SEPTEMBER 2025 • VOLUME 96 • NUMBER 9

Aerospace Medicine and Human Performance

THE OFFICIAL JOURNAL OF THE AEROSPACE MEDICAL ASSOCIATION

Aerospace Medicine and Human Performance

SEPTEMBER 2025 VOLUME 96 NUMBER 9 [ISSN 2375-6314 (print); ISSN 2375-6322 (online)]

This journal, representing the members of the Aerospace Medical Association, is published for those interested in aerospace medicine and human performance. It is devoted to serving and supporting all who explore, travel, work, or live in hazardous environments ranging from beneath the sea to the outermost reaches of space.

AEROSPACE MEDICAL ASSOCIATION is an organization devoted to charitable, educational, and scientific purposes. The Association was founded when the rapid expansion of aviation made evident the need for physicians with specialized knowledge of the flight environment. Since then, physicians have been joined in this Association by professionals from many fields and from many countries, all linked by a common interest in the health and safety of those who venture into challenging environments.

AEROSPACE MEDICINE AND HUMAN PERFORMANCE, formerly *Aviation, Space, and Environmental Medicine*, is published monthly by the Aerospace Medical Association, a non-profit charitable, educational, and scientific organization of physicians, physiologists, psychologists, nurses, human factors and human performance specialists, engineers, and others working to solve the problems of human existence in threatening environments on or beneath the Earth or the sea, in the air, or in outer space. The original scientific articles in this journal provide the latest available information on investigations into such areas as changes in ambient pressure, motion sickness, increased or decreased gravitational forces, thermal stresses, vision, fatigue, circadian rhythms, psychological stress, artificial environments, predictors of success, health maintenance, human factors engineering, clinical care, and others. This journal also publishes notes on scientific news and technical items of interest to the general reader, and provides teaching material and reviews for health care professionals.

MEMBERSHIP—The Aerospace Medical Association welcomes members interested in aerospace medicine and human performance. Membership applications may be obtained online at www.asma.org or from the Aerospace Medical Association's headquarters at 631 US Highway 1, Suite 307, North Palm Beach, FL 33408, or phone the Membership Department at (703) 739-2240 x 107; skildall@asma.org.

SUBSCRIPTIONS—*Aerospace Medicine and Human Performance* is provided to all members of the Aerospace Medical Association (online; a print subscription may be purchased separately). Subscriptions and changes of address should be sent to the Subscription Department, *Aerospace Medicine and Human Performance*, 631 US Highway 1, Suite 307, North Palm Beach, FL 33408, at least 90 days in advance of change. Institutional Subscription Rates (Online only): Tier 1-$615, Tier 2-$900, Tier 3-$1311, Tier 4-$1716. Individual Subscription Rates (Online only): U.S.-$275, Canada-$275, Other countries-$275. Single copies and back issues: $30+P/H ($7.50 U.S./$25 International Air). NOTE TO INTERNATIONAL SUBSCRIBERS: Please add $50 for bank handling charges on checks not drawn on U.S. banks.

Aerospace Medicine and Human Performance [ISSN 2375-6314 (print); ISSN 2375-6322 (online)], is published monthly by the Aerospace Medical Association, 631 US Highway 1, Suite 307, North Palm Beach, FL 33408. Periodicals postage paid at Alexandria, VA, and at additional mailing offices. POSTMASTER: Send address changes to *Aerospace Medicine and Human Performance,* 631 US Highway 1, Suite 307, North Palm Beach, FL 33408.. Phone (703) 739-2240. Printed in U.S.A. CPC Int'l Pub Mail #0551775.

Aerospace Medicine and Human Performance

SEPTEMBER 2025 VOLUME 96 NUMBER 9

2026 AsMA & UHMS Annual Scientific Meeting "Boundless Frontiers— Relentless Progress"

Sheraton Denver Downtown Hotel
Denver, CO, United States; May 17–21, 2026

Call for Abstracts Deadline: Jan. 4, 2026; ***NO Exceptions!***

The 2026 AsMA-UHMS Annual Scientific Meeting will be held in Denver, CO, United States. The theme for the 2026 Annual Scientific Meeting is **"Boundless Frontiers—Relentless Progress."** With emerging technology and new entrants into the aviation and space environment, it is now more important than ever to encourage the next generation of young people to consider entering career fields like aerospace medicine, engineering, aviation, maintenance, air traffic control, and remotely piloted vehicle operations, to name a few. To quote a staff member, "if a young person can't see it, they can't be it." Many of our youth have no awareness of the career opportunities in aerospace medicine. We need to be out in our schools and youth organizations telling our story. In addition, AsMA members will need to maintain a full awareness, and in many cases, a working knowledge of the innovations so we can better respond to needs of the aviation and space communities. The future will require us to think differently as the airspace system changes.

The Annual Scientific Meeting is the premier international forum to learn and discuss evolving trends and multidisciplinary best practices in research, clinical applications, human performance, and flight safety. The 2026 AsMA-UHMS Annual Scientific Meeting welcomes abstracts in the many areas related to Aerospace Medicine. For a complete list, see the box on p. 2 of this form.

AsMA ABSTRACT SUBMISSION PROCESS

LIMIT: 350 words/2500 characters including spaces; NO Tables or Figures or References should be included in the abstract. All abstracts must be submitted via the electronic submission system link on the meeting website: *https://asma-uhms-asm.org/abstracts/asma-call-for-abstracts.html*.

ATTENTION: You MUST use personal email addresses when entering your abstracts and those of your co-authors.

ABSTRACT PRESENTATION TYPES

The Annual Scientific Meeting highlights four types of presentation formats.

1. Poster: Individual Digital Poster presentations are integrated into a Poster session, grouped by topic. The presentation must be submitted as a PowerPoint with up to a maximum of 10 slides. Video and audio clips can be embedded. They will be displayed digitally. Posters are on display for two full days, each in an assigned space. Authors will be asked to present their poster for a single designated 90-min period on one of these days.

2. Slide: Standalone 15-minute slide presentation with questions/discussion that will be integrated into an oral slide session, grouped by topic. PowerPoint presentations will be organized by topic area and presented during 90-minute blocks of time, 6 periods of 15 minutes each. Individual PowerPoint Oral presentations are limited to 15 minutes, including 3–5 minutes for questions and discussion.

3. Panel: Invited Presentation that will link to support a Panel Overview containing five (non-case study) or six (case study) abstracts presented as a cohesive whole. Panels also have 90 minutes, ideally 5 presentations of 15 minutes each followed by a 15-minute discussion period.

4. Workshop: Invited Presentation that will link to and support a Workshop Overview. Overview abstracts should reflect the material to be presented in this long format for up to 8 hours of CME credit.

PRESENTATION CATEGORIES

There are two presentation categories based on the topic. (Templates and examples are provided for each type and will be available on the abstract submission website). Authors will be required to enter abstract text under the headings as described below.

1. Original Research: Material that is original in nature and has not been previously presented. Original analysis of a hypothesis involving data collection and analysis. Headings include Introduction, Methods, Results, and Discussion.

2. Education: Typically, a discussion of information that is already available.

a. Program/Process Review: Description of a program or process that is used to solve a problem or accomplish a task. Headings include Background, Description, and Discussion.

b. Tutorial/Review: An educational session intended as a review of established material. Headings include Introduction, Topic, and Application.

c. Case Study: A single clinical or human performance event. Headings include Introduction, Case Description, and Discussion.

PANEL GUIDANCE

Panels must be composed of a coordinated sequence of 5 abstracts that flow logically from one to another supporting the central theme. Panels must contain abstracts that allow 15 minutes of structured discussion at the end of the session.

Case Study Panels: Case Study Panels can have 6 abstracts and are intended to highlight a particular institution, community, or aeromedical issue, usually presented from the same institution or aeromedical community.

It is the responsibility of the Panel Chairperson to enter all supporting abstracts and to ensure that all supporting abstracts clearly describe how each supports the Panel theme. If the Panel theme is not clearly identified and/or the abstracts do not support a central theme, the Scientific Program Committee may decline the proposed Panel in total. Unrelated abstracts from a laboratory or organization do not constitute a Panel (unless they are Case Studies).

Panel Chairs are also responsible for preparing questions and discussion points to facilitate a moderated discussion with the audience during the sixth period. Each Panel speaker should cite or link directly to the Panel theme, and at the end of their talk should provide a logical segue to the next abstract.

WORKSHOP GUIDANCE

Rules for workshops and the review process are similar to those for Panels (above). Individual abstracts must be entered for each invited presenter and all necessary information must be entered in the same manner as all other abstracts, including financial disclosure statements. Course materials should be made available for registrants.

A separate registration fee is charged for Workshops registration. For additional information contact Gisselle Vargas, Deputy Executive Director, at gvargas@asma.org.

AsMA ABSTRACT SUBMISSION PROCESS

All abstracts must be submitted via the electronic submission system linked to on the association's website: *https://asma-uhms-asm.org/abstracts/asma-call-for-abstracts.html*. Click on the link to the abstract submission site--available on the AsMA home page and

Meetings page on or about September 1, 2025. Authors with questions regarding the abstract submission process should contact AsMA directly at (703) 739-2240, x101 (Mrs. Rachel Trigg), email rtrigg@asma.org or x102 (Mrs. Stella Sanchez), email ssanchez@asma.org.

The following information is required during the submission process: Abstract title, presenting author information (including complete mailing and email addresses and telephone numbers), topic area (from list provided on back of form), contributing authors names, emails and institutions, abstract content **(LIMIT: 350 words/2500 characters including spaces), at least 2 Learning Objectives** (the Accreditation Council for Continuing Medical Education requires this for all presentations). In addition, three (3) multiple choice or True/False questions and answers are required for each Poster, Slide, and Panel presentation for enduring materials for CME credit. Read instructions online for additional details. ***Poster presenters are required to upload their poster as a PowerPoint in advance of the meeting no later than February 23, 2026, 11:59 PM ET.***

PLEASE NOTE: All Presenters (including panelists) are required to register for the meeting. *There is a discounted fee for non-member presenters. Registration limited to the day of presentation will be available on site.*

Financial Disclosure/Conflict of Interest/Ethics

Abstracts will not be accepted without a financial disclosure form. The form is included as part of the website abstract submission process. The presenting author must agree to comply. Scientific presentations at AsMA-sponsored events will adhere to the highest standards of scientific ethics, including appropriate acknowledgment or reference to scientific and/or financial sources. Presenters must avoid the endorsement of commercial products in their abstracts and during their presentations. There must be no advertisements on Posters, slides, or handout materials.

Presentation Retention Policy

AsMA will use live capture technology to record all oral presentations during the meeting. Recorded presentations will be made available to registrants after the meeting. Authors are required to provide permission for live capture and a nonexclusive license to repurpose the content. PDF copies of Poster presentations must be uploaded to the designated submission site.

Permissions and Clearances

It is the author's responsibility to obtain all necessary permissions and clearances prior to submission of the abstract. AsMA assumes no liability or responsibility for the publication of any submitted material.

Acceptance Process

Abstracts will be reviewed by a minimum of three members of the AsMA Scientific Program Committee. Acceptance will be based on the abstract's originality, relevance, scientific quality, and adherence to the guidelines provided. Criteria for non-acceptance include, but are not limited to: insufficient, inconsistent, or ambiguous data; commercialism; or reviews of previously published literature. Abstracts must be 100% complete upon submission, including all final data and results. How well authors abide by submission and format guidelines will also be one of the criteria used to determine acceptance of abstracts.

Presenters are limited to one Slide OR Poster AND one Panel presentation unless given specific prior permission by the Scientific Program Committee Chair, Amanda Lippert, at sciprog@asma.org. Following review by the Scientific Program Committee in January, all contributors will receive a notification of acceptance or non-acceptance by email. Accepted abstracts will be published in *Aerospace Medicine and Human Performance*.

While the Scientific Program Committee strives to honor the presenter's desired presentation format, for reasons such as space limitations or dissimilar content, an abstract may be changed to an alternative presentation format. Assignment of an abstract to either a poster or a slide presentation will be recommended by the Scientific Program Committee, but the final decision will be made by the Program Committee Chair.

Abstract Withdrawal

Withdrawing abstracts is strongly discouraged. However, if necessary, a request to withdraw an abstract should be sent to Amanda Lippert, the Scientific Program Chair, at sciprog@asma.org and Rachel Trigg at rtrigg@asma.org. The request for withdrawal must include the abstract title, authors, ID number, and reason for withdrawal. Abstract withdrawal decisions must be sent to the Scientific Program Chair as soon as possible.

Mentorship

Optional review / feedback for all presenters at AsMA 2026

AsMA is continuing its mentorship initiative for all authors for the 2026 Scientific Meeting. You have the option to submit a draft of your abstract to a group of senior AsMA members for review and feedback. If you have questions about this opportunity, please e-mail sciprog@asma.org. E-mail your abstract to sciprog@asma.org no later than December 15, 2025. The Program Mentor Group will review provide feedback via e-mail by December 22, 2025. The abstract will still need to be finalized in the submission system.

TOPIC AREAS: (These will be listed on a drop-down menu on the submission site. They are used to organize the abstracts into sessions.)

1: Human Performance
- 1.1 Personnel Selection
- 1.2 Training
- 1.3 Hypobaric & Hyperbaric Physiology
- 1.4 Thermal Physiology
- 1.5 Acceleration / Vibration/ Impact
- 1.6 Fatigue
- 1.7 Neurophysiology & Sensory (inc. Vision, Auditory, Vestibular, Spatial Disorientation)
- 1.8 Aerospace Human Factors & Psychology
- 1.9 Aerospace Human Systems Integration

2: Clinical Medicine
- 2.1 Aviation Medicine
- 2.2 Health Promotion and Wellness Programs
- 2.3 Medical Standards / Aircrew Health
- 2.4 Occupational / Environmental Medicine
- 2.5 Operational Medicine
- 2.6 Hyperbaric Medicine

3: Travel and Transport Medicine
- 3.1 Travel Medicine
- 3.2 Aeromedical Transport / Air Evacuation
- 3.3 Air Transport Medicine
- 3.4 Commercial
- 3.5 Pandemic Preparedness

4: Space Medicine
- 4.1 Space Medicine
- 4.2 Space Operations

5: Safety and Survivability
- 5.1 Escape / Survival
- 5.2 Flight Safety / Accident Investigation

6: Other
- 6.1 History of Aerospace Medicine
- 6.2 Ethics

Follow the link on our website: *https://asma-uhms-asm.org/abstracts/asma-call-for-abstracts.html*

- **Submission hard deadline: Sunday, January 4, 2026, 11:59 PM ET (there will be no extensions)**
- Notice of acceptance by Saturday, January 31, 5 pm ET.
- **No updates to abstracts will be accepted after Saturday, February 28, 2026, 11:59 PM ET**
- **Poster presentations: PDF/PPT must be submitted to the UHMS by Monday, February 23, 11:59 PM ET - NO updates will be accepted after this date, not even on site.**

Aerospace Medical Association

631 US Highway 1, Suite 307, North Palm Beach, FL 33408, USA
(703) 739-2240, Ext. 107 | (703) 739-9652 FAX
www.asma.org

APPLICATION FOR MEMBERSHIP

OUR MEMBERSHIP APPLICATION IS AVAILABLE ONLINE. GO TO www.asma.org AND CLICK ON "MEMBERSHIP"

Please Send CV or Bio to the Journal Department: rtrigg@asma.org

You will automatically receive access to the online journal with your membership.

PLEASE PRINT – (Last Name, First Name, Middle Initial) ________ (Military Rank, Service, Corps) ________ (Degrees) ________

(Mailing Address) ________

(City, State, Zip, Country) ________

(Email address) ________ (Work Phone / Mobile Phone) ________

(Date of Birth) ________ (Gender) ________ (Area of Specialty) ________

Are you a physician? ☐ YES ☐ NO

MEMBERSHIP RATES: (check one)

☐ Regular Membership	$300
☐ Emeritus Membership[1]	$60
☐ Student[2]	$50
☐ Resident[3]	$175
☐ Allied Membership[4]	$50
☐ Technician	$130
☐ 3-Year Membership	$820

[1]**Must be 65 yrs old + 25 yrs of AsMA membership**
[2]**Requires proof of full-time student status**
[3]**Requires proof of Medical Residency**
[4]**Requires residence in Low or Low-Middle Income country**
(see list online: https://www.asma.org/membership/individual**)**

PAYMENT METHOD:

☐ Visa ☐ Amex ☐ Discover ☐ MasterCard ☐ Diners

Card Number: ________ CVV: ______

Exp. Date: ________ Amount: $________

☐ Pay by Check Check Number: ________

Signature: ________
(Required for credit card transactions)

☐ *Life Membership $5,500*

NOTE: Payment **MUST** be made by check**.**

Please contact AsMA Membership Department at skildall@asma.org for details.

☐ Bank Transfer

NOTE: all Bank Transfers must include a $35.00 US processing fee.

Please contact AsMA Membership Department at skildall@asma.org for bank details.

For United States Federal Income Tax purposes, you can deduct as a charitable contribution the price of the membership renewal less the estimated cost of your ***Aerospace Medicine and Human Performance*** journal subscription. We estimate the cost to produce the journal to be $100 per year. Any membership contribution in excess of $100 per year is tax deductible.

For Non-U.S. members, the entire membership fee is related to the activities of the Aerospace Medical Association to improve the professional knowledge and practice of its members. This includes subscription to the Association's professional journal, itself part of the education effort of the Association.

Specialties: Please select from the following list of specialties all that apply to you.

- ☐ Administrative Medicine – physicians
- ☐ Aerospace and Aviation Medicine
- ☐ Aerospace Flight Nursing
- ☐ Aerospace Human Factors & Human Engineering
- ☐ Aerospace Physiology
- ☐ Airline Medical Director
- ☐ Allergy
- ☐ Anesthesiology
- ☐ Aviation Medical Examiner
- ☐ Biochemistry
- ☐ Bioengineering
- ☐ Biomedical Engineering
- ☐ Biophysics
- ☐ Cardiology or cardiovascular disease
- ☐ Certified in Aerospace Physiology
- ☐ Dermatology
- ☐ Development & Manufacturing Industry
- ☐ Diplomate, ABPM, Cert in Aero Med
- ☐ Emergency Medicine
- ☐ ENT
- ☐ Environmental Sciences
- ☐ Epidemiology
- ☐ Family Practice
- ☐ Forensic Medicine
- ☐ Gastroenterology
- ☐ General Practice
- ☐ General Surgery
- ☐ Geriatrics
- ☐ Hand Surgery
- ☐ Human Performance
- ☐ Human Systems Integration
- ☐ Hyperbaric Medicine
- ☐ Industrial or Occupational Medicine
- ☐ Industrial or Traumatic Surgery
- ☐ Internal Medicine
- ☐ Legal Medicine
- ☐ Life Insurance Medicine
- ☐ Life Science
- ☐ Maxillofacial Surgery
- ☐ Medical Anthropology
- ☐ Military Command
- ☐ Neurological Surgery
- ☐ Neurology
- ☐ Nuclear Medicine
- ☐ Nursing/Patient Transport
- ☐ Obstetrics and Gynecology
- ☐ Occupational Diseases
- ☐ Ophthalmology
- ☐ Optometry
- ☐ Orthopedic Surgery
- ☐ Otolaryngology and Otology
- ☐ Pathology
- ☐ Pediatrics
- ☐ Pharmacology
- ☐ Physical Medicine & Rehabilitation
- ☐ Physiology
- ☐ Plastic Surgery
- ☐ Preventive Medicine – General
- ☐ Proctology
- ☐ Psychiatry
- ☐ Psychology
- ☐ Public Health
- ☐ Pulmonary Disease
- ☐ Radiology & Roentgenology
- ☐ Research and Research Scientist
- ☐ Rheumatology
- ☐ Space Medicine
- ☐ Sports Medicine
- ☐ Surgery
- ☐ Thoracic Surgery
- ☐ Toxicology
- ☐ Tropical Medicine
- ☐ Urology

Please consider joining one or more of the following Constituent Organizations:

- Aerospace Human Factors Association
- Aerospace Medicine Student and Resident Organization
- Aerospace Nursing and Allied Health Professionals Society
- Aerospace Physiology Society
- American Society of Aerospace Medicine Specialists
- International Airline Medical Association
- International Association of Military Flight Surgeon Pilots
- Life Sciences & Biomedical Engineering Branch
- Society of NASA Flight Surgeons
- Society of U.S. Air Force Flight Surgeons
- Society of U.S. Army Flight Surgeons
- Society of U.S. Naval Flight Surgeons
- Space Medicine Association
- Space Surgery Association

More Information on AsMA Corporate Sponsors

Warren Silberman, D.O.

In this President's Page, I shall inform our members and interested parties about several of the Aerospace Medical Association's other corporate sponsors. As we reminded you in the last update, you can visit many of our sponsors at the Exhibits during our annual meeting.

PharmaFlight ZRT: According to the website, PharmaFlight "… accompany the players of the aviation industry from selection through training to retirement." The program was started by Gyula Gyori and functioned as a scientific center.

The institution was founded in 2012. Its facility was built in Debrecen, Hungary, in 2015. It provides university-level pilot training along with research and development. The company collaborates with the University of Debrecen. They offer a 3.5-year professional pilot B.Sc. program and a 1.5-year helicopter pilot training program. The students can obtain an ATPL and type ratings in an Airbus or Boeing simulator.

The center also conducts joint drug research with the University of Debrecen to promote the development of medicinal products that flight crews can use safely. PharmaFlight also has equipment that can assess the fitness of workers throughout the entire transport system. The facility also offers medical and professional rehabilitation services when needed. A breakdown of the capabilities that the facility provides includes a flying academy, a simulator center, an aeromedical center that provides medical examinations and certification for flight crews, and a physiological science center.

Franklin Scientific LLC: Their mission statement reads: "Franklin Scientific LLC provides superior Contractor Logistics Support services on each customer's unique set of needs. Our professional, technical lines are well maintained to maximize availability." They have contracts with the U.S. Army and the U.S. Air Force that provide maintenance support for 14 altitude training chambers across the United States. Their employees design, manufacture, operate, and provide maintenance support for various systems, including human centrifuges, spatial disorientation trainers, hypobaric chambers, hyperbaric chambers, ejection seat trainers, night vision trainers, and briefing and debriefing systems.

Franklin Scientific can perform all services on physiological training equipment. They can install or dismantle, transport, assemble, and manage all services, including transportation, mechanical, electrical, and rigging. The company can also assist in performing start-up and testing to get the equipment back to functioning order.

MD Onboard: These individuals provide crews in commercial or business aviation with advice on in-flight medical events, in-flight medical emergency response training, and preflight passenger clearance. To achieve these goals, they provide consultative medical services tailored to the aviation industry.

MD Onboard can evaluate an airline's training program and equipment to ensure they meet regulatory requirements. Then, they ensure that the equipment functions seamlessly with their telemedical services.

The group can also provide the airline with assessments of hotels in the countries they connect to. This enables managers to understand the risks to their flight crews. They even have a mobile app that allows the airline to reach out to a crew on a layover about a crisis so the crew can check in and confirm their condition.

Harvey Watt & Co.: Any member of AsMA should be familiar with Harvey Watt & Co. If I recall the history correctly, Harvey Watt was an airline pilot who started his own company, flying around in his airplane and selling insurance to pilots. This ultimately led to the establishment of the company. They have been in existence since 1951.

Harvey Watt & Co. provides life and pilot disability insurance to airlines and individual pilots for loss of medical license. Once the pilot has a medical condition that may require a special issuance (waiver), they have physicians and nurses who will assist the pilot in providing the proper evaluations and testing to present their case to the FAA (or another nation's certifying authority) to get the pilot back in the air. If the pilot is grounded or denied, then they provide disability insurance until they can return to the cockpit. Their agents will walk the pilot through the recertification process. Their staff is also available for phone consultations to assist pilots with medical questions.

Harvey Watt is one of AsMA's more visible corporate sponsors. You will often see Sean Daigre and Robin Alston at our meetings. They sponsor the President's reception each year.

Martin Baker Aircraft Co.: This privately owned company has been the leader in the design and manufacture of crashworthy ejection seats for at least 90 years. They currently have over 16,500 seats in service, are in 72 different aircraft types, their products are in 81 countries, and they provide 54% of the global market share.

The maintainers service their seats worldwide. They can say that because of the seats and the maintainers servicing them, they

DOI: https://doi.org/10.3357/AMHP.969PP.2025

CONTACT DETAILS:
Email: President@asma.org • **Website:** www.asma.org • **Facebook:** Aerospace Medical Association • **X:** @Aero_Med • **YouTube:** @Aero_Med

PRESIDENT'S PAGE, *continued*

have saved over 7,715 lives. Martin Baker has a "historic product policy". This defines that any ejection seat that is not in its original military role for which it was designed is considered a historic product, meaning that all activities to maintain that product in service become unsupported.

The company not only provides training in the use of their seats but also covers associated systems, including parachutes, personal survival gear, and seat survival kits.

Among much recognition, Martin Baker Aircraft Co. was presented with the National Aviation Hall of Fame 2019 Spirit of Flight Award.

Inomedic Health Applications (IHA): IHA offers quite a menu of health, safety, and environmental capabilities. The company is woman-owned and its President is one of our long-time AsMA members—Leroy P. Gross, M.D., MPH. Dr. Gross is an Aerospace Medicine specialist who was a USAF Pilot/Physician. He is a Fellow of the American College of Preventive Medicine and a Fellow of the Aerospace Medical Association.

The company is located in Hampton, VA. They provide services in medical, environmental, and environmental health fields. The list of tasks they can perform is quite extensive. Here are just some of the services: occupational health program assessments, aerospace medicine consultation, nurse case management, medical education and training, regulatory compliance consulting, environmental assessments, post-emergency cleanup, air quality monitoring, geographical information systems, industrial hygiene-risk assessment, OSHA compliance assessments, hazardous chemical sampling, ionizing and non ionizing radiation surveys, food safety inspections, and epidemiological studies. Please see their website for the complete list.

Websites

FranklinScientificLLC: https://www.franklinscientificllc.com/
Harvey Watt & Co: http://harveywatt.com/
Inomedic Health Applications: http://www.ihamedical.com/
Martin-Baker Aircraft Company: http://martin-baker.com/contact/martin-baker-uk/
MD Onboard LLC: https://mdonboard.com/
PharmaFlight: http://www.pharmaflight.hu/

Pilot Ultraviolet A Exposures in the Cockpit of Flying Commercial Aircraft

Nicola A. Emslie; J. Ben Liley; Paul Johnston

INTRODUCTION: Pilots have an increased incidence of cutaneous melanoma compared to the general population; occupational exposure to ultraviolet (UV) radiation is one of several potential risk factors. Cockpit windshields effectively block UVB (280–315 nm) but further analysis is needed for UVA (315–400 nm). The objective of this observational study was to assess transmission of UVA through cockpit windshields and to measure doses of UVA at pilots' skin under daytime flying conditions.

METHODS: A spectrometer was used to measure in-flight spectral transmission through each of the 6 cockpit windshields in 15 Airbus A320/A321 jets, across 39 flights, most originating in or destined for Auckland, New Zealand. UVA- and UVA1-weighted dose rates were calculated from the recorded data.

RESULTS: All front windshields blocked UVA effectively. Several cockpit side and rear windshields allowed transmission of UVA above approximately 350 nm. Diffuse, scattered light in the cockpit contributed negligible levels of UVA, but direct light through a poorly attenuating windshield allowed UVA1 (340–400 nm) doses of up to 2.29 mW · cm^{-2} on exposed skin. The use of shielding blinds on side windshields blocked UVA transmission effectively.

DISCUSSION: Aircraft windshield manufacturers should ensure consistent UVA blocking capability of all cockpit windshields. Pilots should be encouraged to wear sunscreen on exposed skin and use side windshield visors if skin is in the direct light beam. Given the variable performance of cockpit windshields, and increased rates of skin cancer among pilots, further research on other commercial jet aircraft types is recommended.

KEYWORDS: ultraviolet radiation, UVA, melanoma, airline pilot.

Emslie NA, Liley JB, Johnston P. *Pilot ultraviolet A exposures in the cockpit of flying commercial aircraft*. Aerosp Med Hum Perform. 2025; 96(9):803–809.

Several studies have indicated that pilots have an elevated incidence of cutaneous melanoma and keratinocyte skin cancers. Two meta-analyses report an approximate doubling of risk of melanoma compared to the general population.[1,2] The etiological basis for this remains unclear, but occupational exposure to ultraviolet radiation (UVR) is one of several exposures of interest, along with cosmic radiation, circadian dysrhythmia, and nonoccupational UVR exposure.[3] Both ultraviolet A (UVA) and ultraviolet B (UVB) are implicated in the development of skin cancers, including melanoma.[4] UVR levels are higher at altitude than at sea level and may be increased further by reflection off clouds or a snow layer.[5,6] An absolute change in UVA irradiance with altitude of 2% per 1000 ft (305 m) has been reported, based on in-flight measurements.[7]

Glass is known to block UVB effectively. However, a ground-based study investigating UVR transmission through cockpit windshields showed that UVA blocking performance was variable in multilaminate glass windshields.[8] There have been few published studies assessing UVA exposures inside the cockpit of flying commercial aircraft[7,9,10] and, to our knowledge, none from Australasia, a region known to have higher peak levels of ambient UVR than other regions of comparable latitude elsewhere in the world.[11,12]

From the National Institute of Water and Atmospheric Research, Lauder, New Zealand.

This manuscript was received for review in February 2025. It was accepted for publication in May 2025.

Address correspondence to: Dr. Nicola Emslie, Occupational Health and Safety Service, Middlemore Hospital, 100 Hospital Rd, Auckland 2025, New Zealand; nemslie@yahoo.com.

DOI: https://doi.org/10.3357/AMHP.6647.2025

Previous studies have demonstrated significant variability in the UVA attenuating (blocking) properties of windshields, sometimes even within the same aircraft.[7,13] Higher cockpit UVA levels were observed when the aircraft position relative to the sun was such that direct sunlight was entering the cockpit, but the levels reduced when visors were deployed to block nuisance light.

The UVA-attenuating characteristics of cockpit windshields and the related levels of UVA are important to assess given the many hours pilots spend in the cockpit over a career that may span decades. The objectives of this observational study were to assess the spectral transmission of UVA into the cockpit of passenger commercial aircraft and to calculate the dose of UVA at the pilots' skin during spring and summer daytime flying.

METHODS

We obtained spectral measurements from 15 different A320/A321 aircraft (each with 6 windshields) on 17 flying days between November 1, 2019, and January 17, 2020 (southern hemisphere late spring and summer months). Data was obtained across 39 flights—these flight sectors comprised domestic, trans-Tasman, and Pacific Island routes out of Auckland, New Zealand.

Subjects

The research did not require New Zealand Health and Disability Ethics Committee review. Data was collected noninvasively during work that the subjects would have undertaken had no experiment existed. Pilots were briefed on the research prior to study commencement, and participation was voluntary.

Equipment

An Ocean Optics (OO) (Dunedin, FL) USB4000 spectrometer was used for spectral measurements and was connected to an OO diffuser using an OO fiber optic. This diffuser collected light in close proportion to the cosine of the incidence angle, so that the system measured irradiance (the combined diffuse and direct components of radiation onto a flat surface). The fixing of the fiber at the OO entrance port was achieved using an in-house-manufactured bracket to ensure constant throughput in cockpit use. A Microsoft (Redmond, WA) Surface-Pro Tablet was used to run OO SpectraSuite software for the measurements and to provide power for the USB4000.

Procedure

A total of 39 flight sectors were flown, with more than 370 in-flight spectral measurements undertaken. The aircraft were being operated as regular scheduled commercial flights and originated in, or were bound for, Auckland, New Zealand (latitude −37.0 S, longitude 174.8 E). Most flights were relatively short domestic sectors within New Zealand, on A320 aircraft, and involved approximately north–south flying and vice versa between main airports (Auckland, Wellington, Christchurch, Dunedin, and Queenstown) on the two largest islands. These flights were typically 1–2 h in duration. Six short international sectors were undertaken in an A320 Neo and two A321 Neo aircraft flying out of Auckland (to Noumea, New Caledonia, and to Sydney and Coolangatta, Australia, and return). These flights were each around 3-h duration per sector.

Each A320/A321 aircraft has six cockpit windshields: two large front windshields directly in front of where the pilots sit, two smaller side windshields directly adjacent to each pilot, and two rear windshields located further back along the fuselage, just behind the pilots. In-flight spectral measurements were taken at cruise altitude [typically 35,000–39,000 ft (10,668–11,887 m)] through all 6 individual windshields within each of 15 aircraft tested. Measurements were not taken during critical phases of flight, such as takeoff and landing.

Spectral measurements were obtained by attaching the mounted suction cup to the inner surface of each cockpit windshield, which placed the diffuser in aligned contact with the windshield. Each measurement comprised 30 s of 0.5–1.0-s spectrum integration, depending on light intensity, providing an average spectrum. Measurements were also periodically taken at pilots' exposed arm or face when it was noted that their skin was in the direct light beam through a windshield. Dark spectra were also routinely measured. Cloud conditions, altitude, and spectrometer temperature were noted for each windshield measurement taken.

Statistical Analysis

Software developed by the New Zealand National Institute of Water and Atmospheric Research, using Ocean Optics' SpectraSuite tools, was used to collect the raw measurement counts per second, subtract the dark spectrum, correct for stray light, and convert to physical units. Using calibrations against an internationally calibrated double-monochromator instrument at the National Institute of Water and Atmospheric Research facility, located in Lauder, Central Otago (45.0°S,169.7°E), the data processing algorithm converted these signals to irradiances ($mW \cdot cm^{-2} \cdot nm^{-1}$) from which the biologically weighted quantities of interest, in particular UVA- and UVA1-weighted dose rates ($mW \cdot cm^{-2}$), were calculated. Our statistical error estimate is ±8%. The precision of the results is estimated to be about ±0.02 $mW \cdot cm^{-2}$.

RESULTS

UVB (280–315 nm) transmission was not detected through any cockpit windshields; UVB was attenuated effectively by each of the 6 windshields in all 15 aircraft tested. We provide our results for the rest of this report in terms of UVA1 wavelengths (340–400 nm), as no significant transmission occurred at shorter wavelengths below 340 nm.

UVA1 is not routinely used in the context of environmental UV, for which total UVA, UVB, and especially erythemally-weighted UV are standard. However, UVA1 is used in phototherapy to treat sclerosing skin conditions and other

Table I. Maximal UVA1-Weighted Dose Rates Measured Through Side or Rear Cockpit Windshields (mW · cm^{-2}) for Each Aircraft Tested.

AIRCRAFT	DATE (mo/yr)	TIME	WINDSHIELD POSITION	MAXIMAL UVA1-WEIGHTED DOSE RATE (mW · cm^{-2})
A320 #1	November 2019	14:32	Rear	2.1
A320 #2	December 2019	13:35	Side	1.8
A320 #3	November 2019	14:46	Side	1.8
A320 #4	January 2020	09:30	Rear	3.0
A320 #5	November 2019	11:45	Side	0.01
A320 #6	November 2019	16:00	Side	2.6
A320 #7	December 2019	14:38	Side	2.8
A320 #8	December 2019	13:30	Rear	1.5
A320 #9	December 2019	14:13	Side	2.2
A320 #10	December 2019	16:15	Rear	0.02
A320 #11	January 2020	15:57	Side	2.2
A320 #12	January 2020	12:44	Side	1.6
A320 Neo #1	January 2020	15:13	Rear	0.1
A321 Neo #1	January 2020	11:00	Rear	0.2
A321 Neo #2	January 2020	12:56	Rear	0.2

dermatitides.[14] Though less damaging than UV of shorter wavelengths, UVA1 conveys many of the same risks at lower intensity;[15] therefore, attempting to quantify occupational exposures is of interest.

The 2 front windshields on all 15 aircraft tested showed very minimal UVA1 transmission. The maximum UVA1-weighted dose rate at the inner surface of a cockpit front windshield was 0.17 mW · cm^{-2}; the average was 0.04 mW · cm^{-2} for the left front windshield and 0.05 mW · cm^{-2} for the right. UV transmission through cockpit side and rear windshields was much more variable than through the front windshields. Several side and rear windshields allowed transmission of UVA at wavelengths beyond approximately 340–350 nm. A maximal UVA1 weighted dose rate of 3.0 mW · cm^{-2} was obtained from the inner surface of a rear windshield, and a maximal UVA1 weighted dose rate of 2.8 mW · cm^{-2} was obtained from a side windshield, demonstrating significantly higher transmission of UVA1 compared to the front windshields, as shown in **Table I**.

Certain side and rear windshields consistently performed poorly in terms of attenuating UVA transmission. All such windshields were subsequently found to belong to a subgroup made by one manufacturer and sharing related identifying "part numbers." The maximal UVA1-weighted dose rate for this group of poorly attenuating windshields, averaged across all flights, was 1.7 mW · cm^{-2}, with a maximal single measurement of 3.0 mW · cm^{-2}. All other side and rear windshields performed much better in terms of UVA attenuation—these windshields (produced by three different manufacturers, one of which had also produced the poorly performing subgroup, but with a different part-number) showed an average maximal UVA1-weighted dose rate of 0.07 mW · cm^{-2}. This difference in attenuation performance depending on the part-number was consistent across all measurements taken throughout the study. Superior performing windshields were fitted in all 6 positions of some aircraft (A320 #5, A320 #10, A320 Neo #1, A321 Neo #1 and 2), resulting in very low levels of UVA1 being transmitted into the cockpit, as shown in Table I.

The variation in attenuation performance is illustrated in **Fig. 1**, which compares a poor performing side windshield with that of a superior performing side windshield located in the same position on a different A320 aircraft. These measurements were taken 3 d apart, in December 2019, at similar times of day (14:13 and 13:59, respectively) on domestic flights within New Zealand. Note, the two plots of UVA1 irradiance are not directly comparable, as the two windshields did not receive the exact same levels of sun striking the windshields; nonetheless, the difference in UVA1 blocking performance is apparent. The poorly performing windshield allowed a UVA1-weighted dose rate of 2.0 mW · cm^{-2}, compared to 0.0 mW · cm^{-2} in the

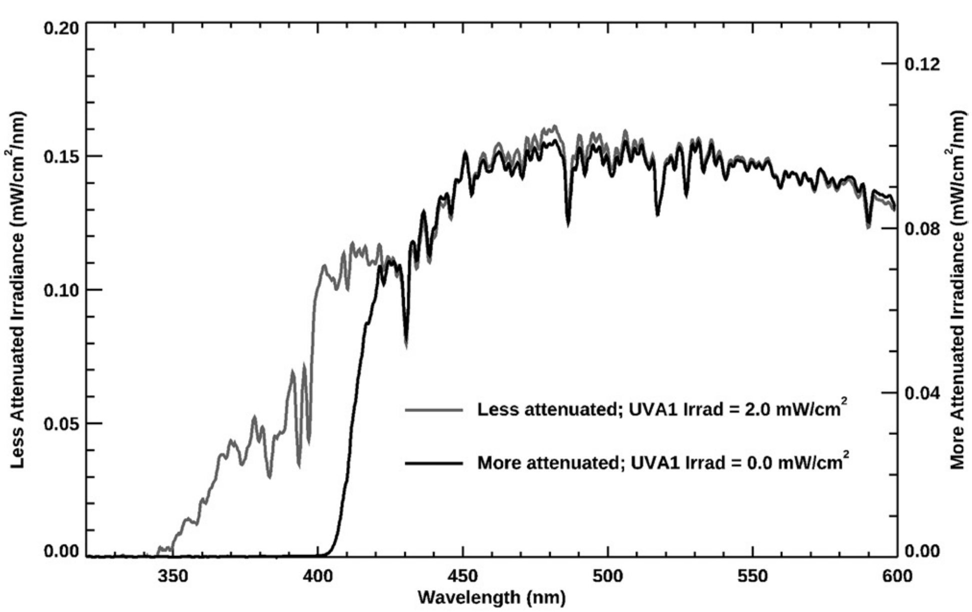

Fig. 1. Comparison of UVA1 irradiance inside the cockpit from behind inferior and superior attenuation windshields. Two y-axes are shown because the spectra have been rescaled to be comparable in the visible (400–700 nm) region.

Table II. Maximal UVA1-Weighted Dose Rates Measured at Pilots' Skin Exposed to Direct Light Through Inferior Attenuation Side Windshields.

