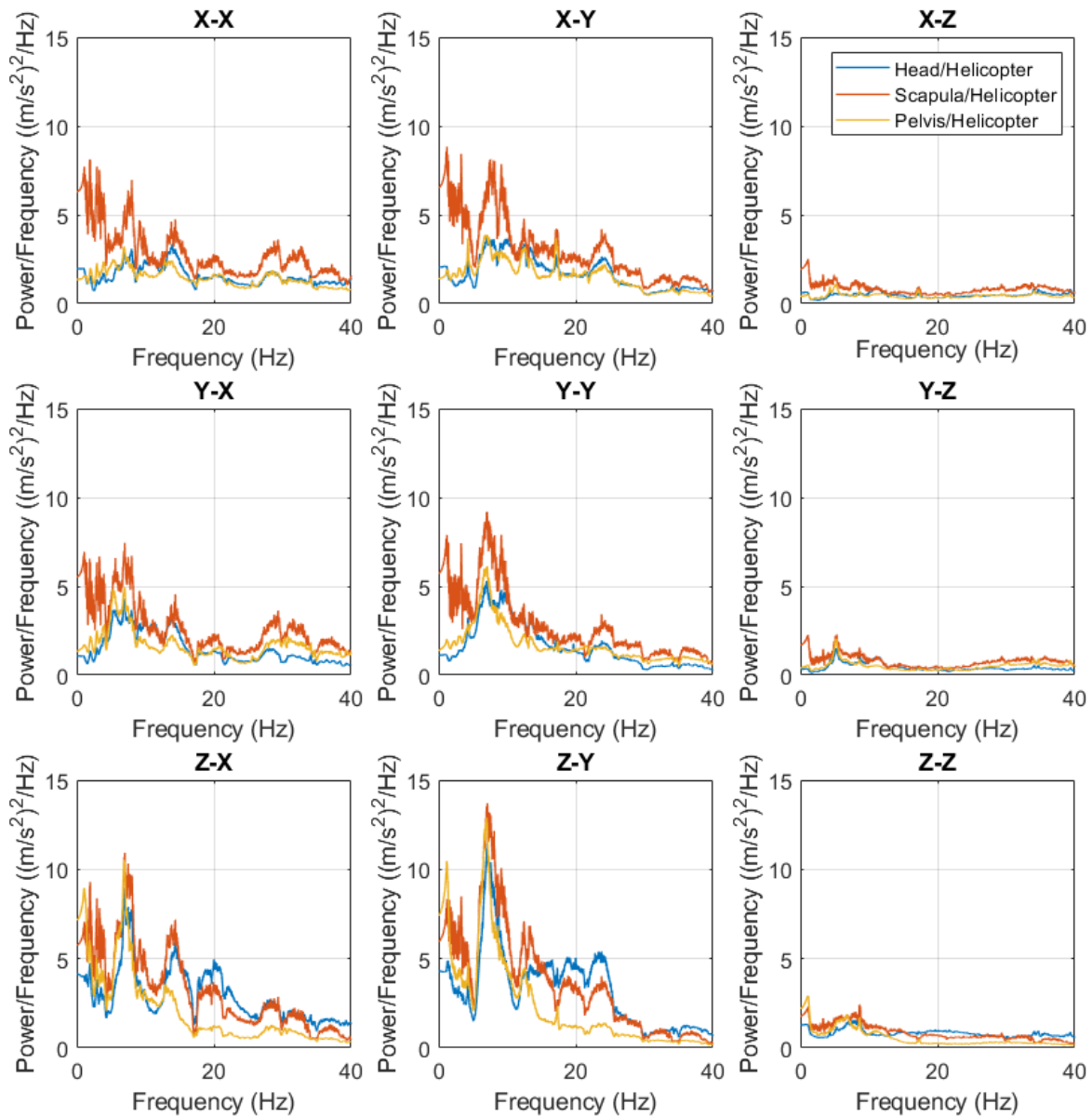


Figure 39. Average transmissibility of acceleration data – standard profile.

Figure 40 shows the average transmissibility of the acceleration data for the tactical profile animals during transport. The highest peaks can be seen in the Z/X and Z/Y graphs, with the peaks for the scapula reaching 13.4 at 7.1 Hz and 14.3 at 7.2 Hz, respectively. Similar to the standard profile, the transmissibility for the vertical input graphs have lower transmissibility than the rest of the axes.

Average Transmissibility of Accelerometer Data FFT - Tactical Profile

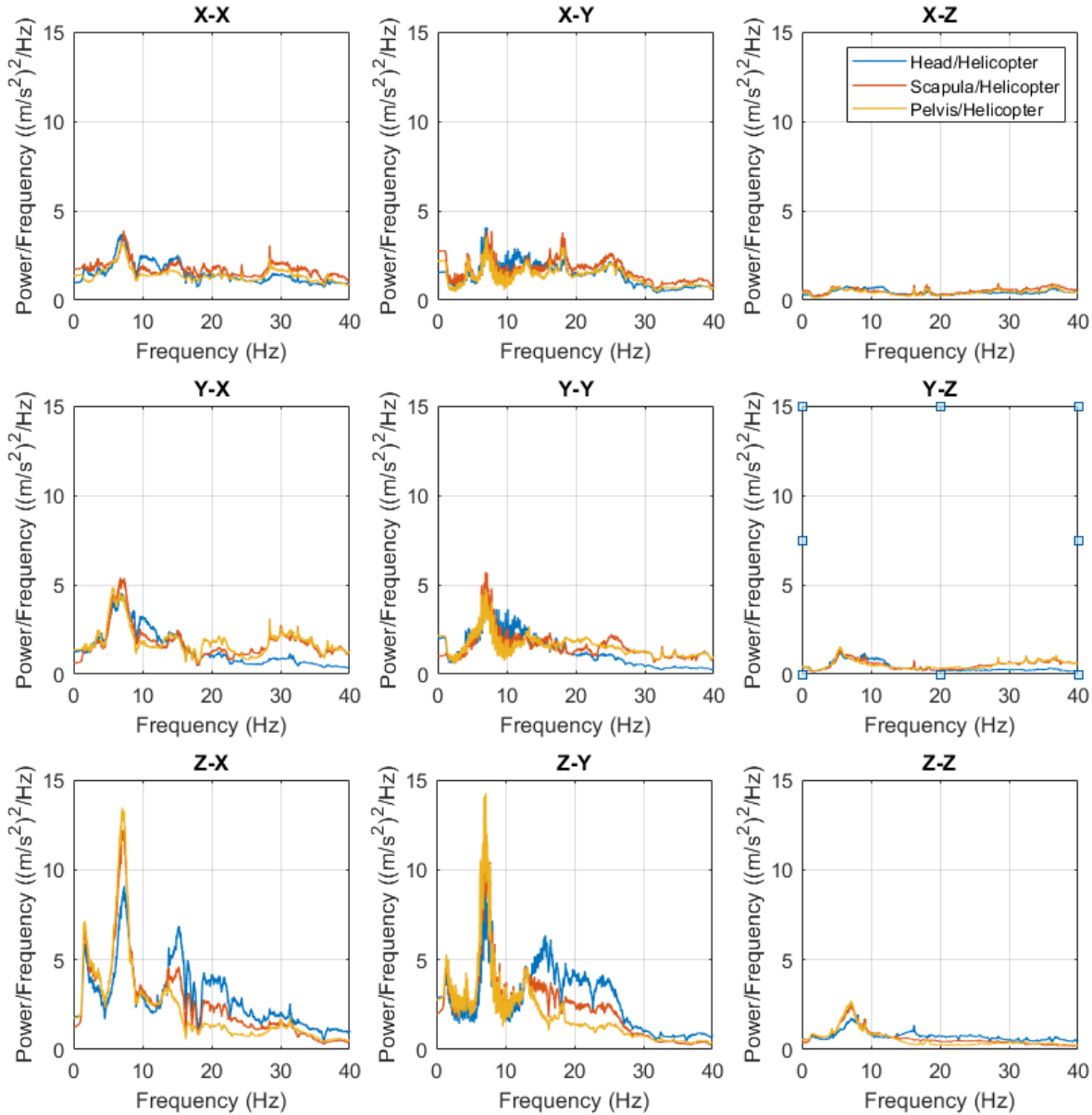


Figure 40. Average transmissibility of acceleration data – tactical profile.

Figure 41 shows the average transmissibility of the rotational data for the standard profile animals during transport. The scapula sensor shows the highest transmissibility in all of the axes, peaking at 26.1 at 8.1 Hz. In the vertical input graphs (X/Z, Y/Z, and Z/Z), there is low transmissibility compared to the lateral and longitudinal input graphs. There is a peak in the lower frequencies (< 1 Hz), and this is likely an artifact due to the filtering of the data.

Average Transmissibility of Gyroscope Data FFT - Standard Profile

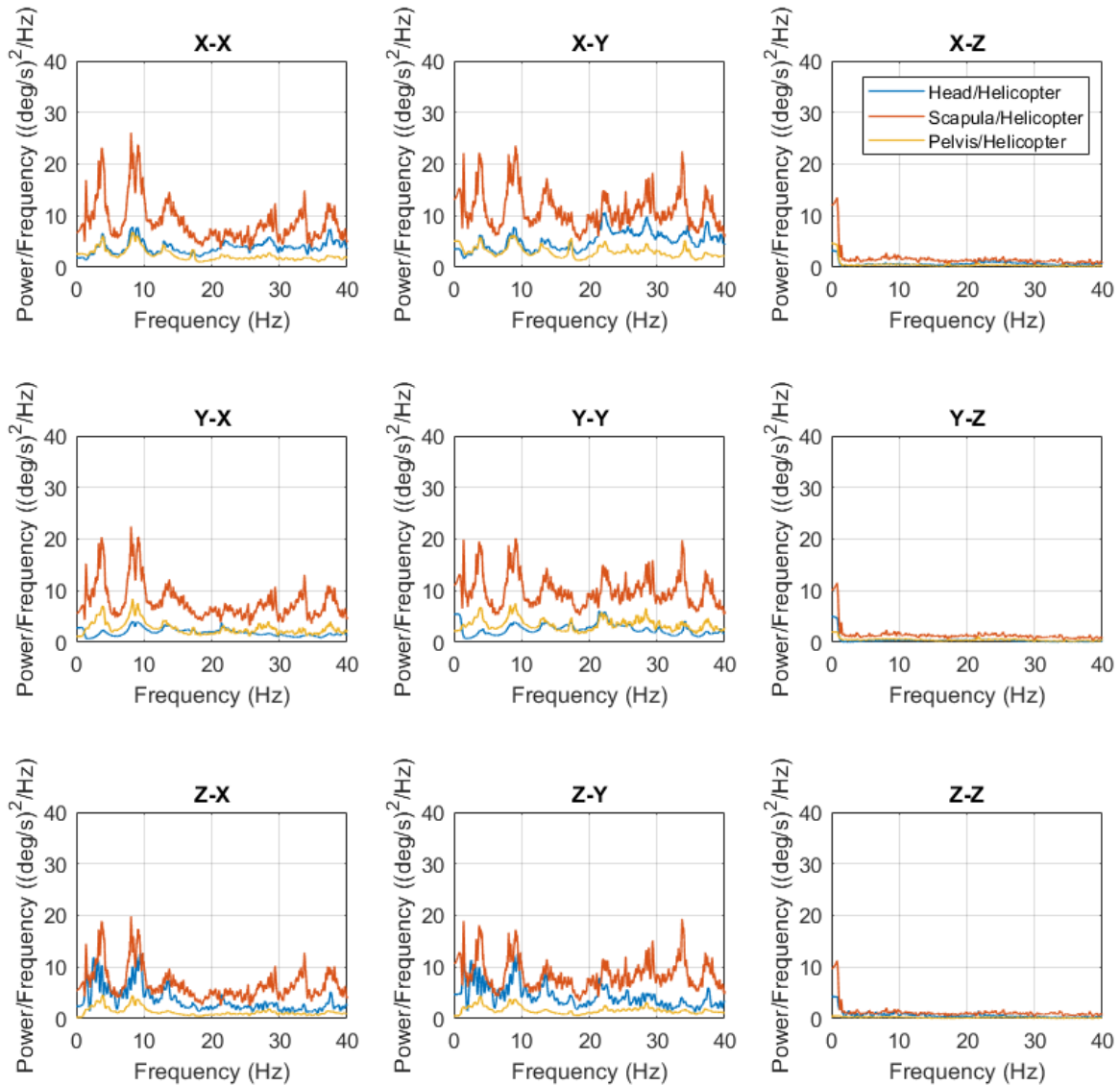


Figure 41. Average transmissibility of gyroscope data – standard profile.

Figure 42 shows the average transmissibility of the rotational data for the tactical profile animals during transport. The longitudinal input (X/X, Y/X, and Z/X) graphs show a low ratio value compared to the rest of the input axes. The vertical input axes show the highest transmissibility at 31.5 at 15.5 Hz for the (X/Z) graph and 27.4 at 17.5 Hz for the (Y/Z) graph.

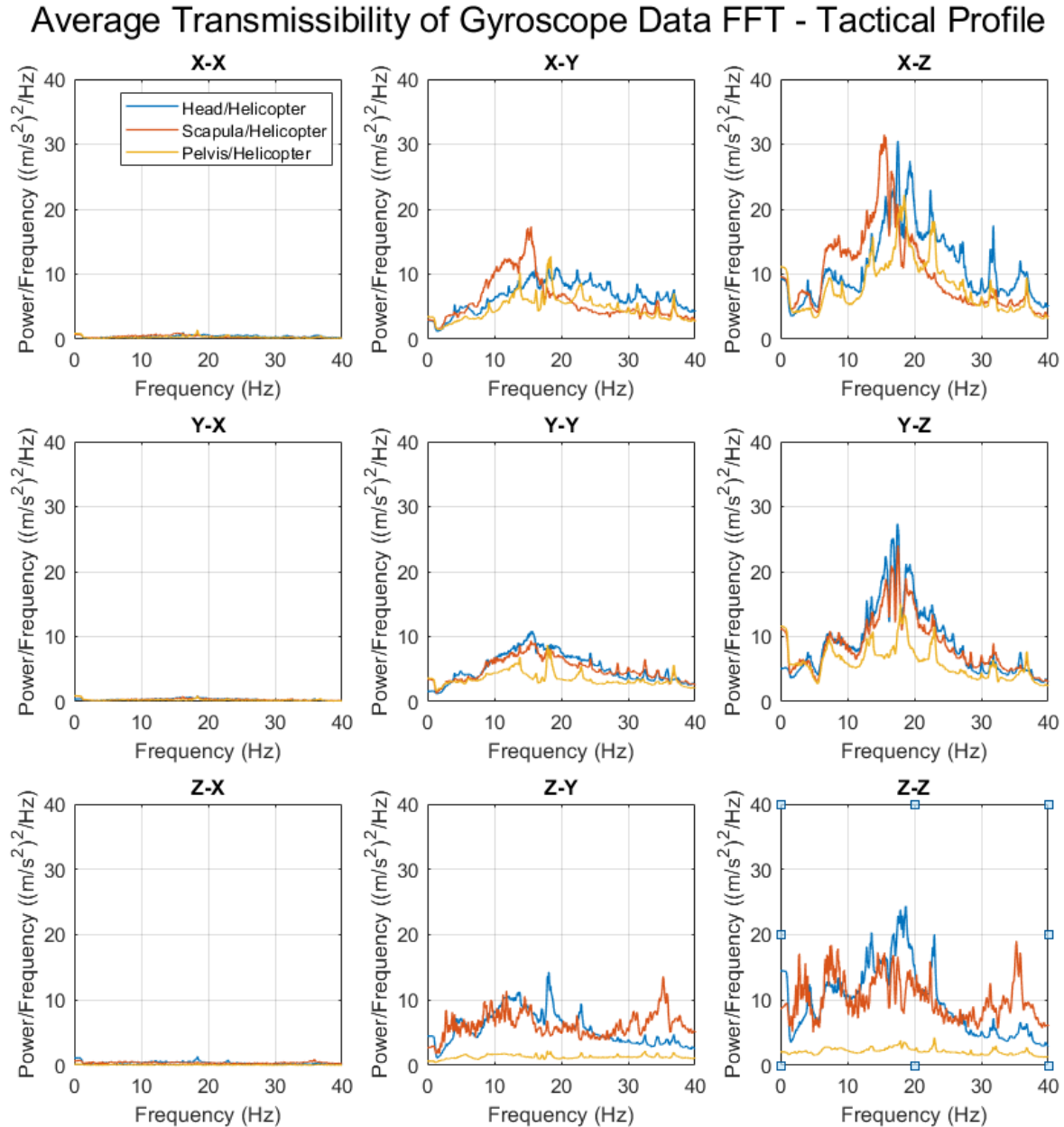


Figure 42. Average transmissibility of gyroscope data – tactical profile.

ABP.

To calculate the MAP, the systolic and diastolic blood pressures were found on the waveforms by finding the local minimums and maximums. The MAP was found by using those values in the Gauer formula (Gauer, 1960).

$$\text{MAP} = \text{Diastolic Pressure} + \frac{1}{3}(\text{Systolic Pressure} - \text{Diastolic Pressure})$$

The data for each epoch was then averaged over the epoch (5 minutes of data when possible) and can be found in Tables 10 through 12 for the different flight profiles. The individual figures for each flight profile can be found in Appendix D, Figures D1-D3. Data for each epoch for all subjects was not always available. If there was no usable data in the 10-minute window around the epoch, then no data was pulled for the epoch for that animal, this is indicated by “No data” in the tables. All values are in mmHG. The epochs are fully defined in the methods section but the acronyms are as follows: BL, TBI, BD105, Start AE, Mid AE, End AE, and BD210.

Table 10. Average MAP Values for the Standard Profile

Subject IDs – Standard								
	3667	3638	3679	3663	3676	3637	3640	Average
BL	64.96	No data	60.83	76.59	76.96	69.38	57.43	67.69
TBI	23.36	No data	18.27	No data	24.55	13.96	27.66	21.56
BD105	53.66	No data	66.62	46.61	45.40	65.12	56.85	55.71
Start AE	86.09	88.39	62.13	93.32	87.74	95.29	87.11	85.72
Mid AE	118.49	61.49	57.45	84.15	100.93	99.59	90.09	87.45
End AE	120.98	54.54	64.55	71.71	99.96	106.24	92.39	87.20
BD210	No data	51.05	52.58	72.23	96.71	47.39	73.29	65.54

Note. All values are in mmHg.

Table 11. Average MAP Values for the Tactical Profile

Subject IDs – Tactical								
	3620	3642	3665	3716	3719	3709	3635	Average
BL	86.48	78.80	No data	66.72	106.98	No data	86.90	85.18
TBI	20.53	56.62	No data	24.18	26.99	No data	12.78	28.22
BD105	50.97	No data	100.54	63.56	76.92	91.51	71.09	75.76
Start AE	75.67	108.54	129.98	No data	103.71	71.61	121.82	101.89
Mid AE	66.11	104.44	121.39	No data	115.07	109.28	124.96	106.88
End AE	67.03	134.48	111.72	No data	131.59	127.18	109.97	113.66
BD210	59.37	106.47	97.41	No data	118.91	115.18	70.79	94.69

Note. All values are in mmHg.

Table 12. Average MAP Values for the Mock Profile

	Subject IDs – Mock						
	3631	3641	3720	3711	3724	3728	Average
BL	68.69	60.76	No Data	79.98	No Data	74.95	71.10
TBI	22.41	34.72	50.71	40.60	45.70	15.83	35.00
BD105	55.30	54.26	63.08	57.39	54.33	62.49	57.81
Start AE	81.36	40.70	71.39	85.31	88.23	77.70	74.12
Mid AE	66.68	80.07	85.04	106.00	96.61	73.03	84.57
End AE	83.46	77.46	97.58	83.65	102.61	72.04	86.13
BD210	74.08	62.65	84.07	61.83	84.78	59.79	71.20

Note. All values are in mmHg.

Figure 43 shows the average MAP for all three flight profiles at the different epochs. The average MAP of all three flight profiles is also indicated in Figure 42 by the red dotted line. For all the epochs except TBI, the tactical profile had higher values. However, the tactical profile cohort also started with a higher baseline MAP than the other two configurations by an average of 15.8 mmHg. The general trend of the data for all profiles shows a large decrease in MAP after the TBI and hemorrhagic shock procedures. The average decrease was 44.0 mmHg over all profiles. The standard profile displayed an average decrease of 46.1 mmHg; the tactical profile had an average decrease of 57.0 mmHg, and the mock profile showed an average of 57.0 mmHg. At the BD105 epoch, the MAP recovered to an average of 82.8% of the baseline value. The MAP values for each profile continued to increase until the end of the AE profile. After the end of the AE period, each profile showed a decrease in MAP compared to the flight transport. The final BD210 average MAP values were within an average of 4.6 % of the BL values. In a separate publication (Mayer et al., 2026), the MAP values were grouped as pre-flight (BL, TBI, and BD105) and post-flight (Start AE, Mid AE, End AE, and BD210) then compared between the groups. The MAP of the SEF cohort during pre-flight was significantly lower ($p < 0.05$) than the TEF and mock flight profiles.