AIRCRAFT	DATE (mo/yr)	TIME	EXPOSED SKIN	UVA1 (mW · cm^{-2})
A320 #2	December 2019	13:37	Forearm (left)	1.65
A320 #9	December 2019	07:28	Face (left)	1.35
		14:16	Forearm (left)	1.80
A320 #11	January 2020	15:49	Forearm (right)	1.86
		17:53	Face (left)	1.68
A320 #12	January 2020	13:00	Forearm (right)	1.15
A320 #7	January 2020	09:48	Forearm (left)	2.29
		11:52	Forearm (right)	2.13
A320 #4	January 2020	07:43	Hand (left)	1.35
		09:29	Hand (left)	2.12

windshield with effective UVA attenuation properties, under similar environmental conditions. Note, the increase in transmission above 400 nm is expected even for the superior attenuation windshield as the electromagnetic spectrum above about 380 nm is visible to the human eye; that is, the windshield is allowing visible light wavelengths through.

UVA levels were also measured periodically within the cockpit itself, with the diffuser directed toward the windshield to measure incoming UVR but held adjacent to exposed skin, such as the pilot's forearm or the side of his/her face. If the exposed skin was not in the direct light beam coming in through the windshield, and was therefore only illuminated by diffusely scattered light, measured UVA levels were insignificant. However, if the exposed skin was in the direct light beam, maximal UVA1 levels of 1.15–2.29 mW · cm^{-2} were detected (see **Table II**). These maximal measurements were obtained from direct light coming through inferior attenuation windshields. In contrast, direct sunlight through superior attenuation windshields resulted in negligible measured UVA1 levels at the exposed skin surface.

When the sun is shining directly on the pilot's arm or the side of the pilot's face through the cockpit side windshield, he/she has the option to use a yellow-tinted, pull-up, transparent blind to block the light rays. This was observed to be used frequently, for both thermal and ocular comfort in bright light conditions. On several occasions, a routine spectral measurement was taken at a side windshield, followed by a second measurement from directly behind the blind. The blind very consistently blocked all UVA wavelengths from passing through and onto the pilot's skin. This is illustrated in **Fig. 2**, with UVA1 measurements from A320 #2 taken between 13:35–13:38 in late December 2019.

DISCUSSION

Several previous studies have sought to quantify pilots' exposures to UVR in the cockpit of flying aircraft.[9,13,16] While the presence of UVB was excluded in an early study by Diffey,[17] more recent work has focused on ocular and skin exposures to UVA wavelengths.[7,10,13] Knowing that other studies have shown that aircraft windshields may not completely block UVA exposures and that there can be significant variation in attenuation characteristics between different individual windshields, we sought to measure in-flight UVA levels in several A320/A320 Neo/A321 Neo aircraft, systematically assessing the six windshields in each aircraft. The windshields studied were all multilayer (laminated) glass windshields but were produced by three different manufacturers. Within a single aircraft, there can be a combination of windshields from different manufacturers.

In the 15 Airbus A320/A320 Neo/A321 Neo aircraft tested, the 30 cockpit front windshields showed consistently good UVA attenuation performance and effectively blocked UVA wavelengths. However, we found considerable variability in the UVA attenuation performance of cockpit side and rear windshields (see Table I). The key determinant of whether a given side or rear windshield showed good UVA blocking properties was the "part number" (determined by manufacturer and intended position of the windshield within the cockpit, i.e., front, side, or rear). We found that a grouping of side and rear windshields with related part numbers, from a single manufacturer, allowed much higher levels of UVA1 transmission into the cockpit than all other windshields fitted in the various aircraft studied. Fig. 1 illustrates one example of the contrast in UVA attenuation performance between different side windshields, based on differing part numbers. This difference was observed consistently across the study. One or two of these poorly attenuating side or rear windshields were found to be fitted in 10 of the 15 aircraft tested (all A320s). The A320 Neo and A321 Neo aircraft (total three), all had full sets of windshields that blocked UVA well.

We were able to demonstrate that, when the angle of the sun allows the direct light beam to be transmitted through poorly attenuating cockpit windshields, this can result in UVA1 exposures at the pilot's uncovered skin. The vast majority of pilots who took part in this study wore short sleeved shirts in the cockpit. Direct light through the adjacent side windshield was often observed on the pilot's forearm. Less frequently, direct light was also observed on the side of the pilot's face. A maximal UVA1 level of 2.29 mW · cm^{-2} was measured at a pilot's forearm, and measures in the range of 1–2 mW · cm^{-2} were common. It is noteworthy that the use of the yellow-tinted blind described above was highly effective in blocking UVA transmission, as has been reported previously[9] and as demonstrated in Fig. 2.

It was noted that on early morning and late afternoon flights, significant UVA1 levels were measured within the cockpit. This related to the sun being relatively low in the sky, and the direct beam being unobstructed by the cockpit fuselage above the level of the windshield. A UVA1 level of 1.35 mW · cm^{-2} was recorded at the side of a pilot's face at 07:28 in December 2019, and again, 1.35 mW · cm^{-2} was recorded at a pilot's hand at 07:39 in January 2020. This finding is important because there is general awareness among the public that outdoor UV levels are particularly high around the middle of the day and in summer. However, most people do not think of using sun protection in the early or late daylight hours, in the winter months, or, indeed, when seated behind a window or windshield.

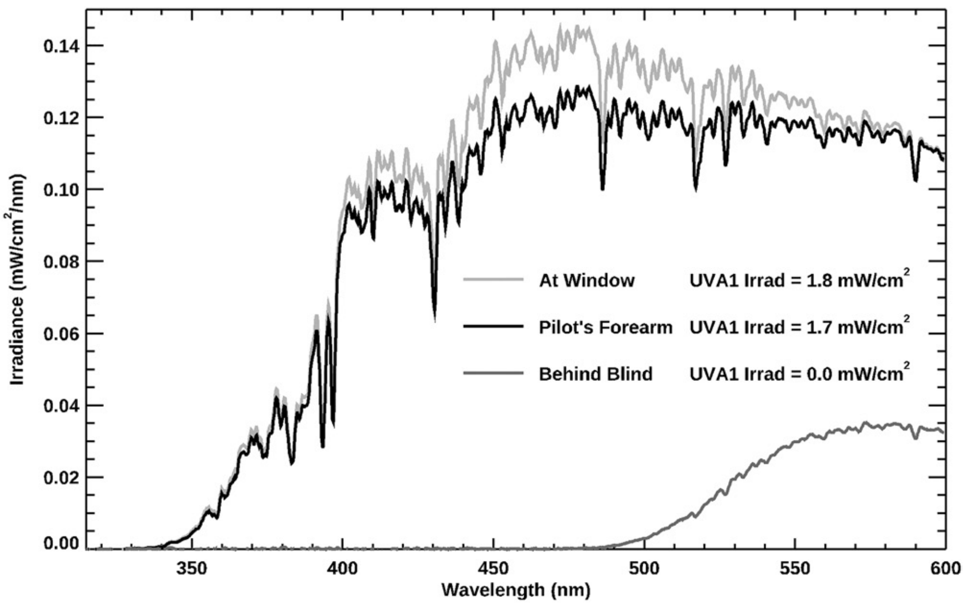

Fig. 2. UVA1-weighted dose rates recorded at cockpit side windshield, at pilot's forearm, and behind windshield blind. For the two upper curves, integration times optimized for UVA measurement caused counts to overflow in the higher intensity visible region. This has been corrected by imputation from the most similar unsaturated spectra on that day, with no effect on UVA results.

We have reported UVA1 levels in the Airbus A320/A321 cockpits, through some poorly attenuating side and rear windshields (all with the same part-number), of up to 3.0 $mW \cdot cm^{-2}$ as a maximal reading and, on average, 1.7 $mW \cdot cm^{-2}$ (measured at the inner surface of the windshields). Cadilhac and colleagues[9] used a UV radiometer to take measurements during 14 flights in Airbus and Boeing 777 aircraft during July through October 2016, along with some ground-based measurements at Charles de Gaulle Airport in Paris. Measurements were taken at four points within the cockpit: at the eye and elbow of both pilots. In-flight data were collected for Airbus A319, A330, A380, and Boeing 777. Cadilhac's group did not find any UVA radiation in any of the Airbus cockpits during the flights. This is in contrast to our findings in A320 aircraft, in which we found UVA1 levels of up to 3.0 $mW \cdot cm^{-2}$, through the poorly attenuating subgroup of side and rear windows.

Cadilhac's group also took in-flight UVA measurements in the cockpit of Boeing 777 aircraft with a reported range of 0.01–1.22 $mW \cdot cm^{-2}$. The average across 165 measurements was 0.34 $mW \cdot cm^{-2}$. We did not take measurements in any Boeing aircraft in the current study and, therefore, cannot make a comparison. Some ground UVR measurements were also obtained by Cadilhac's group outdoors on the taxiway at Charles de Gaulle Airport, Paris, between 12:25–13:50 on September 13, 2016. UVA levels of 2.4–2.8 $mW \cdot cm^{-2}$ were found. Several of our summertime in-flight measurements within the A320 cockpit at cruise altitude exceeded those outdoor ground levels in Paris in early autumn.

New Zealand is known to have higher peak levels of erythemal UVR than northern hemisphere locations of similar latitude.[11,12] Some of the difference relates to ozone, which does not affect UVA1, but other effects (Earth–Sun distance, aerosols, and clouds) do imply higher UVA1 in the southern hemisphere. Outdoor UVA1 levels of up to around 4.0 $mW \cdot cm^{-2}$ have been measured at Lauder (in New Zealand's South Island), around midday in unobscured sun during early spring and midsummer, when UVA levels are typically at their highest. It is a strength of our study that we have been able to contribute Southern Hemisphere in-flight data on UVR exposures in flight.

At a cruise altitude of 38,000 ft (11,580 m), there is much less atmosphere to attenuate UV exposures, and even early morning and late afternoon sun can carry significant UV levels. Furthermore, unlike UVB, UVA levels are relatively constant year-round. Thus, it is important for fair-skinned pilots to understand that whatever the time of day or season, if there is direct light on their exposed skin and they do not know that the particular windshield in their aircraft blocks UVA well, protection of their skin with clothing, sunscreen, and/or use of blinds is recommended.

Several studies (including two large meta-analyses) have indicated that pilots have approximately twice the risk of developing, and dying from, cutaneous melanoma compared to the general public.[1–3] A study of Australian commercial pilots reported no elevation of invasive melanoma compared with the general population, however, they did report a modestly raised risk of in situ melanoma among pilots [standardized incidence ratio of 1.39 (95% CI = 1.08–1.78)].[18]

Historically, UVB has been considered the exposure of concern with regard to carcinogenesis, because with shorter wavelengths (280–315 nm), it carries more energy capable of causing cellular damage. A growing body of evidence suggests that UVA (315–400 nm) also plays a significant role in both the initiation and promotion of melanoma.[4,19,20] UVA can damage DNA and other intracellular structures directly and indirectly by creating reactive oxygen species; it also has a suppressive effect on immune functions involved in DNA repair and may increase invasiveness of melanoma cells.[15,21]

Of the solar UVR that reaches the Earth's surface, approximately 95% is UVA and 5% is UVB, although the precise ratio varies with solar elevation and ozone. Thus, UVA is far more prevalent than UVB; UVA can also penetrate glass and is able to penetrate the skin itself more deeply than UVB (to the dermal layer rather than just the epidermis).[20] In New Zealand, melanoma rates are high among the general population—approximately 35 per 100,000 people are diagnosed with melanoma each year, one of the highest age-standardized rates in the world.[22] New Zealand, like Australia, has high ambient levels of UVR compared to other regions of comparable latitude.[11]

Occupational exposure limits, such as those published by the Australian Radiation Protection and Nuclear Safety Agency and the International Commission on Non-Ionizing Radiation Protection, are not easily applied to exposures of relatively low and variable levels of UVA1 at a pilot's skin.[23,24] Even behind a windshield with known spectral transmission characteristics, the actual exposures will fluctuate significantly over time, e.g., due to the relative position of the sun and to behavioral effects. The occupational exposure standards were not developed for this type of exposure, but rather for artificial sources of UVR in the workplace, such as UVA lamps, welding, and solar UVR in outdoor workers.

Outdoor solar UVR is of course another exposure with high variability, and the Australian Radiation Protection and Nuclear Safety Agency states that for outdoor workers, "application of the exposure limits…is not practical and limiting UVR exposures to as low as possible is the most effective approach."[23] It is the authors' opinion that this is also an appropriate approach for pilot exposures to UVA in the cockpit of flying aircraft, in which levels of UVA are certainly less than outdoor summer sun exposures but may have as yet unknown long-term health effects over many years of chronic low-level exposure. Given that we do not have good evidence on what a "safe" level of UVA exposure is in this setting, nor to what extent (if any) such exposures may increase pilots' risk of skin cancers, it is important to limit pilots' exposure to UVA in the cockpit as much as possible.

Protecting pilots from UVA exposures can be achieved in the short term through the use of broad-spectrum sunscreens on exposed skin and the use of shielding blinds (if fitted) over the side and rear cockpit windshields, as described previously. However, higher-level definitive control measures are required: specifically, cockpit windshields that consistently block the transmission of all UVA wavelengths. We have demonstrated that some windshields achieve this well, but others do not. Manufacturers need to ensure adequate broad-spectrum UVA protection, not just in the multilaminate layers of the front two windshields, but in all six windshields of the cockpit.

A weakness of the current study is that we are not able to generalize our results more widely to other aircraft types, which may be fitted with windshields with differing spectral transmission characteristics. Further data from airlines flying different aircraft types, and in different regions of the world, would help to build upon the current data from this and other previous in-flight studies.[9,10,13]

Through multiple measurements of the spectral transmission characteristics of cockpit windshields in a number of commercial Airbus aircraft, we have demonstrated significant variability in UVA-blocking performance, with many windshields allowing UVA1 transmission into the cockpit and onto pilots' exposed skin. Aircraft windshield manufacturers should ensure consistent UVA-blocking capability of all cockpit windshields. When flying in an aircraft that has not been confirmed to have UVA-blocking windshields, pilots should be encouraged to wear sunscreen on exposed skin and use side windshield blinds if skin is in the direct light beam. Given the variable performance of cockpit windshields, further research on other commercial jet aircraft types is recommended.

ACKNOWLEDGMENTS

The authors would like to thank the Australasian Faculty of Occupational and Environmental Medicine and the Australasian Society of Aerospace Medicine for providing funding to enable this study. Drs. Tim Sprott and Ben Johnston provided support through their advice and mentorship. Thanks must also be extended to the Air New Zealand pilots who were so willing to take part in this research.

Financial Disclosure Statement: The authors have no competing interests to declare.

Authors and Affiliations: Dr. Nicola A. Emslie, MB ChB, MAvMed, Middlemore Hospital, Health New Zealand, Auckland; and J. Ben Liley, M.Sc., B.Sc. (Hons), and Paul Johnston, B.Sc., National Institute of Water and Atmospheric Research, Lauder, New Zealand.

REFERENCES

1. Sanlorenzo M, Wehner MR, Linos E, Kornak J, Kainz W, et al. The risk of melanoma in airline pilots and cabin crew: a meta-analysis. JAMA Dermatol. 2015; 151(1):51–8.
2. Miura K, Olsen CM, Rea S, Marsden J, Green AC. Do airline pilots and cabin crew have raised risks of melanoma and other skin cancers? Systematic review and meta-analysis. Br J Dermatol. 2019; 181(1):55–64.
3. Hammer GP, Auvinen A, De Stavola BL, Grajewski B, Gundestrup M, et al. Mortality from cancer and other causes in commercial airline crews: a joint analysis of cohorts from 10 countries. Occup Environ Med. 2014; 71(5):313–22.
4. Fadadu RP, Wei ML. Ultraviolet A radiation exposure and melanoma: a review. Melanoma Res. 2022; 32(6):405–10.
5. Blumthaler M, Ambach W, Ellinger R. Increase in solar UV radiation with altitude. J Photochem Photobiol B. 1997; 39(2):130–4.
6. Meerkötter R. An estimation of the UV radiation inside the cockpits of large commercial jets. CEAS Aeronaut J. 2017; 8(1):93–104.
7. Schennetten K, Meier MM, Scheibinger M. Measurement of UV radiation in commercial aircraft. J Radiol Prot. 2019; 39(1):85–96.
8. Nakagawara VB, Montgomery RW, Marshall WJ. Optical radiation transmittance of aircraft windscreens and pilot vision. Oklahoma City (OK): Civil Aerospace Medical Institute, Federal Aviation Administration; 2007 Jul. Report No.: DOT/FAA/AM-07/20. Sponsored by the Office of Aerospace Medicine, Federal Aviation Administration.

9. Cadilhac P, Bouton MC, Cantegril M, Cardines C, Gisquet A, et al. In-flight ultraviolet radiation on commercial airplanes. Aerosp Med Hum Perform. 2017; 88(10):947–51.
10. Baczynska KA, Brown S, Chorley AC, O'Hagan JB, Khazova M, et al. In-flight UV-A exposure of commercial airline pilots. Aerosp Med Hum Perform. 2020; 91(6):501–10.
11. Seckmeyer G, McKenzie RL. Increased ultraviolet radiation in New Zealand (45° S) relative to Germany (48° N). Nature. 1992; 359:135–7.
12. McKenzie R, Bodeker G, Scott G, Slusser J, Lantz K. Geographical differences in erythemally-weighted UV measured at mid-latitude USDA sites. Photochem Photobiol Sci. 2006; 5(3):343–52.
13. Chorley AC, Baczynska KA, Benwell MJ, Evans BJ, Higlett MP, et al. Occupational ocular UV exposure in civilian aircrew. Aerosp Med Hum Perform. 2016; 87(1):32–9.
14. York NR, Jacobe HT. UVA1 phototherapy; a review of mechanism and therapeutic application. Int J Dermatol. 2010; 49(6):623–30.
15. Bernerd F, Passeron T, Castiel I, Marionnet C. The damaging effects of long UVA (UVA1) rays: A major challenge to preserve skin health and integrity. Int J Mol Sci. 2022; 23(15):8243.
16. Sanlorenzo M, Vujic I, Posch C, Cleaver JE, Quaglino P, et al. The risk of melanoma in pilots and cabin crew: UV measurements in flying airplanes. JAMA Dermatol. 2015; 151(4):450–2.
17. Diffey BL, Roscoe AH. Exposure to solar ultraviolet radiation in flight. Aviat Space Environ Med. 1990; 61(11):1032–5.
18. Olsen CM, Miura K, Dusingize JC, Hosegood I, Brown R, et al. Melanoma incidence in Australian commercial pilots, 2011–2016. Occup Environ Med. 2019; 76(7):462–6.
19. Khan AQ, Travers JB, Kemp MG. Roles of UVA radiation and DNA damage responses in melanoma pathogenesis. Environ Mol Mutagen. 2018; 59(5):438–60.
20. Tewari A, Grage MM, Harrison GI, Sarkany R, Young AR. UVA1 is skin deep: molecular and clinical implications. Photochem Photobiol Sci. 2013; 12(1):95–103.
21. Kamenisch Y, Baban TS, Schuller W, von Thaler AK, Sinnberg T, et al. UVA-irradiation induces melanoma invasion via the enhanced Warburg effect. J Invest Dermatol. 2016; 126:1866–75.
22. New cancer registrations [Internet]. Wellington (New Zealand): New Zealand Cancer Registry, Health New Zealand, Te Whatu Ora. 2019 [cited April 8, 2025]. Available from: https://www.health.govt.nz/statistics-research/statistics-and-data-sets/cancer.
23. Radiation protection standard: occupational exposure to ultraviolet radiation. Radiation protection series No.12. Yallambie (Australia): Chief Executive Officer of Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). 2006 Dec. Sponsored by the Australian Government.
24. International commission on non-ionizing radiation protection statement on protection of workers against ultraviolet radiation. Health Phys. 2010; 99(1):66–87.

Real-Flight Observations of Head and Trunk Movements of Fast Jet Pilots

Rene Lingscheid; Kirsten Albracht; Fabian Goell; Roland Nuesse; Robert Rein; Bjoern Braunstein

INTRODUCTION: Military fast jet pilots face significant physical challenges, including high G_z accelerations during dynamic maneuvers. The objectives of this study were threefold: 1) to record pilot movements during real flights, 2) to quantify head and trunk movements under standardized G_z conditions and during basic fighter maneuvers (BFMs), and 3) to categorize compensatory strategies used to mitigate physical strain.

METHODS: A total of 20 Eurofighter pilots (mean age: 28.2 ± 1.4 yr, all men) with >500 h EF2000 flight experience participated in the study. Video footage collected during the execution of a standardized mission card, including predetermined head movements and jet parameters (5, 7, 9 G_z), and free basic fighter maneuvers were analyzed.

RESULTS: During scripted high-G_z maneuvers, 38.5% of pilots prepositioned their head for the up-max movement at 9 G_z. During check six, coping strategies were applied in 35.7% (5 G_z), 30.8% (7 G_z), and 33.3% (9 G_z) of the flights. During basic fighter maneuvers, an average of 63.6 ± 32.1 head movements per session and 27.2 ± 13.7 per set were performed by the pilots. It was observed that end-range movements (e.g., check six) were associated with a greater usage of coping strategies. The most commonly included strategies were the use of support points such as canopy rails.

DISCUSSION: This real-flight study reveals frequent use of anticipatory head positioning and compensatory strategies under high G_z loads, especially during end-range movements. These behaviors appear to serve the purpose of reducing cervical strain and injury risk. The findings underscore the necessity for targeted training and the optimization of ergonomic design in pilot equipment.

KEYWORDS: military aviation, real flight, head movements, human performance, extreme environments, fast jet, human factors.

Lingscheid R, Albracht K, Goell F, Nuesse R, Rein R, Braunstein B. *Real-flight observations of head and trunk movements of fast jet pilots*. Aerosp Med Hum Perform. 2025; 96(9):810–818.

In the fast-paced and dynamic environment of military jet aviation, the capacity of pilots to make rapid decisions is of paramount importance. In particular, during air combat, split-second decisions often determine the outcome of a battle. To make good decisions, pilots must monitor the aircraft's performance metrics, sensors (e.g., radar), weapons systems, and countermeasure capabilities. They must also actively scan the aircraft's surroundings using specific head movements. However, pilots are often exposed to large changes in acceleration, which place stress on the neck region. A study by Drew confirmed that both cervical and lumbar spine pain are prevalent among military pilots due to repeated high-G exposure.[1] The functional mobility of the cervical spine and the protective surrounding structures help counteract the effects of the resultant high gravitational accelerations.[2]

The scanning behavior that pilots employ during flight to assess the airspace is comparable to the cross-checking and scanning behavior observed in athletes and during team sports.[3,4] Pilots use scanning behavior to capture information from both inside and outside the cockpit.[3,5] The head and upper body movements performed during scanning facilitate the perception of visual stimuli from the environment, and acquiring such information enhances the situational awareness of the

From the Institute of Movement and Neuroscience, German Sport University, Cologne, North Rhine-Westphalia, Germany.

This manuscript was received for review in December 2024. It was accepted for publication in May 2025.

Address correspondence to: Rene Lingscheid, M.Sc., Schwalbacher Str. 49, Cologne NRW 50969, Germany; renelingscheid@gmail.com.

DOI: https://doi.org/10.3357/AMHP.6631.2025

pilot. It is thus unsurprising that as the frequency of acquiring action-relevant information about the airspace and technical environment increases, so too does the pilot's situational awareness and the amount of decision-relevant information.[6] Accordingly, during flight, pilots seek to maximize their situational awareness by continuously gathering and integrating critical information from both the cockpit instruments and the surrounding airspace. This enables them to make rapid, informed decisions, which is essential for effective maneuvering and mission success.

In a study conducted with pilots in a trainer jet engaged in simulated air combat, it was found that the pilots used four distinct head positions: the neutral position, a position in which the neck was maximally extended, a position that involved rotation to a self-selected side around the transverse axis, and the check six position.[7] In military aviation, check six refers to the anatomical rotation of the upper body and head as far back as possible to monitor the area behind the aircraft. In the context of this study, it was postulated that the risk of injuring the cervical spine may be elevated by performing terminal rotation, flexion, and/or extension of the neck.[7–9] Prior research has indicated that head movements from the neutral position, particularly during periods of high acceleration, are associated with an elevated risk of acute musculoskeletal damage due to overload.[10] In a real-flight study, Netto and Burnett[7] measured the activation of the neck muscles in six subjects under different G_z accelerations (1 G_z, 3 G_z, and 5 G_z) using surface electromyography on the neck and shoulder muscles. They found that the check six position resulted in the highest level of muscle activity (up to 71.5% maximal voluntary contraction). These findings can be confirmed through a centrifuge study by Honkanen, who demonstrated a positive correlation between muscle activity and $+G_z$, independent of pilots' high-performance aircraft experience.[11] The present observations are consistent with the findings of Chumbley et al., who previously identified specific flight-related risk factors for cervical spine pain in F-15C pilots, particularly those associated with check six positioning and high G exposure.[12] However, the authors of that study did not provide detailed information on the duration of exposure to a specific position or the number of times the head was (re)positioned. Given the potential impact of sustained high muscle activation under dynamic flight conditions, more detailed investigations of the head movements of pilots are essential to achieve a full understanding of their implications for pilot health and performance.[13]

In an early and important study, Newman[14] examined self-reported head positioning techniques among 42 F/A-18 pilots of the Royal Australian Air Force, identifying a variety of individualized strategies designed to protect the cervical spine during air combat maneuvers. These included prepositioning the head before G onset, using cockpit structures for support, constraining head movements to one plane at a time, and positioning the head against the ejection seat or canopy.

Therefore, the objective of this study was to assess the effect that high G_z accelerations have on head movement strategies to enhance our understanding of how such physiological demands affect pilot performance and identify how to mitigate the occurrence of musculoskeletal strain during high-intensity maneuvers. The three aims of this study were as follows: to observe relevant standardized head movements at set G_z accelerations (5 G_z, 7 G_z, and 9 G_z); to gain insight into G_z loading and the duration of head movements during real-flight air combat scenarios; and to identify, describe, and categorize potential coping strategies (compensatory movements) employed by pilots.

METHODS

Subjects

A total of 20 Eurofighter pilots (age: 26–30 yr; height: 176–180 cm; mean ± SD body mass: 81.5 kg ± 10.1 kg; EF2000 flying experience: >500 h; dominant hand: right, in all subjects) from the German Air Force with a valid Wehrfliegerverwendungsfähigkeit certification (the German equivalent of a military flight medical test) and the status "Maneuver Category Unlimited" took part in this study. All subjects were men. At the time of data collection, there were no female pilots with the required qualifications available. The exclusion criteria included acute neuromusculoskeletal complaints in the neck region and a Neck Disability Index score >20%.[15]

All subjects were informed about the details of the study in both written and verbal form. Participation was voluntary. The study was approved by the Ethics Committee of the German Sport University Cologne (Approval No: 19/2019). The ethical principles of the Declaration of Helsinki were applied in this study. Each participant was permitted to withdraw their consent at any time during the study without providing a reason.

Equipment

The flights were conducted in a Eurofighter Typhoon aircraft (EF2000, Eurofighter Jagdflugzeug GmbH, Hallbergmoos, Bavaria, Germany) equipped with a bulk storage device (BSD; Grupo Oesía, Madrid, Spain). BSDs are used to record data on a wide range of selected parameters associated with a jet's in-flight performance. Data on the translational accelerations of the jet in the x, y, and z directions were extracted. The Cartesian coordinate system originated from the Eurofighter's navigation system. The x-axis (longitudinal axis) lies in the plane of symmetry of the aircraft and runs parallel to the longitudinal fuselage datum, with positive values indicating a position toward the front of the aircraft. The y-axis (lateral axis) is perpendicular to the plane of symmetry and positive to the right side of the aircraft. The z-axis (normal axis) is situated in the plane of symmetry, is perpendicular to the longitudinal axis, and points in a downward direction.

The pilots were seated in an MK16A Eurofighter ejection seat (Martin-Baker Aircraft Company, Uxbridge, United Kingdom), which features a seat tilt of 13° backward. For context, the F-22 has a seat tilt of 12°–13°, while the F-16 and F-35 have a seat tilt of 30°. For duty-related reasons, the pilots used two different helmet systems, each of which was currently in use. Nine pilots used the BAE Systems, Inc. (London, United Kingdom), helmet-mounted equipment assembly (HEA) helmet (mass: 2243 g ± 2 g) in conjunction with a mask (mass: 312.5 g ± 5.5 g). There were 11 pilots who used the Gentex (Gentex Corporation, Carbondale, PA, United States) air combat fixed wing helmet system (mass: 1494 g ± 13.9 g) in conjunction with a mask (mass: 307 g ± 5.7 g). The HEA helmet includes an integrated helmet sighting and targeting system that enables the pilot to display flight and target information on their visor and to control the aircraft's sensors, such as the radar and target acquisition system, with their head movements.

Procedure

The flights were conducted in accordance with a standardized, predetermined study-specific "mission card" and were divided into four sets. Sets 1, 2, and 4 comprised predetermined maneuvers and were conducted as "split ops," with each pilot operating independently. Sets 1, 2, and 4 included a comparable set of components, such as instructions for the jet's turn directions (left and right) and the head movements to be performed in each case (max-up, max-up-left, max-up-right, and check six). In Set 1, the movements were to be performed at 5 G_z. In Set 2, they were to be performed at 7 G_z. In Set 4, they were to be performed at the maximum possible G_z level allowed by the jet's main computer. The head position was to be maintained for at least 5 s. In the case of an inability to reach the final position at the predefined G_z level, the pilots were permitted to place their head in the required position prior to the acceleration. The pilots were instructed to establish full backstick and fast snapping acceleration in order to reach the required G_z level as quickly as possible.

Set 3 consisted of one-on-one aerial combat scenarios during which the pilots were permitted to freely perform basic fighter maneuvers (BFM) as they competed in direct duels to gain tactical advantages and thus make the best use of the jet's weapon systems. No limiting factors were specified, including for the duration of the set, the speed of the jet, or the limitation of the weapons. This approach was applied to allow observation of the natural movement patterns of the pilots. The BFM sets were concluded when a neutral situation could not be resolved or when one of the two pilots reached a position where the selected weapons could be used with a high probability of causing lethal damage. The number of BFM sets was not predetermined; it was limited by the quantity of remaining fuel. The precise onset rate of acceleration of the jet in both scripted maneuvers and BFM cannot be delineated in this context due to confidentiality constraints.

To ensure that the pilots were rested before participating in the study, the flights were conducted on Monday mornings as the initial flight of each week. Prior to each flight, in addition to the mandatory safety briefing conducted by the flight lead, the pilots were provided with a mission card and a detailed briefing by the scientist responsible for the mission. This briefing outlined the objectives and procedures for the flight. The takeoff, transit (to and from the training area), and landing phases were excluded from the analysis.

Each pilot was filmed using two cameras (GoPro, Model 4, San Mateo, CA, United States). These were installed in the cockpit at approximately 50° left and right in front of the pilot to record their upper body and head movements. Additionally, head-up display (HUD) video recordings enabled the G_z acceleration of the aircraft to be determined.

Prior to the flights, the cameras were installed and aligned by the responsible scientist in compliance with the local squadron's safety regulations. This was done using approved mounts (RAM Mounts, National Products Incorporated, Seattle, WA, United States). Prior to powering up the jet's engines, recording was initiated and synchronized using a trigger signal.

The GoPro and HUD video recordings were merged to create a synchronized video using video editing software (Blackmagic Design, DaVinci Resolve Studio 19, Melbourne, Australia). The data were reviewed and analyzed by an authorized scientist with an appropriate level of security clearance (security level: NATO Secret) in a secure area explicitly designated for this purpose. The scientist who performed the data collection and analysis was the only individual in possession of the requisite security clearance. The data could not be disseminated to other scientists due to the confidential status of the collected raw data.

To analyze the scripted maneuvers, the specific times at which the pilots performed the scripted sequences were identified from the videos. The execution of the required flight parameters and head movements, the accuracy of the movements (which was determined by analyzing the actual head movements or positions) (**Fig. 1**), the G_z level achieved, and the duration of the exposure were documented and compared against the scripted requirements. Furthermore, the occurrence of lateral flexion or rotation of the upper body was documented. The individual coping strategies employed by the pilots were identified and documented during all flights. After comprehensively reviewing all the documented coping strategies, we classified them using an anatomy–action–fixpoint system (e.g., left hand–hold–left handle).

To ensure that all the head movements and movement patterns that the pilots exhibited during the BFM sets were comprehensively recorded and analyzed, 12 gaze corridors were defined (**Fig. 2**). The HUD corridor was defined as the head being in a central and neutral (habitual) position. The maximum upward (up-max) corridor was defined as the trajectory from the HUD to the cranial vertex, encompassing the entire vertical movement, and limited by the helmet contacting the headrest. The left and right corridors were defined by a rotational movement around the vertical axis of the head, commencing from the neutral position of the head. The left-up and right-up corridors were defined by a rotational movement around the vertical axis of the head to the left or right, respectively, in conjunction with a nonterminal upward extension of the neck. The left-up-max and right-up-max corridors were defined by a rotational movement around the vertical axis of the head to the left or right, respectively, combined with an

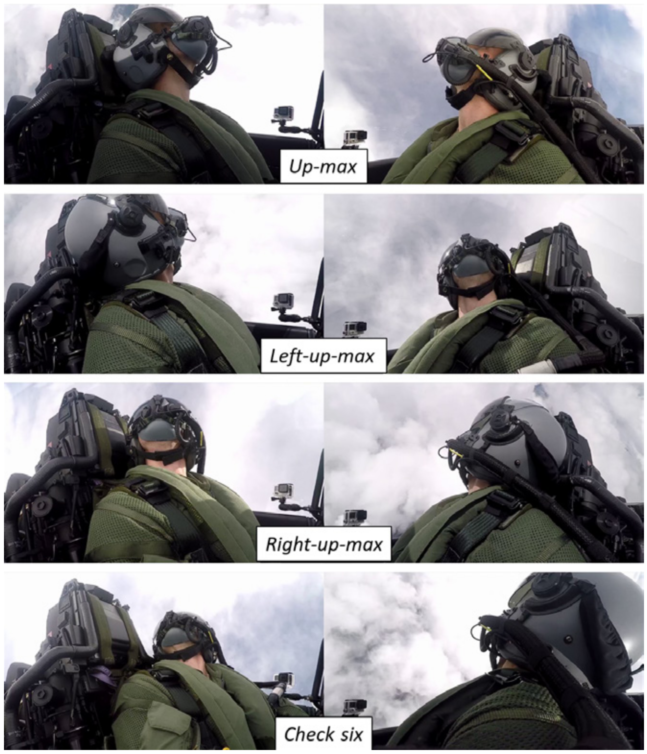

Fig. 1. Pictures of the left and right front perspectives of the GoPro cameras showing the scripted head movements (up-max, left-up-max, right-up-max, and check six).

upward extension of the neck limited by the headrest of the ejection seat. The left down, right down, and head down display (HDD) corridors were used to reflect when the gaze was directed to an area within the cockpit. The final corridor, designated check six, was used to reflect when the pilot's gaze and orientation shifted to view an area behind the aircraft.

The amount of time that each pilot's head was in a specific position (determined by the gaze corridors used) and the minimum and maximum G_z values during that time were recorded. As with the scripted maneuvers, data on the pilots' upper body movements (lateral flexion or rotation), combined movements, and individual coping strategies were also recorded.

Statistical Analysis

Cochran's Q test was conducted using RStudio (RStudio: Integrated Development Environment for R, Posit Software, PBC, Boston, MA, United States; version: 2024.4.2.764) to examine the effects across three G_z levels (5 G_z, 7 G_z, and 9 G_z) on three binary outcomes (head positioning, coping strategy, and central trunk position) within each head movement category. This nonparametric test is suitable for analyzing repeated measures data when the same subjects are evaluated under different conditions (in this case, the G_z level was varied). When the Cochran's Q test results indicated a statistically significant effect, McNemar's post hoc test was not performed due to the rarity of observations, which made pairwise comparisons impractical. All statistical analyses were performed using R,

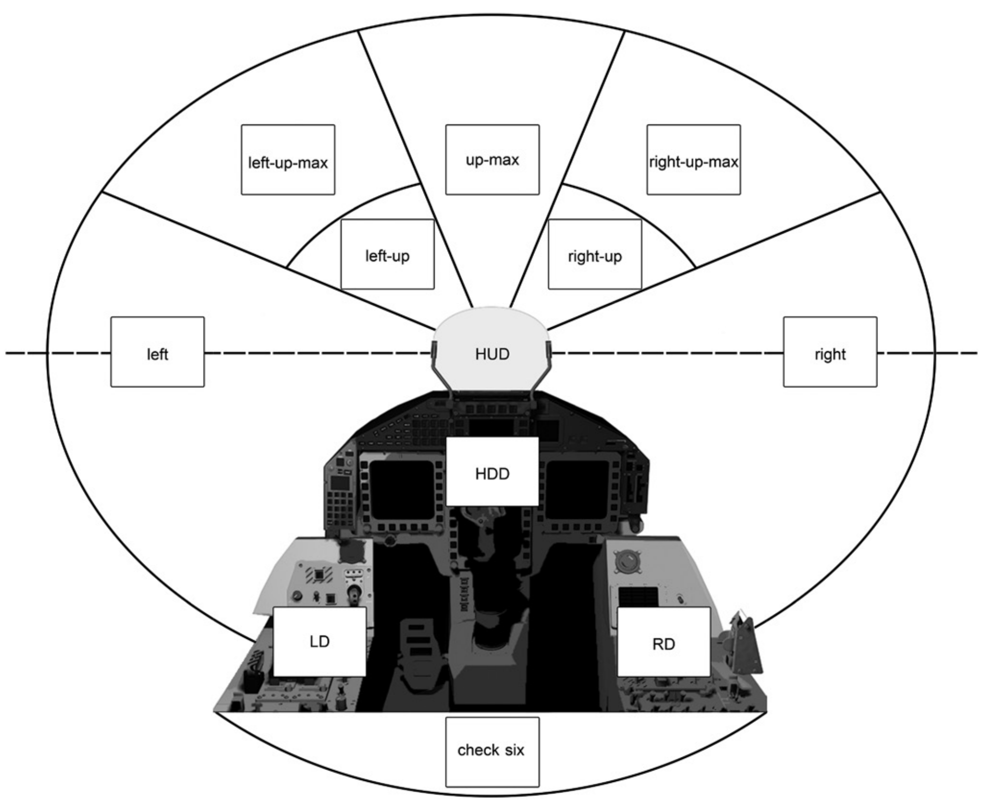

Fig. 2. Overview of the 12 gaze corridors: the head-up display (HUD, head in a functionally neutral position), head down display inside cockpit (HDD), left down inside cockpit (LD), right down inside cockpit (RD), up-max, left, right, left-up, right-up, left-up-max, right-up-max, and check six corridors.

and when *P* was <0.05, the result was considered statistically significant.

To assess the effects of helmet type and gaze direction during basic fighter maneuvers, gaze corridors were grouped into three clusters: central (HUD, HDD, left down, right down), peripheral (left, left-up, right, right-up, up-max), and extreme (left-up-max, right-up-max, check six). Repeated measures analysis of variance (ANOVA) was conducted for variables with a normal distribution, with gaze cluster (within-subject) and helmet type (between-subject) as factors. Once significant effects were identified, post hoc analyses were conducted with the use of the Bonferroni method. For nonnormally distributed data, aligned rank transform (ART) ANOVAs were used. In instances where applicable, violations of sphericity were addressed using Greenhouse-Geisser corrections. All analyses were conducted in R (version 4.4.1) using the anova_test package with an alpha level of 0.05.

RESULTS

All 20 pilots completed their planned flights. Due to technical issues with the cameras (e.g., vibration at very high G_z accelerations), only 14 of the 20 video data sets were suitable for inclusion in the analysis. Among the 14 data sets, 7 pilots wore the HEA helmet, while the remaining 7 wore the air combat fixed wing helmet system.

The data from the sets that involved scripted head movements and maneuvers are summarized in **Table I**. The distribution of the actual G_z levels in relation to the required G_z levels, differentiated according to the specified head movements of the pilots, is shown.

During Set 2 (7 G_z), one pilot did not perform the check six movement. During Set 4 (maximum G_z level), the max-up and max-up-left movements were not performed by one pilot each. Also, at the maximum G_z level, the max-up-right and check six movements were not performed by two pilots. As the acceleration increased, the pilots tended to place their head in the required position before the start of the maneuver rather than during the maneuver.