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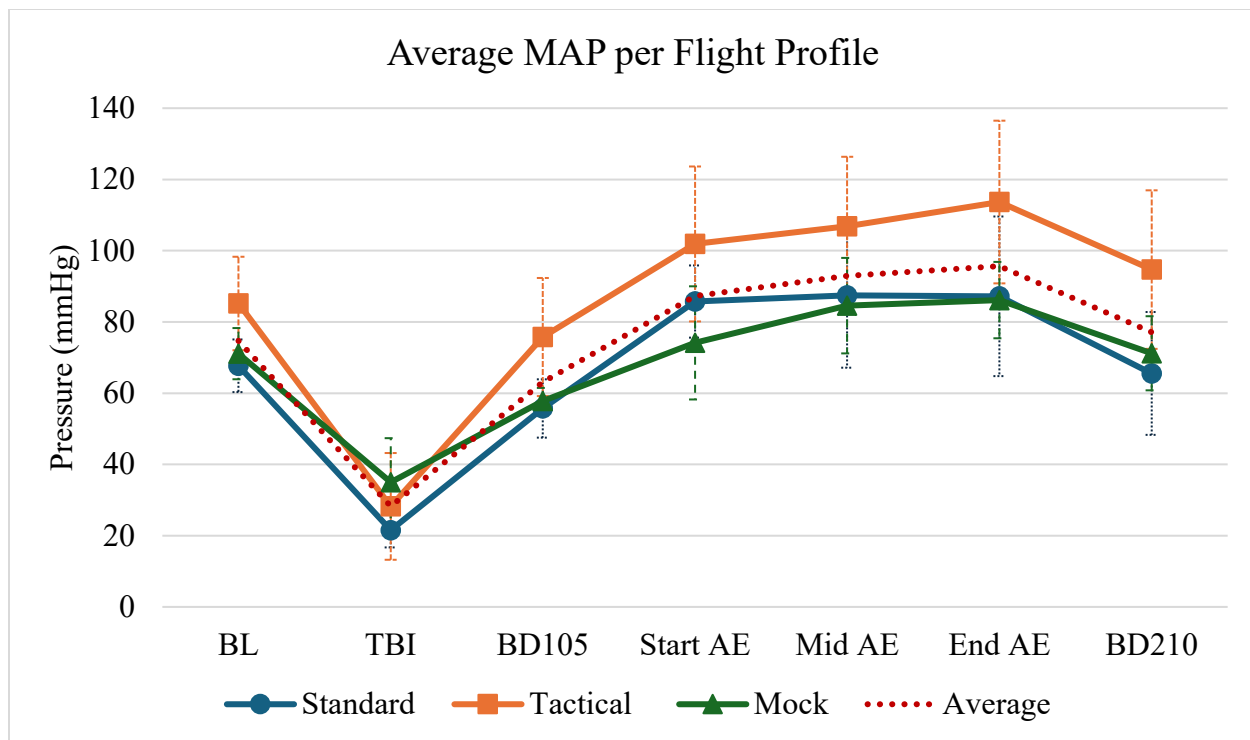


Figure 43. Average MAP for each flight profile.

ICP.

The ICP data was filtered and prepared as defined in the methods sections then the window of data for each epoch was averaged and can be found in Tables 13 through 15. The individual figures for each flight profile can be found in Appendix D, Figures D4-D6. Data for each epoch for all subjects were not always available. If there was no usable data in the 10-minute window around the epoch then no data was pulled for the epoch for that animal; this is indicated by “No data” in the tables. The epochs are fully defined in the methods section but the acronyms are as follows: BL, TBI, BD105, Start AE, Mid AE, End AE, and BD210.

Table 13. Standard Profile Average ICP Values

Subject IDs – Standard								
	3667	3638	3679	3663	3676	3637	3640	Average
BL	11.59	No data	14.11	12.19	10.08	10.33	16.48	12.46
TBI	13.08	No data	6.63	No data	6.98	7.78	7.97	8.49
BD105	7.84	No data	7.71	14.03	4.27	13.12	12.14	9.85
Start AE	12.96	13.98	9.76	17.79	11.03	17.89	19.13	14.65
Mid AE	15.22	13.61	11.39	23.63	11.29	19.06	17.45	15.95
End AE	14.84	13.79	10.64	21.96	9.35	17.95	17.78	15.19
BD210	No data	14.14	10.24	19.38	11.80	20.00	17.03	15.43

Note. All values are in mmHg.

Table 14. Tactical Profile Average ICP Values

	Subject IDs – Tactical							
	3620	3642	3665	3716	3719	3709	3635	Average
BL	15.46	20.17	No data	16.37	19.61	No data	14.29	17.18
TBI	13.23	21.41	No data	10.86	17.16	No data	13.06	15.14
BD105	No data	No data	17.07	18.04	14.68	16.08	12.16	16.85
Start AE	No data	24.03	22.76	No data	20.89	16.83	18.09	21.70
Mid AE	No data	25.94	21.85	No data	18.88	23.05	21.84	23.17
End AE	No data	37.80	22.19	No data	20.13	18.98	19.95	24.05
BD210	No data	14.72	22.22	No data	22.40	15.11	21.34	19.92

Note. All values are in mmHg.

Table 15. Mock Profile Average ICP Values

	Subject IDs – Mock						
	3631	3641	3720	3711	3724	3728	Average
BL	18.15	9.69	No data	21.18	No data	9.38	14.60
TBI	11.83	13.00	12.97	14.08	20.08	9.73	13.61
BD105	8.01	11.29	11.50	16.59	12.02	8.93	11.39
Start AE	14.14	17.30	18.63	21.79	15.62	13.38	16.81
Mid AE	12.88	18.69	17.37	20.46	19.89	16.64	17.65
End AE	15.29	17.82	16.82	18.17	20.05	17.64	17.63
BD210	16.88	16.99	14.44	16.46	17.20	13.90	15.98

Note. All values are in mmHg.

Figure 44 shows the average ICP for all three flight profiles at different epochs. The average ICP across all three flight profiles is indicated by the red dotted line. For all the epochs, the tactical profile had higher values, which is similar to the average MAP values. However, the tactical profile cohort also started with a higher baseline ICP than the other two configurations by an average of 3.7 mmHg. The general trend of the data shows a decrease in ICP after the injury model. Then by the beginning of the AE, the ICP has increased to above the BL average and continues to increase until the middle to the end of the transportation. At BD210, the ICP recovered slightly above the BL value (average increase of 13.7%). In a separate publication (Mayer, Lloyd, et al., 2026) the ICP values were grouped as pre-flight (BL, TBI, and BD105) and post-flight (Start AE, Mid AE, End AE, and BD210) then compared between the groups. The ICP of the TEF and mock cohorts during pre-flight was significantly higher ($p < 0.05$) than the SEF flight profile.

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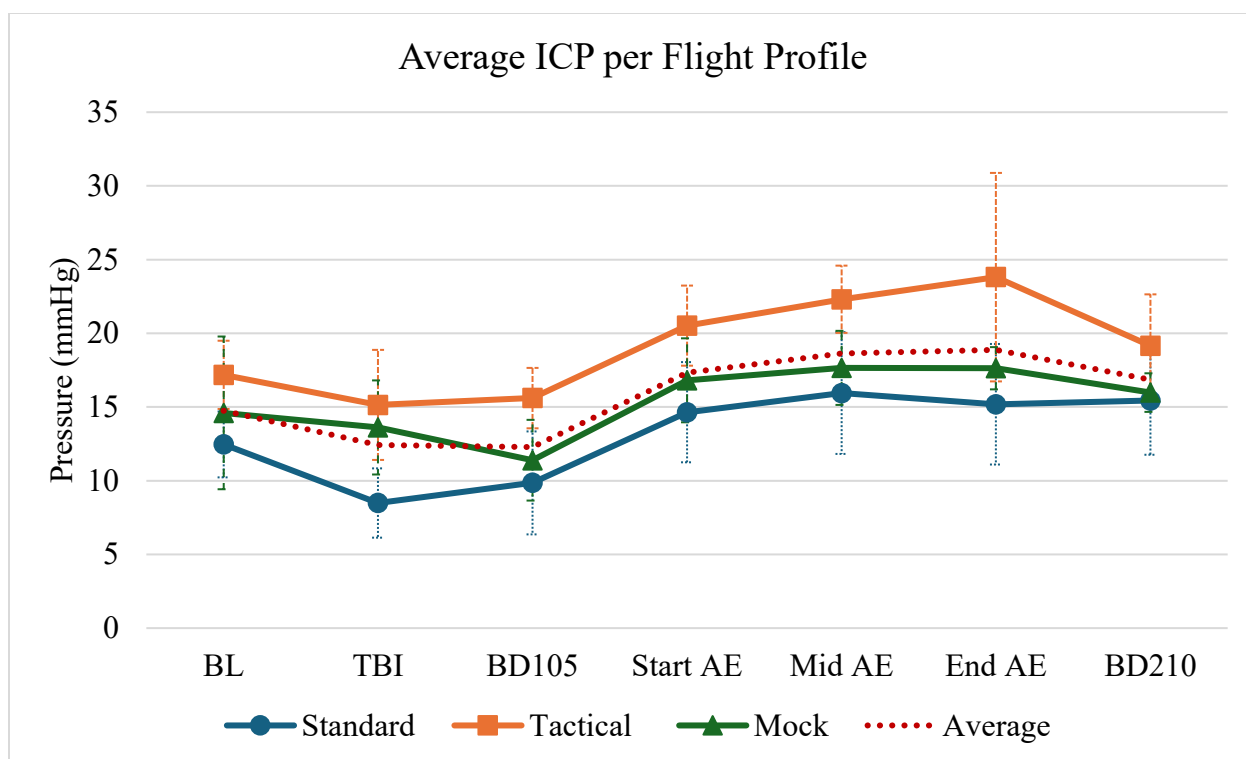


Figure 44. Average ICP per flight profile.

The mean ICP was also examined to compare the ground time and transport times for each subject. The ground time was defined as the time the subject was transferred to the packaging area and prior to transport. The transport time was defined as the duration of the actual transport for the different transport conditions, as shown in Table 16. Note that the time period between the transfer to the packaging area and transfer to the transport platform varied per animal, with the minimum time being 49 minutes, the maximum time being 1 hour and 12 minutes, and the average time being 59 minutes.

Table 16. Mean ICP Comparison Between Ground and Transport

Profile	Mean ICP (mmHg), Ground	Standard Deviation ICP (mmHg), Ground	Mean ICP (mmHg), Transport	Standard Deviation ICP (mmHg), Transport
Standard ($n = 5$)	10.09	3.35	19.09	4.75
Tactical ($n = 5$)	14.44	2.57	23.47	2.64
Mock ($n = 6$)	10.74	2.54	19.28	1.74

While the mean ICP for the tactical flight was higher for the tactical transport condition than the standard or mock transport conditions by 4.19-4.38 mmHg (21.7-22.9%), the mean ICP for the tactical cohort was also higher on the ground than the standard and mock cohorts by the same margin. The mean ICP for the subjects in the standard and mock transport conditions were nearly identical for both the ground and transport time ranges, though the standard deviation was

higher for the standard cohort in both time ranges. The difference between the mean ground ICP and the mean transport ICP for all three transport conditions was about 9 mmHg.

CPP.

The CPP data was filtered and prepared as defined in the methods sections then the window of data for each epoch was averaged and can be found in Tables 17 through 19. The individual figures for each flight profile can be found in Appendix D, Figures D7-D9. If either the ICP or MAP data was not available, then the CPP could not be calculated, which is indicated by “No data” in the tables below. All values are in mmHG.

Table 17. Standard Profile Average CPP Values

Subject IDs – Standard								
	3667	3638	3679	3663	3676	3637	3640	Average
BL	71.01	58.63	No data	50.35	87.37	No data	72.59	55.23
TBI	7.30	35.22	No data	13.32	9.83	No data	0.29	13.07
BD105	27.86	No data	83.47	45.53	62.24	75.42	58.92	45.86
Start AE	48.05	84.51	107.22	No data	82.83	54.77	103.72	71.08
Mid AE	38.65	78.49	99.54	No data	96.20	86.23	103.12	71.51
End AE	41.75	96.68	89.53	No data	111.46	108.19	90.03	72.01
BD210	35.62	91.76	75.19	No data	96.51	100.07	49.46	50.11

Note. All values are in mmHg.

Table 18. Tactical Profile Average CPP Values

Subject IDs – Tactical								
	3620	3642	3665	3716	3719	3709	3635	Average
BL	53.37	No data	46.72	64.40	66.88	59.07	40.97	67.99
TBI	10.28	No data	11.65	No data	17.57	6.18	19.69	13.08
BD105	45.83	No data	58.90	32.58	41.13	51.99	44.70	65.12
Start AE	73.14	74.41	52.38	75.53	76.71	77.40	67.97	86.61
Mid AE	103.27	47.88	46.07	60.52	89.64	80.54	72.63	92.72
End AE	106.14	40.75	53.91	49.75	90.61	88.29	74.61	99.18
BD210	No data	36.91	42.33	52.85	84.91	27.41	56.25	82.60

Note. All values are in mmHg.

Table 19. Mock Profile Average CPP Values

Subject IDs – Mock							
	3631	3641	3720	3711	3724	3728	Average
BL	50.54	51.08	No data	58.80	No data	65.56	56.49
TBI	10.58	21.72	37.74	26.53	25.61	6.10	21.38
BD105	47.30	42.97	51.57	40.79	42.31	53.57	46.42
Start AE	67.23	23.40	52.76	63.52	72.62	64.29	57.30
Mid AE	53.81	61.38	67.67	85.54	76.73	56.39	66.92
End AE	68.17	59.64	80.76	65.48	82.56	54.39	68.50
BD210	57.20	45.66	69.62	45.37	67.58	45.89	55.22

Note. All values are in mmHg.

Figure 45 shows the average CPP for all three flight profiles at the different epochs. The average CPP across all three flight profiles is indicated by the red dotted line. The tactical profile had the highest value for each epoch except for the TBI. The general trend of the data follows the MAP graph with a large decrease in CPP after the TBI and then an increase until the end of the AE. At the BD210 epoch, the standard cohort had a CPP value that was 9.7% higher than the baseline, and the mock cohort had a value that was 2.3% higher than the baseline. For the tactical cohort, the value at the BD210 epoch was 19.4% higher than the baseline, which is double the standard cohort increase. In a separate publication (Mayer et al., 2026) the CPP values were grouped as pre-flight (BL, TBI, and BD105) and post-flight (Start AE, Mid AE, End AE, and BD210) then compared between the groups. The CPP of the TEF cohort during post-flight was significantly higher ($p < 0.05$) than the SEF and mock flight profiles.

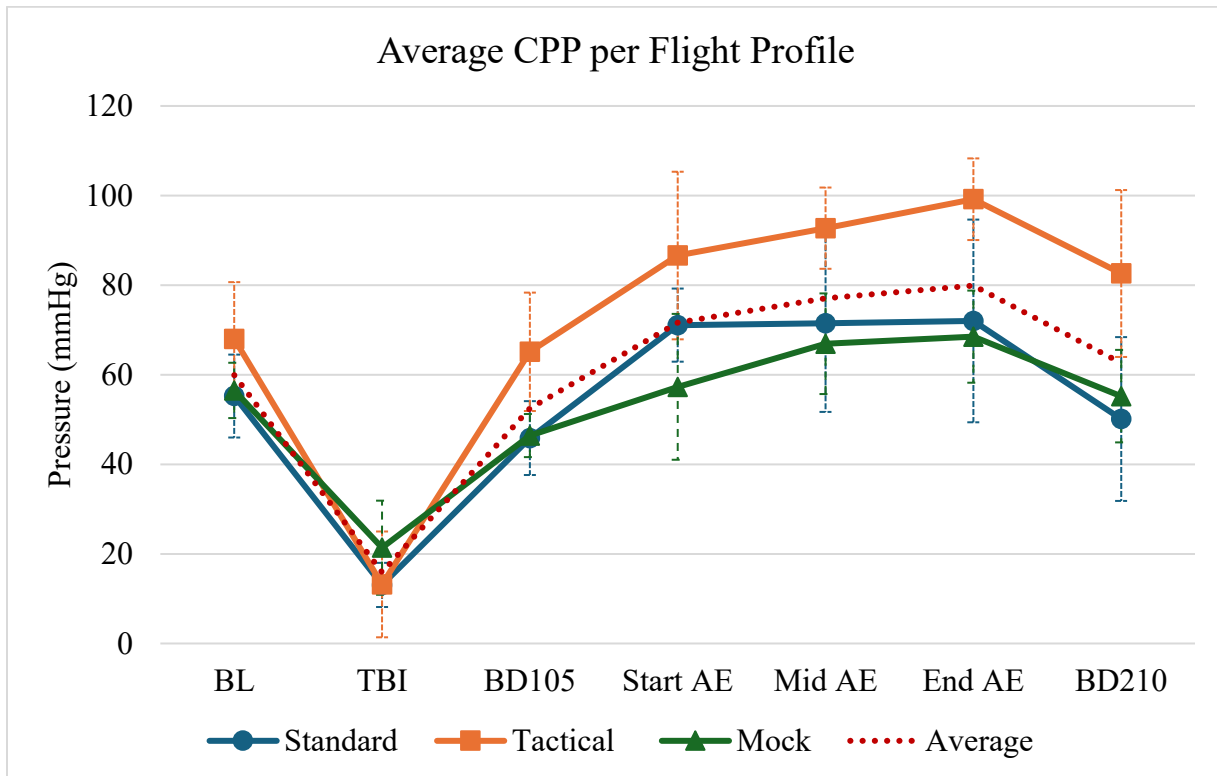


Figure 45. Average CPP per flight profile.

Environmental effects on physiological vital signs.

Statistical analysis was completed using R studio software to determine correlations between the environmental factors and the physiological vital signs of the subjects. Only the ICP was used in these comparisons because the MAP data contained a low frequency sinusoid that interfered with any statistical calculations. The correlation between the ICP and z-axis vibration and the correlation between the ICP and resultant RMS data were calculated. For both comparisons, no correlation was found.

The correlation between the ICP and altitude was also examined. The results of the correlations can be seen in Figure 46. There was a slight positive correlation found between the

ICP and altitude for the standard cohort (0.40 average, $ps < 0.05$), but no correlation found for the tactical cohort (-0.03 average, $ps < 0.05$).

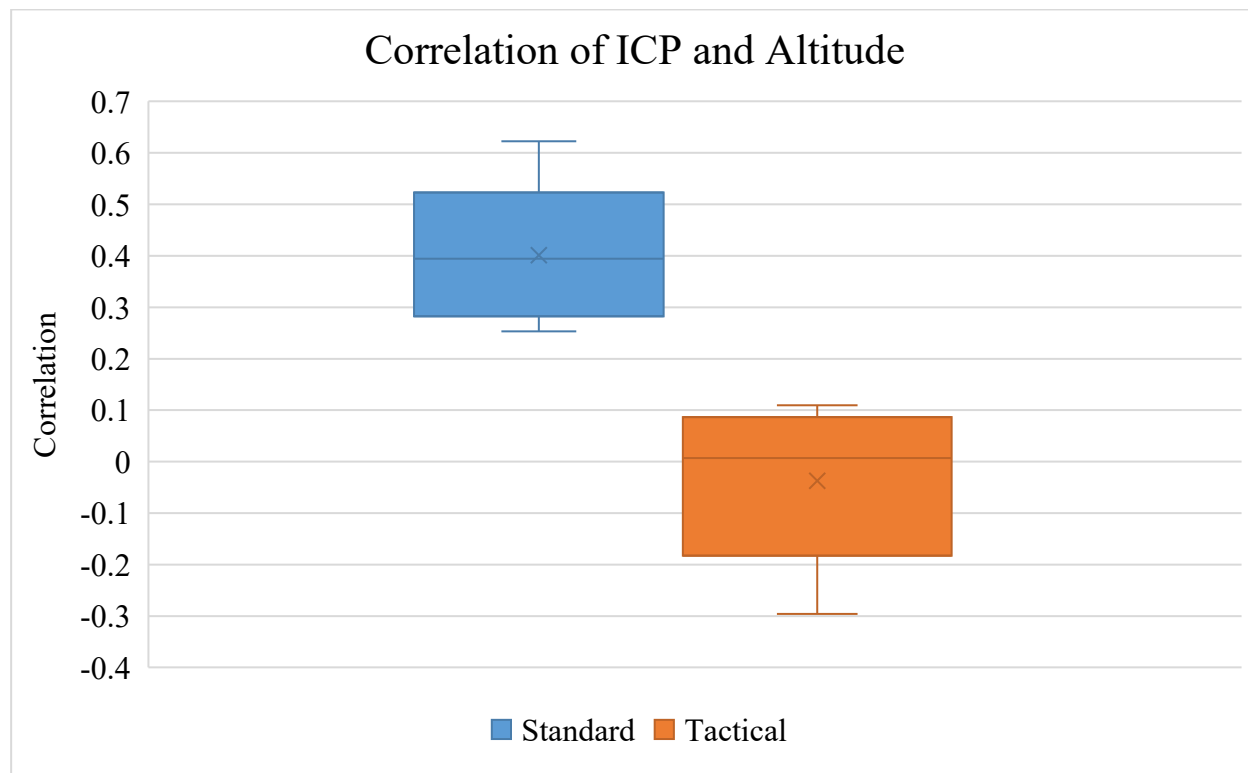


Figure 46. Correlation of ICP and altitude.

Discussion

GPS data showed that the relative flight paths for the standard profile and tactical profiles followed the study design. Standard cohort animals were exposed to a smooth high altitude flight path with minimal changes in altitude. There was one animal in the standard cohort that had a maximum altitude of 7800 ft, which was 700 ft lower than the rest of the cohort. This lower altitude matches the flight logs. Therefore, this lower altitude is not due to an error in the GPS and could have been a safety decision by the pilots due to weather. Tactical animals were exposed to a variety of maneuvers like sharp banking, rapid changes in altitude, and high velocity speeds.

The temperatures recorded in the cabin during transport showed no statistical difference between the standard and tactical cohorts. This could have been because the aircraft's heaters were used in both flight profiles. Hypothermia prevention was also used for the animal, as they were covered with standard U.S. Army wool blankets and a heating blanket. Sound levels for both cohorts were around 110 dB which is the standard sound level in a U.S. Army Black Hawk aircraft (Department of Defense, 2015). All study personnel wore hearing protection, but no hearing protection was given to the animal, which is standard in U.S. Army medical evacuation.

The average acceleration RMS data for the tactical profiles showed higher amplitudes than the standard in all but three of the axes, but there was only a statistically significant

difference in the board z-axis (difference was seen in both A and B board configurations). When looking at the rotational RMS, the values recorded from the sensors on the animals are all higher for the tactical profile versus the standard profile. The board and helicopter rotational RMS values are very similar between both profiles. The RMS values that were compared were taken over the entire flight duration. The resultant RMS values for the tactical acceleration values were on average 5.9% higher than the standard acceleration values and the tactical rotational values were on average 13.5% higher than the standard rotational values. The statistical significance in the board z-axis, combined with a 5.9% increase in overall acceleration, highlights increased vertical and vibratory stressors. For patients with impaired cerebral autoregulation from TBI and HS, this increased kinetic load can contribute to adverse physiological responses during tactical transport.

The FFT, PSD, and transmissibility calculations are characterized by peaks around 17.2 Hz, which is likely linked to the resonance frequency of the helicopter blade passage from the main rotor. The fundamental frequency of the Black Hawk motor is 4.3 Hz, which is multiplied by the number of blades (4) to create the energy at 17.2 Hz frequency seen in the majority of the graphs. The transmissibility is a useful measure of the characteristics of a system under vibration because it defines how the vibrations are altered while traveling through a material or structure, either attenuating, amplifying or shifting energy to different frequencies. However, the metric gives less accurate results when a very narrow band of input vibration is present. One of the notable features in the transmissibility graphs is that nearly all values are above 1, meaning that the energy input from the vehicle was being exacerbated for nearly all input-output combinations. But caution must be exercised when examining this analysis, given the possibility for compounding errors in a narrow frequency band.