The isolated and combined torso movements of the pilots are presented in **Supplemental Table AI** (found in the online version of this article). The prevailing coping strategies used by the pilots to perform the checksix movement are illustrated in **Fig. 3** and **Supplemental Table AII** (found in the online version of this article). The Cochran's Q test was used to assess whether there were statistically significant effects across the three G_z levels (5 G_z, 7 G_z, and 9 G_z) for each head movement on head positioning, coping strategy, and central trunk position. A statistically significant effect on head positioning was observed across the G_z levels for all head movements [check six: Q(2) = 6.0, *P* = 0.0498; max-up: Q(2) = 7.0, *P* = 0.0302; max-up-left: Q(2) = 8.0, *P* = 0.0183; and max-up-right: Q(2) = 6.5, *P* = 0.0388], indicating that the distribution of head positioning varied statistically significantly among the G_z levels. No statistically significant effect on the use of coping strategies was found for max-up-left [Q(2) = 2.7, *P* = 0.2636] or max-up-right [Q(2) = 1.0, *P* = 0.6065] movements. It was not possible to analyze the max-up movement due to insufficient variation among the G_z levels. Cochran's Q test yielded no significant effect of G_z level on the use of coping strategies during the check six movement [Q(2) = 0.0, *P* = 1.000]. Although a few subjects changed their response patterns across conditions, the overall distribution of coping behavior remained constant. There was no statistically significant effect on the central trunk position across the G_z levels for the max-up-right [Q(2) = 1.5, *P* = 0.4724], check six [Q(2) = 3.0, *P* = 0.2231], or max-up-left [Q(2) = 0.8, *P* = 0.6873] movements. The results for the max-up movement were also inconclusive in this analysis due to insufficient variation among the G_z levels. Cochran's Q test yielded no significant effect of G_z level on coping behavior during the check six movement [Q(2) = 0.00, *P* = 1.000]. Although a few participants changed their response patterns across conditions, the overall distribution of coping behavior remained constant.

Table I. Overview of the Scripted Head Movements and G_z Accelerations and the Actual Movements and Accelerations Achieved.

SCRIPTED HEAD MOVEMENT	G_z	NO. OF PILOTS	G_z MAX				DURATION (s)		HEAD POSITIONING		COPING STRATEGY		CENTRAL TRUNK POSITION	
			M	SD	MIN	MAX	M	SD	*N*	%	*N*	%	*N*	%
Up-max	5	14	5.6	0.5	4.7	6.2	12.2	3.0	0	0.0	0	0.0	14	100.0
Up-max	7	14	7.3	0.5	6.4	8.2	11.8	3.1	2	14.3	0	0.0	14	100.0
Up-max	9	13	8.6	0.4	7.9	9.0	11.3	3.1	5	38.5	0	0.0	13	100.0
Left-up-max	5	14	5.8	0.6	4.9	7.1	12.0	4.5	0	0.0	0	0.0	6	42.9
Left-up-max	7	14	7.4	0.5	6.8	8.4	12.2	3.9	1	7.1	3	21.4	4	28.6
Left-up-max	9	13	8.5	0.4	7.8	9.0	11.8	3.0	4	30.8	2	15.4	3	23.1
Right-up-max	5	14	5.4	0.4	4.9	6.2	13.7	5.4	1	7.1	2	14.3	5	35.7
Right-up-max	7	14	7.5	0.5	6.4	8.5	12.8	4.6	1	7.1	3	21.4	3	21.4
Right-up-max	9	12	8.5	0.3	7.9	9.0	10.8	3.2	4	33.3	2	16.7	2	16.7
Check six	5	14	5.8	0.7	4.9	7.2	12.6	4.6	0	0.0	5	35.7	1	7.1
Check six	7	13	7.7	0.3	7.2	8.3	11.7	3.2	0	0.0	4	30.8	2	15.4
Check six	9	12	8.5	0.3	8.1	8.9	10.9	3.3	3	25.0	4	33.3	0	0.0

The table shows the number of pilots who reached the scripted G_z acceleration and performed the scripted movement, the maximum G_z acceleration achieved, the duration of the movement or maneuver, and the number of pilots who exhibited pre-acceleration head positioning, employed coping strategies, and maintained their trunk in a central position.
M = mean; SD = standard deviation; MAX = maximum value; MIN = minimum value.

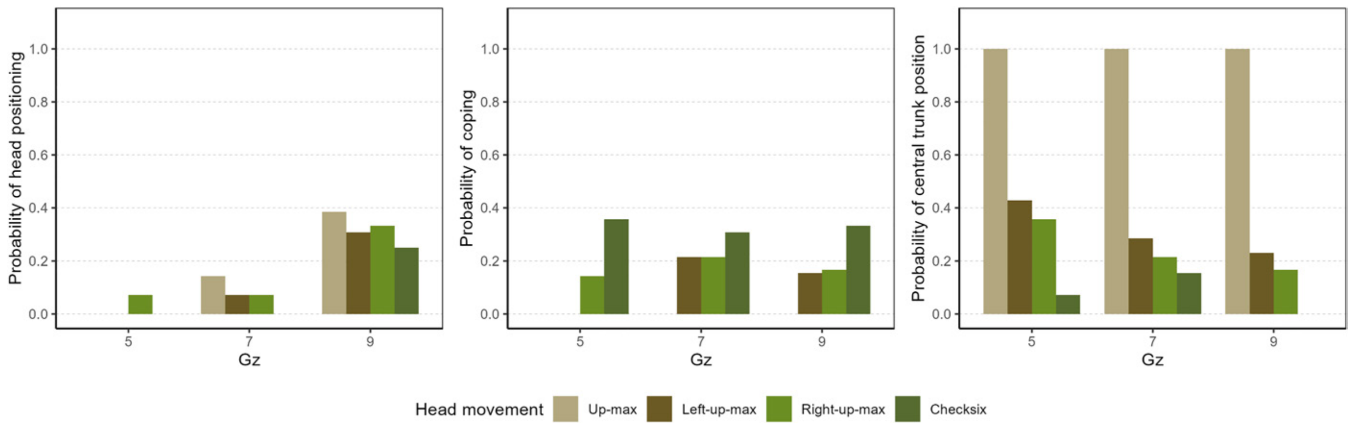

Fig. 3. Probability of positioning the head before performing a maneuver, using a coping strategy, and having a central trunk position.

We next analyzed the data acquired from the BFM sets. A total of 35 BFM sets were completed. The mean duration of the BFM sessions was 454.8 s (SD = 268.7 s; range: 63.6–968.6 s), and the mean number of BFM sets per session was 2.5 (SD = 1.2; range: 1–5). Individual sets lasted an average of 169.8 s (SD = 46.7; range: 63.6–242.2 s). The pilots performed an average of 63.6 head movements per session (SD = 32.1; range: 21.0–129.0) and 27.2 movements per set (SD = 13.7; range: 12.5–64.5).

Table II summarizes the pilots' use of coping strategies and selected parameters in different gaze corridors, categorized by different helmet types. The isolated and combined torso movements of the pilots are presented in **Supplemental Table AIII** (found in the online version of this article). The statistical comparisons between helmet conditions and gaze clusters for both dependent variables are presented in summary format in **Table III**.

A total of 51 categorized coping strategies were observed across participants. The most frequently employed strategy was identified as "left hand–hold–left handle" (*N* = 13), followed by "left hand–pull–left handle" (*N* = 12), and "left hand–push–left handle" (*N* = 8). The analysis identified additional strategies, including the sequence of "left shoulder–support (at)–left canopy rail" (*N* = 4) and the combination of shoulder support and head contact with the canopy, as in the sequence "left shoulder–support (at)–left canopy rail AND head–lean on–canopy" (*N* = 4). Less frequent strategies involved cross-body actions such as "left hand–pull–right handle (cross action)" (*N* = 2), as well as singular occurrences of strategies like "left forearm–support (at)–left canopy rail" (*N* = 1) or "left hand–push–left glare shield" (*N* = 1). A comprehensive assignment of each strategy to the respective gaze corridors is provided in **Supplemental Table AIV** (found in the online version of this article).

DISCUSSION

The objective of this study was to gain a better understanding of the physical challenges experienced by Eurofighter pilots, as well as the coping strategies they use, and the impacts that their movements have on their bodies and performance. To achieve this objective, we examined the head and upper body movements of Eurofighter pilots when they were subjected to standardized G_z accelerations and participating in highly dynamic air combat scenarios.

The analysis of the scripted maneuvers demonstrated that the pilots adopted a stable head position prior to acceleration and tended to maintain the position as the G_z acceleration increased. Their anticipatory behavior was particularly pronounced under maximum G_z conditions (Table I, column: Head positioning). This may be interpreted as a strategy used to protect the musculoskeletal structures of the head and neck from the consequences of experiencing high G_z acceleration. This prepositioning of the head is consistent with the findings of previous studies, which have demonstrated that at G_z values of up to 7 G_z, there is a notable increase in neck muscle activity, even in the absence of head movement.[11,13] For example, Netto and Burnett showed that the neck extensors exhibited up to 71.5% of the maximum voluntary contraction at +5 G_z.[7] These findings emphasize the need to adopt a cautious approach to head positioning to minimize the load on the head and neck during high G_z accelerations and reduce the risk of injury.

When we analyzed the movements exhibited by the pilots during the BFM sets, considerable variability in both the frequency of head movements and the G_z acceleration was observed (see Table II). The analysis of the torso movements observed during the BFM sets revealed that the pilots showed a tendency toward lateral flexion and torso rotation, particularly during terminal head movements, which were often oriented to the left. This asymmetry may be indicative of a preferred orientation among the pilots. The Eurofighter features a central stick position, and the throttle quadrant is placed to the left, which may suggest an ergonomic preference toward the left side. Our results are consistent with those of Coakwell et al.[16] and Newman et al.[17]

A key finding of this study was that G_z accelerations were generally associated with a high frequency of end-range movements. This finding, in conjunction with those of Netto and Burnett,[7] who demonstrated through electromyographic measurements that muscular activity is markedly elevated during high G_z accelerations, indicates that G_z accelerations may be

Table II. Overview of the Pilots' Gaze Corridors and Selected Parameters During the Sets of Basic Fighter Maneuvers Grouped by Helmet Type.

GAZE CORRIDORS	HELMET	NO. OF PILOTS	G_z MAX				DURATION PER VIEW (s)				VIEWS PER MINUTE (s)				DURATION PER MINUTE (s)				NO. OF COPING PILOTS
			M	SD	MIN	MAX	M	SD	MIN	MAX	M	SD	MIN	MAX	M	SD	MIN	MAX	
HUD	No HEA	7	5.7	0.7	4.6	6.4	4.2	1.5	3.0	7.3	6.9	2.7	4.2	11.5	27.2	7.6	14.0	34.4	0
HUD	HEA	7	5.8	1.6	3.4	7.8	3.1	1.8	1.5	6.9	5.2	2.2	2.9	8.1	14.7	6.6	4.5	24.6	4
HDD	No HEA	2	1.5	0.3	1.3	1.7	1.5	0.3	1.3	1.7	0.1	0.2	0.0	0.6	0.2	0.4	0.0	1.1	1
HDD	HEA	1	1.2		1.2	1.2	1.7		1.7	1.7	0.1	0.4	0.0	1.0	0.2	0.6	0.0	1.7	1
LD	No HEA	2	3.2	0.4	3.0	3.5	1.2	0.2	1.0	1.3	0.1	0.1	0.0	0.2	0.1	0.1	0.0	0.2	1
LD	HEA	3	2.8	1.6	1.0	3.9	1.3	0.2	1.0	1.4	0.2	0.3	0.0	0.9	0.3	0.5	0.0	1.3	1
RD	No HEA	3	1.4	0.4	1.0	1.7	1.5	0.7	1.0	2.2	0.2	0.2	0.0	0.6	0.2	0.3	0.0	0.6	1
RD	HEA	2	3.6	0.4	3.4	3.9	1.4	0.2	1.3	1.6	0.1	0.2	0.0	0.4	0.1	0.2	0.0	0.5	1
Left	No HEA	7	4.3	1.4	2.1	6.0	3.8	2.2	1.3	7.3	1.2	0.9	0.5	2.7	3.7	1.9	1.7	6.4	0
Left	HEA	6	4.6	1.9	1.5	7.5	3.8	2.5	1.9	8.6	1.4	1.1	0.0	3.3	5.0	4.6	0.0	12.3	2
Right	No HEA	5	3.5	1.5	1.6	4.8	4.8	3.6	1.2	10.8	0.8	0.7	0.0	1.9	2.4	1.9	0.0	4.4	1
Right	HEA	6	3.6	1.6	1.5	5.3	5.4	2.2	2.9	9.1	0.5	0.4	0.0	0.9	2.5	1.8	0.0	5.3	2
Left-up	No HEA	7	6.2	1.6	4.0	8.1	3.4	1.4	2.1	5.2	2.0	2.1	0.3	6.4	6.1	4.9	0.6	13.9	0
Left-up	HEA	7	5.0	1.9	2.4	7.4	7.5	7.6	2.1	23.9	2.6	2.7	0.2	7.8	14.9	12.1	0.3	34.9	2
Right-up	No HEA	5	3.7	1.3	1.6	4.8	4.1	2.9	1.5	7.5	0.4	0.5	0.0	1.2	1.8	2.8	0.0	8.1	1
Right-up	HEA	5	5.6	1.1	3.8	6.4	4.2	2.8	1.2	7.8	1.0	1.2	0.0	3.5	3.6	3.8	0.0	9.4	2
Up-max	No HEA	7	5.6	1.3	3.7	7.3	3.8	2.9	1.7	10.0	0.9	0.4	0.4	1.4	3.7	3.6	1.2	10.7	0
Up-max	HEA	5	3.9	1.6	1.8	5.8	6.1	3.0	3.7	11.1	0.4	0.4	0.0	1.0	2.1	2.1	0.0	5.8	1
Left-up-max	No HEA	7	5.7	1.8	3.3	8.1	3.8	2.0	1.6	8.0	1.8	1.2	0.7	3.8	6.3	5.7	2.5	18.8	0
Left-up-max	HEA	7	6.7	1.4	5.1	8.8	10.4	11.3	2.9	35.3	1.4	1.5	0.5	4.7	10.3	8.7	2.5	27.6	3
Right-up-max	No HEA	6	3.3	1.9	1.3	6.0	5.7	4.1	1.8	12.6	0.3	0.2	0.0	0.6	1.6	1.4	0.0	3.9	1
Right-up-max	HEA	5	5.2	1.6	2.6	6.8	5.8	2.2	3.0	9.0	0.7	0.8	0.0	1.9	3.1	3.3	0.0	9.1	2
Check six	No HEA	5	4.8	1.9	3.4	8.1	6.2	3.7	2.1	11.4	1.4	1.3	0.0	3.5	6.6	5.8	0.0	16.2	3
Check six	HEA	5	3.5	1.4	1.5	5.3	8.3	5.5	3.6	17.7	0.5	0.6	0.0	1.7	3.2	2.6	0.0	6.1	4

The table shows the 12 gaze corridors (HUD: head up display, HDD: head down display, LD: left down console, RD: right down console), including helmet type used, respective maximum G_z acceleration achieved, duration of exposure per movement in seconds, frequency of movements per set, duration of exposure per set in seconds, and the number of pilots exhibiting coping strategies. M = mean; SD = standard deviation; MAX = maximum value; MIN = minimum value.

Table III. Overview of Basic Fighter Maneuvers Results.

PARAMETER	GAZE CORRIDORS	NO HEA			HEA			DIFFERENCE		POST-HOC *P* ADJ	MAIN EFFECT HELMET	INTERACTION EFFECT HELMET × GAZE CORRIDOR
		M	SD/IQR	*N*	M	SD/IQR	*N*	M	SE			
G_z max	Central	5.7	0.7	7	5.8	1.6	7				$F(1, 12) = 0.035$, $P = 0.855$	$F(1.27, 15.23) = 0.487$, $P = 0.540$
	Peripheral	6.4	1.5	7	6.1	1.2	7					
	Extreme	6.2	1.5	7	6.7	1.4	7					
Duration per minute (s)	Central	27.7	7.9	7	15.3	6.7	7	−12.4	3.9	0.008	$F(1, 12) = 0.000$, $P = 1.000$	$F(2, 24) = 4.907$, $P = 0.016$
	Peripheral	17.8	4.8	7	28.1	10.1	7	10.3	4.2	0.032		
	Extreme	14.5	5.7	7	16.6	10.5	7	2.1	4.5	0.652		
Views per minute*	Central	7.3	2.8	7	5.6	2.4	7				$F(1, 36) = 0.944$, $P = 0.338$	$F(2, 36) = 0.614$, $P = 0.547$
	Peripheral	5.3	1.6	7	5.8	2.7	7					
	Extreme	3.4	1.2	7	2.6	1.4	7					

The gaze corridors were grouped into three clusters: central (HUD: head-up display, HDD: head down display, LD: left down, RD: right down), peripheral (left, left-up, right, right-up, up-max), and extreme (left-up-max, right-up-max, check six). This table presents the results of the analysis of variance (ANOVA) conducted to assess the effects of helmet type and gaze corridor on the outcomes during basic fighter maneuvers, including the mean or median values across helmet conditions and gaze corridors, the between-group differences with their standard errors, as well as the main and interaction effects. Adjusted *P*-values were calculated using the Bonferroni correction. M = mean or median; SD = standard deviation; IQR = interquartile range; *N* = number of subjects; SE = standard error; *P* ADJ. = Bonferroni-adjusted *P*-value. HEA: helmet equipment assembly.

*ART ANOVA applied for views per minute and values are expressed as median and interquartile range.

associated with a higher risk of injury. The significance of our results is supported by the fact that they were generated via quantitative and qualitative analyses of actual movements and positions observed during real flights. In particular, we found that as the G_z load increased, the pilots increasingly placed their head in the required position prior to performing a maneuver and used coping strategies. In accordance with the findings of Sovelius et al.,[10] it can be assumed that pilots experience elevated levels of neck muscle activation during head movements, especially under augmented Gz loads and while wearing the HEA helmet, which is comparable to the Joint Helmet-Mounted Cueing System. However, this assumption is based on indirect observations, as muscle activity was not directly measured in the present study. The results of this study indicate that head movements deviating from a neutral position may potentially contribute to muscle strain and overload. Hence, our findings support the hypothesis that pilots employ protective strategies, such as preemptive head positioning, to reduce cervical muscle strain and the risk of injury under high G_z accelerations. This finding aligns with the results reported by Kang et al., who indicated that cumulative G_z exposure contributes significantly to the development of neck pain symptoms in high-performance pilots.[18]

In the final part of this study, we analyzed the coping strategies used by the pilots. Our results showed that the pilots used coping strategies more frequently during end-range movements, such as the check six movement, executed during maximum G_z accelerations. Isolated or combined lateral flexion and trunk rotation were necessary to achieve the terminal head position. Our observations are consistent with those reported in previous studies that have indicated that lateral flexion and rotation distribute the mechanical load on the neck and upper back.[13,14] Consequently, these movements may prove to be safer alternatives to isolated head movements with respect to the risk of cervical discomfort or injury.

In terms of the coping strategies that the pilots were observed to use during the aerial combat scenarios, the following actions were recorded: isolated and combined trunk movements; use of a supporting surface (i.e., canopy rail or headrest); and holding onto, pulling on, or pushing on a fixed point (e.g., the canopy handle). The observation that coping strategies were used most frequently when the pilots performed specific head movements (e.g., the left-up-max, right-up-max, and check six movements) during the times of highest G_z acceleration lends support to the assumption that these movements are particularly challenging and could carry an increased risk of injury.

Collectively, these findings indicate that helmet-mounted display systems, such as the HEA, exert a substantial influence on spatial gaze behavior during dynamic air combat. Specifically, pilots equipped with an HEA spent more time looking into peripheral and extreme gaze corridors, whereas pilots without such a system maintained their focus longer on centrally located displays. This shift may be indicative of a functional redistribution of visual attention, a phenomenon that could be facilitated by the augmented visual capabilities of the helmet system. However, as demonstrated by Sovelius et al.,[9] the utilization of helmet-mounted systems that are similar to the HEA helmet has been shown to be associated with higher levels of neck muscle activity, particularly during periods of head movement which may be due to the additional mass of the helmet system. These findings underscore the importance of considering not only the visual but also the musculoskeletal demands introduced by such technologies.[9] This concern is further substantiated by the findings of Barrett et al.,[19] who employed biomechanical modeling to simulate cervical spine loading under various helmet and posture conditions. The results of the study indicate a notable increase in joint reaction forces and torque at the cervical vertebrae. This increase is driven by altered mass distribution in advanced helmet designs, which consequently alter the center of gravity.[19] Grossman et al.[20] conducted a systematic review that underscores the multifactorial nature of helmet design. The type of aircraft and its specific flight dynamics are also significant contributors to the prevalence and localization of musculoskeletal symptoms. This might suggest that future risk assessments should account for the complex interaction between pilots' personal equipment, aircraft type, and operational context.[20]

A strength of this exploratory study is its real-world study design, which enabled the collection of data while pilots performed maneuvers in Eurofighters. At the time of data collection, the sample size of this study constituted a representative population of experienced German fighter pilots. The observed head movement patterns are similar to those documented in the literature by Sovelius et al.,[10] suggesting that the results are robust. Further research should be conducted with larger samples and over longer periods to comprehensively investigate the long-term effects of repeated high G_z loads on the musculoskeletal health of pilots. Furthermore, due to the confidential nature of the raw data, only one investigator was permitted to view the data and prepare it for further analysis. Therefore, the data were analyzed at the aggregate rather than individual level.

In this study, Eurofighter pilots were observed to perform a multitude of movements during high G_z accelerations of up to $+9\ G_z$ with varying durations (from 0.3 s to >60 s). Left-oriented movements were found to occur at high frequencies, as were movements in end-range positions. Thus, a considerable mechanical load may have been placed on the pilots' neck muscles, which may have added to the physical demand on the pilots during the high G_z accelerations. The findings of this study can be used by those developing procedures, technologies, and training systems to reduce the risk of pilot injury and enhance their performance during real-flight conditions.

ACKNOWLEDGMENTS

We, the authorship, would like to express our sincerest gratitude to the Tactical Air Force Wing 31 "Boelcke" for their invaluable support throughout this research project. We would be remiss if we did not extend our sincerest gratitude to the pilots for their unwavering dedication, expertise, and willingness to participate, which were absolutely essential to the realization of this study. Furthermore, we are indebted to the Flight Surgeon unit for their collaboration and commitment to ensuring the health and safety of all involved. The completion of this research would not have been feasible without the exemplary professionalism and cooperation demonstrated by all parties involved.

Financial Disclosure Statement: The present study was funded by the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (Funding-No.: MA ZB KD007_KF555). The authors have no competing interests to declare.

Authors and Affiliations: Rene Lingscheid, M.Sc., Institute of Movement and Neurosciences, German Sport University, Cologne, Germany, and 1st Squadron, Tactical Air Force Wing 31 "Boelcke", German Air Force, Noervenich, Germany; Kirsten Albracht, Ph.D., Institute of Movement and Neurosciences, German Sport University, Cologne, Germany, and Faculty of Medical Engineering and Technomathematics, Aachen University of Applied Sciences, Germany; Fabian Goell, M.Sc., Institute of Movement and Neurosciences, German Sport University, Cologne, Germany; Roland Nuesse, M.D., Flight Surgeon, Tactical Air Force Wing 31 "Boelcke", German Air Force, Noervenich, Germany; Robert Rein, Institute of Training and Computer Science in Sports, German Sport University, Cologne, Germany; and Bjoern Braunstein, Ph.D., the Institute of Movement and Neurosciences, the Institute of Biomechanics and Orthopaedics, and the German Research Centre of Elite Sport, German Sport University, and the Centre for Health and Integrative Physiology in Space, Cologne, Germany.

REFERENCES

1. Drew WE Sr. Spinal symptoms in aviators and their relationship to G-exposure and aircraft seating angle. Aviat Space Environ Med. 2000 Jan; 71(1):22–30.
2. Riches A, Spratford W, Witchalls J, Newman P. A systematic review and meta-analysis about the prevalence of neck pain in fast jet pilots. Aerosp Med Hum Perform. 2019 Oct 1; 90(10):882–890.
3. McGuckian TB, Cole MH, Chalkley D, Jordet G, Pepping GJ. Visual exploration when surrounded by affordances: frequency of head movements is predictive of response speed. Ecol Psychol. 2019 Jan 2; 31(1):30–48.
4. Pokolm M, Kirchhain M, Müller D, Jordet G, Memmert D. Head movement direction in football - a field study on visual scanning activity during the UEFA-U17 and -U21 European Championship 2019. J Sports Sci. 2023 Apr 3; 41(7):695–705.
5. Aksum KM, Pokolm M, Bjørndal CT, Rein R, Memmert D, Jordet G. Scanning activity in elite youth football players. J Sports Sci. 2021 Nov 2; 39(21):2401–2410.
6. Yu CS, Wang EM, Yang Li WC, Braithwaite G, Greaves M. Pilots' visual scan patterns and attention distribution during the pursuit of a dynamic target. Aerosp Med Hum Perform. 2016 Jan 1; 87(1):40–47.
7. Netto KJ, Burnett AF. Neck muscle activation and head postures in common high performance aerial combat maneuvers. Aviat Space Environ Med. 2006 Oct; 77(10):1049–1055.
8. Oksa J, Hämäläinen O, Rissanen S, Salminen M, Kuronen P. Muscle fatigue caused by repeated aerial combat maneuvering exercises. Aviat Space Environ Med. 1999 Jun; 70(6):556–560.
9. Sovelius R, Mäntylä M, Heini H, Oksa J, Valtonen R, et al. Joint helmet-mounted cueing system and neck muscle activity during air combat maneuvering. Aerosp Med Hum Perform. 2019 Oct 1; 90(10): 834–840.
10. Sovelius R, Mäntylä M, Huhtala H, Oksa J, Valtonen R, et al. Head movements and neck muscle activity during air combat maneuvering. Aerosp Med Hum Perform. 2020 Jan 1; 91(1):26–31.
11. Honkanen T, Oksa J, Mäntysaari MJ, Kyröläinen H, Avela J. Neck and shoulder muscle activation among experienced and inexperienced pilots in +Gz exposure. Aerosp Med Hum Perform. 2017 Feb 1; 88(2): 90–95.
12. Chumbley EM, Stolfi A, McEachen JC. Risk factors for cervical pain in F-15C pilots. Aerosp Med Hum Perform. 2017 Nov 1; 88(11):1000–1007.
13. Wang P, Peng H, Huang J, Li Y, Dou Q, Suo T. Effect of flight helmet mass characteristics and neck stress postures on pilot neck impact injury. Theor Appl Mech Lett. 2024 Sep; 14(5):100538.
14. Newman DG. Head positioning for high +Gz loads: an analysis of the techniques used by F/A-18 pilots. Aviat Space Environ Med. 1997 Aug; 68(8):732–735.
15. Vernon H. The Neck Disability Index: state-of-the-art, 1991–2008. J Manipulative Physiol Ther. 2008 Sep; 31(7):491–502.
16. Coakwell MR, Bloswick DS, Moser R. High-risk head and neck movements at high G and interventions to reduce associated neck injury. Aviat Space Environ Med. 2004 Jan; 75(1):68–80.
17. Newman P, Riches A, Mara J, Spratford W. The effect of helmet mass and aircraft acceleration on cervical spine loads during typical fast jet aircraft pilot head motions. J Sci Med Sport. 2022 Oct; 25(10):855–860.
18. Kang S, Hwang S, Lee ET, Yang S, Park J. Measuring the cumulative effect of G force on aviator neck pain. Aviat Space Environ Med. 2011 Nov 1; 82(11):1042–1048.
19. Barrett JM, McKinnon CD, Dickerson CR, Laing AC, Callaghan JP. Posture and helmet configuration effects on joint reaction loads in the middle cervical spine. Aerosp Med Hum Perform. 2022 May; 93(5): 458–466.
20. Grossman A, Nakdimon I, Chapnik L, Levy Y. Back symptoms in aviators flying different aircraft. Aviat Space Environ Med. 2012 Jul 1; 83(7): 702–705.

Cognitive Engagement Profiling of Pilots in High-Speed, High-Threat Scenarios

Matthew D'Alessandro; Ryan Mackie; Tom Berger; Carl Ott; Christopher Sullivan; James Barnett III; Ian Curry

INTRODUCTION: This study investigated pilot cognitive engagement patterns across diverse flight conditions using electroencephalography (EEG)-based measurements in a high-fidelity rotary-wing simulation environment.

METHODS: A total of 8 experienced U.S. Army test pilots completed 24 flights across 3 distinct route designs using the National Aeronautics and Space Administration Ames Vertical Motion Simulator, with airspeeds ranging from 120 to 240 kn. Analysis focused on EEG Beta/(Alpha + Theta) ratios as indicators of changing cognitive engagement over time.

RESULTS: Analyses revealed distinct cognitive engagement patterns across routes: highly variable individual responses in routes with changing navigation demands, more consistent cognitive engagement in systematic route designs, and intermediate variability in mixed-demand routes. Airspeed effects on cognitive engagement became particularly pronounced above 200 kn, though these effects varied significantly by route and individual pilot. Temporal analysis demonstrated evolving patterns of cognitive adaptation, with routes eliciting different progression patterns over extended flight periods. Regression analysis showed that EEG Beta/(Alpha+Theta) values increased significantly during all three routes, with mean increases ranging from 0.0051–0.0146.

DISCUSSION: These findings provide quantifiable metrics for optimizing route design, developing personalized training approaches, and implementing real-time monitoring systems for enhanced aviation safety and performance.

KEYWORDS: cognitive engagement, aviation, simulated flight.

D'Alessandro M, Mackie R, Berger T, Ott C, Sullivan C, Barnett J III, Curry I. *Cognitive engagement profiling of pilots in high-speed, high-threat scenarios*. Aerosp Med Hum Perform. 2025; 96(9):819–828.

The integration of neurophysiological measurements in aviation research has revolutionized our understanding of pilot cognitive workload and performance during complex flight operations.[1] While traditional studies have relied on behavioral metrics, electroencephalography (EEG)-based measurements offer valuable insights into the real-time cognitive demands placed on pilots during flight.[2,3] These neurophysiological indicators provide a window into the subtle variations in mental workload that may not be apparent through conventional performance measures alone.

Previous research has established the importance of understanding cognitive workload variations in aviation, particularly regarding route characteristics and airspeed conditions.[4,5] However, the complex interplay of these factors at the high airspeeds not yet attainable by current military rotorcraft remains unknown due to the lack of such capabilities and the inherent risks. The U.S. Army Combat Capabilities Development Command Aviation & Missile Center (DEVCOM AvMC) has developed a Future Vertical Lift (FVL) simulation capability to explore design trade studies and inform requirements which leverages a generic tiltrotor flight dynamics model and full flight envelope flight control system.[6] The model was integrated into the NASA Ames Vertical Motion Simulator (VMS), which provides the capability to simulate flight at the full operational envelopes of advanced aircraft configurations via its unparalleled reproduction of realistic flight dynamics, extensive vertical motion range, and acceleration cues. Using this advanced

From the U.S. Army Aeromedical Research Laboratory, Fort Rucker, AL, United States; and the U.S. Army Combat Capabilities Development Command Aviation & Missile Center, Moffett Field, CA, United States.

This manuscript was received for review in February 2025. It was accepted for publication in May 2025.

Address correspondence to: Matthew D'Alessandro, Ph.D., 6901 Farrel Rd., Fort Rucker, AL 36362, United States; matthew.g.dalessandro2.mil@health.mil.

DOI: https://doi.org/10.3357/AMHP.6664.2025

facility, we investigated three distinct route designs under airspeed conditions ranging from 120 to 240 kn. The simulator's unique capabilities enabled simultaneous, time-synchronized capture of EEG measurements and flight performance metrics while pilots experienced authentic physical sensations of flight, bridging the gap between laboratory studies and real-world operations. This information is critical for the development of the U.S. Army's aviation modernization priorities of the FVL program which will achieve advanced flight capabilities. The current investigation employed the EEG Beta/(Alpha+Theta) (BAT) ratio as a primary metric for cognitive engagement, building upon established research in aviation neurophysiology and human factors.[2,3] This specific ratio has proven particularly sensitive to changes in mental engagement during complex cognitive tasks, making it an ideal measure for understanding the demands of different flight conditions.[7,8] By tracking the BAT neurophysiological indicator across time and flight conditions, we were able to identify patterns of cognitive adaptation and potential areas of increased mental demand.

The current study's design incorporates multiple flights per condition, allowing for detailed analysis of both immediate responses to changing conditions and longer-term adaptation patterns. This approach enabled us to examine not only the overall impact of route and airspeed variations, but also individual differences in cognitive strategies and adaptation mechanisms. Understanding these individual variations is crucial for developing more effective training protocols and route design guidelines that can accommodate different cognitive processing styles while maintaining high safety standards. By combining precise experimental design with advanced neurophysiological measurements, this research aims to provide practical insights that can inform and optimize automated flight route planning tools, pilot training protocols, and aviation safety systems. The findings have potential implications for real-time monitoring systems, adaptive automation, and the development of more sophisticated approaches to route classification and pilot workload management.

METHODS

Subjects

Eight experienced U.S. Army test pilots with a minimum 1500 flight hours participated in the study. All pilots were U.S. Army-trained and current on operational requirements. The experimental protocol was approved by the DEVCOM AvMC Human Research Protection Program (HRPP) #23-016.

Procedure

Pilots in this study conducted high-speed flight simulations using the NASA Ames VMS at Moffett Field, CA—a facility renowned for its unmatched motion range and dynamic fidelity. The VMS replicates real-world flight dynamics through a 60-ft vertical motion envelope, expansive horizontal range, and precise acceleration cues that closely replicate the physical sensations of actual flight. Its advanced computational systems simulate aircraft behavior across speeds spanning 120 to 240 kn, a critical threshold for the U.S. Army's FVL program, which aims to develop next-generation rotorcraft capable of unprecedented performance. By testing at 240 kn—a speed representative of FVL capabilities and well above typical operational terrain flight speeds—the VMS provides the capability to gain insight to unique cognitive workload demands under extreme conditions, providing the potential to directly inform FVL design and safety protocols.

The tiltrotor aircraft flight model used in the testing was developed by the Army's DEVCOM AvMC and was representative of the size and performance capabilities of the FVL aircraft.[6] The simulator's integrated data acquisition systems enable the ability to capture pilot performance metrics, physiological data (including EEG), and flight dynamics, enabling researchers to bridge controlled experimentation with real-world operational demands. This synergy of high-fidelity simulation and multidimensional data analysis offers actionable insights into adaptive decision making and workload management in complex aviation environments. During all simulated flights, continuous wireless EEG was recorded using the B-Alert ×24 system, consisting of 20 EEG channels based on the International 10-20 system. All 20 channels were recorded during simulated flights, but only the frontal channels were used to calculate the EEG BAT ratio.

Three distinct flight routes were developed to explore different operational contexts, enabling a comprehensive assessment of aircrew capabilities across the aircraft's designed mission set. Although each route was constrained to approximately 20 miles in length—considerably shorter than typical operational missions—and maintained at constant speed, they effectively generated the data required for this research effort. The routes presented here are for simulation purposes only and do not represent actual Army operational scenarios. The routes incorporated varying degrees of flight maneuvering allowances, which produced a spectrum of pilot aggressiveness and workload conditions. To maintain operational relevance, evaluate perceived workload, and assess pilot responses to threats, three radar-guided threats were incorporated into each route. The Air Force's Advanced Framework for Simulation, Integration, and Modeling software was used to model the threats. Subject matter experts helped determine threat locations using various templates, which were modified across the routes to provide aircrews with diverse tactical challenges.

Route 1, "Narrow Corridor," simulated a large-scale air assault operation requiring 10 aircraft to fly over flat to rolling terrain. The tactical scenario established a narrow air corridor that permitted the air assault to proceed. Due to the narrow corridor constraints and the presence of nine simulated aircraft following in formation behind the test aircraft, strict maneuvering limitations were imposed, restricting aircraft to a maximum angle of bank of ±15°, but allowed for the pilots to vary the altitudes flown. These limitations effectively prevented aircrews from executing maneuvers to avoid radar detection or engagement, requiring them to maintain precise speed control and route adherence with minimal deviation from the established

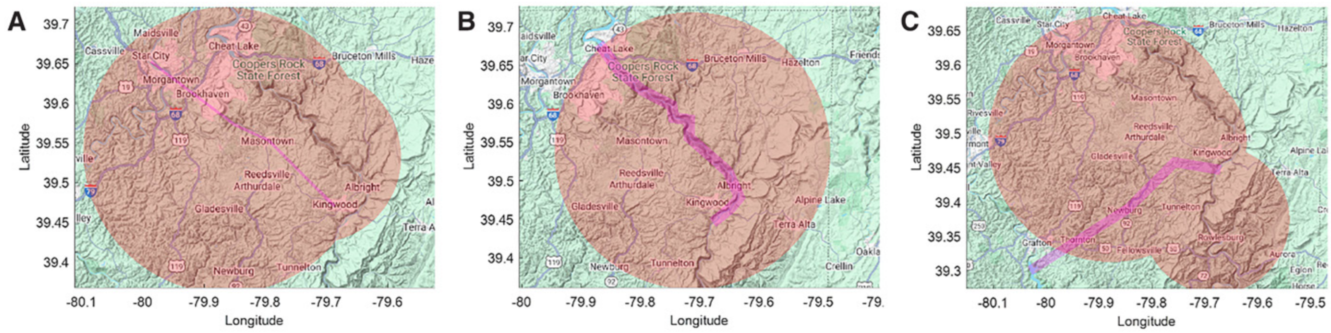

Fig. 1. Mission routes. A) Route 1 (Narrow Corridor). B) Route 2 (Deep River Valley). C) Route 3 (Wide Corridor). Mission routes are further described in the Methods/Flight Routes section of this manuscript. Scenarios are for simulation purposes only and do not represent actual operational Army scenarios.

centerline. The mission route terminated upon crossing the designated release point (**Fig. 1A**).

Route 2, "Deep River Valley," simulated a flight mission involving two aircraft navigating primarily through a deep river valley. The valley's topography offered radar detection protection when the aircraft maintained altitude below the valley rim. The test aircraft led with a simulated trail aircraft in free cruise formation, allowing pilots to employ aggressive maneuvering capabilities (up to 45° of bank and 800-m deviations from the course line) while maintaining the prescribed airspeed. These parameters enabled pilots to optimize their position within the river valley. The route concluded upon reaching the designated release point (**Fig. 1B**).

Route 3, "Wide Corridor," replicated a two-aircraft deep insertion mission conducted within a wide corridor over flat to rolling terrain. With the simulated trail aircraft in free cruise formation, pilots were authorized to maneuver within 800 m of the centerline to maximize terrain masking opportunities. The route parameters permitted aggressive maneuvering up to 45° of bank while maintaining constant airspeed. This route uniquely required pilots to not only cross a release point, but also to execute an approach to establish a 50-ft hover over a designated hover point (**Fig. 1C**).

Statistical Analysis

Each route was flown under four airspeed conditions: 120, 160, 200, and 240 kn. Pilots were instructed to maintain constant airspeed as much as possible during flights. Each pilot completed two flights per airspeed and route for a total of 24 flights (eight flights per route across three routes). The order of route presentation was randomized between pilots, but airspeed was not. Pilots completed all flights for a given route, starting with 120-kn flights, increasing to 240 kn. All 24 flights were completed by 7 pilots. Pilot 26 was not able to complete 1 flight (the Deep River Valley route at 240 kn) due to time constraints using the flight simulator. Pilots were assigned different numbers for deidentification purposes.

The time to complete simulated flights ranged from approximately 4.5 to 11.5 min depending on the route and airspeed. To facilitate statistical analysis of EEG data of varying duration, each flight was divided into four segments (further referred to as flight segments). The Narrow Corridor and Deep River Valley flights were divided into four equal segments. The Wide Corridor flight route required pilots to decelerate to a hover at the end of the route. Therefore, flight segment 4 for the Wide Corridor flights was defined as the time when deceleration began until the end of the flight. Flight segments 1–3 for the Wide Corridor flights were defined as equal thirds of the flight before deceleration.

B-Alert Live software was used to automatically remove common EEG artifacts and calculate power spectral density (PSD) values in 1-s intervals. For each EEG channel, the B-Alert Live software calculated PSD values for common frequency bands, including theta (3–7 Hz), alpha (8–13 Hz), and beta (13–30 Hz). PSD values for each frequency band were averaged across all frontal EEG channels (fp1, fp2, f3, f4, f7, f8, and fz). Mean frontal PSD values were then used to calculate the BAT ratio. BAT values were then averaged over each flight segment to produce four mean BAT values for each flight. These BAT values were used for all regression analyses detailed below. As baseline EEG levels can vary day-to-day and between individuals, the data presented in **Fig. 2**, **Fig. 3**, and **Fig. 4** show the change in BAT values relative to flight segment 1 (these values are further referred to as delta BAT values). The shaded regions in panel A for each of these figures illustrate the range of delta BAT values for each pilot, airspeed, and flight segment. Panel A for each figure also shows the mean delta BAT value as points. These figures additionally show the mean delta BAT values combined across all airspeeds for each pilot (panel B) and combined across all pilots for each airspeed (panel C). Supplemental **Table AI**, **Table AII**, **Table AIII**, **Table AIV**, **Table AV**, and **Table AVI** (all found in the online version of this article) provide summary statistics for the mean delta BAT values.