The main physiological vital signs analyzed during this study were MAP and ICP. Using both of those measures, the CPP was also calculated. Looking at the MAP values, there was a decrease in blood pressure from the BL after the TBI and hemorrhagic shock was completed. This is to be expected after the 40% reduction in blood volume. The average MAP values before the start of the AE were above the starting BL value. During the AE portion of the flight, the subjects were reinfused with 20% of the shed blood and there is an expected increase in blood pressure. For the ICP values, there was a decrease in pressure after the injury model, then an increase in ICP during the AE for all profiles including the mock. The increase in ICP for all three transport conditions was an average of 9 mmHg, before returning to close to the base level seen before the injury model was applied. A recent study on interhospital air transport of TBI patients saw a 6.2 mmHg increase in ICP during transport (from 19.9 mmHg to 26.1 mmHg); the brain injury impairs cerebrovascular reactivity and autoregulation (Trofimov et al., 2025). The increase of ICP seen in this study indicates similar impaired autoregulation during transport.

The CPP shows a similar average pressure trend to the MAP data. During the AE portion of the flight, the tactical animals did exhibit a pressure value that was above the average for all points. When looking at the environmental effects on the animal's physiological data, the only effect was found for the altitude. The increased altitude in the standard profile showed a slight positive correlation to the ICP, meaning that when the altitude increased so did the ICP. For the tactical animals after AE, the CPP was elevated above the recommended survivable CPP of 60-70 mmHg (Carney et al., 2017).

During the transport, continuous invasive ICP was collected during the rotary-wing transport on a military aircraft; this appears to be novel in the literature. Historically, aeromedical evacuation studies have relied heavily on pre- and post-flight snapshots or non-invasive estimates, which fail to capture the dynamic physiological events occurring mid-flight. By successfully recording continuous, real-time physiological responses to the unique mechanical stressors of military aviation, such as tactical maneuvers and multi-axis vibration, this dataset provides a crucial link between physical kinetic forces and secondary brain injury. Ultimately, insights gained from this type of continuous monitoring are essential for informing both clinical guidelines for en route care and the engineering of advanced, vibration-dampening transport equipment.

Recommendations

The final sample size for this study was small. The standard and tactical cohorts had $N = 6$, and the mock cohort had $N = 5$. There were five animals that either did not survive to transport or were removed from the data pool. An increased number of animals could have led to a stronger statistical significance when comparing data.

There were some issues with instrumentation. The EFDAS was connected to the 6DOF sensors using LEMO connectors, which were not locking connectors. In the flight environment, the ambient vibration led to several instances of the LEMO connectors coming loose during flights. Since the study team was monitoring the data live, generally the connectors were plugged back in quickly. In future studies, the EFDAS will be equipped with locking LEMO connectors to prevent data loss due to loose connectors.

The standard flight profiles had little variability during the flight, while the tactical flight profiles are all very different in terms of maneuver types and timing. In future studies, it would be beneficial for the data analysis if all profile configurations were more standardized.

Conclusion

This study examined the effect of transportation stresses on a polytrauma swine model during different flight profiles. The study also collected continuous physiological vital sign data during the study. The collection of invasive ICP during rotary-wing transport on a military aircraft appears to be novel in the literature. A methodology has been defined to link physiological data collected during rotary-wing transport to environmental transport parameters. This methodology, in addition to survival rates, blood-based biomarkers, and other clinical indications, will be useful for evaluating the effects of transport on trauma patients. Additionally, this methodology can help to inform algorithm development for systems designed for semi- or fully autonomous patient transport.

In summary, though there were differences in response to the rotary-wing transport flight profiles, the study did not determine many significant differences in physiological indicators between the different configurations.

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Appendix A. Acronyms and Abbreviations

°/s	Degrees per Second
2D	Two Dimensional
3D	Three Dimensional
6DOF	6 Degrees of Freedom
ABP	Arterial Blood Pressure
AE	Aeromedical Evacuation
AWR	Airworthiness Release
BL	Baseline
BD105	Blood Draw at 105 minutes
BD210	Blood Draw at 210 minutes
bpm	Beats per Minute
C	Celsius
CPP	Cerebral Perfusion Pressure
CO ₂	Capnography
deg/s	degree per Second
dB	Decibel
DTIC	Defense Technical Information Center
EFDAS	Environmental Factors Data Acquisition System
EtCO ₂	End tidal Carbon Dioxide
FFT	Fast Fourier Transform
ft	Feet
g	Unit of Gravity
GPS	Global Positioning System
HS	Hemorrhagic Shock
Hz	Hertz
ICP	Intracranial Pressure
LBRI	Lovelace Biomedical Research Institute
m/s ²	Meters per Second Squared
MAP	Mean Arterial Pressure
Max	Maximum
MEDEVAC	Medical Evacuation
MES	Medical Equipment Set
Mid AE	Middle of Aeromedical Evacuation
mmHg	Millimeters of Mercury
mV/g	millivolt per Unit of Gravity
mV/deg/s	millivolt per Degree per Second
NAR	North American Rescue
NSN	National Stock Number
RMS	Root Mean Square
S	Standard
SEF	Standard Evacuation Flight
SMOG	Standard Medical Operating Guidelines
Start AE	Start of Aeromedical Evacuation

T	Tactical
TBI	Traumatic Brain Injury
TEF	Tactical Evacuation Flight
PbrO ₂	Partial Pressure of Brain Tissue Oxygen
PSD	Power Spectral Density
USAARL	U.S. Army Aeromedical Research Laboratory

Appendix B. Sensor Configurations

Table B1. A Board Sensor 6DOF Configuration

Sensor Configuration	Sensor Location	Sensor Type	Channel	Axis	Sensitivity	Range
A Board	Animal's brow ridge (S/N: 163)	6DOF (Combined accelerometers and gyroscopes)	3-6	AX	208.7 millivolt per unit of gravity (mV/g)	±6 unit of gravity (g)
			3-7	AY	207.5 mV/g	±6 g
			4-0	AZ	207.8 mV/g	±6 g
			4-1	GX	0.968 millivolt per degree per s (mV/deg/s)	±1000 degree per s (deg/s)
			4-2	GY	0.974 mV/deg/s	±1000 deg/s
			4-3	GZ	1.010 mV/deg/s	±1000 deg/s
A Board	Animal's scapula (S/N: 164)	6DOF	5-2	AX	211.6 mV/g	±6 g
			5-3	AY	197.6 mV/g	±6 g
			5-4	AZ	204.8 mV/g	±6 g
			5-5	GX	0.946 mV/deg/s	±1000 deg/s
			5-6	GY	1.060 mV/deg/s	±1000 deg/s
			5-7	GZ	1.062 mV/deg/s	±1000 deg/s
A Board	Animal's pelvis (S/N: 166)	6DOF	4-4	AX	212.5 mV/g	±6 g
			4-5	AY	210.9 mV/g	±6 g
			4-6	AZ	208.1 mV/g	±6 g
			4-7	GX	1.027 mV/deg/s	±1000 deg/s
			5-0	GY	0.978 mV/deg/s	±1000 deg/s
			5-1	GZ	1.052 mV/deg/s	±1000 deg/s
A Board	Center of backboard (S/N: 167)	6DOF	3-0	AX	208.9 mV/g	±6 g
			3-1	AY	211.5 mV/g	±6 g
			3-2	AZ	208.8 mV/g	±6 g
			3-3	GX	1.026 mV/deg/s	±1000 deg/s
			3-4	GY	0.940 mV/deg/s	±1000 deg/s
			3-5	GZ	0.987 mV/deg/s	±1000 deg/s
A Board and B Board	Center of litter berth (S/N: 315)	6DOF	6-0	AX	214.6 mV/g	±6 g
			6-1	AY	204.8 mV/g	±6 g
			6-2	AZ	200.2 mV/g	±6 g
			6-3	GX	1.064 mV/deg/s	±1000 deg/s
			6-4	GY	1.098 mV/deg/s	±1000 deg/s
			6-5	GZ	1.055 mV/deg/s	±1000 deg/s

Table B2. B Board Sensor 6DOF Configuration

Sensor Configuration	Sensor Location	Sensor Type	Channel	Axis	Sensitivity	Range
A Board	Animal's brow ridge (S/N: 316)	6DOF (Combined Accelerometers and Gyroscopes)	3-6	AX	213.5 mV/g	±6 g
			3-7	AY	203.2 mV/g	±6 g
			4-0	AZ	196.6 mV/g	±6 g
			4-1	GX	1.0588 mV/deg/s	±1000 deg/s
			4-2	GY	1.0483 mV/deg/s	±1000 deg/s
			4-3	GZ	1.0487 mV/deg/s	±1000 deg/s
A Board	Animal's scapula (S/N: 277)	6DOF	5-2	AX	211.6 mV/g	±6 g
			5-3	AY	208.4 mV/g	±6 g
			5-4	AZ	205.2 mV/g	±6 g
			5-5	GX	0.9937 mV/deg/s	±1000 deg/s
			5-6	GY	1.0527 mV/deg/s	±1000 deg/s
			5-7	GZ	1.0768 mV/deg/s	±1000 deg/s
A Board	Animal's pelvis (S/N: 313)	6DOF	4-4	AX	212.7 mV/g	±6 g
			4-5	AY	207.4 mV/g	±6 g
			4-6	AZ	202.4 mV/g	±6 g
			4-7	GX	1.0458 mV/deg/s	±1000 deg/s
			5-0	GY	1.0749 mV/deg/s	±1000 deg/s
			5-1	GZ	1.0242 mV/deg/s	±1000 deg/s
A Board	Center of backboard (S/N: 314)	6DOF	3-0	AX	215.1 mV/g	±6 g
			3-1	AY	212.0 mV/g	±6 g
			3-2	AZ	210.4 mV/g	±6 g
			3-3	GX	1.0949 mV/deg/s	±1000 deg/s
			3-4	GY	1.0312 mV/deg/s	±1000 deg/s
			3-5	GZ	0.9696 mV/deg/s	±1000 deg/s
A Board and B Board	Center of litter berth (S/N: 315)	6DOF	6-0	AX	214.6 mV/g	±6 g
			6-1	AY	204.8 mV/g	±6 g
			6-2	AZ	200.2 mV/g	±6 g
			6-3	GX	1.064 mV/deg/s	±1000 deg/s
			6-4	GY	1.098 mV/deg/s	±1000 deg/s
			6-5	GZ	1.055 mV/deg/s	±1000 deg/s

Appendix C. RMS Data by Subject

The following tables are the acceleration RMS full datasets for each subject. Table C1 shows the *x*-axis acceleration, Table C2 shows the *y*-axis acceleration, and Table C3 shows the *z*-axis acceleration. Any value with a (*) next to the value had to be removed for data analysis purposes. The data was removed because there were issues resulting in the data not collecting accurately. The LEMO connectors on the EFDAS were not locking connectors and would sometimes vibrate loose during data collection. A loose connection in the acceleration RMS values generally present as a zero or close to zero value.

Table C1. Acceleration RMS Values – x-Axis

Standard Profile					
Subject ID	Head	Scapula	Pelvis	Board	Helicopter
3637	0.496	0.651	0.653	0.545	0.646
3638	0.560	0.473	0.001*	0.395	0.569
3640	0.444	0.627	0.675	0.566	0.615
3663	0.503	0.603	0.586	0.464	0.631
3667	0.466	0.830	0.564	0.503	0.489
3676	0.467	0.624	0.553	0.436	0.576
3679	0.572	0.740	0.680	0.493	0.625
Tactical Profile					
Subject ID	Head	Scapula	Pelvis	Board	Helicopter
3620	0.403	0.467	0.399	0.370	0.528
3635	0.615	1.009	0.691	0.611	0.801
3642	0.414	0.592	0.492	0.444	0.502
3665	0.481	0.484	0.593	0.445	0.554
3709	0.572	0.740	0.680	0.493	0.625
3716	0.596	0.792	0.671	0.565	0.583
3719	0.497	0.784	0.737	0.616	0.827

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Table C2. Acceleration RMS Values – y-Axis

Standard Profile					
Subject ID	Head	Scapula	Pelvis	Board	Helicopter
3637	0.382	0.632	0.606	0.878	0.616
3638	0.271	0.579	0.001*	0.880	0.671
3640	0.340	0.572	0.406	0.566	0.892
3663	0.381	0.558	0.505	1.048	0.737
3667	0.310	0.444	0.402	0.497	0.528
3676	0.354	0.463	0.529	0.459	0.830
3679	0.313	0.496	0.639	0.488	1.106
Tactical Profile					
Subject ID	Head	Scapula	Pelvis	Board	Helicopter
3620	0.410	0.564	0.460	0.738	0.486
3635	0.444	0.570	0.622	0.583	1.033
3642	0.277	0.665	0.558	0.867	0.422
3665	0.337	0.483	0.412	0.402	0.735
3709	0.313	0.496	0.639	0.488	1.106
3716	0.487	0.556	0.566	0.476	1.006
3719	0.374	0.472	0.531	0.840	1.028

Table C3. Acceleration RMS Values – z-Axis

Standard Profile					
Subject ID	Head	Scapula	Pelvis	Board	Helicopter
3637	0.778	0.833	0.473	0.522	0.995
3638	0.759	0.512	0.002*	0.597	1.005
3640	0.651	0.431	0.569	0.421	1.331
3663	1.030	0.500	0.337	0.556	0.864
3667	0.622	0.355	0.368	0.481	1.704
3676	0.965	0.509	0.482	0.483	1.072
3679	0.737	0.480	0.396	0.550	1.232
Tactical Profile					
Subject ID	Head	Scapula	Pelvis	Board	Helicopter
3620	0.718	0.382	0.430	0.525	1.457
3635	0.033*	0.670	0.683	0.736	1.612
3642	0.901	0.385	0.397	0.537	0.838
3665	0.853	0.532	0.492	0.651	1.056
3709	0.737	0.480	0.396	0.550	1.232
3716	1.153	0.545	0.657	0.669	1.101
3719	0.919	0.589	0.727	0.679	1.221

The following tables are the full datasets of gyroscopic rotational velocity RMS for each subject. Table C4 shows the *x*-axis rotation, Table C5 shows the *y*-axis rotation, and Table C6 shows the *z*-axis rotation. Any value with a (*) next to the value had to be removed for data analysis purposes. The data was removed because there were issues resulting in the data not collecting accurately. The LEMO connectors on the EFDAS were not locking connectors and would sometimes vibrate loose during data collection. A loose connection in the gyroscope RMS values generally presents as a very small or large value.

Table C4. Gyroscope RMS Values – x-Axis

Standard Profile					
Subject ID	Head	Scapula	Pelvis	Board	Helicopter
3637	6.969	4.932	2.051	1.302	0.635
3638	2.473	2.048	0.035*	1.640	0.735
3640	2.080	2.159	3.358	1.291	1.094
3663	3.384	2.169	2.083	1.837	0.310
3667	1.332	1.687	2.251	1.296	0.894
3676	3.134	3.454	4.035	1.197	0.793
3679	1.477	1.718	3.896	1.258	1.102
Tactical Profile					
Subject ID	Head	Scapula	Pelvis	Board	Helicopter
3620	1.992	2.943	2.578	1.869	0.806
3635	3.257	3.985	4.186	1.343	1.393
3642	4.700	2.448	2.694	1.793	0.863
3665	1.978	2.362	3.694	1.212	0.777
3709	1.477	1.718	3.896	1.258	1.102
3716	2.356	1.939	4.129	1.296	0.754
3719	6.514	3.775	4.027	2.303	30.142*

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Table C5. Gyroscope RMS Values – y-Axis

Standard Profile					
Subject ID	Head	Scapula	Pelvis	Board	Helicopter
3637	3.719	5.192	2.501	0.500	0.437
3638	1.962	1.462	0.020*	0.445	0.520
3640	1.975	2.219	2.570	0.482	0.485
3663	3.217	2.494	1.863	0.495	0.354
3667	2.302	1.456	1.987	0.379	0.405
3676	2.598	2.450	3.522	0.393	0.434
3679	1.967	1.611	1.915	0.563	0.601
Tactical Profile					
Subject ID	Head	Scapula	Pelvis	Board	Helicopter
3620	2.721	1.460	1.218	0.526	0.455
3635	3.836	2.396	3.154	0.536	0.487
3642	2.812	2.431	1.426	0.472	0.456
3665	2.719	2.228	2.347	0.431	0.350
3709	1.967	1.611	1.915	0.563	0.601
3716	3.903	1.968	2.769	0.547	0.349
3719	5.103	2.734	3.439	0.568	0.534

Table C6. Gyroscope RMS Values – z-Axis

Standard Profile					
Subject ID	Head	Scapula	Pelvis	Board	Helicopter
3637	2.867	1.634	0.886	0.335	0.324
3638	1.567	0.683	0.048*	0.261	0.336
3640	2.176	1.236	1.056	0.350	0.354
3663	3.381	0.610	0.450	0.324	32.968*
3667	1.737	0.575	0.902	0.374	0.355
3676	2.540	1.493	0.686	0.375	0.356
3679	1.294	1.061	0.865	42.810*	0.358
Tactical Profile					
Subject ID	Head	Scapula	Pelvis	Board	Helicopter
3620	2.834	0.698	0.724	0.351	0.341
3635	3.728	1.154	0.587	0.421	0.389
3642	2.477	0.834	0.810	0.429	0.368
3665	2.034	0.860	0.732	0.380	0.345
3709	1.294	1.061	0.865	42.810*	0.358
3716	1.725	1.102	0.819	9.746*	0.344
3719	4.103	12.025	0.961	0.442	0.375

Appendix D. Physiological Vital Sign Graphs

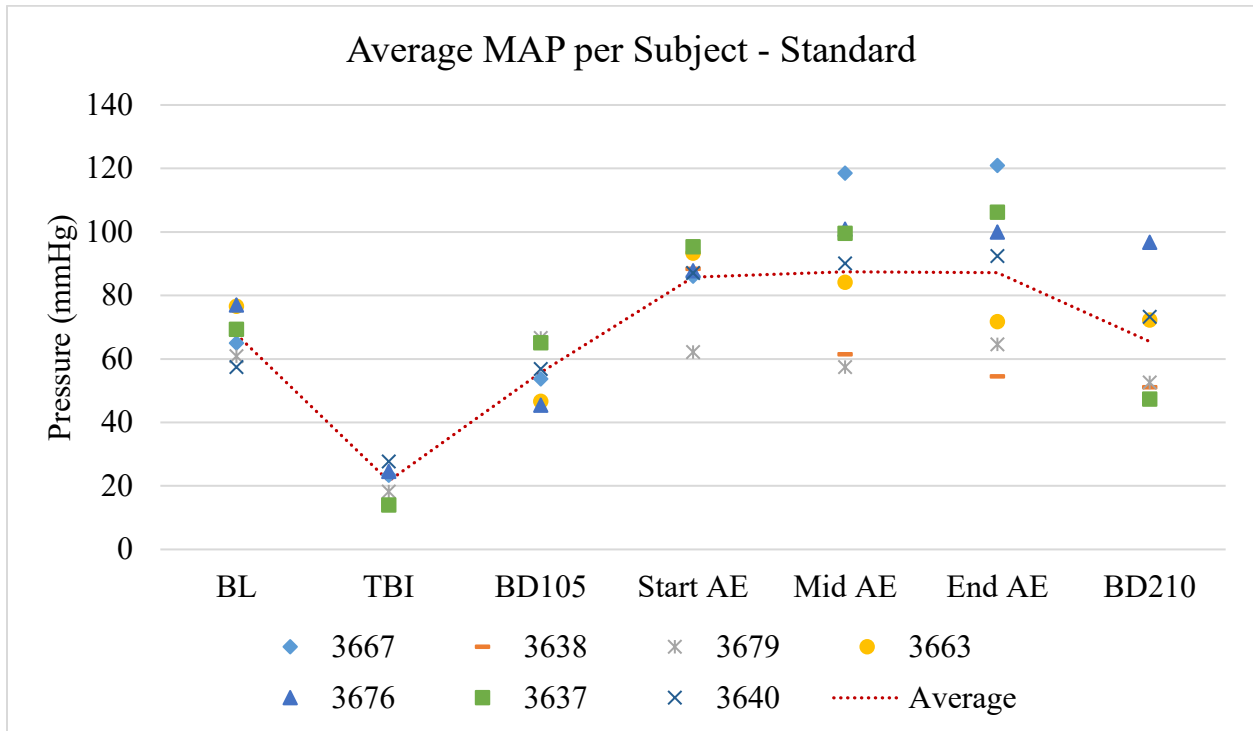


Figure D1. Average MAP value per subject in the standard profile.

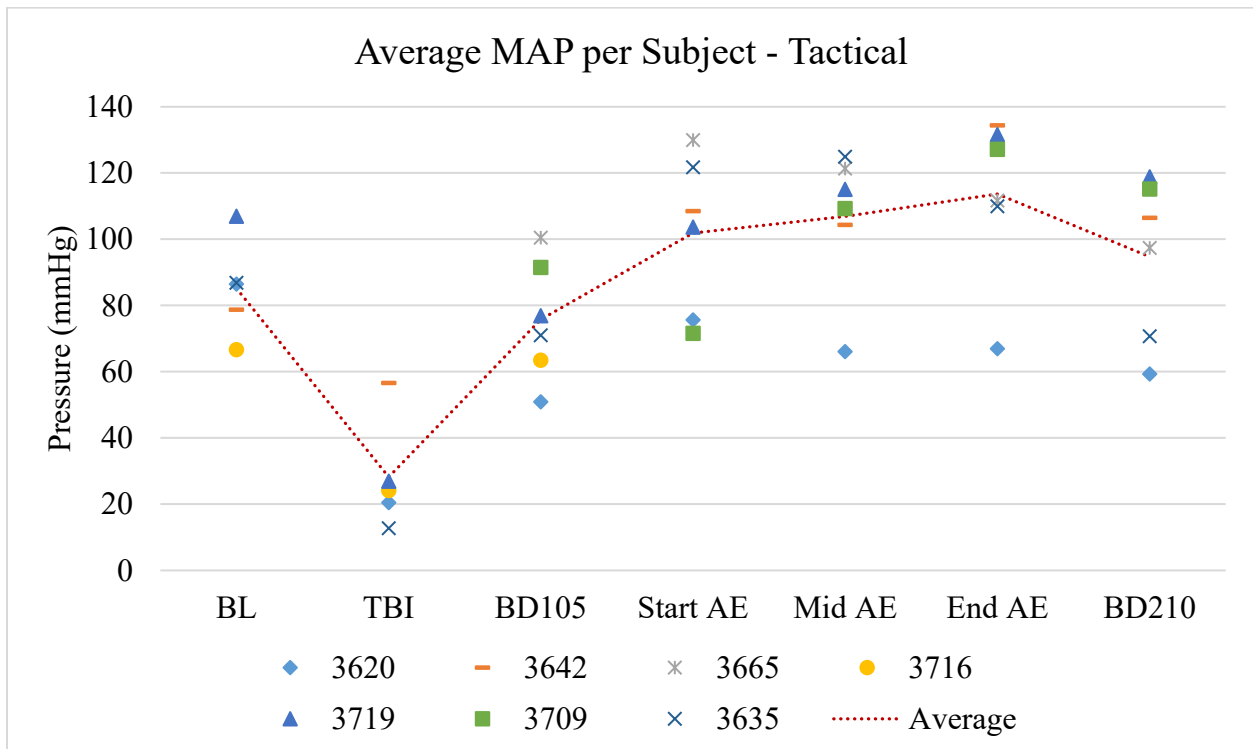


Figure D2. Average MAP value per subject in the tactical profile.