All statistical analyses were performed using R and R Studio with the following packages: tidyverse, lmerTest, emmeans, and rstatix. All statistical tests were evaluated at a significance level of 0.05. To analyze average changes in BAT values while accounting for individual EEG baselines between pilots, BAT values for each route were analyzed separately using mixed-effects linear regression models. Each regression model consisted of fixed categorical effects for airspeed (four levels) and flight segment (four levels), a fixed interaction effect between airspeed and flight segment, and a random intercept for each

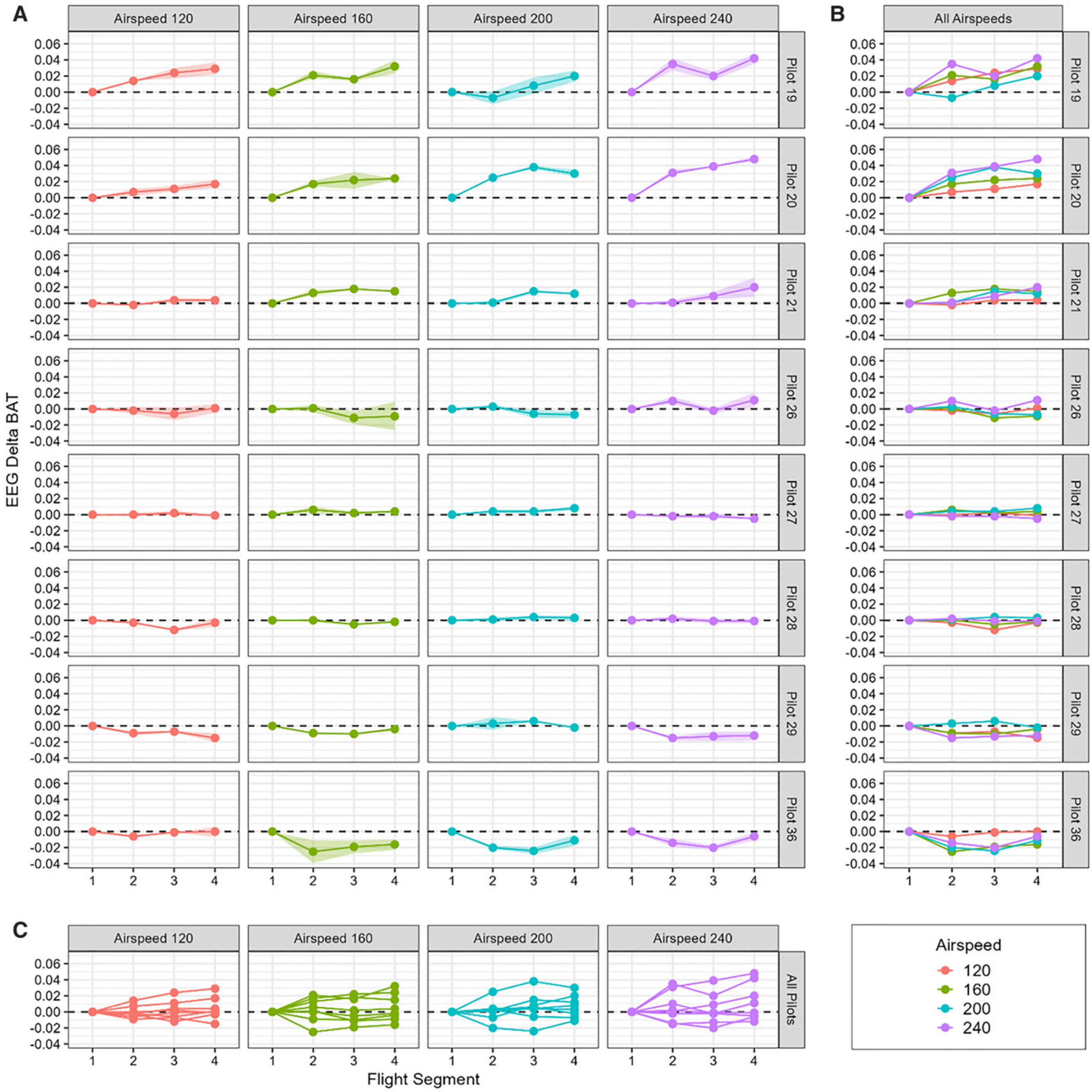

Fig. 2. Route 1 (Narrow Corridor) mean EEG delta BAT values. A) Mean delta values for duplicate flights by each pilot and airspeed. Shaded regions show range of mean delta values from individual flights. B) Mean delta values by pilot for all airspeeds. C) Mean delta values by airspeed for all pilots.

pilot. Statistical assumptions of the regression model were checked by confirming that the residuals followed a normal distribution with equal variance across the range of data. Omnibus Type III analysis of variance tests were used to determine if any main effects in the regression models reached overall statistical significance. Significant results were followed up with appropriate pairwise comparisons. All *P*-values for pairwise comparisons were adjusted using the Benjamini-Hochberg method to control the false discovery rate and balance controlling for Type 1 and Type 2 errors. For significant effects of flight segments, pairwise comparisons were limited to comparisons against the first flight segment.

RESULTS

Analysis of EEG frontal BAT ratios across the three routes revealed distinct patterns of cognitive engagement changes across airspeeds, flight segments, and individual pilots. For the Narrow Corridor flights, the data demonstrated substantial

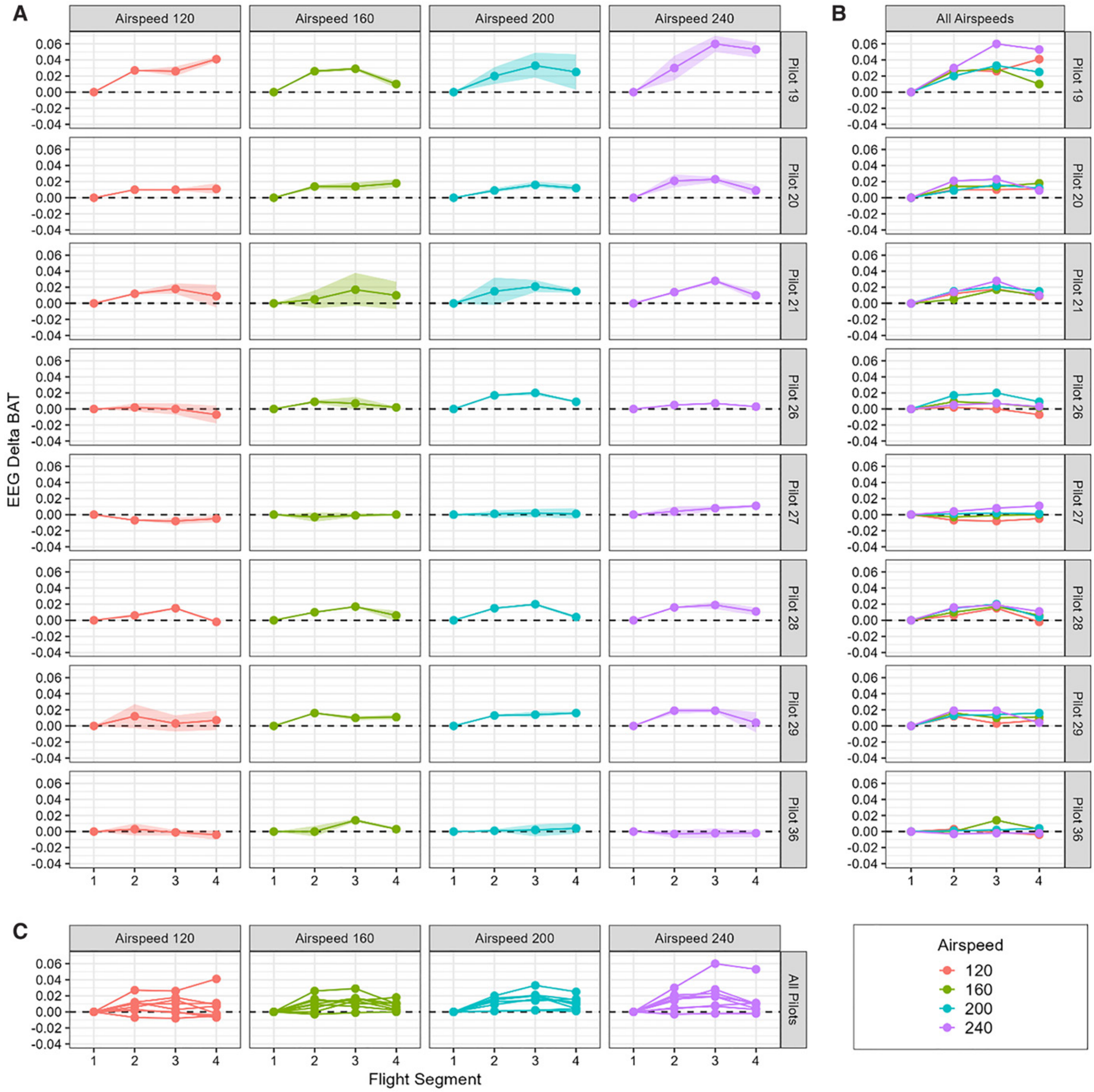

Fig. 3. Route 2 (Deep River Valley) mean EEG delta BAT values. A) Mean delta values for duplicate flights by each pilot and airspeed. Shaded regions show range of mean delta values from individual flights. B) Mean delta values by pilot for all airspeeds. C) Mean delta values by airspeed for all pilots.

interindividual variability in delta BAT patterns, reflecting different approaches to task management across flight conditions (Fig. 2 and supplemental Table AI and Table AII, found in the online version of this article). At the individual level, pilots 19 and 20 exhibited predominantly positive changes in BAT ratios that varied with airspeed, reaching mean delta values of 0.042 and 0.048, respectively, at 240 kn during flight segment 4. Pilots 27 and 28 maintained relatively stable delta BAT ratios near baseline across conditions. Pilots 21, 26, 29, and 36 demonstrated both positive and negative changes in delta BAT ratios across conditions, with mean values ranging from −0.025–0.020, suggesting varying cognitive strategies in response to task demands.

Temporal analysis for the Narrow Corridor flights revealed evolving patterns of changing cognitive engagement. During the early phase (flight segment 2), mean delta values ranged from −0.025–0.035, with the greatest variability observed in high-speed conditions. The midsegments showed more consistent patterns across pilots, with mean delta values ranging from −0.024–0.039 and increased variability compared to the

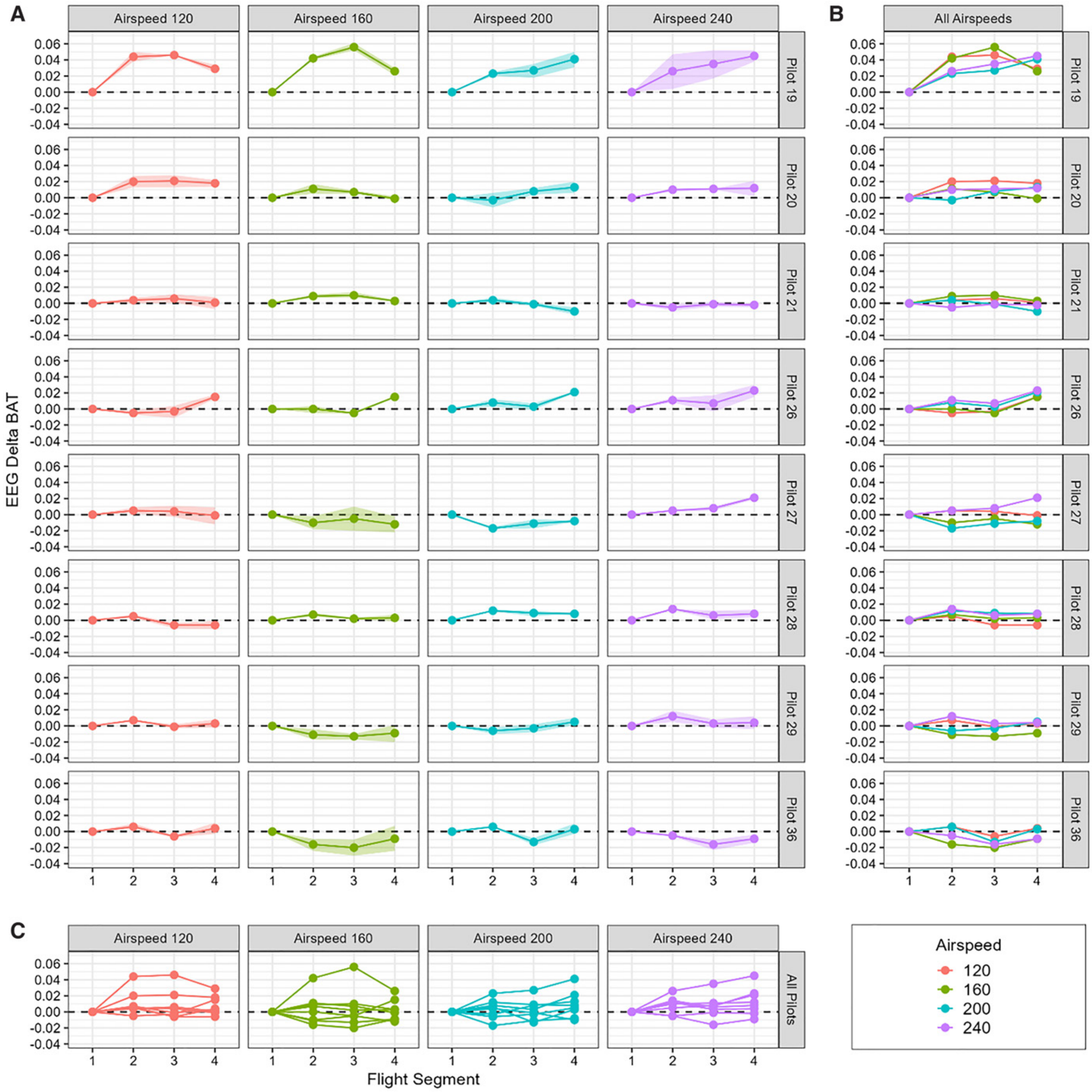

Fig. 4. Route 3 (Wide Corridor) mean EEG delta BAT values. A) Mean delta values for duplicate flights by each pilot and airspeed. Shaded regions show range of mean delta values from individual flights. B) Mean delta values by pilot for all airspeeds. C) Mean delta values by airspeed for all pilots.

early phase. The late segments exhibited the broadest range of mean delta BAT ratios, ranging from −0.016–0.048, suggesting diverse cognitive strategies among pilots during extended flight periods.

Airspeed conditions in the Narrow Corridor flights produced systematic changes in cognitive engagement measures. At 120 kn, mean delta BAT ratios ranged from −0.015–0.029 with minimal variability (SD = 0.007–0.013). As airspeed increased to 160 kn, increased variability emerged (SD = 0.015–0.017) with mean delta ratios ranging from −0.025–0.032, suggesting a transition point in cognitive engagement. At 200 kn, mean delta ratios ranged from −0.024–0.038, with individual differences becoming more apparent. The 240–kn condition showed the widest range of responses, with mean delta ratios from −0.020 –0.048 and the highest variability (SD = 0.019–0.023).

Statistical results from the regression model for the Narrow Corridor flights revealed a significant effect of flight segment [$F(3, 233) = 5.35$, $P = 0.001$], predicting an increase in the mean BAT ratio over time (supplemental **Fig. A1**, found in the online version of this article). Pairwise comparisons showed a significant increase in mean BAT values from flight segments 1 to 4 [$t(233) = 3.96$, $P < 0.001$]. The airspeed main effect [$F(3, 233) = 1.19$, $P = 0.32$] and the interaction effect between airspeed and flight segment [$F(9, 233) = 0.59$, $P = 0.81$] were not significant.

The Deep River Valley flight analysis revealed more consistent trends compared to the Narrow Corridor flights, though still demonstrating substantial interindividual variability in delta BAT patterns at the individual level (Fig. 3 and supplemental Table AIII and Table AIV, found in the online version of this article). Pilot 19 demonstrated notably high delta BAT ratios, particularly at higher airspeeds, with mean delta BAT values reaching 0.060 at 240 kn during flight segment 3. Pilot 20 maintained more moderate and consistent mean delta BAT ratios across conditions, ranging from 0.009–0.023, suggesting a more stable cognitive engagement pattern. The remaining pilots displayed diverse response patterns, with some showing predominantly positive delta ratios (Pilot 28) and others showing both positive and negative values (Pilot 36).

The temporal progression in the Deep River Valley flights showed distinct patterns across flight segments. The early phase demonstrated mean delta values ranging from −0.007–0.030, with moderate variability (SD = 0.007–0.011). The midphase showed slightly higher overall means (−0.008–0.060) with increased variability (SD up to 0.019), while the late phase demonstrated the most variable responses, with means ranging from −0.007–0.053 and standard deviations up to 0.017.

Airspeed conditions produced systematic changes, beginning with relatively low mean delta BAT ratios at 120 kn (−0.008–0.041) and moderate variability (SD = 0.010–0.016). As airspeed increased to 160 kn, slightly higher means emerged (−0.003–0.029) with similar variability (SD = 0.006–0.009). At 200 knots, means remained consistent (0.001–0.033) with moderate variability (SD = 0.007–0.010), while the 240-kn condition demonstrated the highest mean delta ratios (−0.003 – 0.060) and greatest variability (SD = 0.011 – 0.019).

Regression analysis for the Deep River Valley flights revealed a significant effect of flight segment [$F(3, 229) = 29.37$, $P < 0.001$], predicting an increase in the mean BAT ratio from flight segment 1–3, and a decrease from flight segment 3–4 (supplemental **Fig. A2** found in the online version of this article). Pairwise comparisons showed that mean BAT ratios were significantly different between flight segment 1 and segments 2, 3, and 4 [2: $t(229) = 6.62$, $P < 0.001$; 3: $t(229) = 9.04$, $P < 0.001$; 4: $t(229) = 5.82$, $P < 0.001$]. The airspeed main effect [$F(3, 229) = 2.04$, $P = 0.22$] and the interaction effect [$F(9, 229) = 1.00$, $P = 0.44$] were not significant.

The Wide Corridor route analysis revealed distinct patterns that differed notably from the previous routes (Fig. 4 and supplemental Table AV and Table AVI). At the individual level, pilot 19 maintained consistently high mean delta BAT ratios across conditions, with changes ranging from 0.023–0.056, particularly during flight segment 3 at 160 kn. Pilot 20 demonstrated moderate delta BAT ratios that generally decreased with increasing airspeed, ranging from 0.021 at 120 kn to −0.003 at 200 kn. Pilot 21 showed relatively stable but low delta BAT ratios across conditions, ranging from −0.010–0.010. The remaining pilots exhibited more variable patterns, with pilot 36 showing predominantly negative delta ratios (−0.020–0.006) and pilot 28 maintaining relatively stable positive delta ratios (−0.006–0.014).

Temporal analysis for the Wide Corridor flights showed evolving patterns, with the early phase displaying mean delta values ranging from −0.017–0.044 and moderate variability (SD = 0.010–0.018). The midphase showed similar means (−0.020–0.056), but with increased variability (SD up to 0.023), while the late phase demonstrated relatively consistent means (−0.012–0.045) with moderate variability (SD = 0.012–0.017).

Airspeed conditions produced less systematic changes compared to the other routes, with mean delta BAT ratios ranging from −0.006–0.046 at 120 kn with moderate variability (SD = 0.008–0.011). At 160 kn, means were lower (−0.020–0.056) with higher variability (SD = 0.013–0.023), while the 200-kn condition showed similar means (−0.017–0.041) with moderate variability (SD = 0.012–0.016). At 240 kn, means increased slightly (−0.016–0.045) with consistent variability (SD = 0.010–0.017).

Regression analysis for the Wide Corridor flights revealed a significant effect of flight segment [$F(3, 233) = 5.42$, $P = 0.001$], predicting an increase in the mean BAT ratio over time (supplemental **Fig. A3**, found in the online version of this article). Pairwise comparisons showed that mean BAT ratios were significantly different between flight segment 1 and segments 2, 3, and 4 [2: $t(233) = 3.10$, $P = 0.003$; 3: $t(233) = 2.41$, $P = 0.017$; 4: $t(233) = 3.78$, $P < 0.001$]. The airspeed main effect [$F(3, 233) = 0.68$, $P = 0.57$] and the interaction effect [$F(9, 233) = 0.75$, $P = 0.66$] were not significant.

Together, the findings across all three routes demonstrate that changes in cognitive engagement, as measured by delta BAT ratios, show both temporal progression and considerable individual variation, with pilots employing different cognitive strategies across conditions while successfully completing their assigned missions.

DISCUSSION

Analysis of BAT ratios across pilots, routes, airspeeds, and flight segments provided valuable insights into the cognitive demands placed on pilots, building upon existing research in aviation neurophysiology and human factors. The observed variations in BAT ratios provided important information for optimizing flight paths and understanding pilot cognitive engagement. A comparative analysis across the three routes revealed distinct patterns in several key areas. Looking at individual differences, the Narrow Corridor route exhibited high variability in individual responses with clear adaptation patterns. The Deep River Valley route demonstrated more consistent individual responses and clearer relationships with task demands. The Wide Corridor route fell somewhere in the middle, showing intermediate variability with fewer systematic patterns compared to the other routes.

When examining airspeed effects, each route displayed unique characteristics. The Narrow Corridor route exhibited an increase in cognitive engagement with airspeed, particularly above 200 kn. The Deep River Valley route demonstrated the strongest relationship between airspeed and delta BAT ratios, while the Wide Corridor route showed less systematic airspeed-related changes, suggesting different task demands were at play. Temporal patterns also varied significantly across the routes. The Narrow Corridor route showed increasing variability across flight segments, while the Deep River Valley route maintained more consistent patterns across time. The Wide Corridor route demonstrated moderate variability with less clear temporal progression. In terms of overall cognitive engagement, the Deep River Valley route generally elicited higher delta BAT ratios across conditions, while the Narrow Corridor route showed moderate but variable cognitive engagement levels. The Wide Corridor route demonstrated lower overall delta BAT ratios with less systematic variations.

These findings suggest that each route posed unique cognitive demands. The Deep River Valley route appeared to impose the most systematic cognitive engagement patterns, while the Wide Corridor route showed less airspeed-dependent variation. The Narrow Corridor route demonstrated intermediate patterns with clear individual differences in adaptation. The variations across routes likely reflect differences in navigational complexity, task demands, and required pilot strategies, with the Deep River Valley route potentially requiring the most consistent cognitive engagement across conditions. The airspeed-dependent variations in cognitive engagement, particularly evident in the Narrow Corridor and Deep River Valley routes, show that airspeeds exceeding 200 kn led to increased cognitive demands, suggesting a threshold where pilot workload management becomes more challenging. The Deep River Valley route, in particular, became more difficult to fly at higher speeds during some segments because of the challenging winding river canyon topography.

These findings align with Di Stasi et al.'s findings on attention allocation during actual flight. These insights could inform airspeed restrictions and optimal cruise airspeed recommendations for different route segments.[4] Moreover, individual differences in pilot responses emphasize the need for flexible route design that accommodate various cognitive strategies. This variability aligns with Dehais et al.'s work on individual differences in pilot cognitive states during flight operations.[5] The observed adaptation patterns, particularly evident in the Narrow Corridor route, suggest that pilots develop individual approaches to managing workload over time, supporting Hancock and Matthews' theory of cognitive resource management in complex environments.[9]

The temporal evolution of cognitive engagement across all routes indicates dynamic changes in mental resource allocation during flight. These findings parallel Rosa et al.'s research on fatigue and attention management in extended flight operations.[10] The implications for route design suggest the importance of considering both airspeed and navigational complexity when planning routes, particularly for extended operations where sustained attention demands may impact pilot performance. The BAT ratio patterns observed in this study provide quantifiable metrics for assessing cognitive demands, building upon the U.S. Army Aeromedical Research Laboratory's (USAARL) previous work on EEG-based cognitive engagement assessment in aviation.[2,3] The higher variability in the Narrow Corridor route compared to the Deep River Valley route suggests that predictable task demands might facilitate more efficient cognitive resource allocation, supporting theories of cognitive load management in complex task environments.

The integration of neurophysiological metrics with automated flight route planning protocols presents opportunities for enhanced route optimization. Arico et al.'s comprehensive review of neurometric data integration in automated flight systems provide a foundational framework for such applications.[11] Our findings suggest that incorporating cognitive engagement parameters into route planning algorithms could facilitate the development of neuroadaptive navigation protocols, particularly in high-density airspace where cognitive demands present great challenges. The observed correlation between airspeed parameters and cognitive engagement metrics provides significant implications for next-generation aircraft design and automated flight systems. Recent technical analyses from USAARL examining neuroadaptive automation frameworks demonstrate that real-time cognitive state monitoring could enable dynamic adjustment of automated support systems.[12] This approach suggests that implementing intelligent systems capable of responding to variations in pilot cognitive states could optimize workload distribution and enhance operational efficiency across diverse flight conditions. The systematic variations in BAT ratios with airspeed changes are one such physiological measure that could provide potential triggers for future adaptive systems.

From a training perspective, the individual differences observed in cognitive adaptation strategies suggest the need for personalized training approaches. The clear patterns of individual variation in our data support the development of training programs that account for different cognitive processing styles while maintaining standardized performance outcomes. The progressive changes in BAT ratios over flight segments indicate potential windows for optimal performance and risk periods that should be considered in route planning. Furthermore, our findings also have implications for the development of real-time monitoring systems. The clear relationship between route characteristics and EEG patterns suggests the possibility of developing predictive models for cognitive workload, similar to those proposed by Jiang et al. for cognitive competency. Such models could provide early warning of potential cognitive overload situations, allowing for proactive intervention.[13]

The relationship between route design and cognitive demands appears more nuanced than traditional difficulty metrics suggest. Our findings highlight the benefits of advanced assessment methods, particularly neurophysiological measurements, in FVL platforms. By quantifying cognitive engagement through EEG derived metrics, we gained valuable insights that can shape aviation system design, training protocols, and safety procedures. However, incorporating a more diverse array of physiological metrics is imperative to gain a comprehensive understanding of cognitive workload. This evidence-based approach to understanding pilot cognitive demands offers a more precise tool for optimizing route design and operational decision making.

Flight simulators, while valuable training tools, cannot fully replicate the actual experience and demands of operating a real aircraft, which may influence how pilots process information and make decisions. To gain a more comprehensive understanding of pilots' cognitive processes, researchers should consider expanding their measurement techniques beyond basic EEG metrics. Limitations of the EEG metrics that are captured during this experiment are highlighted in our previous publication.[2] Additional EEG measurements could reveal more nuanced aspects of cognitive demand patterns during different flight phases and decision-making scenarios. Furthermore, incorporating other physiological measurements such as heart rate variability and pupillometry could provide deeper insights into how pilots' workload and cognitive demands fluctuate throughout flight. These complementary measurement approaches could help identify subtle changes in mental workload that might not be captured by EEG alone. The limited scope of the three flight routes examined in this study, while providing valuable data, represent only a narrow segment of possible flight scenarios. To develop a more complete understanding of pilots' cognitive approaches and decision-making strategies, future research should examine a broader range of flight routes with varying complexities, environmental conditions, and operational challenges. This expanded scope would help identify how pilots adapt their cognitive strategies across different flight scenarios and conditions.

The data obtained from this study directly informs the design of experimental routes for upcoming FVL program evaluations. Building upon the observed relationships between airspeed, route characteristics, and cognitive workload, test matrices are being developed that systematically explore cognitive demands at airspeeds exceeding 240 kn. The findings of increased cognitive load above 200 kn suggest the need to carefully examine pilot performance at the speeds that FVL aircraft will achieve. Route segments are being designed that deliberately incorporate the elements found to induce consistent cognitive engagement patterns in the Deep River Valley route, while strategically integrating the variable navigation demands from the Narrow Corridor route that produced adaptive cognitive responses. These hybrid routes will help evaluate how pilots manage cognitive resources when transitioning between high-speed cruise segments and complex tactical maneuvers. The temporal patterns observed in the current study are informing the duration and sequencing of these test segments.

Additionally, the USAARL team is developing real-time EEG monitoring protocols specifically calibrated for high-speed flight conditions. These protocols will incorporate machine learning algorithms trained on the current dataset to predict potential cognitive overload situations during FVL flight testing. This neurophysiological monitoring system will be particularly crucial during initial envelope expansion flights, where pilots will be operating in complex and difficult flight scenarios.

The individual differences in cognitive adaptation strategies observed in this study are guiding the development of pilot selection and training protocols for FVL aircraft. Future experiments will evaluate whether these individual response patterns remain consistent at higher speeds and whether specific cognitive strategies correlate with enhanced performance in FVL-specific mission sets.

The analysis of EEG-based cognitive engagement measurements provides valuable insights for aviation route design and pilot performance optimization. The study reveals that different route characteristics elicit distinct patterns of cognitive engagement, with implications for safety, training, and operational efficiency. The systematic variations observed across routes, airspeeds, and time periods demonstrate the utility of EEG measurements in understanding and optimizing pilot workload.

The findings suggest that route design should consider not only traditional factors like distance and fuel efficiency, but also cognitive demands on pilots. The integration of EEG data in route planning could lead to more balanced flight paths that optimize pilot performance while maintaining safety margins. Future research should focus on developing standardized metrics for cognitive workload assessment in route design and investigating the relationship between EEG patterns and pilot performance outcomes.

The results also highlight the importance of individual differences in cognitive response patterns, suggesting that flexible route designs and personalized training approaches may be beneficial. The implementation of these findings could lead to improved route design methodologies that better account for human factors and cognitive limitations, ultimately enhancing aviation safety and efficiency.

ACKNOWLEDGMENTS

The authors would like to acknowledge the efforts and contributions of the U.S. Army Aeromedical Research Laboratory and the U.S. Army Combat Capabilities Development Command. Specifically, we would like to recognize Amanda Hayes in her supportive role as she made significant editorial contributions to this manuscript. Amanda Hayes aided in manuscript syntax and grammatical revision.

The opinions, interpretations, conclusions, and recommendations presented in this article are solely those of the authors and should not be interpreted as an official Department of the Army position, policy, or decision unless designated by other official documentation. The appearance of external hyperlinks does not constitute endorsement by the U.S. Department of Defense of the linked websites, or the information, products, or services contained therein. The Department of Defense does not exercise any editorial, security, or other control over the information you may find at these locations.

Financial Disclosure Statement: This research was supported in part by an appointment to the Postgraduate Research 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 have no competing interests to declare.

Authors and Affiliations: Matthew D'Alessandro, Ph.D., Research Psychologist, Warfighter Performance Group, and Ryan Mackie, M.S., James Barnett III, Christopher Sullivan, M.S., and Ian Curry, BM, BS, U.S. Army Aeromedical Research Laboratory, Fort Rucker, AL, United States; and Tom Berger, Ph.D., and Carl Ott, M.S., U.S. Army Combat Capabilities Development Command Aviation & Missile Center, Moffett Field, CA, United States.

REFERENCES

1. van Weelden E, Alimardani M, Wiltshire TJ, Louwerse MM. Aviation and neurophysiology: a systematic review. Appl Ergon. 2022 Nov; 105: 103838.
2. D'Alessandro M, Mackie R, Berger T, Ott C, Sullivan C, Curry I. Real-time neurophysiological and subjective indices of cognitive engagement in high-speed flight. Aerosp Med Hum Perform. 2024 Dec; 95(12):885–96.
3. Feltman KA, Vogl JF, McAtee A, Kelley AM. Measuring aviator workload using EEG: an individualized approach to workload manipulation. Front Neuroergon. 2024 Jun 10; 5:1397586.
4. Di Stasi LL, Diaz-Piedra C, Suárez J, McCamy MB, Martinez-Conde S, et al. Task complexity modulates pilot electroencephalographic activity during real flights. Psychophysiology. 2015 Jul; 52(7):951–56.
5. Dehais F, Duprès A, Blum S, Drougard N, Scannella S, et al. Monitoring pilot's mental workload using ERPs and spectral power with a six-dry-electrode EEG system in real flight conditions. Sensors (Basel). 2019 Mar 16; 19(6):1324.
6. Berger T, Juhasz O, Lopez MJS, Tischler MB, Horn JF, et al. Modeling and control of lift offset coaxial and tiltrotor rotorcraft. CEAS Aeronaut J. 2020; 11:191–215.
7. Prinzel LJ, Freeman FG, Scerbo MW, Mikulka PJ, Pope AT. A closed-loop system for examining psychophysiological measures for adaptive task allocation. Int J Aviat Psychol. 2000 Oct; 10(4):393–410.
8. Fernandez Rojas R, Debie E, Fidock J, Barlow M, Kasmarik K, et al. Electroencephalographic workload indicators during teleoperation of an unmanned aerial vehicle shepherding a swarm of unmanned ground vehicles in contested environments. Front Neurosci. 2020 Feb 14; 14:40.
9. Hancock PA, Matthews G. Workload and performance: associations, insensitivities, and dissociations. Hum Factors. 2019 May; 61(3):374–92.
10. Rosa E, Gronkvist M, Kolegard R, Dahlstrom N, Knez I, et al. Fatigue, emotion, and cognitive performance in simulated long-duration, single-piloted flight missions. Aerosp Med Hum Perform. 2021 Sep 1; 92(9): 710–19.
11. Arico P, Borghini G, Di Flumeri G, Bonelli S, Golfetti A, et al. Human factors and neurophysiological metrics in air traffic control: a critical review. IEEE Rev Biomed Eng. 2017; 10:250–63.
12. Vogl J, D'Alessandro M, Wilkins J, Ranes B, Persson I, et al. Optimizing adaptive automation in aviation: a literature review on dynamic automation system interaction. Fort Novosel (AL): U.S. Army Aeromedical Research Laboratory; 2024. Report No.: USAARL-TECH-TR–2025-09.
13. Jiang S, Chen W, Ren Z, Zhu H. EEG-based analysis for pilots' at-risk cognitive competency identification using RF-CNN algorithm. Front Neurosci. 2023 Apr 21; 17:1172103.

Gleaning from Diaries in Long-Duration Isolation

James R. Kass; Raye Kass

INTRODUCTION: A 264-d isolation simulation, SFINCSS-99, was conducted in Moscow to replicate typical scenarios on an orbital space station. One long-term group of four Russian crewmembers occupied the isolation complex for most of the duration (240 d), while two international groups of four each spent 110 d successively at the complex. Additionally, there were several short visits by medical personnel. The main objective of this paper is to investigate group and individual behavioral dynamics, particularly the intercultural challenges faced during long-duration isolation, using insights from crewmembers' diaries.

METHODS: A variety of instruments and training activities, employed before, during, and after the mission, formed this multifaceted experiment. One key component, crewmembers' diaries, is the primary data source for this analysis.

RESULTS: While unstructured instruments can be challenging to analyze, these diaries proved especially useful for studying group dynamics and identifying behavioral and intercultural issues. The crewmembers found our unstructured formats, such as these journals and post-mission interviews, to be a more effective means of expressing themselves compared to structured instruments.

DISCUSSION: Personal journals, open-ended questions, and the freedom from constraints typically imposed by feedback instruments used for quantitative analysis are invaluable for observing and expressing crewmembers' psychological status, as well as inter-crew and intercultural dynamics. Personal journals can also provide a basis for constructive intervention by ground personnel, researchers, or psychologists. Insights from this study can be applied to current challenges, such as the adoption of self-isolation as prevention against spread of COVID-19.

KEYWORDS: isolation, intercultural, behavior, spaceflight, simulation, group dynamics, diaries.

Kass JR, Kass R. *Gleaning from diaries in long-duration isolation*. Aerosp Med Hum Perform. 2025; 96(9):829–840.

Personal journals or diaries have long been used to analyze various aspects of crewmembers well-being and group dynamics in isolated or extreme environments, including space stations, analog space missions, and simulations of isolated space missions. In 1980, cosmonaut Valery Ryumin famously wrote in his personal diary, "All the necessary conditions to perpetrate a murder are met by locking two men in a cabin of 18 by 20 feet… for two months."[1] Similarly, in 1982, Soyuz cosmonaut Valentin Lebedev noted in his *Diary of a Cosmonaut: 211 Days in Space*[2] that his flight with Anatoli Berezovoi was marked by near silence due to their frayed nerves. Recent and detailed studies on crewmembers' diaries have also emerged from the International Space Station (ISS),[3,4] with previous analyses focusing on French remote duty stations, which served as analog[5] space missions. The most recent simulations of long-duration spaceflight include the 264-d SFINCSS[6] and the 520-d Mars500[7] missions. While diaries were utilized in the SFINCSS mission, they were notably absent from Mars500.[8] This paper focuses on analyzing the diaries from the SFINCSS mission and evaluating their utility.

The SFINCSS project aimed to simulate an international space station, providing a ground-based testbed for experiments that could inform real-life operations on the ISS, which was nearing its operational phase. Additionally, it served as a precursor for future long-duration simulations of missions to Mars, such as Mars500.

From James R. Kass Space Consulting, Voorburg, Netherlands, and the Department of Applied Human Sciences, Concordia University, Montreal, Canada.

This manuscript was received for review in October 2020. It was accepted for publication in April 2025.

Address correspondence to: Dr. James R. Kass, Human Spaceflight & Psychosocial Issues, James R. Kass Space Consulting, Kersengaarde 209, Voorburg, South Holland NL-2272ND, Netherlands; kass.james@gmail.com.

DOI: https://doi.org/10.3357/AMHP.5802.2025

In 1999, the Institute of Biomedical Problems (IBMP) in Moscow conducted the 264-d isolation simulation, "SFINCSS: A Simulation of Flight of International Crew on Space Station."[6] The study involved three crews of four individuals confined in a pressurized chamber complex simulating an international space station. Crew-1 commenced the mission and remained 240 d. Crew-2 joined from the 3rd to 18th week (110 d), while Crew-3 joined from the 22nd to 38th week (110 d) and were the last to exit. There were three short visits by medical doctors and psychologists. The entire timeline is depicted in **Fig. 1**.

The authors conducted a series of interrelated experiments and training activities throughout the pre-mission, in-mission, and post-mission phases of SFINCSS.[9] These experiments employed a variety of instruments[10] including:

- Pre-Mission: interviews, questionnaires, discussion and demonstration sessions, team-building exercises, intra- and intergroup simulation activities, and group debriefing.[9]
- Isolation Mission: surveys and reactionnaires,[9] team-talk sessions,[11] and personal diaries[11] (reactionnaires represent written reactions to specific situations or activities, e.g., team-talk sessions).
- Post-Mission: group debriefing, individual interviews, and questionnaires.[9]

An overview of these instruments has been described elsewhere,[10] with some results published in greater detail.[11,12] This paper primarily draws on data from diaries, supplemented by crewmembers' reports prepared for Mission Control (MC) and data from post-mission interviews conducted by the investigators.

One of the intrinsic goals of this experiment was to enhance understanding of personal traits and behaviors. In the long run, this understanding could facilitate more effective and efficient work, the ability to learn from mistakes, and, most importantly, constructive interactions with fellow crewmembers. The package of instruments aimed not only to measure group dynamics but also to equip the subjects with a better understanding of these dynamics, allowing for practical and useful learning. However, due to limited pre-mission time, achieving a comprehensive understanding of these goals was only partially realized. It is important to note that this experiment differed from most other experiments on this mission,[6] which primarily employed structured instruments to collect data and did not engage in pre-mission group dynamics activities; their focus was on measurement rather than facilitation of change.

The terms "personal journals" and "diaries" are used interchangeably in this paper. "Reports" refer to the required daily structured reporting by representatives of each crew (usually commanders) to MC. "Letters" refer to letters written by the crew, sometimes in their diaries and sometimes in emails to us. The term "logs" generally refers to all these sources.

METHODS

Subjects

Crew-1 comprised four Russian men, Crew-2 comprised three Russian and one East-German man (commander), and Crew-3 comprise one woman (French-Canadian), and three men [Japanese, Russian, and Austrian (commander)]. The experiment protocol GP-006, "Understanding group processes under long term isolation", Principal Investigator – R. Kass, Concordia University, Canada, was approved by the Biomedical Ethics Commission at the State Scientific Center of the Russian Federation – the Institute of Biomedical Problems, the Physiological Section of the Bioethics Committee of Russian Academy of Sciences, protocol number 55, May 6, 1999. Informed consent was obtained by IBMP from each subject prior to the start of the experiments.