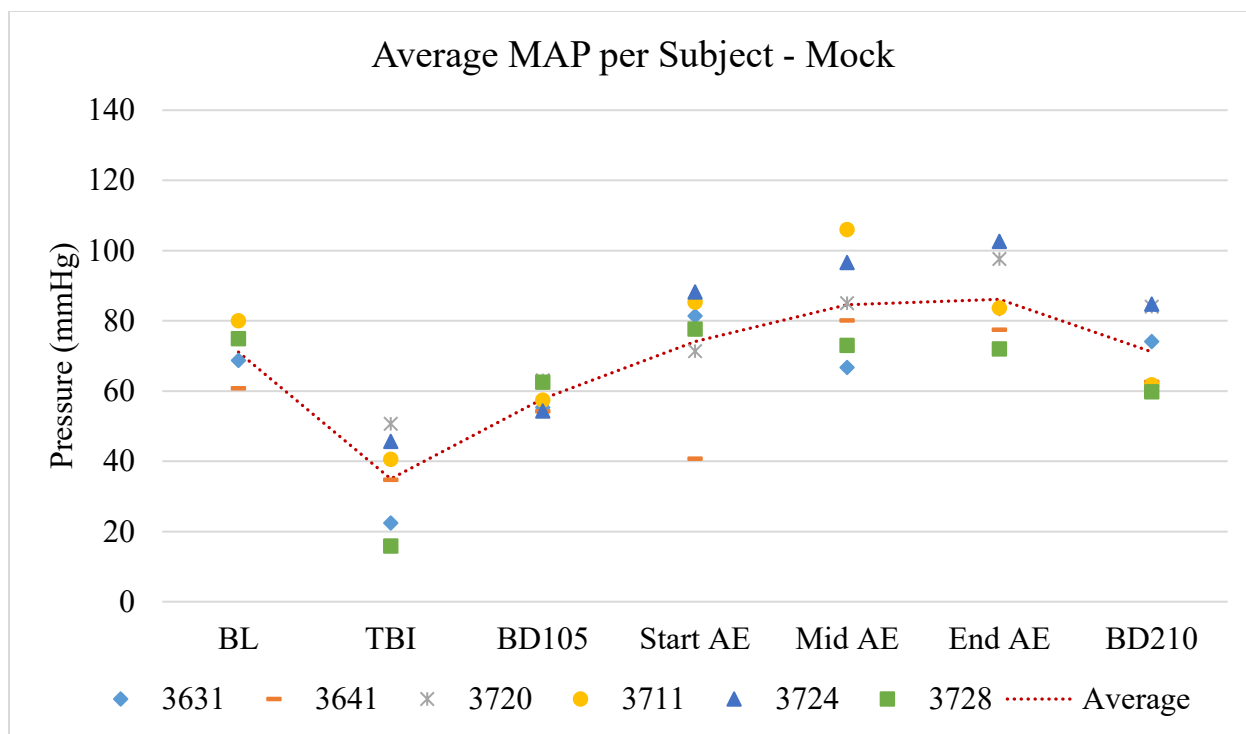


Figure D3. Average MAP value per subject in the mock profile.

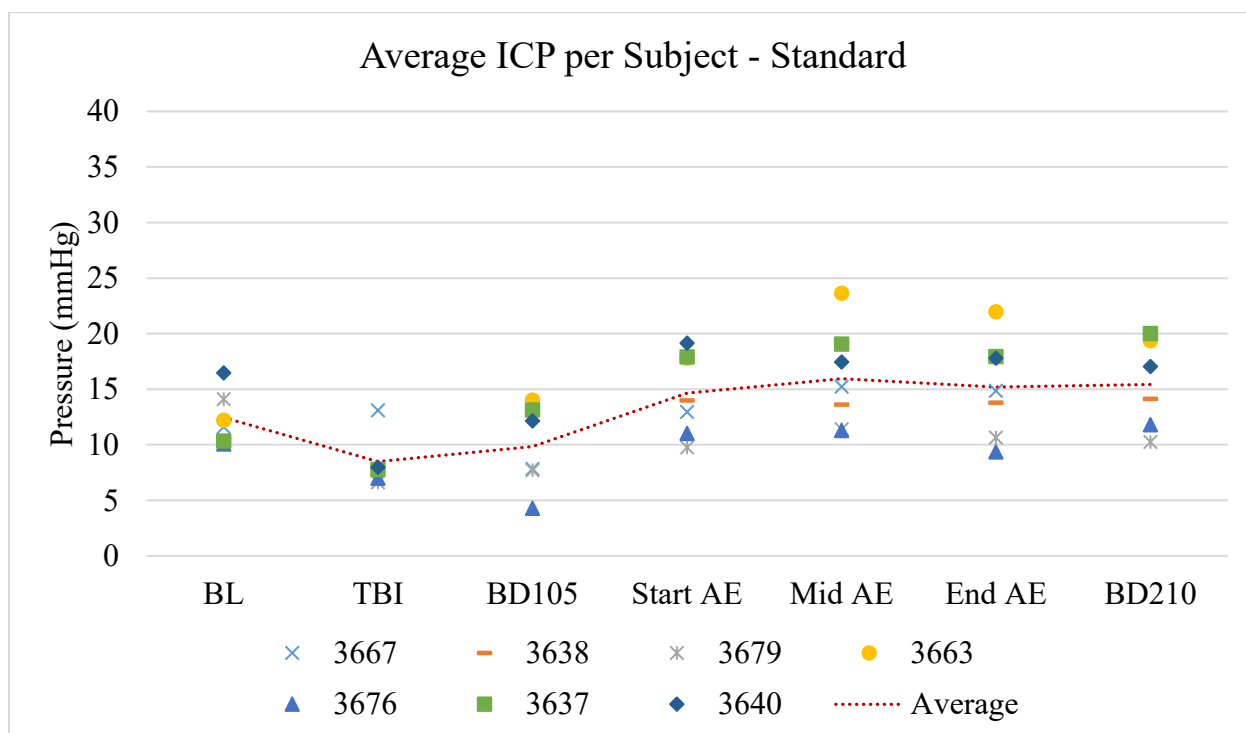


Figure D4. Average ICP for standard flight profile subjects.

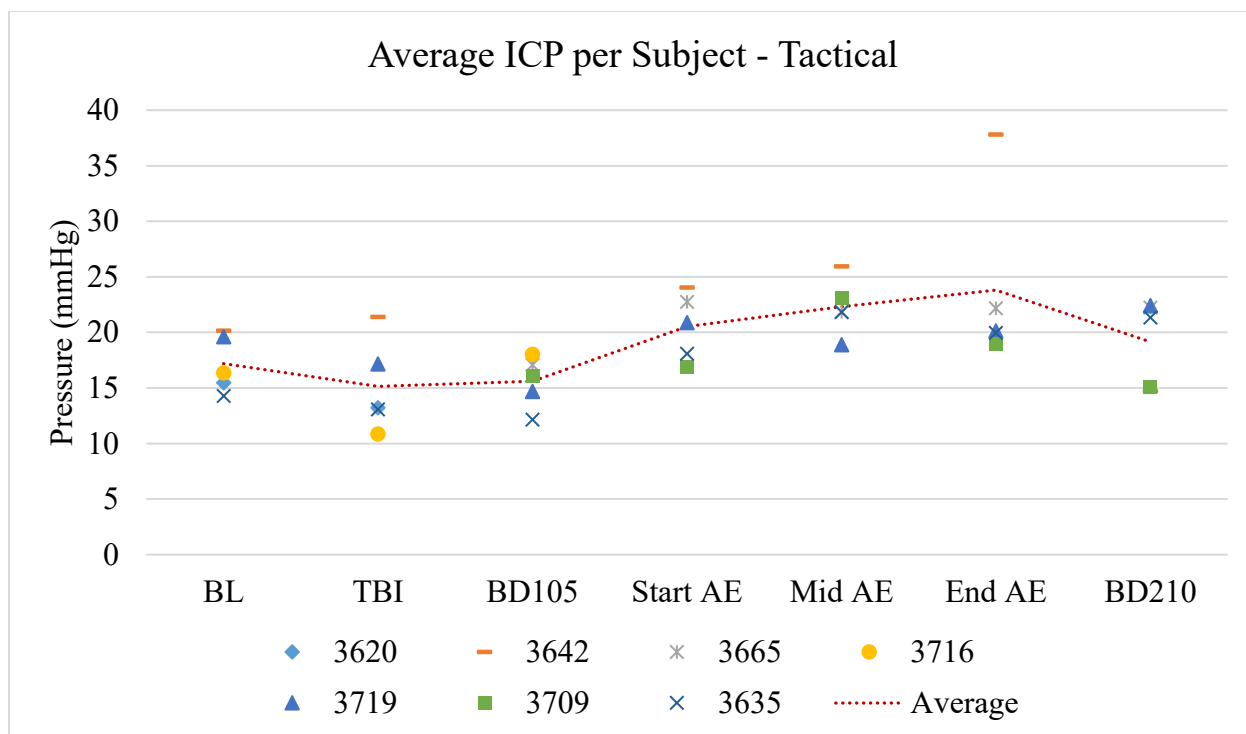


Figure D5. Average ICP for tactical flight profile subjects.