The following nomenclature is used for the crewmember(s) and the three teams: Crew-1: 21n; Crew-2: 22n; Crew-3: 23n. Commanders: 211(RU), 221(GE), 233(AU). Crew-3 Russian "interpreter": 231; Japanese: 232; CAN/woman: 234. All others, Russian. EIQ = Essential Intercultural Qualities ($N = 1, 2, 3$, or 4). Each entry is referenced as [crew-no, date] and is placed in chronological order.

Equipment

The complex had two chambers to accommodate two crews simultaneously.[6] In the first chamber, Crew-1 ate, slept, and

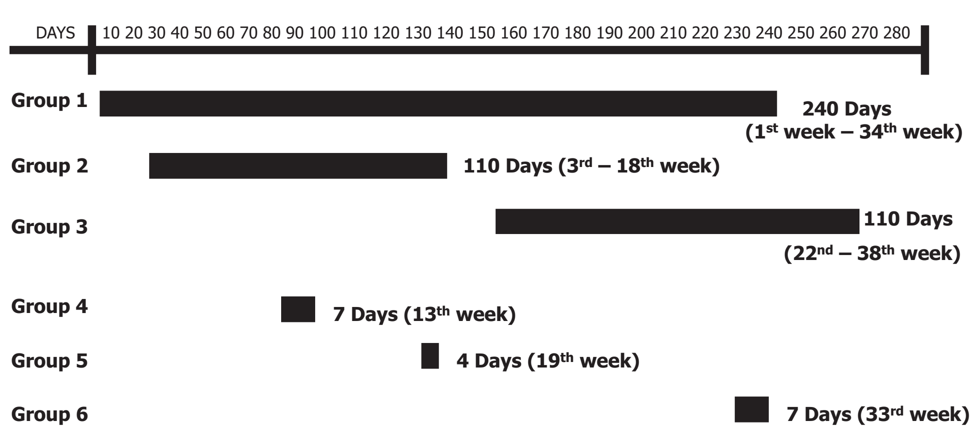

Fig. 1. SFINCSS timeline.

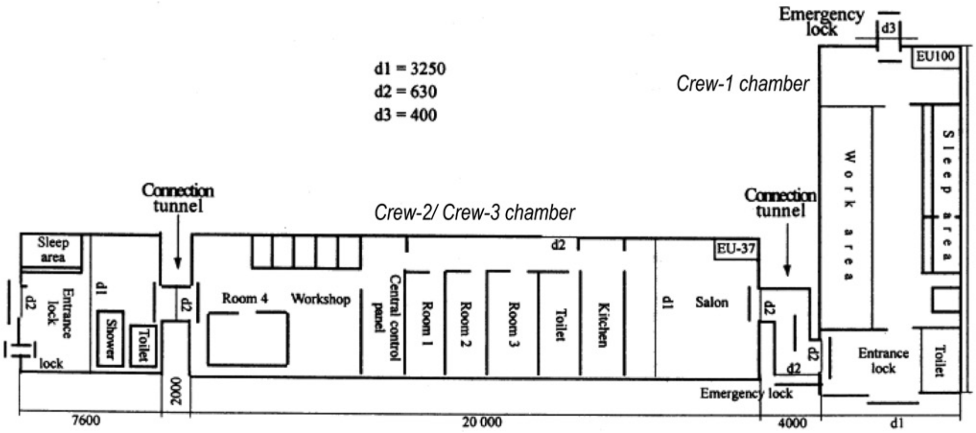

Fig. 2. Diagram of chambers used for the SFINCSS-99 mission simulation.

worked for 240 d; they shared bunk beds, and the same chamber served for sleeping, living, and working. In the second chamber, which Crew-2 and Crew-3 used in succession, there was a work area separated from individual sleeping compartments and a kitchen area. Each chamber was equipped with toilet and kitchen facilities, while showers, which Crew-1 also used, were accessible only from Chamber 2. A diagram of the chambers used for the accommodation of the crew groups is provided in **Fig. 2**.

Procedure

This experiment comprised in-flight instruments, applied during isolation, and post-flight interviews after isolation. Key instruments on which this paper is based, among several used to gather in-flight responses, were a variety of weekly and daily structured reports (e.g., regular Commander Reports) and unstructured personal journals [e.g., diaries and letters to the investigators (authors)]. The language of these varied, as some were written in English while others had to be translated from Russian. Although time-consuming and involving a detailed process, it was theorized that these journals could reveal aspects of the crews' behavioral issues and group dynamics[13,14] critical to the success of a long-duration space mission. The data presented below affirms this hypothesis.

Unlike the other instruments within the package of experiments carried out by these authors on this long-duration mission, most of which comprised structured responses, activities, and mission reports, this experiment's key instrument, diaries, was unstructured. The subjects were free to enter what they wished and felt was important: thoughts, feelings, insights, experiences, etc. We asked the crewmembers to submit them as frequently as they wished, even every day, but at least once per week. Most crewmembers adhered to a regular once-per-week routine.

In addition to diaries, the commanders submitted daily Commander Reports to MC. These reports comprised four domains: cooperation, scientific, operational, and medical. Because the data in the first domain, cooperation, also provided useful personal and group-dynamics information, in some cases very pertinent and comparable with diary entries, these data were also studied when available to us.

Lastly, unsolicited letters were addressed to us by some of the crewmembers. The letters commenced after a couple of critical incidents that occurred around the turn of the New Year. Several of the crew, especially those involved in the incidents, felt the need to write personal "letters" to us, in place of or in addition to entries in their weekly diaries, a personal rapport having been established with us during the pre-mission period of training and data collection. Some of these letters only reached us after the mission. These various in-mission sources upon which we based our analyses, except those from the international subjects, had to be translated from Russian.

Post-mission, the interviews carried out were based on a list of some three-dozen open questions (and subquestions). The interviews were recorded on video, and as far as practically possible, also typed in real time simultaneously. Details of these analyses are not presented in this paper, except for data that aided with the understanding of the diaries.

Statistical Analysis

To examine the data, we employed various instruments from interpersonal communication, group theory, and human relations theory. This qualitative approach was chosen in recognition of the fact that the scientific (and objective) aspects of previous experiments have often overshadowed the human relations (and subjective) dimensions, especially in the context of long-term confinement. Our research focused on analyzing the dynamics within each crew, as well as the impact of the multicultural[15] composition of the three crews. The journals documented the experiences of the 12 crewmembers, providing insights into their work and living environments and revealing issues related to behavior and intra- and intergroup relations.

The diary entries were analyzed systematically, with each reading offering a different perspective on the data:

1. First Reading: This initial reading provided an overview of the approximately 350 pages of logs and established a timeline of events recorded weekly for each crew. Major themes were noted, such as a general sense of calm in Crew-1, active team-building efforts in Crew-2, and a sense of mistrust from Crew-3 toward Crew-1 and MC.

2. Second Reading: The focus shifted to identifying recurring words and themes that reflected the mood or morale of the crews. This reading highlighted the relational dynamics within and between the crews and MC.
3. Third Reading: We sought specific indicators, such as external or internal resources, that influenced crew morale. Factors considered included gender aspects and the impact of external events on team morale (e.g., a bomb blast in Moscow raised concerns about relatives nearby).
4. Fourth Reading: This reading concentrated on identifying and elaborating on intercultural aspects, guided by the nine essential qualities of "the interculturally effective person."[16]
5. Final Reading: The last reading aimed to draw conclusions and formulate recommendations useful for future long-duration space missions.

RESULTS

The results and analysis presented here focus on the key aspects and situational challenges identified from the data. These factors significantly impacted the mission, crewmembers' well-being, successes, and failures, offering insights into challenges faced and lessons learned. Our findings are categorized into three main areas: Systemic Challenges/Biases, Critical Incidents, and Essential Intercultural Qualities.

Below each area discussed, we provide a table with selected diary excerpts. Most entries were originally in Russian (except for international crewmembers and Russian crewmember-231) and were translated into English. Ellipses ("…") indicate omissions for brevity while preserving the core message. We first discuss the systemic biases and challenges—those inherent and unchanging aspects of the system—that influenced the subjects and were frequently mentioned in the diaries.

Regarding selection of subjects (**Table I**), the selection process was unequal. Some Russian crewmembers were professional subjects or staff of IBMP, placing them in a different position from the others. Some were investigators conducting experiments. One Russian subject (231) was IBMP staff, with his wife, an investigator, observing the crewmembers from MC. Diaries indicate that 231 was torn between pleasing his wife and fulfilling his IBMP duties, which hindered his integration with fellow crewmembers. Additionally, 232 was noted to have questionable motives for participating.

Language barriers (Table I) were a significant disruptive challenge, particularly for non-Russian Crew-3 members who did not speak Russian. Except for the Crew-1 commander and a Russian Crew-3 member who spoke English, the Russian subjects and MC staff had limited or no English proficiency. The diaries reveal that the international crewmembers felt like foreigners dealing with an opaque organization that neither understood their language nor their needs. Some experiment procedures were provided in Russian, adding to their frustration.

During two crises on New Year's Eve, the lack of English-speaking MC staff meant they were unaware of the severity of the situations. The crew's inability to contact their agencies or investigators over Christmas exacerbated the issue. Commander-3 (233) and other international members could not follow conversations with MC without interpretation by Ru-231, compromising 233's independence and confidentiality. The interpreter (231) often found himself divided between loyalty to his fellow Russians and his team, unable to satisfy both parties during conflicts.

Table I. Systemic Challenges.

SYSTEMIC CHALLENGE NO.	TOPIC	QUOTES	CREW	DATE
1	Selection	About 231 … problem … he has to work as usually in IBMP, and his wife wants him to. … it is necessary to separate family and work	233	20/11/99
2	Selection	About 232 … perhaps inappropriately chosen? … he was using SFINCSS as a means to fund further education	233	20/11/99
3	Language	Due to my poor English I have to talk thru 211/ 231, which makes communication and acquaintance difficult …mother was right saying: "Study English, son".	212	21/12/99
4	Language	From our understanding, the main language of the SFINCSS experiment is English. However very often, we have faced different situations, where this can't be fulfilled … and had to rely excessively on 231	233	21/12/99
5	Language	I believe … that duty personnel should have some basic knowledge of most English expressions and we, as subjects, …of some Russian expressions. It isn't right that our Russian [231] should be also interpreter and get involved in our personal discussion because it affects relations between crewmembers… [and becomes] a one-person [231] responsibility	233	26/12/99
6	Language	Just imagine for a second that you are put in such a foreign environment where high performance is expected but the problem is with basic working conditions: you cannot read, speak, understand, write [all is in Russian].	233	30/12/99
7	Habitat	Psychological support means many times: communication with relatives and friends via … telephone, telecommunication	212	05/09/99
8	Habitat	Videoconf.. with my wife presented me 20 min of happiness and vital energy.	213	26/09/99
9	Habitat	Two different crews are now living here but live separately. We communicate only if necessary. From the beginning, Crew-3 strove to be independent. We don't mind, though we are always ready to help them and engage in joint activities.	211	25/12/99

Note: All crewmembers were Russian except for 221(GE), 233(AT), 232(JP), 234(CA-only female).

Regarding accommodations and environment (Table I), the living conditions were unequal, potentially affecting group dynamics. Crew-1, sharing bunk beds and work quarters, had little privacy but did not complain, possibly reflecting their collective cultural background. In contrast, Crew-2 and Crew-3 had individual sleeping cubicles, with their module housing the only showers. The situation worsened after a harassment incident when MC closed the hatch separating the two modules, causing discomfort for Crew-1. Russian crewmembers had almost unlimited access to Russian TV and frequent, easy communication with family and friends, a luxury not available to the international crew, which amplified Crew-3's difficulties during crises.

Crew-1 valued their shared common space, referring to it as "our barrel" and "a hospital," where they spent leisure and work time, helping them become a "community." Crew-1 and Crew-2 created a congenial atmosphere, sharing meals, singing, and playing card games. In contrast, Crew-3 rearranged the space to suit their needs, unsettling Crew-1, who interpreted these changes as signs of homesickness. Crew-3, with a heavier schedule, often lacked time for socializing or even scheduling meals together. The logs indicate a lack of shared leisure activities and a general disinterest in card-playing among Crew-3 members.

Overall, Crew-1 viewed their shared space positively, while Crew-2 and Crew-3 seemed to prefer personal space. Crew-1 felt their setup fostered a collective identity, while Crew-2 and Crew-3 valued individual space for maintaining their sense of self.

Several critical incidents (**Table II**) nearly led to the mission's premature termination. These incidents occurred on New Year's Eve and primarily involved Crew-1 and Crew-3.

In the first incident, a Crew-l member admitted jealousy of a Crew-3 Russian member's ability with English (enabling communication with the internationals). The ensuing discussion turned into a fistfight witnessed by the Japanese member, who separated them. The latter felt traumatized, withdrew, and eventually abandoned the mission prematurely.

In a second incident, Crew-1's commander (211) attempted to kiss intimately a female (Crew-3) member (234), leaving her feeling extremely violated. The Russian crewmembers and their supporting agency viewed this incident far less seriously. In the ensuing days, over the New Year's holidays, the Russian technical staff failed to grasp the significance and severity of these

Table II. Critical Incidents.

CRITICAL INCIDENT NO.	INCIDENT	QUOTES	CREW	DATE
1	Fistfight	231 reported that "212 came into the kitchen. He said, he is jealous that I [231] communicate so easily in another language and he's not good for anything. I asked what he wanted from me. And he starts hitting me, that my eyeglasses fell down and I hit back… And I knew from the Commander-2 that at he [221] had physical fights with 212". When 212 writes about it he simply calls it "an unpleasant episode" with no details about who was involved or what happened; [231 writes nothing about it.]	233	01/01/00
2	Fistfight	While we set the table, spent the old year, celebrated the New Year, talked a lot, joked, exchanged gifts. Had a great time. At the end of the holiday there was a ridiculous episode, which overshadowed the impression of the holiday. In the morning, to the surprise of learning about another unpleasant episode, which arose in general simply because of lack of understanding. I hope that the situation will be resolved positively.	212	01/01/00
3	Fistfight	We were supposed to have a party with Group-1. I expected that we would finish at midnight, with fun, but without any problem. However, … when I returned to the kitchen at one point, I witnessed 231 fighting with 212, who had bleeding nose, 231 a bleeding forehead. Although I couldn't grasp the situation very well, I tried to stop the fighting … I was somewhat scared of 212, because I guessed intoxication mainly drove him to violence …I shouted, "stop him!". Three of other Crew-1 caught him firmly …and we could put an end with this problem.	232	31/12/99
4	Harassing	And yesterday we celebrated the New Year… It's not a simple one, it's 2000, …not a new century, but still the date is round. In my opinion, everything went well and fun.	211	01/01/00
5	Harassing	211 took me (234) by the hand after I had openly said that I was not agreeing to this, and he pull me in the kitchen and tried to kiss me on the mouth with his tongue. I pushed him away of course and said this was unacceptable. But he tried again. Finally, I could manage to leave the kitchen. However, he said just, "sorry if I was too active. The next day he did not apologize at all. He said let's celebrate Canadian New Year and he tried to kiss me again." [233 Diary entry, reported by 234; no entry in 234's diary]	234	02/01/00
6	Harassing	… my concerns right now are not so much that I cannot deal with cohabiting with Crew-1; I will if I have to, until February, and even with open doors completely. After 11 d …I certainly do not understand the logic behind taking those steps after all this time, nor will I praise later such action. Therefore, cohabiting is not an issue, for me anymore, it is more that actually no disciplinary actions have been taken, as of yet, and an attitude of almost ignorance of the significance of those issues for the future has been demonstrated by the outside, especially IBMP.	234	11/01/00
7	Harassing	The second week of the new year was "marked" by an unpleasant event … the closing of the hatch be-tween the two modules of the station. …	211	15/01/00

Note: All crewmembers were Russian except for 221(GE), 233(AT), 232(JP), 234(CA-only female).

events felt by the international crew, and especially the victim, and English-speaking psychologists were hard to reach, leaving the victim feeling isolated and abandoned. In the ensuing days, the hatch between the two modules was closed on orders from MC (and requested by Commander-3 and his Japanese crewmember); inter-crew relations sunk to an all-time low.

Logs show that MC did not attempt to foster a more congenial atmosphere until much later. Commander-1 tried to resolve the situation internally, but these attempts were rebuffed by Commander-3. Eventually, MC sent in a special crew of space veterans to mediate, but this intervention was largely unsuccessful. Crew-1 and Crew-3 interacted minimally for the remainder of the experiment. As 213 (Crew-1) wrote, "we can say unequivocally that the Station operates two absolutely independent expeditions, which are seemingly close to each other but at the same time – very, very far away." Crew-1 members expressed regret that the critical situation couldn't be resolved internally, while Crew-3 internationals felt victimized and even suggested replacing the responsible Crew-1 members with other subjects.

Given the significant intercultural aspects, we analyzed the data using Vulpe's Nine Essential Qualities for the Interculturally Effective Person (IEP)[16] as a framework. We provide a brief description of each quality, adapted for this investigation, followed by an analysis of the data from the diaries and logs.

The first quality considered is the ability to cope with the stress of culture shock and the ongoing challenges of living in another culture (**Table III**). The Russian crewmembers were the most familiar with the host culture, as it was their own. Additionally, some were employees of the host agency. They recognized their role as "subjects," understanding that complaining about MC would be inappropriate and potentially penalized. In Soviet spaceflight, disobedience or mistakes often carried consequences, fostering a culture of obedience and restraint from complaints among Russian crewmembers. However, they expressed dissatisfaction with certain psychological experiments and support services. Notably, Commander-1 was particularly critical of psychological assessments, exhibiting "negative leadership" by discouraging fellow crewmembers from engaging with such questionnaires.

Commander-2 learned over time that complaining and demanding were ineffective and eventually adopted a more collaborative approach. Crew-2 seemed to find visiting crewmembers stressful.

Crew-3 and its commander were not always able to "deal with stress in a positive manner, for example, by talking over problems with foreign and local colleagues or by making a conscious effort to participate in the local culture."[16] The international members believed they had certain rights that were being denied and never fully adapted to the ongoing challenge of living in a "culture" different from their own or from what they had expected. They avoided contact with Crew-1 and did not attempt to find common activities, as Crew-2 had done. It appeared that Crew-1 initially attempted to be helpful but lacked the ability to engage Crew-3 in the same way they had engaged Crew-2. When the New Year's Eve crises occurred, Commander-1 wanted to discuss the events afterwards; however, Commander-3 chose not to engage in dialogue with him, instead reporting it to the outside agencies, which did not endear him to MC.

The second quality (modesty, respect/understanding culture abroad) considered is the ability to demonstrate an attitude of modesty and respect (**Table IV**). Commander-2 seemed to possess the greatest ability to learn modesty and respect the host culture. Perhaps, as the only non-Russian, he recognized that his success would depend on his ability to do so. Fluent in Russian, he did not address or refer to MC or his colleagues disrespectfully, even when frustrated. He managed unplanned changes from MC effectively, making the best of otherwise irritating situations with his teammates.

In contrast, Commander-3's logs exhibited a bias against the host culture. One of his team members made an uncomplimentary reference to the host culture as "vodka." It may be presumed that the greatest difficulty for the internationals of Crew-3 was the failed expectation that English would be a working language with MC.

Table III. EIQ-1, Stress, Culture Shock.

EIQ	QUOTES	CREW	DATE
1.1	No psychological support is needed [repeated frequently]	211	15/08/99
1.2	Psychological support has only a negative influence on me	211	22/08/99
1.3	What can I do if I don't have any psychological strain? I had no stress. But one more such questionnaire – and they will appear.	211	23/08/99
1.4	… stupid advice of chief doctor [regarding nutrition]	211	12/09/99
1.5	Especially difficult week. Most remarkable day – when visiting crewmembers were in a separate chamber for the whole day. The most pleasant event – leaving of the visitors! … "aliens" appeared around our table, it hampers, food lost its taste. Some "mode of life" questions became more complicated … washing… working… sleeping… toilet	224	04.10 –10.10.99
1.6	[of 232] He is not interested in anything, except performing sport... He told me he likes only Videos in Japanese language	233	20/11/99
1.8	From the very beginning, the third Crew was striving to be independent. We do not mind- though we are always ready to help them and participate in the joint activities.	211	25/12/99
1.9	…from a phone-conference it appears that IBMP is seriously influencing others in a very questionable way. It appears now that circumstances relating to events of violence and harassment have been replaced now by such matters like: Crew-3 personality traits, adaptation after one month, over-reacting to events, Crew-3-Commander being unstable in his mind.	234	15/01/00

Note: All crewmembers were Russian except for 221(GE), 233(AT), 232(JP), 234(CA-only female).

Table IV. EIQ-2, Modesty, Respect/EIQ-3, Understanding Culture Abroad,.

EIQ	QUOTES	CREW	DATE
2.1	We had to found out that again there have been changes in the procedures which have not been agreed or even discussed with the PI (me) … with the marvelous help and patience of …Crew-1 we succeeded in the end.	221	28/07/99
2.2	People [MC] outside have no idea… We continued the antimilitary style, or should I say the adult style …we do not need any outside support, I mean no Russian or Japanese" [both sponsors of the mission].	233	11/12/99
2.3	It is a great fun to work with vodka… [referring to Russians]	232	18/12/99
3.1	…duty personnel [MC] should have some basic knowledge of most frequent English expressions and we, as subjects, should also have some frequent Russians expressions	233	26/12/99
3.3	'fighting' is one of the most primitive actions to resolve conflict. We adults are never allowed to have such primitive action, I think.	232	31/12/99
3.4	We were surprised to learn about the other unpleasant episode [kissing] which originated from simple misunderstanding	212	01/01/00
3.2	I do not want to discuss now an inadequate reaction of some representatives of the Crew-3 on the celebration of the New Year. It is not the time yet.	211	08/01/00
3.5	In Canada events of December 31st are considered criminal; also in Japan, Austria; how in Russia?	233	08/01/00
2.4	…we are in Russia and in Russia, international crewmembers were told they were only guests and should behave accordingly	234	22/01/00
3.6	[On 232 early exit] …absolutely groundless… As one Russian proverb says, 'If you have joined the harness, do not say that you are feeble'. He complains about lack of care for him … participation in such an experiment is not a Sunday walk on a yacht. …the task is to live and work in extreme conditions.	211	29/01/00

Note: All crewmembers were Russian except for 221(GE), 233(AT), 231(JP), 234(CA-only female).

The third quality considered is the understanding of the concept of culture and the pervasive influence it will have on life and work abroad (Table IV). Vulpe's third quality emphasizes the necessity of cultural awareness for intercultural effectiveness. This simulation, though hosted by the Russian IBMP, involved multiple cultures, particularly when Crew-3 entered. The subjects seemed unaware of how linguistic and cultural diversity would impact their work. Commander-3 highlighted the importance for MC and his fellow crewmembers to understand basic expressions in both English and Russian.

The lack of cultural awareness was especially evident during the New Year's Eve events. Other Crew-1 and Crew-3 members did not comprehend the difficulty the Japanese member faced in witnessing and breaking up the Russian fistfight. The Russians involved appeared to dismiss the incident, possibly because discussing mistakes was discouraged among cosmonauts. The victim of the fistfight made no mention of the incident in his subsequent weekly reports. For the Japanese member, it was a significant act of violence. The Crew-1 Russians did not grasp how deeply the "kissing" incident affected the Crew-3 woman and her team; to them, it was a simple misunderstanding, and they were surprised by her extreme reaction. For her, it was a major (criminal) violation, particularly as she had refused the advance.

During the New Year's Eve incidents, the international Crew-3 expected to be treated according to their own terms; two members felt their rights had been violated, prompting them to lodge an immediate international protest with various agencies, even invoking the UN charter on human rights. Over time, they realized that this approach brought hardship on Crew-1. Once the hatch was closed, Crew-1 no longer had access to regular showers, while confined inside the closed, hot, and humid "barrel".

The fourth quality considered is having a deep understanding of the host country and continually seeking to expand that knowledge (**Table V**). The logs indicate that Commander-2 endeavored to immerse himself in the host culture, not only through games played but also by engaging with the music performed by the Russian crewmembers. Conversely, Commander-3

Table V. EIQ-4, Knowledge of Host Country.

EIQ	QUOTES	CREW	DATE
4.1	We had a very nice evening together [with Russian Crew-1] with a lot of coffee and songs	221	28/07/99
4.2	In the afternoon we fulfilled questionnaires and test of xxx. Without translation into English or German it was very time consumptive for me [German 221 spoke some Russian]	221	30/07/99
4.3	"...here is the list of the researches without any instruction, b) only with a Russian instruction, and c) environments only in Russian language. I hope it is understandable that under such non-optimal conditions for an international experiment such as SFINCSS, …more understanding and cooperation is expected from your side, when everything is not running as smooth as should be. Just imagine for a second, that you are put in such a foreign environment where high performance is expected but the problem is with basic working conditions (you cannot read, speak, understand, or write)	231	30/12/99
4.4	I believe for future isolation studies where English is the main language …that duty personnel should have some basic knowledge of most frequent English expressions and we, as subjects, should also have some frequent Russian expressions. It is not right that [our] Russian crewmember should be [both] interpreter and getting involved in our personal discussions because it affects [our] relations.	233	26/12/99
4.5	[about 231] …it is a bit of a problem, he has not really time to join us due to two things: …he has to work as usually in IBMP, and his wife want him too. I think for such experimentation it is necessary to separate every subject from family and work that they have time together before they go in.	233	20/11/99

Note: All crewmembers were Russian except for 221(GE), 233(AT), 232(JP), 234(CA-only female).

Table VI. EIQ-5, Relationship-Building Skills.

EIQ	QUOTES	CREW	DATE
5.1	Skepticism and demonstrative '*apofigism*' [apogee of indifference, 'screw-it-all' attitude] of the less stable crewmembers has a negative effect on their attitude toward work and life. …group cohesion is negatively affected by excessive irritability, when you start wondering what you may say or do and what you shouldn't.	211	06/08/99
5.2	He [232] has really no humor, activity, motivation, or interest for the experiment. ...He is not interested in anything, except performing sport… his English ability is less than expected… he listens without reactions... other Japanese with much worse English try to react or understand.	211	23/10/99
5.3	We live, work, have meals etc. in the same space. The consequences are … we are more exposed to one another, communicate more, care about one another… take the opportunity to work and rest, as well as try not to disturb and make noise… We watch the same TV program …Crew-2 …have own personal cabins… possible to 'run away,' hide away, make volume loud.	211	06/11/99
5.4	[On 232 after departure] We are all feeling deep loss; he was one of the most respected subjects among us, had great devotion to his work, was a peaceful human-being, …his great compassion for others will be missed… I'll try to insure that 231, with whom he shared the same working place and to whom 231 felt closest, does not feel so alone …	211	26/01/00
5.5	This conflict is playing a significant role because our experiment deals with researching the problems of interactions between… multinational crews on the ISS. Precisely now, it is the time to look for ways of rapprochement, resolution, and overcoming of existing problems, rather than searching for facts that separate us and …for irreconcilable contradictions. If there is no will to understand, to approach and resolve conflict, then real problems can arise. In our simulation it may be not a big problem, but what about a space station? How should one behave in a similar situation there? Should one appeal to Earth each time one has a problem?	211	15/01/00

Note: All crewmembers were Russian except for 221(GE), 233(AT), 232(JP), 234(CA-only female).

expressed a desire to learn Russian but did not pursue it. Generally, it seems that neither the Russians nor the others fully appreciated the importance of understanding each other's language and culture. The diaries do not document any attempts to learn words or phrases in another language. The fistfight was triggered by jealousy, as the Crew-3 Russian knew more English than his Crew-1 counterparts. An examination of the commanders' diaries reveals that Commander-2 was the most effective and culturally sensitive; originating from East Germany, he had worked in Russia and spoke the language.

It is worth noting from Commander-3's logs that the failure to bring Crew-3 together for team-building activities pre-mission was partly due to IBMP's refusal to release the Russian Crew-3 member from work duties, which contributed to the challenges of developing their group into a cohesive team during the mission. Burroughs documented the extensive time Russians and Americans spent in each other's countries for language learning, cultural adaptation, and mission training.[17] However, despite these efforts, significant cultural challenges and problems emerged.

The fifth quality considered is to possess well-developed relationship-building skills, both social/personal and professional (**Table VI**). Commander-1 indicated in his logs a real sensitivity regarding the morale of his own crew, while Commander-2's abilities have been referenced earlier. Commander-3 faced a difficult task. Although he was able to build a relationship with his French-Canadian crewmember in English, his Japanese crewmember spoke little English and was initially reported by 233 to be quite incommunicative. He notes little about how he built a relationship with his English-speaking Russian teammate. This lack of a shared language profoundly hindered relationship-building.

The Canadian Foreign Service Institute[18] warns against creating an "expatriate" ghetto, which isolates individuals from the other culture. When Crew-3 arrived, it appears that two ghettoes developed: international Crew-3 and Russian Crew-1. The Russian Crew-3 member appeared to have become conflicted, hearing reports from both sides about the other, but being unable to bring the two together. Sadly, neither crew managed to win the trust or confidence of the other by attempting to fit in or showing genuine interest in the other culture.

The sixth quality considered is knowledge of one's own personal background, motivations, strengths, weaknesses, and how it has shaped one's thinking, feeling, and reactions (**Table VII**). Except for Commander-2, the logs do not indicate that the subjects demonstrated an awareness that their own cultural perspectives might differ significantly from those of other cultures. Goleman[19] identifies self-awareness as a key factor in one's success in group relations.

In terms of personal knowledge, Crew-1 members noted in their logs the importance of having a hobby or project for leisure-time activities. They seemed to recognize the value of individual pursuits as being resourceful and nurturing in a static and limited environment. Commander-3 also wrote about planning which items to bring into the capsule that would provide relaxation and enjoyment.

The crews exhibited a high level of intrinsic motivation. The logs reflected a strong professional commitment to the experiment, and although the New Year's Eve incidents were a fiasco, many logs mentioned the learning experiences that could be beneficial for future missions. They understood their purpose and were dedicated to performing well.

In the debriefing, Crew-3 expressed concerns about Crew-1's use of pornography during the simulation and how it might have affected healthy attitudes toward the presence of women in the capsule. Crew-1's logs contained negative opinions about a visiting female crewmember, stating that "she had no purpose

Table VII. EIQ-6, Knowledge of Own Background, Motivations, Strengths, Weaknesses.

EIQ	QUOTES	CREW	DATE
6.1	When I want to put a barrier between myself and surroundings I don my headphones and listen to loud music. During last days I listen to Bach, that's strange because normally I didn't receive psychological support and didn't want it	211	02/08/99
6.2	I am trying… unsuccessfully so far, to dissuade one of the female employees … to participate in the visiting expedition …I cannot understand, why she needs this? She does not have any research program; she is not intended to be busy with housekeeping either…as they say, an 'uninvited guest'.	211	10/09/99
6.3	Group-1 like Competition but like small children…only when they are sure to win. They are very good in the card game Preference and tried always to play with Group-2 to win and to show that they are stronger. When 221 taught them Skat game they never played due to fear to lose …in Group-3 nobody likes to play cards …they hate it.	233	20/11/99
6.4	In our case, this [harassment] conflict is playing a significant role because our experiment deals with researching the problems of interactions between representatives of different countries, cultures and sex regarding the multinational crews functioning at the ISS… we are experiencing a unique situation now which may and can be resolved in a peaceful way. We can study it and give recommendations for future space missions	211	15/01/00
6.5	[After conflicts] the only reasons we are willing to continue SFINCSS is because: WE take science seriously; WE are grateful to our agencies for their supportive actions.	211	16/01/00
6.6	other types of harassment…seen in chamber such as pornographic websites, sexually explicit screensavers, posters and calendars of naked women, comments, gender-oriented jokes, gesture/holding by 211 for picture, extensive video camera of her.	234	25/01/00

Note: All crewmembers were Russian except for 221(GE), 233(AT), 232(JP), 234(CA-only female).

in the experiment, that she was making no scientific contribution" and that they didn't need her to do the housekeeping. Perhaps Crew-1 was unaware of the impact their views on women had. Commander-1's response to 234's rejection of his attempt to kiss her was to try again the next day, later saying, "Sorry if I was too active." The presence of a woman in the otherwise all-male crew influenced personal feelings and increased the need for privacy, as Commander-3 wrote to MC protesting against cameras being placed where woman-234 exercised, showered, and used the toilet. Issues regarding appropriate male–female behavior and sexuality would need to be addressed in long-duration flights.

The seventh quality considered is to be able to convey thoughts, opinions, and expectations in a way that is understandable yet culturally sensitive (**Table VIII**). The logs indicate that Commander-2 excelled in conveying thoughts and opinions in a culturally sensitive manner. Commander-1 did not immediately report the incidents but later advocated for discussing the grievances. Commander-3 appeared culturally insensitive, focusing on his own and his fellow crewmembers' rights rather than finding ways to communicate his thoughts and expectations in a manner that would be well-received and facilitate reconciliation. The logs did not document any significant conversations among crewmembers, except for the Russian crewmembers involved in the fistfight. Commander-3 reported 6 wk after the New Year's Eve incidents that they were able to clear the air and understand each other better, although the logs did not specify how this was achieved.

The eighth quality considered is to be able to strive to improve the quality of organizational structures and processes, as well as staff morale, and promote a positive atmosphere in the workplace (Table VIII). The logs generally reported that MC did not take a leadership role in improving structures, processes, and morale. They were described as resolutely in control and quite inflexible, except in some cases concerning food requests. When requests were met with delayed responses,

Table VIII. EIQ-7, Ability to Sensitively Convey Thoughts, Opinions, Expectations/EIQ-8, Improve Processes, Morale, Positive Atmosphere.

EIQ	QUOTES	CREW	DATE
7.1	Common belief seems to be that both crews understand now better each other's perceptions. These perceptions have been shared freely to facilitate mutual understanding on [a] few occasions at least by 234 and 211 [kisses] (when timing felt right). As for 212 and 231 they turned the page the next day after their [fist] fight.	233	16/02/00
8.1	Everybody spoke openly and free about positive feelings- I never met this in a men group before. I'm satisfied that they accepted 'my way' to take command.	221	28/09/99
8.2	[Regarding cameras constantly trained on crewmembers even during exercise] … 211 tried to convince me, "*we are subjects and have to accept this*" …	233	06/12/99
8.3	When communicating representatives of different countries, cultures, mentality, natural, there may be some "overlaps", some mistakes made by one side or another. Misunderstandings or even nonacceptance of certain actions or deeds of others is possible; …in any case …it is necessary to resolve issues, solving first within the team …on the basis of discussion, and search for compromise. … need willingness to understand and meet halfway …we should not seek to dig out what divides us, nor look for irreconcilable contradictions, but rather look for ways and means of rapprochement, resolution and overcoming all conflicts.	211	15/01/00
8.4	[Note to MC] The only way to insure our full support for continuation of SFINCSS is removal of subjects 211, 212; [if] refused, all three international crewmembers insist on keeping doors closed until Crew-1 leaves, [or] …change of commander: 211 either is demoted by IBMP …or resigns command, if he considers this less disgraceful.	233	15/01/00

Note: All crewmembers were Russian except for 221(GE), 233(AT), 232(JP), 234(CA-only female).

Commander-1 remarked, "We are the subjects" and concluded the need to adjust to them. Throughout the diaries, it is evident that Commander-1 closely monitored his own crewmembers' morale.

Commander-2 was able to adapt to the local organizational norms while still seeking to meet his own crew's best interests and needs. He managed to advocate for his crewmembers' needs in a modest manner, which elicited a positive response. He consistently expressed gratitude for prompt replies. Commander-2 demonstrated "a degree of political acuteness such that he was able to assess realistically the balance between competing forces in an organisation and its environment."[16] He could adjust to the MC's approach while still obtaining what he needed for his crew. What seemed to please him the most was being well accepted as Commander. He said at the last Team Talk session, "Everybody spoke openly and freely about positive feelings… I am satisfied that they accepted 'my way' to take command." This appeared to be a man capable of balancing the needs of the group with his style and the powers above.

Commander-3 seemed intent on improving the processes and correcting wrongs in the organizational structure but did not understand the power relations between MC and his crewmembers. He appeared unable to "adopt behaviours crucial in achieving results in the host organisation."[16] In the New Year's Eve incidents, Commander-1 wanted to resolve the difficulties between the crewmembers, partly to avoid punishment but also because (as he stated) he hoped to benefit ongoing research by discovering what could be learned from these conflicts.[20] Commander-3, more intent on righting wrongs, was unwilling to passively submit to authority (MC) and felt compelled to be critical and demanding on issues concerning women's rights and physical violence within the chamber—caring for his own crewmembers' "morale," but not fostering a "positive atmosphere in the workplace."

The ninth quality considered is to have a high level of personal and professional commitment to the assignment and the life experience in the host country. Except for the Japanese member of Crew-3, who joined primarily to finance a master's degree, all other crewmembers indicated a high level of professional commitment to their assignment in their logs. Therefore, it was striking that the only one to leave the experiment was the Japanese member. This underscores the necessity of an IEP having a high level of personal and professional commitment.

The other 11 crewmembers were fully motivated to contribute toward a long-duration mission (e.g., Mars), hoping that their efforts would make a difference. Most expressed surprise at how complicated it was to work with people from different countries. No one was fully able to anticipate or overcome the difficulties of communication. Commander-3 reported that even Commander-2 expressed this more fully post-mission. The non-Russians struggled with the ways that MC/IBMP worked. And yet, all hoped that their experience would be for the betterment of space travel, persevering with that end in mind.

DISCUSSION

Viewing the results, two challenges faced by the subjects, and seemingly insuperable for some of them, becoming stumbling blocks seriously impacting the mission, stand out:

- Differences in culture and language became harmful catalysts, damaging inter-crew relationships, and developed into aggravating stressors.
- Lack of skills on all sides to exercise adept leadership and timely intervention allowed wounds to fester and the resulting crises to boil over out of control.

Differences in culture combined with lack of IEP qualities have been widely documented as causing serious problems in a team, whether on a space mission or a ground-based team. Burroughs[17] has well described how on a MIR mission the American astronaut, Jerry Linenger, certainly did not at all fit the mold of the IEP,[16] with much resulting aggravation, especially in times of crises (when a fire broke out on the MIR station, Linenger insisted on his contractual right to perform strenuous physical exercise, thus further depleting the limited oxygen on the station). Kraft[21] lists several incidents related to multicultural factors on international Shuttle missions having various degrees of impact on these missions. He also points out that there were frequent psychological problems between flight crewmembers and MC, going back to Skylab.

Of course, not all space missions or isolation simulations with multicultural crewmembers and language differences resulted in related aggravation. The EXEMSI 92 (60-d isolation[22]) experiment (three men and one woman) and the Mars 500 isolation simulation (six men) did not record any serious diversity-related problems arising.[6] However, on the Mars 500 mission, conflicts with MC were reported by crewmembers five times more often than conflicts among themselves,[23] highlighting the importance of a good relationship between the crewmembers and mission controllers and the need for greater involvement of MC in pre-mission training.[24]

Regarding lack of skills, the SFINCSS subjects underwent too little pre-mission human-relations training to develop the sort of interpersonal qualities required for such an international and long-term mission (MC, no training at all). Team building in an intercultural context may well be one of the most critical aspects of the orientation to be given to space crews. Kraft writes that "this study showed that cultural background became more explicit and stronger during isolation. Based on this, isolation studies with international crews and intercultural training will be necessary for both the crewmembers…and ground personnel."[24]

One earlier isolation experiment performed by the author[25] did incorporate group-dynamics training, in fact for both the subjects and MC jointly, recognizing the importance of their interdependence. CAPSULS[26] was only of short duration (1 wk) and the subjects were professional (Canadian) astronauts. This training was well received by both the crewmembers and MC, and moreover, included similar experiment protocols for both groups. However, it was not possible to carry out such training protocols or include MC for our experiments and training on SFINCSS.

Regarding the key instruments used, and the data gleaned for this analysis, we conclude that diaries and personal logs are an excellent means:

- to provide early warning of mounting problems, thus facilitating timely intervention during a mission; and
- to gather meaningful data on individual wellbeing and inter-/intra-group dynamics and behavior.

It is noted that although "Mars 500 Diaries" were posted on ESA's portal, these were created for the public about an ongoing mission rather than an intimate record. Personal diaries as in our experiment, and as described by Stuster,[3–5] were absent on Mars 500.

Our findings demonstrated that qualitative analysis of unstructured data sheds significant light on important information seldom exposed via traditional structured instruments. As already mentioned, the subjects reported how they found it much easier to express their feelings using diaries than to respond to multiple-choice, rating-type questions. On an earlier isolation experiment, EXEMSI 92[22] subjects reported getting so fed up with such questions that they stopped taking them seriously, jeopardizing the data's usefulness.