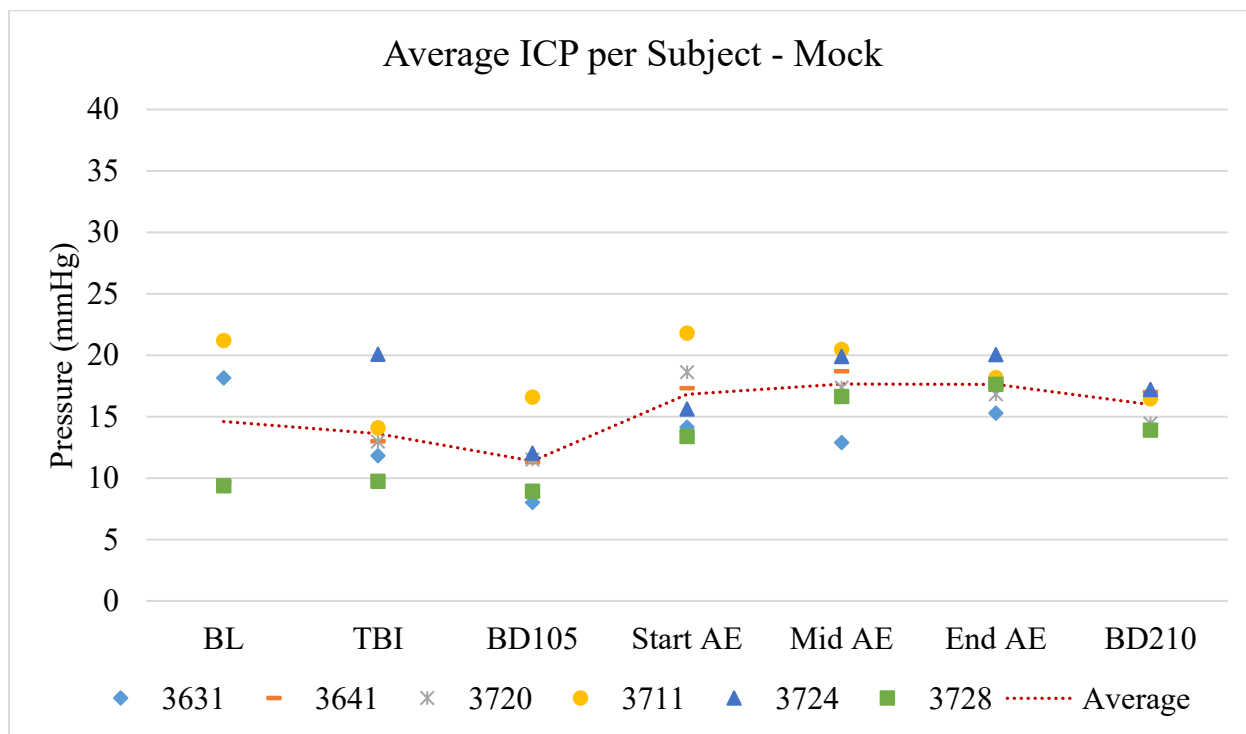


Figure D6. Average ICP for mock flight profile subjects.

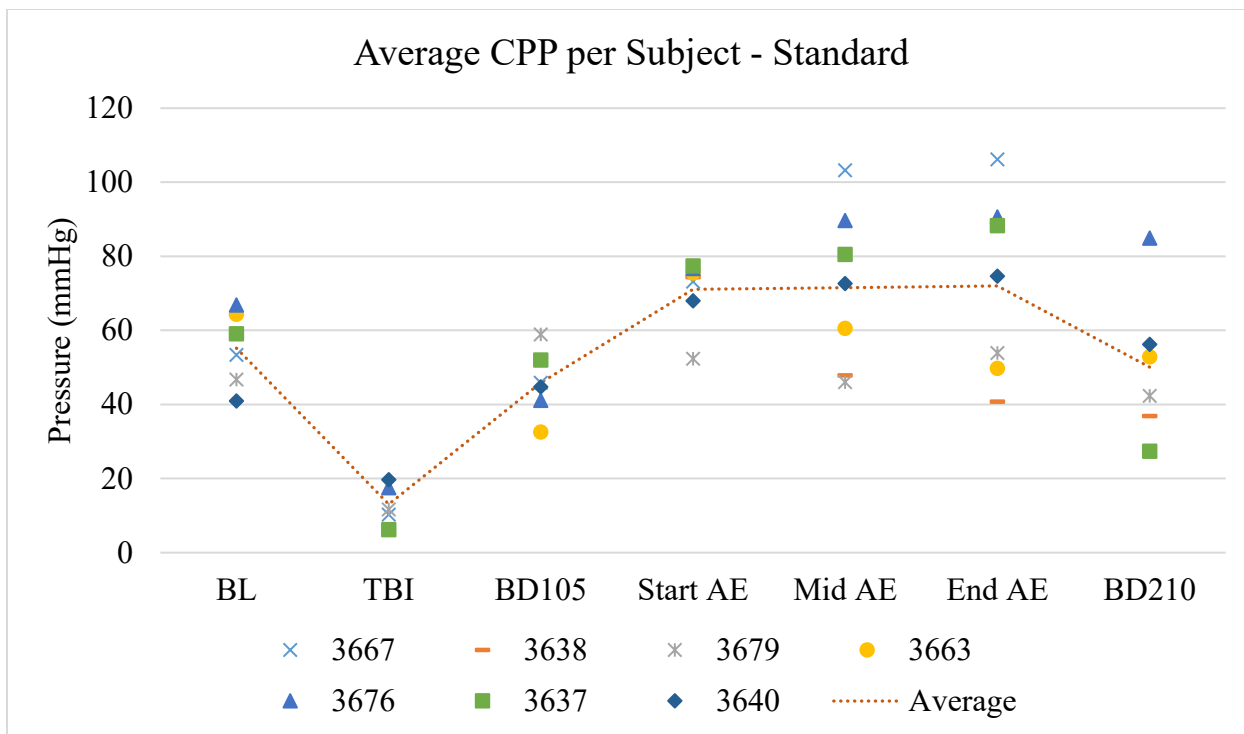


Figure D7. Average CPP for standard flight profile subjects.

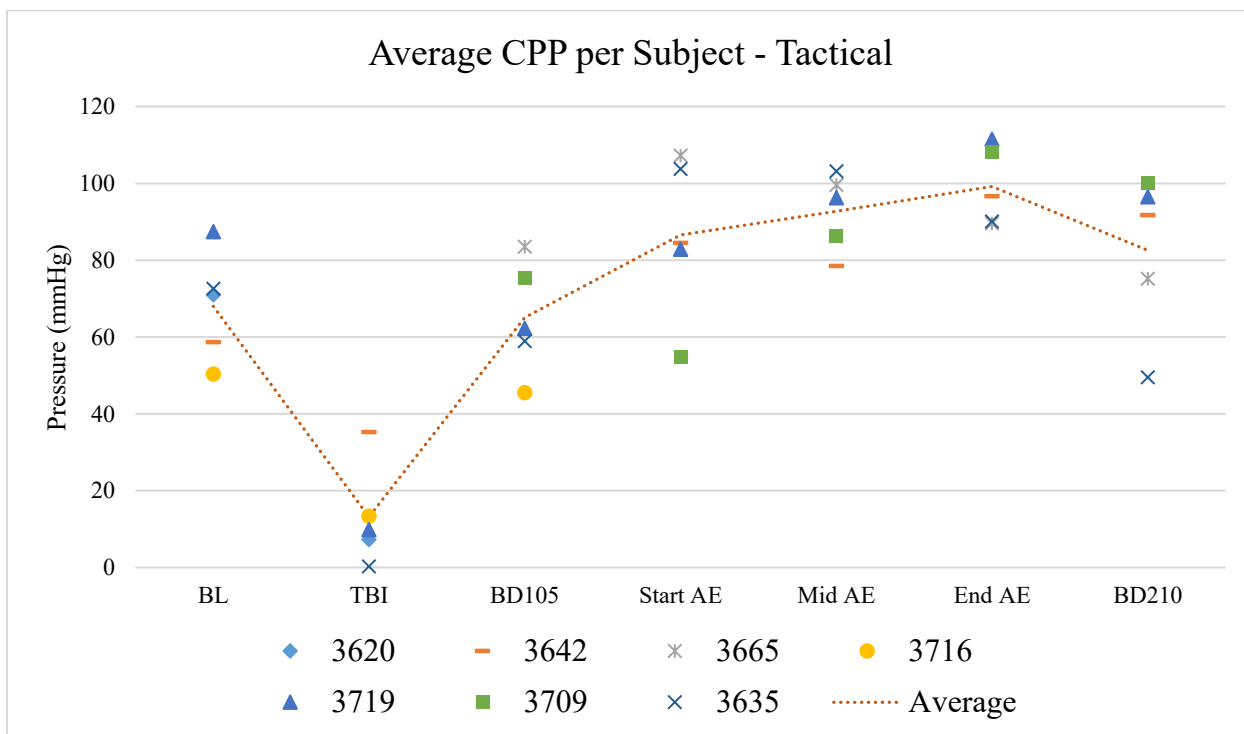


Figure D8. Average CPP for tactical flight profile subjects.

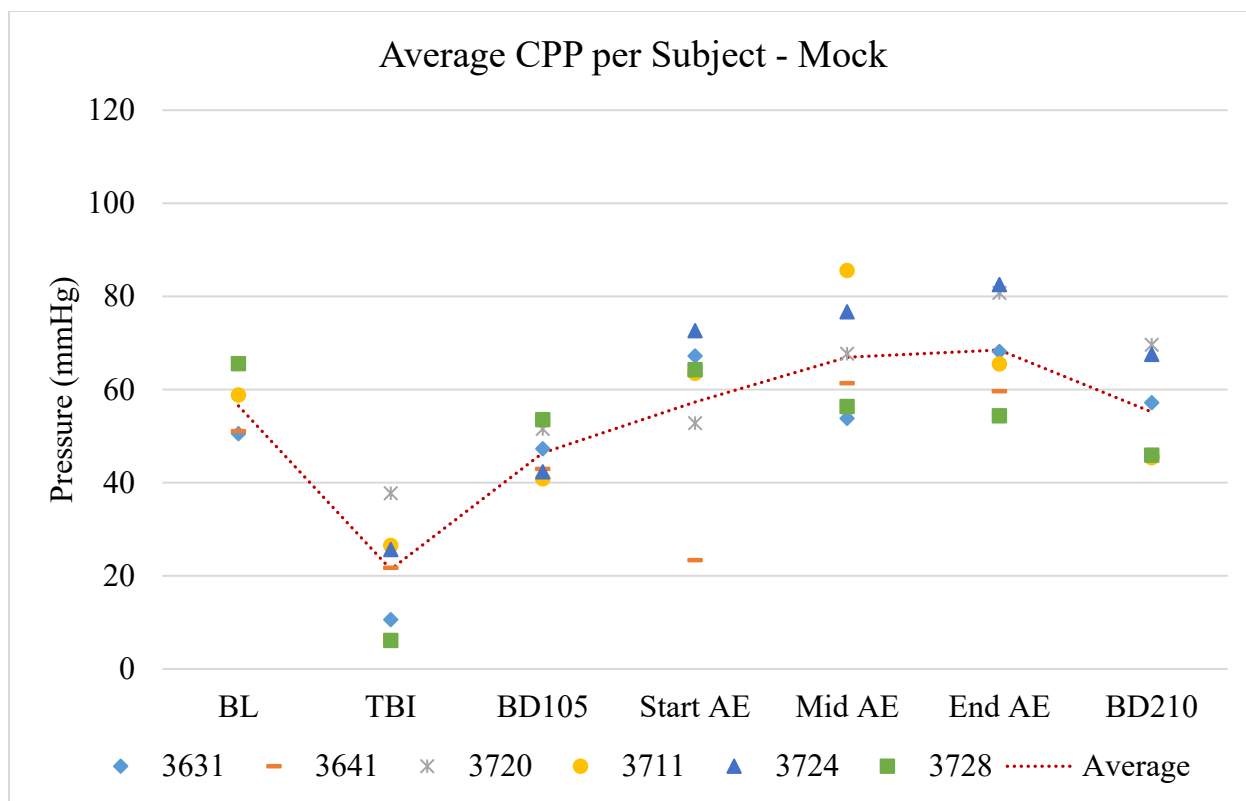


Figure D9. Average CPP for mock flight profile subjects.

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