Lastly, we briefly explore some synergies and applications of isolation experiments, such as this one, and their relevance to our lives on Earth, particularly in light of the recent COVID-19 pandemic. People have faced challenges of isolation unprecedented in recent history, which bear similarities to those encountered in space missions, isolation experiments, and extreme environments. Stuster[27] highlights common challenges experienced during forced isolation due to COVID-19 and those in space missions, including confinement, isolation, inability to meet friends and colleagues, disruption of normal daily activities, boredom, and the strain of being confined to a small space with the same people continuously. These conditions have exacerbated uneasy home situations, leading to increased domestic violence, and the added stress of isolation and confinement has proven difficult to manage. Similar challenges or stressors call for similar solutions or antidotes.

Many lessons can be transferred between everyday life and extreme environments. Ultimately, whether in a scientific environment or an extreme situation on Earth, it is up to us to make the best of it by respecting our obligations and responsibilities or to worsen it by lamenting lost rights or privileges. Whether facing a long-duration mission to Mars or stressful analogs on Earth, we may not always have the luxury of carefully selecting and grouping together a compatible team. However, we can train and equip individuals with the instruments to face challenging circumstances.

A recent review[28] affirms that cross-cultural issues have significantly impacted crews on Shuttle-MIR and ISS missions, highlighting the importance of pre-mission training in this area. Nevertheless, simply undergoing a basic "group dynamics" course is not sufficient. For training to have a lasting effect, a long-term investment of time, energy, and mindset is necessary, followed by the successful application of the skills learned in everyday life. Davidson[29] points out that mindset can be trained to promote resilience and a positive attitude under stress, rather than allowing it to follow a detrimental path of negative emotions.

The key conclusions can be summarized as follows:

1. Importance of Diaries: Diaries are a crucial instrument for collecting and understanding data on a subject's well-being, team health, and the dynamics of both inter- and intragroup interactions and behavioral issues. When maintained in real-time, diaries can provide early warnings of potentially critical situations, allowing for timely and helpful interventions.
2. Intercultural Issues: Intercultural issues are likely one of the most critical barriers to healthy intra- and intergroup interaction and communication, applicable to both crewmembers and MC.
3. Crew Selection for Long-Duration Missions: Considering the international nature of long-duration space missions (e.g., Moon, Mars), it is essential to select crewmembers (and MC personnel) based on their intercultural sensitivity and effectiveness.
4. Pre-Mission Training: Pre-mission intercultural and group-dynamics[13,14] training[25] can equip space crewmembers with the instruments to recognize evolving issues before they become critical, enabling them to take timely preventive and corrective actions themselves.
5. Lessons from Extreme Situations: There are valuable lessons[30] to be learned and exchanged between extreme situations encountered during times of crisis in everyday life and those studied in scientifically extreme environments.

ACKNOWLEDGMENTS

The SFINCSS experiment was sponsored by IBMP, Japan Aerospace Exploration Agency, Canadian Space Agency, and European Space Agency.

We wish to acknowledge the very dedicated and painstaking contribution of Catherine Jean Pott, B.A., M.A. (psychology), in the analysis of data. Catherine Pott is a certified life coach (International Coaching Federation), primarily working on cross-cultural issues with experience in North America, Africa, Europe, and Asia.

Financial Disclosure Statement: The authors have no competing interests to declare.

Authors and Affiliations: James R. Kass, Ph.D., M.S., James R. Kass Space Consulting, Voorburg, Netherlands; and Raye Kass, Ph.D., M.A., Emerita Professor, Department of Applied Human Sciences, Concordia University, Montreal, Canada.

REFERENCES

1. Mundell I. Stop the rocket, I want to get off. New Scientist. April 17, 1993. [Accessed May 16, 2025]. Available from https://www.newscientist.com/article/mg13818693-700/.
2. Lebedev V. Diary of a cosmonaut: 211 days in space. 1st ed. College Station (TX): Phytoresource Research; 1988.
3. Stuster J. Behavioral issues associated with long-duration space expeditions: review and analysis of astronaut journals: Experiment 01-E104

(Journals): final report. Houston (TX): NASA Johnson Space Center; 2010. Report No.: NASA/TM-2010-216130.
4. Stuster J. Behavioral issues associated with long-duration space expeditions: review and analysis of astronaut journals: Experiment 01-E104 (Journals): phase 2, final report. Houston (TX): NASA Johnson Space Center; 2016. Report No.: NASA/TM-2016-218603.
5. Stuster J, Bachelard C, Suedfeld P. In the wake of the astrolabe: review and analysis of diaries maintained by the leaders and physicians of French remote duty stations. Santa Barbara (CA): Anacapa Sciences, Inc.; 1999.
6. Baranov VM, Demin E, Gushin V, Belakovsky M, Sekiguchi C, et al. Project SFINCSS-99—simulation of a flight of international crew on space station. In: Baranov VM, editor. Simulation of extended isolation: advances and problems. Moscow (Russia): Institute of Biomedical Problems, Slovo Ltd Press; 2001:17–24.
7. Polackova I, Šolcová I, Stuchlíková I, Mazehóová Y. The story of 520 days on a simulated flight to Mars. Acta Astronautica. 2016; 126:178–189.
8. Feichtinger E, Sundblad P, Charles R, Fuglesang C, Urbina D, Zell M. MARS 500—a testbed for psychological crew support during future human exploration missions. Paper presented at: 2012 IEEE Aerospace Conference; March 3–20, 2012; Big Sky, MT.
9. Kass R, Kass J. Team-work during long-term isolation: SFINCSS Experiment GP 006. In: Baranov, editor. Simulation of extended isolation: advances and problems. Moscow (Russia): Institute of Biomedical Problems, Slovo Ltd Press; 2001:124–147.
10. Kass R, Kass J. Team-work during long-duration isolation. Paper presented at: 52nd International Astronautical Congress; October 1–5, 2001; Toulouse, France.
11. Kass R Kass J. Team-talk sessions in space: an innovative model to enhance inter-group and intra-group relations. Paper presented at: 72nd Aerospace Medical Association Annual Scientific Meeting; May 6–10, 2001; Reno, NV.
12. Kass R, Kass J. Conflict handling during long-duration isolation. Paper presented at: 14th IAA Humans in Space Symposium: Living in Space: Scientific, Medical and Cultural Implications; May 18, 2003; Banff, Canada.
13. Dimock H, Kass R. How to observe your group. 4th ed. Toronto (Canada): Captus Press; 2007.
14. Dimock H, Kass R. Leading and managing dynamic groups. 4th ed. Toronto (Canada): Captus Press; 2008.
15. Gardenschwartz L, Rowe A. Sources of cultural programming: where we learn the rules. Managing diversity. New York (NY): Pfeiffer and Co; 1993:19–37.
16. Vulpe T, Kealey D, Protheroe D, MacDonald D. A profile of the interculturally effective person. Ottawa (Canada): Centre for Intercultural Learning, Canadian Foreign Service Institute; 2001.
17. Burroughs B. Dragonfly. NASA and the crisis aboard MIR. New York (NY): HarperCollins; 1998.
18. Kealy DJ. Research on intercultural effectiveness and its relevance to multicultural crews in space. Aviat Space Environ Med. 2004; 75(7, Suppl.): C58–C64.
19. Goleman D. What makes a leader? Harv Bus Rev. 1998;76(6):93–102.
20. Kass R, Kass J, Binder H, Kraft N. Conflict-handling mode scores of three crews before and after a 264-day spaceflight simulation. Aviat Space Environ Med. 2010; 81(5):502–506.
21. Kraft N, Lyons TJ, Binder H. Intercultural crew issues in long-duration spaceflight. Aviat Space Environ Med. 2003; 74(5):575–578.
22. Kass JR, Ellmers F, Schiemann J. Operational Evaluation of the EXEMSI Project. EXEMSI'92. In: Bonting SL, editor. Advances in Space Biology and Medicine, Vol. 5. Stamford (CT): JAI Press Inc. 1996:357–373.
23. Basner M, Dinges DF, Mollicone DJ, Savelev I, Ecker AJ, et al. Psychological and behavioral changes during confinement in a 520-day simulated interplanetary mission to Mars. PLoS One. 2014; 9(3):e93298.
24. Kraft N, Inoue N, Mizuno K, Ohshima H, Mural T, et al. Psychological changes and group dynamics during confinement in an isolated environment. Aviat Space Environ Med. 2002; 73(2):85–90.
25. Kass R, Kass J. Group dynamics training for manned spaceflight & the CAPSULS experiment: prophylactic against incompatibility and its consequences? Acta Astronautica. 1995; 36 (8–12):567–573.
26. Sullivan P, Casgrain C, Hirsch N, editors. CAPSULS, a 7-day space mission simulation held on January 20-27, 1994 at the Defence and Civil Institute of Environmental Medicine, Toronto, Ontario, Canada: final report and scientific results. Longueuil (Canada): Canadian Space Agency; 1998.
27. Stuster J. How astronauts handle isolation—6 tips from a space anthropologist [interview]. Pascal Burkhard, Schweizer Radio und Fernsehen; 2020.
28. Kanas N, Sandal G, Boyd JE, Gushin VI, Manzey D, et al. Psychology and culture during long-duration space missions. Acta Astronautica. 2009; 64:659–677.
29. Davidson R. The emotional life of your brain. New York (NY): Penguin Group; 2013.
30. Kanas N, Salnitskiy V, Grund EM, Gushin V, Weiss DS, et al. Lessons learned from Shuttle/Mir: psychosocial countermeasures. Aviat Space Environ Med. 2002; 73(6):607–611.

Otolaryngological and Neuro-Vestibular Considerations for Commercial Spaceflight

Heather Panic; David Wexler; Brooke Stephanian; José Pedro Correia; Marian Sides; Thomas Hoffman

INTRODUCTION: The rapidly expanding commercial spaceflight (CSF) market has fueled increasing interest in spaceflight experiences among individuals without professional astronaut qualifications. Such individuals may present with a range of medical conditions that add uncertainties to medical preparation and risk assessment for spaceflight. As the ear, nose, and throat (ENT) working group of the Aerospace Medical Association Ad Hoc Committee on Commercial Spaceflight, we conducted a scoping review to assess the available biomedical literature for ENT and neuro-vestibular conditions and physiology pertinent to spaceflight for nonprofessional space travelers.

METHODS: The scoping review was conducted in accordance with the Preferred Reporting Items for Systematic Review and Meta-Analyses. The initial database search produced 3232 articles. This set was reduced to 142 relevant publications through a rigorous two-reviewer filtering process using strict inclusion and exclusion criteria.

DISCUSSION: Motion sickness and spatial disorientation were the most common topics of the final set of articles. In contrast, there was limited material on other relevant ENT topics such as hearing loss, sino-nasal dysfunction, and conditions of the pharynx. It becomes clear from this scoping review that the path forward in providing guidance for optimal medical management of CSF passengers will involve the integration of modern biomedical research findings with the accumulated clinical expertise in the civil and military aeromedical communities. We recommend building an industry-wide CSF medical database to address care gaps and improve specialized aerospace medical knowledge.

KEYWORDS: spaceflight, otolaryngology, vestibular, motion sickness, spatial orientation, motor control, hearing, vertigo, mastoid effusion.

Panic H, Wexler D, Stephanian B, Correia JP, Sides M, Hoffman T. *Otolaryngological and neuro-vestibular considerations for commercial spaceflight*. Aerosp Med Hum Perform. 2025; 96(9):841–850.

The age of commercial spaceflight (CSF) has arrived. While space has historically been the exclusive domain of professional astronauts, the spacefarers launching on commercial missions come from a variety of backgrounds and levels of preparation for spaceflight.[1] All space travelers are subject to environmental stressors and risks that vary with mission type and duration,[2] but the new generation of space crew and passengers may present with existing medical conditions that predispose them to additional risks during spaceflight. Current U.S. law mandates that commercial space passengers provide written consent after learning about the risks of spaceflight;[1] however, the standards and limitations of medical evaluation in this population are still being developed, and there is relatively little operational experience in managing spaceflight passengers with chronic medical conditions.

Discussions of medical screenings and standards for the CSF community have occurred previously within the Aerospace Medical Association (AsMA), with position papers published in 2002[3] and 2011[4] for suborbital passengers and crew. The AsMA Ad Hoc Committee on Commercial Spaceflight (hereafter the Ad Hoc Committee) was created to review medical physiology and conditions related to CSF passengers across a range of mission types, including suborbital, orbital, and future

From Massachusetts Eye and Ear, Boston, MA, United States; Space Science Laboratory, University of Massachusetts Lowell, Lowell, MA, United States; Indiana University School of Medicine, Indianapolis, IN, United States; Evangelisches Krankenhaus Bad Dürkheim, Bad Dürkheim, Germany; University of Chicago, Chicago, IL, United States; and Acuity International, Cape Canaveral, FL, United States.

This manuscript was received for review in February 2025. It was accepted for publication in June 2025.

Address correspondence to: Dr. Heather Panic, Massachusetts Eye and Ear, 243 Charles St, Boston, MA 02114, United States; hpanic@mgb.org.

DOI: https://doi.org/10.3357/AMHP.6659.2025

long-duration missions. The primary initial project of the Ad Hoc Committee was to scan the clinical and technical biomedical literature in support of these efforts and to identify gap areas to refine future research strategies. This work was divided among 10 teams. The present report summarizes the work of the ear, nose, and throat (ENT) team.

There is a long history of otolaryngological and neuro-vestibular contributions to flight medicine,[5] particularly relating to spatial disorientation and hearing protection. Medical conditions of the ears, nose, and throat are common in the general population and could easily appear in the medical profiles of CSF passengers. These conditions could create hazards for safe spaceflight through disturbances of sensation (e.g., balance, hearing, smell) and respiration. As an example, advanced hearing loss could prevent an individual from correctly hearing emergency announcements and alarms, potentially jeopardizing the affected individual as well as the flight. As another example, underlying chronic rhinosinusitis would pose a risk factor for barosinusitis pain and barotitis. Special attention will be needed to assess the medical readiness and fitness of individuals who are interested in spaceflight, even if they plan to be a passenger. Since CSF passengers will not undergo the same rigorous selection process as professional astronauts, any available literature developed from primarily nonprofessional astronaut aeromedical research will be useful to incorporate into the preflight medical evaluation.

In this report, we present a scoping review of medical and research literature for otolaryngological and neuro-vestibular information pertinent to the well-being of CSF passengers. Unlike systematic reviews and meta-analyses, scoping reviews seek to broadly survey a topic and map out the range of existing literature sources.[6] Scoping reviews are particularly suitable for initial investigation of topics of complex and heterogeneous nature. The intent is to discover in which areas the knowledge base is well established and in which areas gaps exist. This information can in turn be used to support specific operational objectives, such as safer spaceflight and better preparation for spaceflight passengers. In addition, the scoping review can sharpen further research endeavors and potentially reduce wasted investigative effort.[7]

The present report is the first in a series of 10 planned by the Ad Hoc Committee. The results of the scoping reviews produced by the other teams will be published separately. To our knowledge, this is the first scoping review focusing on ENT and neuro-vestibular physiological issues pertinent to nonprofessional space travelers.

METHODS

Literature Search Strategy

This scoping review was undertaken in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses - Extension for Scoping Reviews.[8] Two lists of search term keywords were developed. The first keyword list (supplemental **Table AI**, found in the online version of this article) included terms related to ENT and neuro-vestibular conditions that could affect the ability of an individual to participate in a spaceflight experience, as well as terms related to associated aspects of physiology or pathophysiology. This list was prepared by the consensus of the ENT team, whose range of expertise included otolaryngology, neurology, audiology, flight nursing, and general medicine. A second list of keywords describing CSF and spaceflight analogs (such as parabolic flight or centrifuge) was developed by the Ad Hoc Committee and was used by all teams (supplemental **Table AII**, found in the online version of this article).

A research librarian used the keyword lists to conduct a systematic search in four bibliographic databases (PubMed, Embase, Web of Science, and Cochrane). Articles were retrieved if they contained at least one keyword each from the ENT and CSF keyword lists and were published within the date range January 1, 2000 through June 9, 2023. The start date was chosen to allow inclusion of references related to the first space tourism flight (Dennis Tito's flight aboard Soyuz in April 2001). The end date was the date of the bibliography search.

Initial Article Review

The list of articles retrieved by the research librarian was reviewed by the team to determine if the paper met predefined inclusion criteria. The criteria were developed by team consensus. As a first pass, the title and abstract were examined and articles that did not meet criteria were discarded. On the second pass, the remaining articles were checked again by examining the full text. During each pass, two team members independently rated the article for inclusion or exclusion. If there was disagreement, a third team member provided the tie-breaking decision. Team teaching sessions were held to ensure a consistent approach to article review. During these teaching sessions team members independently rated a sample article for inclusion or exclusion and discussed with the group their reasoning (**Fig. 1**).

Inclusion Criteria

1. The article must report on an ENT or neuro-vestibular medical condition (or related aspect of physiology) that could have a bearing on the suitability of the individual to safely undertake a spaceflight experience.
2. The article must describe findings from spaceflight or a spaceflight training/analog environment. Relevant analogs are numerous, encompassing both high fidelity simulator environments as well as situations that train or mimic one aspect of spaceflight. Examples include microgravity exposure during parabolic flight, acceleration exposure in a centrifuge, body fluid shifts during head-down bedrest, social isolation enclosures, spatial disorientation by rotating chair or virtual reality, and altitude chambers.
3. The article must describe research on or findings about adult (ages 18 yr or older) human volunteers. This criterion served to exclude studies on tissue samples, nonhuman organisms, and computational models.

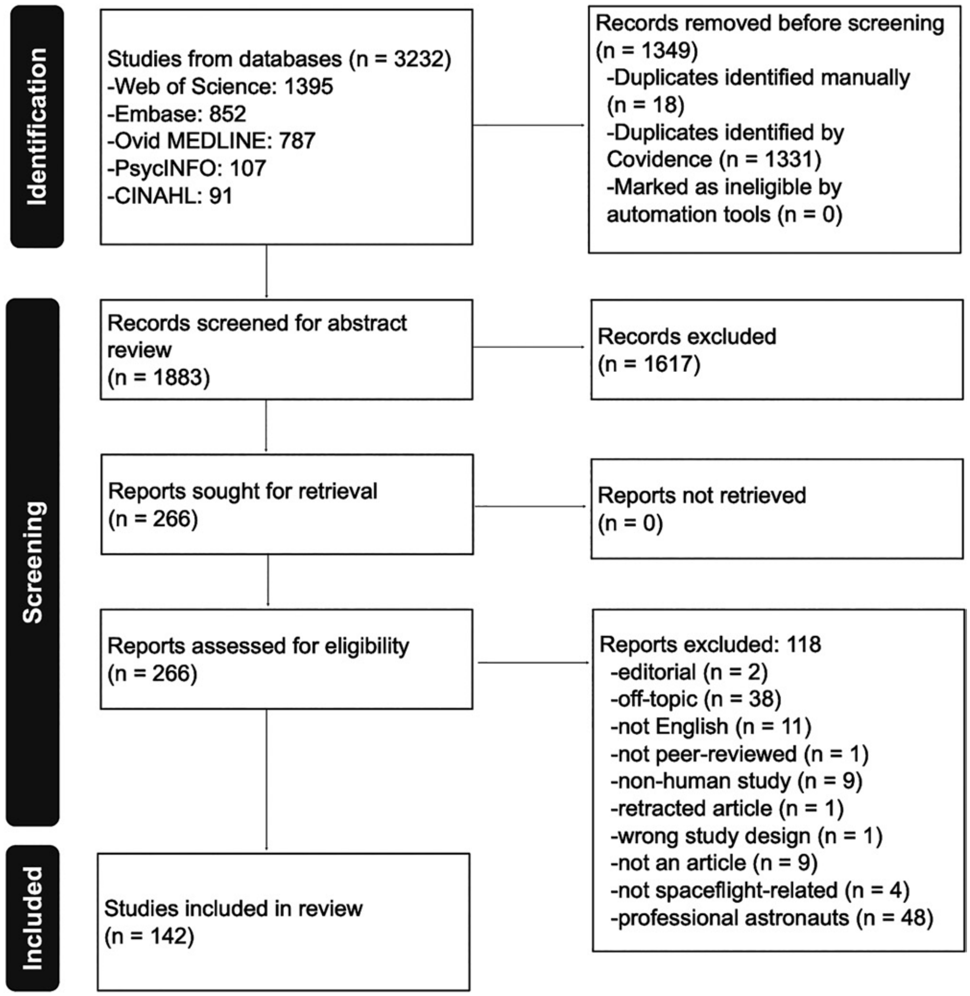

Fig. 1. PRISMA diagram showing the number of articles that were excluded at each stage of screening and the final number of articles included in the review.

4. The article must describe research on individuals other than professional astronauts. Review articles covering both professional astronauts and other research participant groups were accepted. Primary studies on professional astronauts were excluded because individuals within this specialized population have passed stringent medical and physical fitness selection criteria, making them unrepresentative of the typical lay person seeking a CSF experience.
5. The article must have been published under peer review. This criterion excluded editorials and conference posters.
6. The full text of the article must be available in English.
7. The article must be available to public university libraries. This criterion excluded confidential reports such as corporate white papers and military technical reports.

Data Extraction

At the conclusion of the initial article review there were 142 articles that met the inclusion criteria for the scoping review. Each included article was read by two team members who extracted the following data: title, authors, type of article (experiment, case report, or review), environment (spaceflight or analog), and major findings relating to ENT and neuro-vestibular disorders. For experiments, the following information was also collected: experiment type (e.g., randomized controlled trial), number of participants, participant characteristics (e.g., "healthy adults aged 18–30"), and a brief description of the methods used. A quality rating was assigned to the article using the Johns Hopkins Evidence Based Practice – Hierarchy of Evidence.[9] Any disagreement between the two reading team members about the extracted information or the quality rating was resolved by having a third team member provide a final decision. The collected information was entered into a spreadsheet to enable further analysis.

RESULTS

Space Motion Sickness

The scoping review identified 76 articles related to space motion sickness (SMS). Of these, 27 (36%) were review articles (evidence level V) and 23 (30%) were randomized controlled trials (evidence level I). The remaining 26 were quasi-experimental or nonexperimental studies (evidence levels II and III).

General. A consensus of the main points regarding SMS was first assembled from included broad review articles.[10–12] The most distressing features of SMS are nausea and emesis, but drowsiness and lack of motivation (the "sopite syndrome"), as well as cold sweats, may also be present.[13] SMS occurs in roughly 70% of astronauts,[14] with symptoms appearing within minutes to hours of launch.[3] Symptoms typically last up to 3 d,[10] but in extreme cases can continue for more than 1 wk. Re-entry and landing can also lead to substantial nausea and imbalance, particularly after prolonged missions. The exact relationship between SMS and these vestibular readaptation symptoms is unclear, however, both will be covered here.

Etiology. The vestibular system consists of semicircular canals (which detect angular accelerations), otolith organs (which detect linear accelerations and head tilts with respect to gravity), and central processing networks within the brainstem and cerebellum. Vestibular sensory information plays an important role in the control of eye movement and postural balance but has also been shown to affect autonomic functions,[13] certain cognitive abilities, and the development of motion sickness. Individuals with diminished vestibular function exhibit lesser degrees of nausea and emesis during motion sickness.[11]

The sensory conflict theory is the most widely accepted explanation for the development of SMS. This theory proposes that relationships between vestibular, visual, and other sensory inputs[10,15] are learned throughout an individual's life on Earth but are altered by subsequent exposure to the unusual force environment of space. In free fall during orbit or suborbital parabola (hereafter referred to as 0 G), the otolith organs can no longer signal head tilt with respect to gravity but still respond normally to linear accelerations. The brain may react to this change in inputs by deeming the otolith signals to be unreliable and favoring other sensory cues such as vision, or by reinterpreting all otolith signals in 0 G as linear translations. In addition, rotational movements may also be misinterpreted in 0 G since accurate integration of the angular acceleration signal from the semicircular canals appears to depend on gravitational cues.[16,17] Re-entry and landing require sensory readaptation, potentially involving further remapping of vestibular inputs.[18] An altered sense of the vertical direction is a key component of the sensory conflict theory,[12] and head motions in the pitch and roll planes (which provide a tilt with respect to gravity on Earth) are particularly effective in eliciting symptoms.[4] This effect is not limited to microgravity: head movements during the increased-G periods of parabolic flight also stimulate motion sickness.

Many of the symptoms associated with SMS, such as emesis, are mediated by the autonomic system. This connection may involve a pathway from the vestibular nuclei to the nucleus tractus solitarius and dorsal motor nucleus of the vagus nerve, or alternatively to the reticular formation and caudal ventrolateral medulla.[19,20]

Predictive Factors. No reliable physiological or psychological factors have been identified to predict which individuals will develop SMS during spaceflight,[11] although several have been proposed, including prior spaceflight experience,[10] salivary amylase,[21] vestibular dynamics after rotation,[11] and bias of the subjective vertical reference.[12] Curiously, there does not appear to be a reliable correlation between a history of terrestrial motion sickness (e.g., car or sea sickness) and SMS.[10,22] Ground-based analogs such as rotating chairs, centrifugation, and wide-field visual displays can approximate certain aspects of the sensory mismatch thought to cause SMS,[23] but susceptibility to motion sickness when using these devices does not necessarily lead to SMS during spaceflight.

Prevention. Several forms of preflight training to prevent SMS have been proposed. Preadaptation training based on altered visual cues and orientation illusions[4] has shown some promise in laboratory studies but is time-intensive and has yet not entered widespread use. Chen et al.[24] studied visually induced motion sickness in normal volunteers, finding that training by repeated exposure to rotating visual scenes lowered the subsequent visually induced motion-sickness scores by 40%. They hypothesized that this training allowed the participants to become more reliant on their perceived body axis rather than on visual cues for orientation in space. Autogenic feedback training to increase tolerance of nauseogenic vestibular stimuli has also been suggested[25] but is controversial (see discussion by Lackner and DiZio).[11]

During the mission, strategies to prevent SMS fall into behavioral, pharmacological, and technological categories. Behavioral approaches include increasing attention toward required tasks and limiting head and body movements,[10] although limiting movements may prolong the overall adaptation period. Pharmacological prevention has historically relied on scopolamine, with or without dexamphetamine to limit sedation. Oral, nasal,[26] or subcutaneous[27] scopolamine is preferred over patches due to inconsistent transdermal bioavailability. Protective effects begin within 30–60 min and last for 4 h.[28] Technological prevention can include worn devices or foot straps to enhance directional sensory cues,[10,29] reduced ambient temperature within the vehicle to minimize nausea,[4] or vehicle design to standardize the internal visual orientation of habitable modules.[10]

Treatment. The mainstay of treatment of SMS is pharmacotherapy, however, a recent systematic review of SMS countermeasures found inconsistent data to support any single best approach.[30] The most common SMS treatment medication in the U.S. space program has been intramuscular promethazine, sometimes administered together with dextroamphetamine to help counter the sedative properties of the antiemetic.[11] Chlorpheniramine has also been effective against motion sickness symptoms in ground-based analogs.[31] Meclizine has been proposed as an alternative, given its lower rate of cognitive side-effects.[14] All pharmacotherapeutic options currently available carry the risk of sedation, a concern that must be addressed for anyone engaged in essential mission tasks. Regulations may prevent the spacecraft commander or pilot from taking these medications, and other crew or passengers should preferentially be given these medications before sleep.[4]

Relevance for CSF Passengers. It is likely that SMS will occur at least as frequently in the CSF passenger cohort as in professional astronauts and there are currently no reliable predictive factors for estimating this risk. While ground preparations for spaceflight may include experiences that induce motion sickness, it is not established that such training reduces the subsequent likelihood or severity of SMS. Passengers should discuss the available prophylactic and treatment options with their physician. They should also consider the risk and symptoms of SMS as well as the side-effects of treatment when developing their schedule of activities during the flight.

Spatial Orientation and Vertigo

The scoping review identified 42 articles that included content relevant to spatial orientation and motion perception. Of these, 20 (48%) were review articles (evidence level V) and 16 (38%) were randomized controlled trials (evidence level I). The remainder were quasi-experimental or nonexperimental studies (evidence levels II and III).

General. The human nervous system is adept at combining sensory cues into perceptions about our orientation and movement with respect to our surroundings. This ability is thought to occur through the creation of an internal model describing how actions (such as head turns) lead to changes in sensations.[15] As described in the Motion Sickness section, transitions to and from 0 G lead to alterations of the previously learned action-sensation mapping, and available somatosensory,[32] visual,[33] and motor efference cues become more salient. Full adaptation to changes in the gravito-inertial force environment takes place over a timescale of hours to weeks,[15] so perceptual errors tend to be most pronounced during and shortly after G level transitions (e.g., launch and landing). Erroneous perceptions of orientation and movement have the potential to create safety hazards during critical tasks, potentially endangering both the affected individual and the overall mission. While CSF passengers are unlikely to be directly involved in high-risk launch and landing procedures, they may well be responsible for assisting during emergencies and should be capable of safely egressing from the spacecraft after a contingency landing.

Perceptual Alterations. Numerous studies have demonstrated perceptual errors relevant to spaceflight. Individuals overestimate roll tilt during high G[34] and may underestimate roll tilt during low G.[35] In contrast, during 0 G there can be a complete absence of the ability to perceive yaw[16] or roll[36] rotation unless visual cues are available. Transitions to 0 G can produce compelling visual reorientation or inversion illusions in which the individual suddenly feels upside-down.[12] This phenomenon may be related to the tendency in 0 G to perceive the vertical as aligned with the long body axis, regardless of the person's actual orientation relative to the surrounding space. Proposed explanations for this finding include changes in saliency of visual cues[37] and individual differences between individuals who prioritize vestibular cues and those prioritizing somatosensory cues.[38]

Cognitive Changes. Alterations in G level have been associated with reductions in the ability of individuals to perform a spatial updating or perspective-taking task[39] in parabolic flight. Similar conclusions were reached by another group using galvanic vestibular stimulation to simulate loss of normal vestibular cues.[40] Deficits in shape perception, concentration, memory, and multitasking ability during G transitions have also been linked to altered vestibular function.[2]

Countermeasures and Analogs. Considerable research effort has been expended to develop countermeasures to the sensory alterations and disorientation illusions seen in spaceflight. Preflight training with either virtual reality[24] or galvanic vestibular stimulation[41] may hold promise in decreasing disorientation in novel gravitational environments.[42] During a mission, devices could be worn to increase available somatosensory cues[34] or to display enhanced visual guidance to minimize orientation errors.[43] Novel terrestrial analogs of spatial disorientation have also been developed, such as wheelchair head immobilization,[44] which can replicate some of the illusory perceptions experienced in 0 G.

Spacecraft Design Issues. Multicompartment spacecraft such as the International Space Station (ISS) can be disorienting due to the possibility of rooms being connected in any orientation, including vertically.[12] Some initial research into this problem using virtual reality suggests that the use of colors and clear signage can reduce disorientation in spacecraft, as can limiting the number of turns that an individual must make to traverse between locations.[45]

Intermittent use of a short-arm centrifuge has been proposed for future spacecraft as a means of reducing cardiovascular deconditioning and loss of bone and muscle mass during long-duration missions.[46] Head movements during short-arm centrifugation in 1 G frequently cause motion sickness and illusions of tumbling, head tilt, or body tilt.[47,48] Interestingly, head movements during centerline yaw rotation in 0 G do not lead to these tumbling sensations,[49,50] however, this type of rotation would not provide the same benefits to bone and muscle mass.

Positional Vertigo After G-Loading with Vibration. Liston et al.[51] reported that 3 of 16 participants developed benign paroxysmal positional vertigo (BPPV) following combined, repeated exposure to 3.8-G acceleration and 8–16-Hz vibration along the G_x axis, raising concerns that G-loading could be an exacerbating factor for vibration-induced dislodgement of otoconia. Notably, the affected individuals were older participants (ages 50–52) in the study (age range 21–57). Vibration alone in the 1 G_x condition was not associated with development of BPPV. In two cases, positional vertigo resolved after treatment with Epley maneuvers, and in the third case, symptoms resolved over 1–2 mo without specific treatment.

Relevance for CSF Passengers. All CSF passengers should be informed of the likelihood of perceptual alterations during G level transitions and the associated health and safety implications, including increased chance of SMS, disorientation while navigating through larger spacecraft, and potential difficulties carrying out tasks. Preventive strategies (such as maintaining a similar orientation to other crew/passengers or using straps to increase touch cues) can be discussed or practiced during preflight training. The combined G forces and vibration of launch and landing may increase the chance of subsequent BPPV, particularly in older individuals who are more prone to the condition generally. This disorder may not become noticeable until re-exposure to the gravitational field, at which time it could pose hazards during spacecraft egress or emergency procedures.

Balance, Posture, and Motor Control

The scoping review identified 55 articles with content relevant to balance, posture, and motor control. Of these, 24 (44%) were review articles (evidence level V) and 11 (20%) were randomized controlled trials (evidence level I). The remainder were quasi-experimental or nonexperimental studies (evidence levels II and III).

Balance and Posture. The ability to stand upright and walk on Earth depends on our ability to accurately estimate the position of the body relative to gravity and to generate appropriate muscle activations to counteract any postural perturbations. This process involves vestibular, somatosensory, and visual inputs to cortical,[52,53] cerebellar, and brainstem structures. Outgoing vestibulospinal pathway projections control the postural responses.[32] After entry into 0 G, alteration of the vestibulospinal reflexes[54] relevant to the lower limbs occurs over several days,[55] while axial muscles appear to be less affected by gravitational changes.[56]

The major posture-related concern for spaceflight participant safety comes during re-entry and landing. In centrifuge simulations of suborbital vehicle re-entry profiles, approximately half of participants have abnormalities on Romberg testing after their "flight."[23,57] On return to Earth, postural control and balance are typically diminished relative to preflight ability,[10] in a pattern that resembles the deficits seen during the acute vestibular syndrome.[15] These deficiencies may be related to alterations in how the nervous system interprets head rotations.[18] Orthostatic hypotension is also common after 0-G exposure, possibly related to alterations of vestibulo-autonomic activity.[58–60] These deficits could lead to difficulties with egress from the spacecraft in situations where support crew are not available, such as during emergency landings on Earth or during planetary landings in the future. This concern has been noted since the earliest attempts at establishing medical guidelines for CSF participants,[3] and previous recommendations have been made for emergency egress training.[4]

Readaptation to Earth gravity occurs most rapidly during the first 3 d postflight, followed by a slower return to preflight performance levels over the following weeks.[10] Sensorimotor reconditioning can be used to recover satisfactory balance function,[61] and during this time, dynamic head tilts may be useful in uncovering subtle postural instabilities.[62] Walking can produce illusory perceptions during the readaptation period after landing. For example, knee bends can create the illusion that the ground is moving upward toward the torso.[33]

Motor Control. Although most spacecraft control operations will presumably be performed by professional or commercial crewmembers, everyone aboard a spacecraft will likely be expected to perform basic emergency procedures. In addition, passengers may need to carry out experiments or other tasks that require fine motor control. Correlations have been found between vestibular perceptual sensitivity and manual control task precision in 1 G and hypergravity,[63] but not in 0 G.[17] The vibrational characteristics of the spacecraft can also reduce manual task performance,[4] particularly in the 2–16 Hz range. Proprioception[10] and coordination between head, eye, and hand movements are most impaired shortly after orbital insertion and during re-entry,[15] with slow movements affected more than rapid movements. These deficits occur most often in the setting of disorienting flight conditions and increased attentional load,[17] however, some impairments in bimanual control and fine motor control continue after landing.[2]

Vestibular Ocular Motor Control. The control of eye movements by the vestibular system allows for goal-directed movements to fixate on a target of interest and reflexive actions to maintain focus despite movements of the head, body, or environment. Eye misalignments and ocular motor control errors can lead to diplopia (which may be experienced as blurring for smaller errors) and nystagmus. Visual blur has been linked to motion sickness.[64] Nystagmus was noted in 59% of participants after centrifuge simulation of the high-G components of a suborbital flight profile.[23] Two thirds of participants showed reduced nystagmus with further centrifuge runs, while some individuals had worsening nystagmus. Previous research has shown that gaze control and dynamic visual acuity (ability to focus while the head is moving) are impaired during periods of high vibration,[4] shortly after entry into 0 G, and during re-entry.[15] A mild G-dependent vertical skew of up to 2.57° has been found during parabolic flights.[65] The 0-G environment has also been associated with increased vergence of up to 5°, a differential change in torsion between the two eyes,[66] and a reduction or loss of ocular counter-roll in response to head tilts.[54,67] Some of these changes have been seen with short durations of 0 G. Parabolic flight appears to induce vertical and torsional eye misalignments that recur during subsequent flights.[68] Adaptation of the vestibular oculomotor system to 0 G may require months, while full readaptation to Earth gravity requires days to weeks.[66,67]

There is evidence linking the severity of motion sickness with an increased time constant of the vestibulo-ocular reflex (VOR)[20,69] This raises the possibility that training to alter this time constant could reduce motion sickness symptoms. Several experiments have demonstrated that humans are capable of dual adaptation of some types of oculomotor control, meaning that different sensory-motor control strategies can be learned and used for tasks in two different contexts (such as Earth and 0 G). Dual adaptation has been shown for the VOR time constant,[20,70] and there is evidence that gravity can be used as the context cue.[71,72] VOR time constant adaptation has been shown to last for months to years in some cases.[73]

Relevance for CSF Passengers. Passengers should be fully informed about potential difficulties in vehicle egress due to postlanding postural instability or orthostatic hypotension. This is of particular concern when considering spaceflight for individuals with limited mobility. While they may find the 0-G environment freeing, they are likely to be at increased risk during an emergency egress after landing.

Auditory and Tympanomastoid Effects

Hearing. Abel et al.[74] studied the effects of noise at 72 dBA on auditory and psychometric measures during a 70-h ground-based ISS simulation. In this level I evidence study, 25 healthy volunteers with normal hearing were randomly assigned to one of 3 conditions: quiet, continuous noise, or noise only during each 14-h workday. The noise was spectrally shaped to match typical ISS noise and was kept within ±2.5 dB of the target intensity. There were no significant decrements in auditory function or in auditory performance tests, including cognitive and communications tasks. Post-study audiometry revealed mean hearing thresholds were maintained within ±10 dB. The authors noted that this contrasted with the hearing problems previously reported in professional astronauts. While the results were favorable, this study was not able to simulate certain relevant aspects of long-duration missions such as intermittent high noise exposure and vibration. Pre-existing hearing loss, which could be important to the CSF passenger population, was also not evaluated. We note there is a professional astronaut NASA Technical Report indicating that unexpected low-frequency hearing loss occurs variably in a substantial number of astronauts during prolonged space missions. That analysis is as yet unfinished and remains unpublished.

Fluid Shifts and Effusions. Lecheler et al.[75] present evidence level II data on mastoid effusions occurring during a spaceflight analog study. The 24 healthy participants undergoing 60 d of head-down tilt bed rest were assigned to one of three groups: no intervention, 30 min $\cdot$ d^{-1} artificial gravity by short-arm centrifugation, or six 5-min sessions per day of short-arm centrifugation. Prior to the study, all head MRIs were clear of mastoid effusion, but by Day 14, 25% showed mastoid fluid and this increased to 67% by Day 52. In roughly half the cases, the effusions were bilateral. These results were comparable to those previously reported in professional astronauts. Centrifugation did not change the incidence of mastoid effusion development during the study. A single participant developed otitis media, but none developed clinical mastoiditis. There was, unfortunately, no audiometric data or tympanometric data to correlate the presence of mastoid fluid to changes in middle ear ventilation and hearing.

It is assumed that tympanomastoid changes in pressure and aeration during microgravity are related to the increased intracranial pressure (ICP) arising from cephalad fluid shifts. Watkins et al.[76] studied ICP (estimated noninvasively using tympanic membrane displacement) in 15 healthy volunteers during 15° head-down tilt, which served as a spaceflight analog. Use of a lower body negative pressure device was associated with lower estimated ICP. While the possible significance of this study in relation to spaceflight-associated neuro-ocular syndrome (SANS) was discussed, the potential benefits in relieving sinus pressure and mastoid congestion were not addressed.

Relevance for CSF Passengers. Although the noise level inherent to short-duration spaceflight appears to produce little decrease in auditory acuity in individuals with normal hearing, crew and passengers should have access to ear protection until further studies can be performed. Prolonged exposure to 0 G appears to also be associated with MRI signal enhancements suggestive of mastoid effusions, although the clinical and auditory significance of this finding remains unclear.

Other ENT Issues

Chemosensory. Olabi et al.[77] reviewed the literature on the chemosensory functions of taste and smell. They found no definitive evidence for spaceflight-related decrements in taste and smell, however, it should be noted that the subjective experience of flavor involves multisensory integration and may not be captured by studies focusing on a single sense. The role of head-congestion in flattening taste via diminished olfactory function was not clarified in this review.

Wound Healing and Infections. The immune system is undoubtedly affected by the stresses of spaceflight and other extreme environments,[78,79] and this has been studied in a variety of spaceflight analogs. Changes have been found in the amount and distribution of oral and nasal organisms over the course of a 6-mo sealed habitat experiment, including an increase in nasal *Staphylococcus* organisms.[80] Increased rates of herpes zoster reactivation were found in individuals inhabiting the Antarctic research station compared to historical controls[81] (level II evidence). Increased Epstein-Barr virus and varicella zoster virus were found in a head-down tilt bed rest plus centrifugation protocol,[82] although no clear signs of immunocompromise were seen (level III evidence). Stress biomarkers have been detected during parabolic flight[33] as well as during a Mars analog mission.[83] Notably, oral wound-healing was also delayed in that study (level III evidence).

Upper Airways. Microgravity may alter the characteristics of the upper airway structures, and there are reports of reduced sleep apnea, hypopnea, and snoring in 0 G.[84] Airway emergencies may require intubation, possibly by nonphysicians, and several studies have investigated this in a space analog setting. Experts and novices were equally successful at intubation of a mannequin during parabolic flight,[85] despite the experts showing higher proficiency in Earth gravity. In both groups, videolaryngoscopy was more successful than conventional laryngoscopy (level II evidence). A simplified rapid sequence induction of general anesthesia with oro-tracheal intubation was successfully performed by five crewmembers with limited medical training on a simulated injured astronaut at the Mars Desert Research Station.[86]

Relevance for CSF Passengers. CSF passengers with baseline immunological disorders may be at elevated risk during a mission due to immunological stress, however, the impact in terms of increased rates of clinical illnesses or diminished wound-healing is largely unknown. While this topic is very important in the ENT domain (e.g., mucositis, oral ulcers, head and neck infections), the topic is very broad and will be covered in more detail in the report of the Immunology team of the Ad Hoc Committee. In terms of upper airways, cephalad fluid shifts during microgravity aggravate mucosal swelling in upper respiratory passages and increase respiratory resistance. Given that 50% of the total respiratory tract resistance is attributed to the nasal airways, even mild airway constrictions at baseline should be optimized preflight to minimize excessive work of breathing during spaceflight.

DISCUSSION

Our scoping review indicates that within the ENT and neuro-vestibular fields, most of the research relevant to CSF passengers has been focused on the problems of SMS and spatial disorientation. Additionally, it is clear from the review that studies on prophylaxis and treatment of these conditions lag behind basic research on relevant physiology. For example, it is still not possible to predict which individuals will experience SMS, although it will likely affect most CSF passengers on all but the shortest (suborbital) missions. Given the gradual recovery time course from SMS, severe cases could interfere substantially with the spaceflight experience for a significant portion of the mission. Pharmacotherapy remains the mainstay of treatment but is not free of sedative side-effects. Further efforts are required to identify improvements in prevention and treatment, with an increased focus on treatments that minimize cognitive side-effects. Further research on spatial disorientation is also needed given the hazards it can present during emergency procedures and spacecraft egress. Few studies were found covering medical issues related to other areas of otolaryngology.

Historically, astronaut candidates with significant ENT conditions were screened out by the rigorous astronaut selection process. Flight surgeons have accumulated decades of experience with assessing and managing common ENT conditions in this healthy astronaut population. What is less certain is how existing aerospace medical standards (both military and civilian) should be applied to commercial space passengers, who may have a wider range of medical disorders that would previously have been disqualifying. This scoping review provides an initial overview of the literature, but medical evaluations will also need to draw upon the expertise of aerospace medicine specialists within the civilian and military aviation and spaceflight communities. An example of this sort of collaborative endeavor may be found in a standard published by the American Society for Testing and Materials: ASTM F3568-23, Standard Guide for Medical Qualifications for Suborbital Vehicle Passengers.[87] The ASTM is preparing a separate document on space passenger medical guidance for orbital spaceflight.

One prominent finding in this scoping review is the emphasis on outcomes in healthy volunteers within various analog environments. While the scientific rationale for this emphasis is understandable, it sets limits on how the results can be applied. All analog space paradigms are imperfect simulations of spaceflight conditions, often with isolated variables under study. The analog results may not remain valid in the actual spaceflight setting with multiple concurrent stressors. This is especially true when applied to individuals already predisposed to disorders due to chronic ailments. It would be highly impractical to conduct systematic laboratory investigations covering the multitude of infrequent medical disorders. We support the development of an industry-wide collaborative effort to pool spaceflight-related medical knowledge for the benefit of all stakeholders. CSF medical databases can be designed to safeguard crew and passenger privacy. The goal would be to build case-study knowledge of medical conditions affecting or arising in spaceflight, with an eye toward enhancing flight safety. This was previously recommended by the AsMA working group on suborbital crew medical recommendations.[4]

A limitation of this scoping review is the exclusion of studies based entirely on professional astronauts. The rationale was that professionally trained astronauts would have careful medical selection and intensive training for spaceflight that will be lacking in CSF passengers. The scoping review did include numerous review articles, many of which incorporated important knowledge from professional astronaut cohorts. On specific topic investigations, the full range of professional resources should be evaluated. For example, in addition to the analog study of ISS noise and hearing assessments described above,[74] extensive research on noise during spaceflight and on-orbit hearing assessments in professional astronauts is summarized by Danielson et al.[88] and references therein. Another review, by Alford et al.[89] addresses spaceflight-related hearing loss as well as general ENT problems during Space Shuttle flights.

In summary, this ENT and neuro-vestibular scoping review identified strong research efforts undertaken to understand SMS and spatial orientation in healthy, non-astronaut volunteers. Other medical conditions received less attention, with a distinct paucity of data on pre-existing medical conditions that would have previously been disqualifying for professional astronaut crews but which may now need reconsideration for the CSF passenger population. We suspect that similar problems will be encountered in the other medical specialty scoping reviews. This scoping review highlights several areas for further research and the need for an industry-wide, anonymized database of medical findings to further the goal of CSF passenger safety.

ACKNOWLEDGMENTS

We wish to thank J. Karen Klingenberger and Tamara Averett-Brauer for their leadership of the Ad-Hoc Committee and the late Rhonda Allard for her work as research librarian for the team.

Financial Disclosure Statement: The authors have no competing interests to declare.

Authors and Affiliations: Heather Panic, Massachusetts Eye and Ear, Boston, MA; David Wexler, Space Science Laboratory, University of Massachusetts Lowell, Lowell, MA; Brooke Stephanian, Indiana University School of Medicine, Indianapolis, IN; José Pedro Correia, Evangelisches Krankenhaus Bad Dürkheim, Bad Dürkheim, Germany; Marian Sides, University of Chicago, Chicago, IL; and Thomas Hoffman, Acuity International, Cape Canaveral, FL, United States.

REFERENCES

1. Stepanek J, Blue RS, Parazynski S. Space medicine in the era of civilian spaceflight. N Engl J Med. 2019; 380(11):1053–60.
2. Krittanawong C, Singh NK, Scheuring RA, Urquieta E, Bershad EM, et al. Human health during space travel: state-of-the-art review. Cells. 2022; 12(1):40.
3. Rayman RB, Antuñano MJ, Garber MA, Hastings JD, Illig PA, et al. Medical guidelines for space passengers - II. Aviat Space Environ Med. 2002; 73(11):1132–4.
4. Aerospace Medical Association Commercial Spaceflight Working Group. Suborbital commercial spaceflight crewmember medical issues. Aviat Space Environ Med. 2011; 82(4):475–84.
5. Alford BR, Atkins JH. Historical ties between otolaryngology-head and neck surgery and aviation and space medicine. Otolaryngol Head Neck Surg. 1998; 118(3 Pt 2):s2–4.
6. Peters MDJ, Marnie C, Colquhoun H, Garritty CM, Hempel S, et al. Scoping reviews: reinforcing and advancing the methodology and application. Syst Rev. 2021; 10(1):263.
7. Peters MDJ, Marnie C, Tricco AC, Pollock D, Munn Z, et al. Updated methodological guidance for the conduct of scoping reviews. JBI Evid Synth. 2020; 18(10):2119–26.
8. Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, et al. PRISMA extension for scoping reviews (PRISMA-ScR): checklist and explanation. Ann Intern Med. 2018; 169(7):467–73.
9. Dang D, Dearholt SL, Bissett K, Ascenzi J, Whalen M. Johns Hopkins Evidence-Based Practice for Nurses and Healthcare Professionals: Model & Guidelines. 4th ed. Indianapolis (IN): Sigma Theta Tau International; 2021.
10. Young LR. Vestibular reactions to spaceflight: human factors issues. Aviat Space Environ Med. 2000; 71(9 Suppl):A100–4.
11. Chen W, Chao JG, Wang JK, Chen XW, Tan C. Subjective vertical conflict theory and space motion sickness. Aerosp Med Hum Perform. 2016; 87(2):128–36.
12. Clément GR, Boyle RD, George KA, Nelson GA, Reschke MF, et al. Challenges to the central nervous system during human spaceflight missions to Mars. J Neurophysiol. 2020; 123(5):2037–63.
13. Lackner JR, DiZio P. Space motion sickness. Exp Brain Res. 2006; 175(3):377–99.
14. Heer M, Paloski WH. Space motion sickness: incidence, etiology, and countermeasures. Auton Neurosci. 2006; 129(1–2):77–9.
15. Carriot J, Jamali M, Cullen KE. Rapid adaptation of multisensory integration in vestibular pathways. Front Syst Neurosci. 2015; 9:59.
16. Lackner JR, DiZio P. Angular displacement perception modulated by force background. Exp Brain Res. 2009; 195(2):335–43.
17. Vimal VP, DiZio P, Lackner JR. The role of spatial acuity in a dynamic balancing task without gravitational cues. Exp Brain Res. 2022; 240(1):123–33.
18. Merfeld DM. Rotation otolith tilt-translation reinterpretation (ROTTR) hypothesis: a new hypothesis to explain neurovestibular spaceflight adaptation. J Vestib Res. 2003; 13(4–6):309–20.
19. Ortega H, Harm D, Reschke M. Chapter 14, Space and entry motion sickness. In: Barratt MR, Baker ES, Pool SL, editors. Principles of clinical medicine for space flight. 2nd ed. New York (NY): Springer; 2019. p. 441–56.
20. Cohen B, Dai M, Raphan T. The critical role of velocity storage in production of motion sickness. Ann N York Acad Sci. 2003; 1004(1):359–76.
21. Harm DL, Schlegel TT. Predicting motion sickness during parabolic flight. Auton Neurosci. 2002; 97(2):116–21.
22. Thornton WE, Bonato F. Space motion sickness and motion sickness: symptoms and etiology. Aviat Space Environ Med. 2013; 84(7):716–21.
23. Blue RS, Ong KM, Ray K, Menon A, Mateus J, et al. Layperson physiological tolerance and operational performance in centrifuge-simulated spaceflight. Aerosp Med Hum Perform. 2023; 94(8):584–95.
24. Chen W, Chao JG, Zhang Y, Wang JK, Chen XW, Tan C. Orientation preferences and motion sickness induced in a virtual reality environment. Aerosp Med Hum Perform. 2017; 88(10):903–10.
25. Cowings PS, Toscano WB. Autogenic-feedback training exercise is superior to promethazine for control of motion sickness symptoms. J Clin Pharmacol. 2000; 40(10):1154–65.
26. Weerts AP, Pattyn N, Putcha L, Hoag SW, Van Ombergen A, et al. Restricted sedation and absence of cognitive impairments after administration of intranasal scopolamine. J Psychopharmacol. 2015; 29(12): 1231–5.
27. Ritzmann R, Freyler K, Krause A, Gollhofer A. No neuromuscular side-effects of scopolamine in sensorimotor control and force-generating capacity among parabolic fliers. Microgravity Sci Technol. 2016; 28(5): 477–90.
28. Russomano T, da Rosa M, dos Santos M. Space motion sickness: a common neurovestibular dysfunction in microgravity. Neurol India. 2019; 67(8): 214.
29. Lawson BD, Rupert AH, McGrath BJ. The neurovestibular challenges of astronauts and balance patients: some past countermeasures and two alternative approaches to elicitation, assessment and mitigation. Front Syst Neurosci. 2016; 10:96.
30. Khalid A, Prusty PP, Arshad I, Gustafson HE, Jalaly I, et al. Pharmacological and non-pharmacological countermeasures to space motion sickness: a systematic review. Front Neural Circuits. 2023; 17:1150233.
31. Buckey JC, Alvarenga D, Cole B, Rigas JR. Chlorpheniramine for motion sickness. J Vestib Res. 2004; 14(1):53–61.
32. Lackner JR, DiZio P. Vestibular, proprioceptive, and haptic contributions to spatial orientation. Annu Rev Psychol. 2005; 56(1):115–47.
33. Shelhamer M. Parabolic flight as a spaceflight analog. J Appl Physiol (1985). 2016; 120(12):1442–8.
34. Clément G, Arnesen TN, Olsen MH, Sylvestre B. Perception of longitudinal body axis in microgravity during parabolic flight. Neurosci Lett. 2007; 413(2):150–3.
35. Clark TK, Young LR. A case study of human roll tilt perception in hypogravity. Aerosp Med Hum Perform. 2017; 88(7):682–7.
36. Bryan AS, Bortolami SB, Ventura J, DiZio P, Lackner JR. Influence of gravitoinertial force level on the subjective vertical during recumbent yaw axis body tilt. Exp Brain Res. 2007; 183(3):389–97.
37. Dyde RT, Jenkin MR, Jenkin HL, Zacher JE, Harris LR. The effect of altered gravity states on the perception of orientation. Exp Brain Res. 2009; 194(4):647–60.
38. Clément G, Delière Q, Migeotte PF. Perception of verticality and cardiovascular responses during short-radius centrifugation. J Vestib Res. 2014; 24(1):1–8.
39. Stahn AC, Riemer M, Wolbers T, Werner A, Brauns K, et al. Spatial updating depends on gravity. Front Neural Circuits. 2020; 14:20.
40. Dilda V, MacDougall HG, Curthoys IS, Moore ST. Effects of galvanic vestibular stimulation on cognitive function. Exp Brain Res. 2012; 216(2):275–85.
41. Moore ST, Dilda V, Morris TR, Yungher DA, MacDougall HG. Pre-adaptation to noisy galvanic vestibular stimulation is associated with enhanced sensorimotor performance in novel vestibular environments. Front Syst Neurosci. 2015; 9:88.
42. Stroud KJ, Harm DL, Klaus DM. Preflight virtual reality training as a countermeasure for space motion sickness and disorientation. Aviat Space Environ Med. 2005; 76(4):352–6.
43. Galvan-Garza RC, Clark TK, Sherwood D, Diaz-Artiles A, Rosenberg M, et al. Human perception of whole body roll-tilt orientation in a hypogravity analog: underestimation and adaptation. J Neurophysiol. 2018; 120(6):3110–21.
44. Dixon JB, Clark TK. Sensorimotor impairment from a new analog of spaceflight-altered neurovestibular cues. J Neurophysiol. 2020; 123(1): 209–23.

45. Aoki H, Yamaguchi T, Ohno R. A study of orientation in a zero gravity environment by means of virtual reality simulation. J Grav Physiol. 2000; 7(2):P93–4.
46. Clément G, Bareille MP, Goel R, Linnarsson D, Mulder E, et al. Effects of five days of bed rest with intermittent centrifugation on neurovestibular function. J Musculoskelet Neuronal Interact. 2015; 15(1):60–8.
47. Hecht H, Kavelaars J, Cheung CC, Young LR. Orientation illusions and heart-rate changes during short-radius centrifugation. J Vestib Res. 2001; 11(2):115–27.
48. Tays GD, McGregor HR, Lee JK, Beltran N, Kofman IS, et al. The effects of 30 minutes of artificial gravity on cognitive and sensorimotor performance in a spaceflight analog environment. Front Neural Circuits. 2022; 16:784280.
49. Lackner JR, DiZio P. Velocity storage: its multiple roles. J Neurophysiol. 2020; 123(3):1206–15.
50. Takahashi M, Sekine M, Ikeda T, Watanuki K, Hakuta S, Takeoka H. Effect of microgravity on spatial orientation and posture regulation during coriolis stimulation. Acta Otolaryngol. 2004; 124(4):495–501.
51. Liston DB, Adelstein BD, Stone LS. Onset of positional vertigo during exposure to combined G loading and chest-to-spine vibration. Aviat Space Environ Med. 2014; 85(2):183–6.
52. Yuan P, Koppelmans V, Reuter-Lorenz P, De Dios Y, Gadd N, et al. Vestibular brain changes within 70 days of head down bed rest. Hum Brain Mapp. 2018; 39(7):2753–63.
53. Hupfeld KE, Lee JK, Gadd NE, Kofman IS, De Dios YE, et al. Neural correlates of vestibular processing during a spaceflight analog with elevated carbon dioxide (CO2): a pilot study. Front Syst Neurosci. 2020; 13:80.
54. Gupta U, Baig S, Majid A, Bell SM. The neurology of space flight: how does space flight affect the human nervous system? Life Sci Space Res (Amst). 2023; 36:105–15.
55. Arntz AI, van der Putte DAM, Jonker ZD, Hauwert CM, Frens MA, Forbes PA. The vestibular drive for balance control Is dependent on multiple sensory cues of gravity. Front Physiol. 2019; 10:476.
56. Guillaud E, Faure C, Doat E, Bouyer LJ, Guehl D, Cazalets JR. Ancestral persistence of vestibulospinal reflexes in axial muscles in humans. J Neurophysiol. 2020; 123(5):2010–23.
57. Blue RS, Pattarini JM, Reyes DP, Mulcahy RA, Garbino A, et al. Tolerance of centrifuge-simulated suborbital spaceflight by medical condition. Aviat Space Environ Med. 2014; 85(7):721–9.
58. Morita H, Kaji H, Ueta Y, Abe C. Understanding vestibular-related physiological functions could provide clues on adapting to a new gravitational environment. J Physiol Sci. 2020; 70(1):17.
59. Schlegel TT, Brown TE, Wood SJ, Benavides EW, Bondar RL, et al. Orthostatic intolerance and motion sickness after parabolic flight. J Appl Physiol (1985). 2001; 90(1):67–82.
60. Clark JB, Bloomberg JJ, Bacal K. Chapter 23, Neurologic concerns. In: Barratt MR, Baker ES, Pool SL, editors. Principles of clinical medicine for space flight. 2nd ed. New York (NY): Springer; 2019. p. 711–46.
61. Wood SJ, Loehr JA, Guilliams ME. Sensorimotor reconditioning during and after spaceflight. NeuroRehabilitation. 2011; 29(2):185–95.
62. Paloski WH, Wood SJ, Feiveson AH, Black FO, Hwang EY, Reschke MF. Destabilization of human balance control by static and dynamic head tilts. Gait Posture. 2006; 23(3):315–23.
63. Rosenberg MJ, Galvan-Garza RC, Clark TK, Sherwood DP, Young LR, Karmali F. Human manual control precision depends on vestibular sensory precision and gravitational magnitude. J Neurophysiol. 2018; 120(6):3187–97.
64. Bonato F, Bubka A, Thornton W. Visual blur and motion sickness in an optokinetic drum. Aerosp Med Hum Perform. 2015; 86(5):440–4.
65. Karmali F, Ramat S, Shelhamer M. Vertical skew due to changes in gravitoinertial force: a possible consequence of otolith asymmetry. J Vestib Res. 2006; 16(3):117–25.
66. Clarke AH. Listing's plane and the otolith-mediated gravity vector. Prog Brain Res. 2008; 171:291–4.
67. Clarke AH, Kornilova L. Ocular torsion response to active head-roll movement under one-g and zero-g conditions. J Vestib Res. 2007; 17(2-3):99–111.
68. Beaton KH, Huffman WC, Schubert MC. Binocular misalignments elicited by altered gravity provide evidence for nonlinear central compensation. Front Syst Neurosci. 2015; 9:81.
69. Clément G, Reschke MF. Relationship between motion sickness susceptibility and vestibulo-ocular reflex gain and phase. J Vestib Res. 2018; 28(3-4):295–304.
70. Dai M, Kunin M, Raphan T, Cohen B. The relation of motion sickness to the spatial–temporal properties of velocity storage. Exp Brain Res. 2003; 151(2):173–89.
71. Shelhamer M, Zee DS. Context-specific adaptation and its significance for neurovestibular problems of space flight. J Vestib Res. 2003; 13(4–6): 345–62.
72. Shelhamer M, Clendaniel RA, Roberts DC. Context-specific adaptation of saccade gain in parabolic flight. VES. 2003; 12(5–6):211–21.
73. Clément G, Tilikete C, Courjon JH. Retention of habituation of vestibulo-ocular reflex and sensation of rotation in humans. Exp Brain Res. 2008; 190(3):307–15.
74. Abel SM, Crabtree B, Baranski JV, Smith DG, Thompson MM, et al. Hearing and performance during a 70-h exposure to noise simulating the space station environment. Aviat Space Environ Med. 2004; 75(9): 764–70.
75. Lecheler L, Paulke F, Sonnow L, Limper U, Schwarz D, et al. Gravity and mastoid effusion. Am J Med. 2021; 134(3):e181–3.
76. Watkins W, Hargens AR, Seidl S, Clary EM, Macias BR. Lower-body negative pressure decreases noninvasively measured intracranial pressure and internal jugular vein cross-sectional area during head-down tilt. J Appl Physiol (1985). 2017; 123(1):260–6.
77. Olabi AA, Lawless HT, Hunter JB, Levitsky DA, Halpern BP. The effect of microgravity and space flight on the chemical senses. J Food Sci. 2002; 67(2):468–78.
78. Williams D, Kuipers A, Mukai C, Thirsk R. Acclimation during space flight: effects on human physiology. CMAJ. 2009; 180(13):1317–23.
79. Paskovaty A, O'Rangers EA. Health consequences of spaceflight. J Pharm Pr. 2003; 16(2):101–6.
80. Chen Y, Xu C, Zhong C, Lyu Z, Liu J, et al. Temporal characteristics of the oropharyngeal and nasal microbiota structure in crewmembers stayed 180 days in the Controlled Ecological Life Support System. Front Microbiol. 2021; 11:617696.
81. Reyes DP, Brinley AA, Blue RS, Gruschkus SK, Allen AT, Parazynski SE. Clinical herpes zoster in Antarctica as a model for spaceflight. Aerosp Med Hum Perform. 2017; 88(8):784–8.
82. Mehta SK, Crucian B, Pierson DL, Sams C, Stowe RP. Monitoring immune system function and reactivation of latent viruses in the Artificial Gravity Pilot Study. J Grav Physiol. 2007; 14(1):P21–5.
83. Rai B, Kaur J, Foing BH. Wound healing and mucosal immunity during short Mars analog environment mission: salivary biomarkers and its clinical implications. Eurasian J Med. 2012; 44(2):63–7.
84. Bhaskaran S, Jagtap SS, Vidyasagar PB. Life and gravity. Biophys Rev Lett. 2009; 4(4):299–318.
85. Starck C, Thierry S, Bernard CI, Morineau T, Jaulin F, et al. Tracheal intubation in microgravity: a simulation study comparing direct laryngoscopy and videolaryngoscopy. Br J Anaesth. 2020; 125(1):e47–53.
86. Komorowski M, Fleming S. Intubation after rapid sequence induction performed by non-medical personnel during space exploration missions: a simulation pilot study in a Mars analogue environment. Extreme Physiol Med. 2015; 4(1):19.
87. ASTM. ASTM F3568-23: Standard guide for medical qualifications for suborbital vehicle passengers. Conshohocken (PA): American Society for Testing and Materials; 2023.
88. Danielson RW, Allen CS, Limardo JG, Clark JB. Chapter 5, Acoustic and auditory issues. In: Barratt MR, Baker ES, Pool SL, editors. Principles of clinical medicine for space flight. 2nd ed. New York (NY): Springer; 2019. p. 175–200.
89. Alford BR, Clark JB, Danielson RW. Chapter 4.2, Ear, nose, and throat and auditory issues. In: Risin D, Stepaniak PC, editors. Biomedical results of the Space Shuttle program. Washington (DC): NASA; 2013. p. 59–71.

Initial Psychometric Validation of a Self-Report Measure of the Symptoms of Mild Hypoxic Hypoxia

Oshin Vartanian; Fethi Bouak; Quan Lam; Robert Miles

INTRODUCTION: There has been long-standing interest in the physiological and psychological effects of mild hypoxia on aircrew, but to date there is no psychometrically valid self-report measure of subjective symptoms.

METHODS: To address this gap, we developed a self-report scale along three dimensions of impairment: cognitive, sensory and affective. We administered this scale to active and retired aircrew ($N = 354$) with on average 25.04 yr (SD = 11.27) of military service and subjected their responses to exploratory factor analysis using Maximum Likelihood Estimation, followed by reliability analysis to determine cohesiveness of associated items.

RESULTS: We provide initial psychometric validation for our 12-item scale's three-dimensional structure. The internal consistency reliability of the cognitive, sensory, and affective factors was 0.90, 0.75, and 0.85, respectively.

DISCUSSION: Going forward, the consistent use of this instrument will likely reduce the methodological variability in measuring the symptoms of mild hypoxia in the literature.

KEYWORDS: mild hypoxia, altitude, aircrew, cognition.

Vartanian O, Bouak F, Lam Q, Miles R. *Initial psychometric validation of a self-report measure of the symptoms of mild hypoxic hypoxia*. Aerosp Med Hum Perform. 2025; 96(9):851–856.

Hypoxia is the absence of an adequate supply of oxygen in the arterial and capillary blood, resulting in a rapid deterioration of body function, especially in the central nervous system. In turn, hypoxic hypoxia results from reduced alveolar oxygen tension in the lungs caused by low oxygen partial pressure at altitude. Whereas the physiological and psychological effects of hypoxia at altitudes higher than 15000 ft (4572 m) are well understood,[1] the effects of unprotected exposure to hypoxic hypoxia in altitudes up to 14000 ft (4267 m) are less well known. As such, considerable research has focused on the effects of mild hypoxic hypoxia on physiological and psychological functioning in altitudes less than 14000 ft, with mixed results. The inconsistent pattern of findings across studies may be due to many factors, including subtlety of alterations compared to higher altitudes, heterogenous central nervous system response, individual differences in compensatory mechanisms, duration of exposure, presence/absence of exercise, and variation in the methods and measures used to quantify the effects of hypoxic hypoxia.[2,3] The aim of this study is to improve reliability across studies by developing a psychometrically valid self-report scale for the symptoms of mild hypoxia that can be used consistently by researchers going forward—ideally in conjunction with other valid measures of physiological and psychological functioning. This will likely contribute to a reduction in methodological variability in future studies.

Typically, previous studies assessing the effects of mild hypoxic hypoxia (hereafter mild hypoxia) on aircrew performance have included combinations of physiological and psychological measures. For example, in our laboratory, we have assessed the physiological effects of mild hypoxia, via cerebral regional and finger pulse oxyhemoglobin saturation levels and heart and respiration rates, and its psychological effects using computerized cognitive tasks and self-reports of mood, fatigue, and symptoms of mild hypoxia.[4,5] The use of a multitude of measures is predicated on the assumption that the relatively subtle effects of mild hypoxia may be difficult to capture using

From Defence Research and Development Canada, Toronto, Canada.

This manuscript was received for review in December 2024. It was accepted for publication in June 2025.

Address correspondence to: Oshin Vartanian, Ph.D., Defence R&D Canada, 1133 Sheppard Ave. W., Toronto, ON M3K 2C9, Canada; oshin.vartanian@drdc-rddc.gc.ca.

DOI: https://doi.org/10.3357/AMHP.6626.2025

a single measure, and that a broad set of measures is more likely to provide a comprehensive picture of its effects on human functioning and performance. Sound as this assumption may be, the confidence that one might have about the findings will nevertheless depend on the reliability and validity of the individual measures incorporated into a study design. One family of measures that is frequently included involves self-report measures of the symptoms of mild hypoxia, essentially instructing aircrew to report their subjective experiences of its effects on functioning and performance. Critically, there has been a wide range of symptoms that have been assessed across studies, including dizziness, lightheadedness, mental confusion, tingling in fingers/toes, visual impairment, apprehension, cyanosis, euphoria, fatigue, headache, hot/cold flashes, increased heart rate/palpitations, increased respiration, muscle weakness, nausea, numbness, tetany (i.e., involuntary muscle twitching), changes in personality, difficulty with mathematical calculations, impaired judgment, impaired memory/recall, slips or lapses in aircraft operating procedures, difficulty with communications, impaired manual dexterity, and slowed reaction time, among others.[6–8] Nevertheless, despite this variability, certain symptoms have been reported more consistently across studies than others. For example, Deussing et al. found that the three most commonly recorded hypoxia symptoms were tingling (54%), difficulty concentrating (32%), and dizziness (30%).[6] The most commonly-reported symptoms by Nishi et al. included a feeling of warmth, poor concentration, and diminished vision.[7] In turn, the five most common symptoms observed by Woodrow et al. were lightheaded/dizzy, dizziness, mental confusion, visual impairment, and tingling.[8] Overall, these findings suggest that aircrew are most likely to report symptoms that reflect problems in the cognitive (e.g., poor concentration, mental confusion) and sensory (e.g., dizziness, poor vision) domains, although difficulties can extend to other domains and exhibit considerable individual differences.

A particularly important series of studies were conducted to explore not only the symptoms reported by aircrew, but also the veracity of the core methodological assumptions that underlie our interpretations of retrospective self-report data about episodes characterized by mild hypoxia. Specifically, Smith administered a survey to Australian Army helicopter aircrew who had operated at altitudes up to 10,000 ft (3048 m), which revealed that the most common symptoms associated with mild hypoxia were difficulty with calculations (45%), feeling light-headed (38%), delayed reaction time (38%), and mental confusion (36%).[9] That study also found that the relative impact of symptoms that fell into the cognitive, psychomotor, vision, and behavioral categories remained the same regardless of whether aircrew were asked to indicate if they had experienced the features themselves (i.e., “symptoms”) or whether they were aware of their presence in colleagues (i.e., “observations”). Smith concluded that “Rather than providing authoritative data, this study should be seen as a preliminary survey which identifies the need for a structured, objective, rigorous scientific study to evaluate the potential for helicopter aircrew to experience operationally significant hypoxia below 10,000 ft, and to consider the emphasis that is given to it during aviation medicine training of helicopter aircrew” (pp. 797–798).[9] In a follow-up study conducted in Saudi Arabia, Smith collected survey data on the symptoms of mild hypoxia from aircrew on two occasions—first during aviation physiology training at the beginning of the hypoxia lecture, and again after hypoxia awareness training.[10] In Saudi Arabia the hypoxia awareness training is administered to all aircrew as part of a 5-d aviation physiology course during initial aircrew training, followed at 3-yr intervals by a 2-d refresher course. When aircrew completed the survey at the beginning of the hypoxia lecture, they indicated the presence and severity of the symptoms they remembered from their previous hypoxia training. In turn, when they completed the survey after hypoxia awareness training, they indicated the presence and severity of symptoms they had experienced during the training just completed. The key finding was that there was a great deal of agreement between the symptoms reported during experience of acute hypoxia and those they remembered from training up to 3 yr earlier, such as impairment of cognitive function (e.g., poor concentration), psychomotor impairment (e.g., slowing of responses), visual impairment (e.g., blurred vision), and psychological disturbance (e.g., anxiety). Critically, this study demonstrated that aircrew can be relied upon to “remember the symptoms they experience when hypoxic; that the symptom-complex aircrew attribute to hypoxia reflects the symptoms they actually experience during hypoxia; and that the accuracy with which aircrew remember their hypoxia signature does not decline during the interval between refresher training courses” (pp. 54–55)—even up to 3 yr later.[10]

The literature above suggests that aircrew do experience subjective symptoms associated with mild hypoxia, and that they are able to recall and report them accurately. However, across studies, researchers have used variable instruments for assessing the symptoms of mild hypoxia, relying on surveys generated for specific contexts with unknown psychometric properties. We believe that this methodological variability is one of the sources that has contributed to the inconsistency of findings on the effects of mild hypoxia on psychological functioning.[2,3] Our review of this literature suggests that the variety of reported symptoms can be largely grouped into three dimensions: cognitive (e.g., impaired memory, impaired judgment), sensory (e.g., blurred vision, dizziness), and affective (e.g., euphoria, fatigue).

The aim of the present study was to develop and take the initial steps in the psychometric validation of a novel self-report measure of the symptoms of mild hypoxia. We hypothesized that the range of symptoms would be represented by a three-dimensional structure (i.e., cognitive, sensory, affective), tested via factor analysis and reliability analysis. If successful, the adoption of a psychometrically valid scale for self-reporting of the symptoms of mild hypoxia should reduce some of the measurement variability that has plagued studies in this area in the past.[3]

METHODS

Subjects

The protocol for this study was approved by Defense Research and Development Canada's Human Research Ethics Committee (protocol #2018-074). The subjects were recruited via an e-mail distributed by the Royal Canadian Air Force (RCAF) Association of Canada to its members. As stated on its website, the mission statement of the RCAF Association is to serve as "a national aerospace and community service organization established to commemorate the noble achievements of the men and women who have served as members of Canada's air force since its inception, advocate for a proficient and well-equipped air force, and support the Royal Canadian Air Cadet program." As such, its membership consists of active and retired members of RCAF, and represented an ideal opportunity to survey a large number of active and retired aircrew with flight experience to probe the effects of mild hypoxia on cognitive, sensory, and affective symptoms. In cases where the recipients of the solicitation e-mail agreed to participate in a study on the "signs and symptoms of mild hypoxia," they were directed to a link to complete the survey anonymously.

Materials

The survey consisted of 15 items—5 items each for assessing the symptoms associated with the cognitive, sensory, and affective aspects of mild hypoxia (**Appendix A**, found in the online version of this article). The specific items themselves were selected by the authors from previous studies that had examined the self-report symptoms associated with mild hypoxia, reviewed above. For each item (i.e., symptom), the subjects were asked to indicate the extent to which they had experienced it while performing their duties as aircrew in aircraft with unpressurized cabins using a 5-point scale ranging from 1 (Never) to 5 (Always). The survey also included a series of demographic questions for characterizing the sample. The demographics of the sample appear in **Table I**.

Procedure

The survey was administered online via LimeSurvey. Informed consent was obtained from all subjects prior to data collection.

Statistical Analysis

We performed an exploratory factor analysis using maximum likelihood estimation in the MPlus software (Version 8.4, Los Angeles, CA, United States) to identify any problematic items and to determine the underlying factor structure of the measure. We chose maximum likelihood estimation for the added benefit of the various fit indices that it produces, which are useful in guiding factor structure selection. Due to elevated levels of skewness (>2) and kurtosis (>7) in certain items (**Table II**), we used the robust maximum likelihood estimator within MPlus, which compensates for nonnormal data when conducting maximum likelihood estimation. Additionally, observing the findings that oblique rotation (counterintuitively) produces better simple structure, and that uncorrelated factors are commonly theoretically implausible,[11] we specified an oblique rotation to allow factors to correlate freely with one another. Subsequent to exploratory factor analysis, we carried out a reliability analysis on each subscale using the Statistical Package for the Social Sciences (Version 28, IBM, Armonk, NY, United States) to determine the cohesiveness of associated items.

Table I. Demographics.

DEMOGRAPHIC	*N*
Sex	
Male	343
Female	10
Missing	1
Age (yr)	
21–25	4
26–30	12
31–35	4
36–40	7
41–45	8
46–50	14
51–55	15
56–60	54
61 or more	236
Missing	3
Education	
High school diploma	100
College diploma	62
Undergraduate diploma	101
Graduate diploma	76
None of the above	15
Role	
Pilot	216
Copilot	40
Navigator	98
Loadmaster	10
Technician	33
Other	65
Current status	
Reg. Force	59
Reservist	9
Other	286
Current rank	
General/Flag Officer	12
Senior Officer	72
Junior Officer	56
Senior NCM	25
Junior NCM	1
Subordinate Officer	1
Not applicable	187

N = 354; NCM = noncommissioned officer; General/Flag Officer = General, Brigadier General, Major-General, Lieutenant-General; Junior NCM = Private, Corporal, Master Corporal; Senior NCM = Sergeant, Warrant Officer, Master Warrant Officer, Chief Warrant Officer; Junior Officer = Second Lieutenant, Lieutenant, Captain; Senior Officer = Major, Lieutenant-Colonel, Colonel; Subordinate Officer = Officer Cadet; Missing = no information provided by the subject.

RESULTS

In terms of factor rotation, exploratory factor analysis was carried out using maximum likelihood estimation with oblique rotation. Given that our measure contained 15 items, we extracted 1-, 2-, and 3-factor solutions to allow for comparison

Table II. Item Descriptive Statistics.

ITEM	M (SD)	SKEWNESS	KURTOSIS
Confusion	1.38 (0.61)	1.55	1.91
Impaired memory	1.38 (0.70)	1.94	3.66
Slowed reaction time	1.53 (0.71)	1.20	1.20
Difficulty concentrating	1.54 (0.76)	1.32	1.42
Impaired judgment	1.38 (0.64)	1.71	3.12
Dizziness/light-headedness	1.60 (0.79)	1.28	1.31
Hot/cold flashes	1.23 (0.56)	2.76	7.78
Increased heart rate/ palpitation/respiration	1.67 (0.85)	1.07	0.39
Headache	1.47 (0.77)	1.56	1.81
Vision problems	1.40 (0.74)	2.21	5.39
Euphoria	1.42 (0.80)	2.15	4.73
Fatigue	2.14 (0.97)	0.37	−0.59
Nervousness	1.68 (0.82)	0.83	−0.47
Stress	2.03 (0.95)	0.35	−1.08
Depressed mood	1.32 (0.62)	1.96	3.33

M = mean; SD = standard deviation.

Table III. Loadings for the Cognitive (Factor 1), Sensory (Factor 2), and Affective (Factor 3) Factors.

ITEM	FACTOR 1	FACTOR 2	FACTOR 3
Confusion	0.656	0.133	0.012
Slowed reaction time	0.883	0.005	−0.093
Difficulty concentrating	0.857	0.017	0.048
Impaired judgment	0.959	−0.110	0.002
Dizziness/light-headedness	0.183	0.572	−0.165
Hot/cold flashes	−0.221	0.743	0.002
Increased heart rate/ palpitation/respiration	0.014	0.475	0.297
Headache	−0.068	0.543	0.170
Vision problems	0.051	0.588	0.082
Fatigue	0.034	0.185	0.632
Nervousness	−0.021	0.205	0.658
Stress	0.013	−0.008	0.895

of the largest number of factored solutions while still ensuring a sufficient number of potential items for any given factor.[12] Results indicated that not only did the 3-factor solution produce better fit indices [root mean square error of approximation (RMSEA) = 0.044, comparative fit index (CFI) = 0.976, standardized root mean square residual (SRMR) = 0.028] than the 1-factor (RMSEA = 0.123, CFI = 0.736, SRMR = 0.088) and 2-factor (RMSEA = 0.065, CFI = 0.938, SRMR = 0.039) solutions, but it also met conventional criteria of absolute model fit,[13] whereas the other two models fell somewhat short.

In further refining the 3-factor solution, we sought to strike a balance between empirical plausibility and factor interoperability. Problematic items were identified as: 1) items that did not have salient loadings on any factor; 2) items that loaded onto more than one factor; and 3) items whose loadings on a factor did not make theoretical sense. We considered a salient loading as above 0.30.[14] After identifying and removing an item, we re-evaluated the pattern of loadings and identified any additional items for removal. Undertaking this process led us to remove three items in the following order: euphoria, depressed mood, and impaired memory. "Euphoria" did not show salient loading onto any factor (loadings ranged from 0.05–0.28); "depressed mood" loaded onto the wrong factor (i.e., sensory rather than affective); and "impaired memory" showed small salient loadings onto two factors: cognitive (0.427) and sensory (0.418). The remaining 12 items displayed simple structure in forming three factors (**Table III**). The first factor contained items that we had hypothesized would form a cognitive factor: confusion, slowed reaction time, difficulty concentrating, and impaired judgment. These items reflect symptoms associated with cognitive impairments related to mild hypoxia. Similarly, the second factor contained five items (dizziness/light-headedness, hot/cold flashes, increased heart rate/palpitation/respiration, headache, and vision problems) that we had hypothesized would form a sensory factor. Finally, the three items of the third factor—fatigue, nervousness, and stress—formed the hypothesized affective factor. Finally, factor correlations were 0.438 between the cognitive and affective factors, 0.723 between cognitive and sensory factors, and 0.572 between the sensory and affective factors.

Subsequent to performing the Exploratory Factor Analysis, we undertook a reliability analysis to ensure that items formed internally consistent and homogenous factors. The cognitive factor showed an internal consistency reliability of 0.90. Interitem correlations ranged from 0.649–0.788. Three of the four items (i.e., slowed reaction time, difficulty concentrating, and impaired judgment) showed corrected item-total correlations in the low 0.80 range, while the remaining item (i.e., confusion) showed a corrected item-total correlation in the 0.7 range (**Table IV**). The sensory factor had an internal consistency reliability of 0.75. Interitem correlations ranged from 0.343–0.500. Four items (hot/cold flashes, increased heart rate/palpitation/respiration, headache, and vision problems) showed corrected item-total correlations in the 0.50 range, whereas one item (i.e., dizziness/light-headedness) showed a corrected item-total correlation of 0.49 (Table IV). The affective factor had an internal consistency reliability of 0.85. Interitem correlations ranged from 0.590–0.684. All corrected item-total correlations fell in the range between 0.70–0.77 (Table IV).

DISCUSSION

This study was conducted to test the psychometric properties of a new self-report measure of the symptoms of mild hypoxia in a large sample of active and retired aircrew ($N = 354$) with substantial years of military service (M = 25.04 yr, SD = 11.27). Our review of the literature on hypoxic hypoxia showed that although many past studies had probed its symptoms, there was to date no psychometrically validated self-report instrument for measuring such symptoms. The development of such an instrument had been motivated in the literature,[9] at least in part as a potentially useful approach to reducing some of the methodological variability that has plagued past research.[1–3] Our review of the literature suggested further that most self-reported symptoms tend to fall into three categories: cognitive, sensory, and affective. As such, to fill this gap in the literature, we developed a 15-item scale based largely on items used in past studies

Table IV. Corrected Item Total Correlations and Item Endorsements.

FACTOR	ITEM	CORRECTED ITEM-TOTAL CORRELATION	ENDORSEMENT (%)
Cognitive	Confusion	0.72	31.07
	Slowed reaction time	0.80	41.53
	Difficulty concentrating	0.83	40.68
	Impaired judgment	0.82	30.23
Sensory	Dizziness/light-headedness	0.49	44.35
	Hot/cold flashes	0.50	16.67
	Increased heart rate/palpitation/respiration	0.56	46.05
	Headache	0.50	32.49
	Vision problems	0.57	27.97
Affective	Fatigue	0.70	67.80
	Nervousness	0.70	47.46
	Stress	0.77	62.15

Endorsement indicates percentage of subjects who rated the item at least a 2 (i.e., rarely) or higher on the 5-point scale (see Appendix A, found in the online version of this article).

to probe the symptoms of mild hypoxia and subjected the data to exploratory factor analysis, followed by reliability analysis on each subscale to determine cohesiveness of associated items. The results provided initial psychometric validation for a 12-item scale that conforms to our predicted three-dimensional structure (cognitive, sensory, affective) (Tables II–IV).

Our factor structure is consistent with reports from the literature. For example, cognitive impairments have been one of the most consistent findings reported by aircrew in relation to mild hypoxia. A systematic meta-regression analysis of the effects of acute hypoxia on cognitive performance, including data from 22 experiments, demonstrated a moderate, negative mean effect size (Hodges $g = -0.49$, 95% CI −0.64 to −0.34, $P < 0.001$).[15] Consistent with McMorris et al.,[15] we included elementary (e.g., reaction time) and higher-order cognitive (e.g., judgment) symptoms under the common umbrella of cognitive effects. The justification for this was twofold: first, McMorris et al.'s meta-analysis revealed no difference between executive and nonexecutive tasks, indicating that there is no empirical reason to separate them.[15] Second, from a theoretical perspective, one can view the tasks ranging from psychomotor vigilance to executive functions as representing a continuum of tasks that cover elementary to higher-order cognition, all of which have been shown to be impacted by mild hypoxia.[1] The next most commonly reported set of symptoms appear to be sensory in nature, in particular difficulties with vision, dizziness, tingling, and hot/cold flashes, among others. Finally, the third set of symptoms reported by aircrew are affective in nature, representing mood and emotional states, including nervousness and stress.[3,9,10] Indeed, experimental work from our laboratory has demonstrated that acute hypoxic hypoxia can increase the subjective experience of negative mood.[4,5]

Our study had several limitations. First, although we followed statistical best practices for the exploratory factor analysis and reliability analysis,[11–13] further validation work is necessary for the maturation of this instrument, including additional psychometric research (e.g., confirmatory factor analysis in an independent sample of aircrew), as well as validation in situ (i.e., assessing the sensitivity of the instrument following exposure to various levels of altitude). Second, the majority (67%) of the survey responders were 61 yr of age or older, and not active members of the military at time of data collection (Table I). Also, they were asked to consider their history of flight rather than a specific episode of flight. These are important considerations regarding the accuracy of their retrospective memory recall in relation to the symptoms of mild hypoxia, although there is also evidence to suggest that aircrew can recognize and recall the symptoms of mild hypoxia accurately up to 3 yr after experiencing them.[10] This concern can be addressed by investigating the structure of this survey in active aircrew directly after completing a flight session in the future. Despite these limitations, this instrument offers a promising tool for measuring the symptoms of mild hypoxia going forward, negating the need to develop and administer ad hoc questionnaires. Finally, as noted at the outset, the current standard in studies of mild hypoxia is to use a comprehensive set of physiological and psychological measures to capture the full breadth of its effects[4,5] and we see this instrument as one of the components of this multifactorial approach to assessing the effects of this multifaceted phenomenon.

ACKNOWLEDGMENTS

We are grateful to the members of the RCAF Association for completing our survey.

Financial Disclosure Statement: The Department of National Defence provided funding to support this research (Project 03aa05). The authors have no competing interests to declare.

Authors and Affiliation: Oshin Vartanian, Ph.D., B.Sc., Fethi Bouak, Ph.D., M.A.Sc., Quan Lam, M.Sc., B.A., and Robert Miles, Ontario Secondary School Diploma, Defence Research and Development Canada – Toronto Research Centre, Toronto, Ontario, Canada.

REFERENCES

1. Ernsting J, Nicholson A, Rainford D, editors. *Aviation medicine.* 3rd ed. London: Butterworth; 1999.
2. Bahrke MS, Shukitt-Hale B. Effects of altitude on mood, behaviour and cognitive functioning. A review. Sports Med. 1993; 16(2):97–125.

3. Petrassi FA, Hodkinson PD, Walters PL, Gaydos SJ. Hypoxic hypoxia at moderate altitudes: review of state of the science. Aviat Space Environ Med. 2012; 83(10):975–84.
4. Bouak F, Vartanian O, Hofer K. Performance and health effects of mild hypoxic hypoxia in simulated 6-hour exposures between 2,438 and 3,048 metres. J Mil Veteran Fam Health. 2019; 5(2):40–9.
5. Bouak F, Vartanian O, Hofer K, Cheung B. Acute mild hypoxic hypoxia effects on cognitive and simulated aircraft pilot performance. Aerosp Med Hum Perform. 2018; 89(6):526–35.
6. Deussing EC, Artino AR, Folga RV. In-flight hypoxia events in tactical jet aviation: characteristics compared to normobaric training. Aviat Space Environ Med. 2011; 82(8):775–81.
7. Nishi S. Effects of altitude-related hypoxia on aircrews in aircraft with unpressurized cabins. Mil Med. 2011; 176(1):79–83.
8. Woodrow AD, Webb JT, Wier GS. Recollection of hypoxia symptoms between training events. Aviat Space Environ Med. 2011; 82(12):1143–7.
9. Smith A. Hypoxia symptoms reported during helicopter operations below 10,000 ft: a retrospective survey. Aviat Space Environ Med. 2005; 76(8):794–8.
10. Smith AM. Hypoxia symptoms in military aircrew: long-term recall vs. acute experience in training. Aviat Space Environ Med. 2008; 79(1):54–7.
11. Fabrigar LR, Wegener DT, MacCallum RC, Strahan EJ. Evaluating the use of exploratory factor analysis in psychological research. Psychol Methods. 1999; 4:272–99.
12. Costello AB, Osborne J. Best practices in exploratory factor analysis: four recommendations for getting the most from your analysis. Pract Assess Res Eval. 2005; 10:7. [Accessed July 11, 2025]. Available from https://legacyfileshare.elsevier.com/promis_misc/teln-best-practices-in-exploratory-factor-analysis.pdf.
13. Hu LT, Bentler PM. Cutoff criteria for fit indexes in covariance structure analysis: conventional criteria versus new alternatives. Struct Equ Modeling. 1999; 6(1):1–55.
14. Gorsuch RL. Exploratory factor analysis: Its role in item analysis. J Pers Assess. 1997; 68(3):532–60.
15. McMorris T, Hale BJ, Barwood M, Costello J, Corbett J. Effect of acute hypoxia on cognition: a systematic review and meta-regression analysis. Neurosci Biobehav Rev. 2017; 74(Pt A):225–32. Erratum in: Neurosci Biobehav Rev. 2019; 98:333.

Recommended Practices Related to Data Collection in Aviation Peer Support Programs

William Hoffman; Diederik De Rooy; Aedrian Bekker; Robert Bor; David Fielding; Quay Snyder

INTRODUCTION: Aviation peer support programs (PSPs)—comprised of trained volunteers of the same professional background who offer confidential, nonjudgmental support to fellow aviation personnel dealing with stress from any source—have been forwarded as a solution to address mental healthcare avoidance based on expert opinion that PSPs are of sufficient safety and effectiveness. There is a growing interest in data collection in PSPs for a range of reasons as driven by European Union Aviation Safety Agency regulation requirements and an international interest in incorporating mental health functions into an aviation safety management system as outlined in the Federal Aviation Administration Aviation Rulemaking Committee on Mental Health. The current commentary provides recommended practices for data collection in aviation peer support programs guided by a novel bioethical framework.

KEYWORDS: aviation mental health, peer support, aeromedical screening.

Hoffman W, De Rooy D, Bekker A, Bor R, Fielding D, Snyder Q. *Recommended practices related to data collection in aviation peer support programs*. Aerosp Med Hum Perform. 2025; 96(9):857–860.

Aviation safety-sensitive personnel around the globe are subject to regular medical examinations to assess their fitness. Disclosure of mental health symptoms or the use of mental health services risks loss of medical license/certification, which can lead to negative consequences.[1] This is thought to result in healthcare avoidance behavior, which has been reported in as many as 56% of U.S. and Canadian pilots.[2] Mental healthcare avoidance in pilots has become of global interest in recent years with mitigating efforts aiming to optimize mental health and safety in the system.[3–5]

Peer support programs (PSPs)—comprised of trained volunteers of the same professional background who offer confidential, nonjudgmental support to fellow aviation personnel dealing with stress from any source[6]—have been forwarded as a solution to address mental healthcare avoidance based on expert opinion that PSPs are of sufficient safety and effectiveness.[7,8] PSPs are thought to be effective at least partially due to the confidential and non-reportable nature of the service.[6] To improve the health of personnel and improve safety, there is a growing interest in data collection in PSPs for a range of reasons (outlined in **Table I)** as driven by European Union Aviation Safety Agency regulation[9] and an interest in incorporating mental health functions into an aviation safety management system as outlined in the Federal Aviation Administration Aviation Rulemaking Committee on Mental Health.[3] In a rapidly evolving field, the objectives of data collection include understanding and demonstrating service utilization and efficacy, as well as linking mental wellbeing to safety and articulating this link within an operator's safety management system, assessment of clinic and programmatic effectiveness, and safety topics and eventual incorporation into a safety management system. The rationale for this effort ultimately aims to address healthcare avoidance and thereby improve safety in the global aviation system.[10]

To the authors' knowledge, the only current guidance available on data collection in PSPs stems from the regulation in the European Union directing that data should be "handled in a

From the 59th Medical Wing Office of Science and Technology, Aircrew Brain & Mental Health Research Program, Lackland AFB, TX, United States; Aerospace Medical Association Mental Health Working Group, Arlington, VA, United States; Transparant Center for Mental Healthcare, Leiden, The Netherlands; Centre for Aviation Psychology, London, United Kingdom; International Peer Assist Aviation Coalition, London, United Kingdom; and the Aviation Medicine Advisory Service, Centennial, CO, United States.

This manuscript was received for review in January 2025. It was accepted for publication in May 2025.

Address correspondence to: William Hoffman, M.D., Brooke Army Medical Center, 330 Clay St., Unit 22, San Antonio, TX 78204, United States; wrh35@georgetown.edu.

DOI: https://doi.org/10.3357/AMHP.6644.2025

Table I. Reasons for Data Collection in Aviation Peer Support Programs.

REASON	DESCRIPTION
Internal Service Improvement	
Understanding user demographics and reasons for utilizing peer support services	Given how little is known about this area of aviation professionals' wellbeing, it is important to better understand who is using these services and why they might be doing so.
Service review and improvement	Data can be used to review the effectiveness of a service and identify areas for improvement, further investment, and innovation.
Sharing of best practice	Given the diversity of PSPs the sharing of findings across the sector will help promote lessons learned and successes gained.
Contribution to knowledge base	Given the paucity of published findings in this area, and in contrast to the increasing ubiquity of PSPs for aviation professionals, it is important that an accessible knowledge base is built that combines health and safety data in an ethical and meaningful way.
Assessment of Clinical and Program Effectiveness	
Clinical and program effectiveness and the health of the individual user	Understanding how effective the service is in supporting the wellbeing of its users.
Safety Topics and Incorporation into an Aviation Safety Management System	
Safety performance of the user	Better understanding how aviation professional mental health might impact on the safety of their performance.
Incorporation into an aviation Safety Management System (SMS)	Using data in a way that informs and enhances safety of the system through an SMS process.

confidential, non-stigmatizing, and safe environment" and only shared with operators in an anonymized and aggregated manner.[11] That said, more detailed guidance to effectively accomplish the objectives in Table I and recommended practices remain undefined. To our knowledge, aviation PSPs globally employ diverse data collection practices, ranging from zero to very detailed data collection. No consensus exists on data necessary to meet European Union Aviation Safety Agency guidance and the Federal Aviation Administration Aviation Rulemaking Committee's recommendations. Identifying recommended practices has many potential benefits, including shared terminology, data uniformity permitting system-level safety analyses, and the enhanced protection of users and organizations.

Recommended Data Collection Practices

We created an expert opinion-based list of recommended data collection practices generated through a qualitative, consensus-based approach of aviation safety, operations, peer support, aeromedical, and regulatory experts guided by the proposed bioethical framework outlined in **Appendix A** (found in the online version of this article). Recommended practices and data handling are:

1. Data collection must include informed consent and be protected by peer assistance networks' own data protection and privacy policy, procedures, and governance, as well as within an ethical research framework protecting the confidentiality and interests of the individuals;
2. The benefits of data collection to the system must outweigh the risks of data collection to the individual;
3. Findings from all methodologically sound data collection must be used only to support program effectiveness, system safety and individual wellbeing and reported via the program's governance structures (including its link to the Safety Management System or through academic or professional, learned channels), and not used in a manner to present legal, financial, or certification risks to the detriment of the individual or the employer;
4. Data collection and analysis must be methodologically sound to ensure findings can meet recommendation number 3;
5. An intervention must never be withheld for the sake of research; and
6. As program governance and oversight of PSPs is ideally undertaken by a multi-stakeholder and multi-disciplinary steering group (e.g., union, pilot/professional group, mental health provider, safety management, health care, etc., representation) to ensure accountability is shared and not held by any one group, the above 1–5 data criteria are embedded within the governance terms of reference.

To meet the objectives outlined in Table I, **Table II** recommends data to be collected by aviation PSPs.

Discussion

Aviation PSPs have been forwarded to address mental healthcare avoidance behavior and improve safety. While data collection does not currently exist systematically, we anticipate that regulatory requirements and expectations will make this an increasing necessity. Data collection has many benefits, including the assessment of programs, ensuring individuals can access services that ultimately address system-wide safety hazards. PSPs are not a clinical service and the sensitive nature of this field requires special consideration. The authors acknowledge that there is limited consensus on this topic, complicated by diverse considerations, stakeholder incentives, and heterogenicity in PSPs. The authors further acknowledge the many reasons that PSP managers may be reluctant to collect and publicize data, including limited data management skills, budgetary constraints, and organizational politics. To guide efforts, we recommend data protection practices, which should be reviewed in an iterative fashion and overseen by all stakeholders.

Many open questions centered around data protection, data ownership, and data access must be addressed before data collection efforts commence. Data should be collected and stored securely and independently to minimize the risk of unintended disclosure, should only be used for the intended

Table II. Recommended Data Collection in Aviation Peer Support Programs.

CATEGORY	DEFINITION	BENEFITS
Service Provider Operational Description	Nature of operation, preserving operator anonymity [e.g., large international carrier vs. regional, low cost, legacy, unionized, approximate size of flight crew community (e.g., 0–100 pilots; 1000–5000; 5000+) multi- or main base, scheduled, charter, cargo, etc.].	Identify factors unique to the operational environment that could be mitigated through action to improve program effectiveness and system safety.
Peer Support Program Description	Nature of the peer support program, protocols, training paradigms, how operations typically work.	Identify factors unique to the program that could be mitigated through action to improve program effectiveness and system safety.
Demographic Information	Demographic information relevant to identifying specific needs of users based on self-identified categories (e.g., gender, etc.).	Identify patterns of concerns disproportionally occurring in a demographic that could be mitigated through action to improve program effectiveness and system safety.
Phase of career or experience level	Self-identified phase of career/experience.	Identify patterns of concerns disproportionally occurring in a career phase/experience level that could be mitigated through action to improve program effectiveness and system safety.
Profession and position	Profession (e.g., air traffic controller, pilot, cabin crew, engineer); and Position (e.g., captain or first officer, etc.).	Identify patterns of concerns disproportionally occurring in certain professions or positions that could be mitigated through action to improve program effectiveness and system safety.
General topic and severity of interaction/contact	General nature of the discussion (e.g., relationship challenges, fatigue, training challenges, etc.). Where possible, assessing the severity with which the issue impacts the personal and professional life of the user; the complexity or co-occurrence with other issues (e.g., fatigue associated with financial difficulties, failed training check, or health concerns) might be considered.	Identify patterns of concerns occurring in certain domains that could be mitigated through action to improve program effectiveness and system safety. Assessment of severity and possible co-occurrence of concerns addressed by peer support program services.
Number of contacts and time spent with peer support services	Self-reported number of times the peer support user engaged/contacted peer support services; the overall time (i.e., minutes/hours) the peer spent supporting the peer support user.	Identify peer support users who may require additional resources beyond peer support services with the intent of optimizing safety. Provide methods of quantifying and moderating peer workload.
Identification of safety sensitive hazard	Whether the peer support user or the peer identified a safety sensitive hazard (e.g., impaired performance, operational concern, threat to personal/public safety); whether and how hazard was addressed.	Identification of system level hazards that could be mitigated through system level action.
Referral to support professional or external resources	Whether the peer suggested the user access a support professional or external resource (e.g., mental health professional, employee assistance, professional standards, training, union resources, lawyer, etc.).	Identify system level referral patterns and requirements; identify system level severity of mental health concerns; and identification of system level hazards that could be mitigated through system level action.

purpose, and be overseen by a body representing all stakeholders. As our recommendations are meant to facilitate program research and quality, they are distinct from the programs' own procedures for escalation, quality control, and peer resource management. Data should not be used to identify hazardous individuals but instead be incorporated into the operator's safety management systems to identify and control system-wide hazards. A particular risk may arise relating to a serious incident or accident when a PSP may be associated in some way prior to or following the event. Akin to safety reports, data should in principle not be used in criminal or liability proceedings. Ideally, in the long term, the confidentiality of PSPs would also be protected by International Civil Aviation Organization Annex 13 and other regulations. Access to the data, how it is stored, and how this new data set might fit into an existing safety management system are open questions. Complicating factors are the international nature of aviation and the variable laws governing such practices. Importantly, it should be noted that these recommendations should only be implemented under legal guidance.

Other data-driven safety efforts can serve as an example. The Aviation Safety Information Analysis and Sharing (ASIAS) program is a collaborative government-industry partnership aiming to "proactively discover and mitigate emerging safety issues before they result in an incident or accident"[11] through the sharing of data. ASIAS aims to balance similar conflicting values of confidentiality and safety. Lessons learned and approaches from safety programs such as these should benefit the data collection efforts of aviation PSPs.

ACKNOWLEDGMENTS

The authors would like to thank Mr. Elijah Miranda for his time and assistance providing technical writing and support for this manuscript. The authors would also like to thank all aviation peer support volunteers for their dedication to the care of aviation personnel and aviation safety. We also thank the International Peer Assist Aviation Coalition (IPAAC) for the organization's leadership in establishing peer support for aviation personnel across global aviation.

The views expressed are those of the authors and do not reflect the official guidance or position of the U.S. Government, the Department of Defense (DoD), the U.S. Air Force, or the U.S. Space Force. Mention of trade names, commercial products, or organizations does not imply endorsement by the U.S. Government. The appearance of external hyperlinks does not constitute endorsement by the DoD of the linked websites, or the information, products, or services contained therein. The DoD does not exercise any editorial, security, or other control over the information you may find at these locations.

Financial Disclosure Statement: Aedrian Bekker and Robert Bor are stockholders in the Centre for Aviation Psychology; David Fielding is Chair and Quay Snyder is CEO of International Peer Assist Aviation Coalition (not-for-profit). The other authors have nothing to declare.

Authors and Affiliations: William Hoffman, M.D., Aircrew Brain & Mental Health Research Program, 59th Medical Wing Office of Science and Technology, Lackland AFB, TX, United States; William Hoffman, Diederik De Rooy, LLM, M.D., Ph.D., Aedrian Bekker, M.S., Robert Bor, D.Phil., David Fielding, M.A., and Quay Snyder, M.D., MSPH, Aerospace Medical Association Mental Health Working Group, Arlington, VA, United States; Diederik De Rooy, Transparant Center for Mental Healthcare, Leiden, The Netherlands; Aedrian Bekker and Robert Bor, Centre for Aviation Psychology, London, United Kingdom; David Fielding, International Peer Assist Aviation Coalition, London, United Kingdom; and Quay Snyder, Aviation Medical Advisory Service, Centennial, CO, United States.

REFERENCES

1. Hoffman W, Bjerke E, Tvaryanas A. Breaking the pilot healthcare barrier. Aerosp Med Hum Perform. 2022; 93(8):649–650.
2. Hoffman WR, Patel PK, Aden J, Willis A, Acker JP, et al. Multinational comparison study of aircraft pilot healthcare avoidance behaviour. Occup Med (Lond). 2023; 73(7):434–438.
3. Federal Aviation Administration. Mental Health & Aviation Medical Clearance Aviation Rule Making Committee: recommendation report. 2024. [Accessed Nov. 11, 2024]. Available from https://www.faa.gov/sites/faa.gov/files/Mental_Health_ARC_Final_Report_RELEASED.pdf.
4. European Union Aviation Safety Authority. Mental health for aviation safety (MESAFE). [Accessed Nov. 11, 2024]. Available from https://www.easa.europa.eu/en/research-projects/mesafe-mental-health.
5. Ministry of Manpower (MOM), National Trades Union Congress (NTUC) and Singapore National Employers Federation (SNEF). Tripartite Advisory on Mental Health and Wellbeing at Workplaces. 2023. [Accessed Dec. 23, 2024]. Available from https://www.mom.gov.sg/-/media/mom/documents/covid-19/advisories/tripartite-advisory-on-mental-well-being-at-workplaces.pdf.
6. Air Line Pilots Association. Pilot peer support. What is pilot peer support? [Accessed Nov. 11, 2024]. Available from https://www.alpa.org/resources/pilot-peer-support.
7. International Civil Aviation Organization. Electronic Bulletin. EB2020/55. Promoting, maintaining, and supporting mental well-being in aviation during the COVID-19 pandemic. Nov. 10, 2020. [Accessed Nov. 11, 2024]. Available from https://www.icao.int/Meetings/TRIP-Symposium-2018/Documents/EB_20_55_Mental%20Health.pdf.
8. European Union Commission. Regulation 2018/1042. OJ L 188, 25.7.2018,:3–8. [Accessed Nov. 11, 2024]. Available from https://www.easa.europa.eu/en/document-library/regulations/commission-regulation-eu-20181042.
9. Miranda EE, Hoffman WR, Bongers H, Snyder Q, Worley SY, et al. The case for a performance-based approach to mental health screening in aviation. J Occup Environ Med. 2024; 66(2):e77–e79.
10. European Union Aviation Safety Agency. Acceptable means of compliance (AMC) and guidance material (GM) to Annex IV commercial air transport operations [Part-CAT] of Commission Regulation (EU) 965/2012 on air operations. AMC2 CAT.GEN.MPA.215 Support programme. 2019. [Accessed Dec 23, 2024]. Available from https://www.easa.europa.eu/sites/default/files/dfu/Consolidated%20AMC-GM_Annex%20IV%20Part-CAT_March%202019.pdf.
11. Federal Aviation Administration. Report to Congress: report on the status of aviation safety information analysis and sharing (ASIAS) capability acceleration. March 31, 2020. [Accessed Nov 11, 2024]. Available from https://www.faa.gov/sites/faa.gov/files/2021-11/FAA_Report_on_Aviation_Safety_Information_Analysis_and_Sharing_ASIAS_03312020.pdf.

Letter to the Editor re: Beard Length and the Efficacy of an Aviator Oxygen Mask

DEAR EDITOR:

French and Wagner contend that beards do not compromise the respiratory protection afforded by airliner "quick don" emergency oxygen masks.[1] However, their normobaric study design is flawed and their method is insensitive to relevant mask leaks.

At sea level, peripheral oxygen saturation (S_pO_2) resists dilution of mask-supplied air with ambient hypoxic gas, unless leaks are severe and consistent, since initial desaturation must follow the shallow gradient of the hemoglobin oxygen dissociation curve as alveolar partial pressure of oxygen (P_AO_2) falls. However, P_AO_2 and S_pO_2 are already hypoxic at relevant high altitudes [over 33,500 ft (10,211 m)] despite breathing 100% oxygen; any entrainment of ambient air exacerbates hypoxia, severely if S_pO_2 tumbles down the steep portion of the curve. To be representative, normobaric testing should reproduce the most challenging equivalent P_AO_2 before leakage, e.g., mask-supplied 14.1% oxygen simulating steady exposure at 40,000 ft (12,192 m) breathing 100% oxygen [10,000 ft (3048 m) air equivalent: P_AO_2 55 mmHg; S_pO_2 ~91%]. S_pO_2 will then respond more sensitively to inboard leaks of hypoxic gas, albeit remaining a poor surrogate for accurate measurement of leak rates. In this normobaric study, S_pO_2 is insensitive to leaks and "absence of evidence" is not "evidence of absence" of meaningful leaks at high altitude.

Lack of detail concerning the normobaric hypoxia chamber, gas composition, and airflow hinders evaluation of study sensitivity. For normobaric S_pO_2 to drop below 95%, P_AO_2 must fall to ~85 mmHg and fractional inspired (tracheal) oxygen concentration to ~18.5%. To achieve this, assuming 5% ambient oxygen (conservative, as higher concentrations require greater leakage to dilute mask-supplied air), the inspirate must comprise ~15% ambient gas, i.e., consistent 15% inboard leakage. Slightly less conservative assumptions suggest insensitivity to 20% leakage. At 40,000 ft such leak rates would cause severe hypoxia. Further, unlike resting study subjects, pilots would be active while managing an in-flight emergency, with increased ventilatory demand and head movements exaggerating mask leaks and promoting further desaturation. Contrary to the authors' view, leak quantification under representative conditions is essential and readily achievable with respiratory mass spectrometry, a standard tool in contemporary altitude research.

The authors reference an unpublished hypobaric study of pilot oxygen mask efficacy in bearded use, stating erroneously that "beard length did not impact oxygen saturation levels."[2] One bearded subject's S_pO_2 fell to 93% at 25,000-ft (7620-m) pressure altitude despite breathing 100% oxygen supplied under positive pressure, implying gross (~50%) inboard leakage of ambient air. Comparable leaks above 35,000 ft (10,668 m) or following rapid decompression would cause severe hypoxia and likely incapacitation. Robust mask seals are also essential to exclude smoke/fumes during in-flight emergencies. Hence, for research purposes, challenge agent testing should quantify ambient and mask cavity concentrations to determine the protection factor achieved.

Higher quality studies provide compelling quantitative evidence, relevant to quick don systems, that beards degrade the respiratory protection of close-fitting masks.[3–5] Pertinent literature reviews are unambiguous: facial hair that interacts with the seal of a close-fitting mask may compromise its integrity (admittedly unpredictably).[6,7] This remains true for breathing gas supplied under positive pressure.[7–9]

Desmond M. Connolly
Principal Medical Officer, Air & Space Division
QinetiQ PLC
Farnborough, Hampshire, United Kingdom

REFERENCES

1. French J, Wagner SD. Beard length and the efficacy of an aviator oxygen mask. Aerosp Med Hum Perform. 2025; 96(4):322–326.
2. Ferguson S, Warkander D, Hutcheon E, Doesburg S. The efficacy of oxygen delivery masks for commercial pilots with facial hair [Abstract]. Aerosp Med Hum Perform. 2020; 91(3):211–212.

DOI: https://doi.org/10.3357/AMHP.6707.2025

3. Floyd EL, Henry JB, Johnson DL. Influence of facial hair length, coarseness, and areal density on seal leakage of a tight-fitting half-face respirator. J Occup Environ Hyg. 2018; 15(4):334–340.
4. Fothergill D. Purge procedures and leak testing for the Morgan Breathing System (MBS) 2000 closed-circuit oxygen rebreather. Groton (CT): Naval Submarine Medical Research Laboratory; 2005. Report No.: NSMRL Technical Report #1241.
5. Skretvedt OT, Loschiavo JG. Effect of facial hair on the face seal of negative-pressure respirators. Am Ind Hyg Assoc J. 1984; 45(1):63–66.
6. Stobbe TJ, da Roza RA, Watkins MA. Facial hair and respirator fit: a review of the literature. Am Ind Hyg Assoc J. 1988; 49(4):199–204.
7. Bolsover SM. Leakage measurements on wearers of respiratory protective equipment with facial hair/beards/spectacles: summary of a literature search. J Int Soc Respir Prot. 1992; 10:15–22.
8. McGee MK, Oestenstad RK. The effect of the growth of facial hair on protection factors for one model of closed-circuit, pressure-demand, self-contained breathing apparatus. Am Ind Hyg Assoc J. 1983; 44(7): 480–484.
9. Da Roza RA, Cadena-Fix CA, Kramer JE. Powered air purifying respirator study. J Int Soc Respir Prot. 1990; 8(2):15–36.

IN RESPONSE:

The author of the critique provides a learned, if somewhat condescending, tutorial of why he believes our study is "flawed" and "insensitive to relevant mask leaks." We were responding to the 1987 Federal Aviation Administration Advisory Circular[1] that states aviation mask leaks from beards "could result in reduced crew member capability and performance." We couldn't find any peer-reviewed articles that demonstrated aviation masks leak enough from beards to cause impaired performance of pilots.

We have three pieces of evidence supporting our absence of hypoxia finding. First, our study demonstrated that in conditions relevant to aviators exposed to air in a hypoxia chamber at 30,000-ft (9144-m) equivalent using tissue-level sensitive S_pO_2 measures, individuals with beards of any length remained normoxic with the masks on. Second, we showed that as soon as the masks were removed for about 3 min, our measures picked up hypoxic S_pO_2 within seconds. Third, smelling salts were not perceived by our masked individuals.

The author says that our measure of fingertip pulse oximetry (S_pO_2) "resists dilution of mask-supplied air." He seems to be saying that our bearded subjects were experiencing reduced blood-level gases (P_aO_2) and were in fact hypoxic by that measure, which we would not see with our oximeters, even though they wirelessly recorded S_pO_2 at 1 Hz the entire time in the chamber. The masks were worn for at least 20 min at 30,000-ft equivalent air and only normoxic levels were recorded. This is longer than commercial pilots are required wear masks to establish safe altitudes during a decompression. We would like to remind the author that in normoxic individuals, far more of the available oxygen is bound to hemoglobin (S_pO_2) not dissolved in the blood (P_aO_2). Henry's Law tells us this bound oxygen is more important for tissue than oxygen dissolved in blood.

The author suggests a (very confusing) study of what he considers the most challenging situation in a normobaric chamber, and we highly encourage him to try it. Stimulating more research was another purpose of the paper.

He cites three articles that he believes show that beards cause leaks. All used nonaviation conditions and nonaviation masks and had no measure of tissue-level S_pO_2. He seems to have missed the point of the Floyd et al. article.[2] They found that some industrial masks were still effective in meeting the strict Occupational Safety and Health administration fitness standards "even with substantial facial hair in the face seal area." The author also points out that the one person in the Ferguson study[3] had 2 oximeter readings out of 13 (i.e., every 15 s) at 25,000 ft (7620 m) that were 93% S_pO_2 (failing to mention that this is still considered normoxic). He also forgot to mention that this person was in a group of people whom most would not describe as having a beard (length < 0.5 cm). All but this one were in the +97% range. Therefore, we find his references and arguments to be flawed and insensitive to relevant measures of mask leakage.

John French
Professor, Department of Human Factors and Aerospace Physiology
Embry-Riddle Aeronautical University
Daytona Beach, FL, United States

REFERENCES

1. Kern JS. The influence of beards on oxygen mask efficiency. Washington (DC): Federal Aviation Administration; 1987. Advisory Circular No. 120-43. [Accessed May 15, 2025]. Available from https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentid/22765.
2. Floyd EL, Henry JB, Johnson DL. Influence of facial hair length, coarseness, and areal density on seal leakage of a tight-fitting half-face respirator. J Occup Environ Hyg. 2018; 15(4):334–340.
3. Simon Fraser University. Facial hair on pilots: study busts myth. ScienceDaily. 2018. [Accessed May 15, 2025]. Available from https://www.sciencedaily.com/releases/2018/09/180921140157.htm.

Please send suggested books for review as well as reviews of books,
articles of aeromedical interest, films, websites, etc. to
Geff McCarthy, M.D., geffandjulie@comcast.net

Book Review

Koglbauer IV, Biede-Straussberger S, editors. *Aerospace psychology and human factors: applied methods and techniques.* Newburyport (MA): Hofgrefe Publishing Corp; 2025.

From the European Association for Aviation Psychology, *Aerospace Psychology and Human Factors: Applied Methods and Techniques* is a compendium of contemporary research methods in human performance, organized into 14 short chapters on topics familiar and arcane: "Integrating Human Factors into the Design Process," "The Five Pillars of Assistance Systems," "Hazards of Human Space Exploration," etc. The last 7 chapters intensely illustrate progress in virtual reality research and effectiveness in pilot training. Numerous references from a plethora of journals follow each chapter, with a small minority from *Aerospace Medicine and Human Performance* and the *International Journal of Aerospace Psychology.*

Although written by Europeans, the English usage is accurate, especially when describing theoretical concepts; however, its long British sentences may not appeal to American readers. Curiously, the last pages comprise very positive reviews from other human factors researchers! Several design and process block-and-flow diagrams are very useful.

Conversely, some theoretical chapters lack examples, and others recite experimental results with no indication that a global literature search is the source. The chapter entitled "CIMON: The First Artificial Crew Assistant in Space" is both illuminating and charming.

Another chapter on meta-analysis methods will be familiar to physician researchers, perhaps not to engineers, and therefore worthwhile. The chapter on situational awareness will also be familiar to tactical pilots, and perhaps less so to novice airline crews. Spaceflight hazards might be seen as a brief review of space medicine.

The implicit subject of the authors is airline operations and business flying. Rarely mentioned is use of these methods in tactical aircraft. Thus, the chapter on cockpit design does not consider sound and vibration as feedback performance cues for the aviator. Similarly, the extensive discussion of cybersickness minimization in virtual reality does not address adaptation techniques, and the test sessions are surprisingly short at 20 min of simulation.

A brief search for similar human factors texts produced only Proctor and Van Zandt's *Human Factors in Simple and Complex Systems*, Wickens and Hollands' *Engineering Psychology and Human Performance,* and Keebler et al.'s *Human Factors in Aviation and Aerospace*, which are broader and more basic in content.

Aerospace Psychology and Human Factors: Applied Methods and Techniques is current and looks to the future, a worthwhile investment for *Aerospace Medicine and Human Performance* readers. Highly recommended.

Reviewed by
Geoffrey W. McCarthy

DOI: https://doi.org/10.3357/AMHP.6718.2025

Aerospace Medicine Clinic

This article was prepared by Joseph J. Pavelites, II, M.S., B.S.; Shelby L. Dean, D.O., M.P.H.; Jelaun K. Newsome, D.O., M.P.H.; and Joseph J. Pavelites, M.D., Ph.D.

You are a military flight surgeon assigned to a flight medicine clinic. This is your week to man the on-call phone and, as luck would have it, you receive a call from a Dive Medical Officer (DMO) from a sister military service. The DMO states that one of your unit's rotary wing crew chiefs was involved in a recreational diving accident earlier today while on leave. The DMO assures you that the crew chief does not appear to be seriously injured but is being treated in a hyperbaric chamber. You appreciate that the DMO has reached out in a timely fashion and is going to update you periodically throughout the day to make sure that you are informed about the details of the event and the service member's treatment course.

The DMO states that on the second scuba recreational dive of the day, the service member experienced what appeared to be an arterial gas embolism (AGE) after exceeding the travel rate on ascent from his dive. The crew chief is a novice diver who was using compressed air and was in the company of experienced military divers who initiated an emergency action plan. This plan included diving first aid and immediate ground evacuation to a nearby military recompression chamber for recompression treatment under the supervision of the DMO who was on call.

The divers were attempting to dive a shipwreck with a maximum bottom depth of 72 ft of seawater (fsw). The service member left the bottom after 37 min of bottom time. He reached the surface 1.0 min and 7.0 s after leaving the bottom, more than doubling the allowable travel rate. According to the DMO, the prescribed dive table and schedule stated that the service member's ascent was to have taken no less than 2 min and 24 s from 72 fsw. You are not a diver. However, training in aerospace medicine has given you a background in the subject and you ask about how the first dive could have contributed to the problem. The DMO is happy that you asked the question, as repetitive diving can increase the odds of decompression sickness (DCS) due to a series of additive exposures and the possible cumulative retention of nitrogen gas (i.e., "residual nitrogen"). In this case, the first dive was a short test of the equipment and an orientation to the dive environment. It was at a depth of approximately 15 ft (5 m) at a bottom time of 10 min and would not require safety stops or other extensive surface time. With a lot to think about, you turn your attention to ascent rates and what rates the U.S. Navy recommends.

1. What is the generally recommended ascent rate for scuba dives put forth by the U.S. Navy?
   A. 60 ft $\cdot$ min^{-1} (18 m $\cdot$ min^{-1}).
   B. 30 ft $\cdot$ min^{-1} (9 m $\cdot$ min^{-1}).
   C. Ascend slower than the bubbles coming from your respirator.
   D. 75 ft $\cdot$ min^{-1} (22.5 m $\cdot$ min^{-1}).

ANSWER/DISCUSSION

1. B. The U.S. Navy Diving Manual section 9-6.3 states, "The ascent rate from the bottom to the first decompression stop, between decompression stops, and from the last decompression stop to the surface is 30 fsw/min".[1] The National Oceanic and Atmospheric Administration also uses this rate. The Professional Association of Diving Instructors and other civilian diving organizations use 60 fsw/min when ascending from more than 60 fsw. Ascending slower than the bubbles coming from your respirator is a poor rule of thumb that has been used unofficially for years. In addition, it was used by the U.S. Navy from 1957–1991 for hard-hat divers using surface-supplied air. Ascending at 75 ft $\cdot$ min^{-1} (22.5 m $\cdot$ min^{-1}) is too rapid and it is not generally endorsed as a safe procedure.

Your crew chief was ascending at a rate of approximately 65.5 ft $\cdot$ s^{-1} (19.3 m $\cdot$ s^{-1}), not the 30 ft $\cdot$ min^{-1} (9 m $\cdot$ min^{-1}) that would have taken him 2 min and 24 s to surface. Shooting to the surface so quickly greatly increased his risk of developing decompression illness (DCI), and this did not account for the possible decompression stops he may have missed. The service member may have needed to break up his ascent with stops at

DOI: https://doi.org/10.3357/AMHP.6709.2025

intermediate depths for appropriate wait times before continuing the ascent to more safely manage the DCI risk.

2. What are some common reasons for ascending too quickly on a dive?
   A. Diver does not monitor air supply, resulting in an out-of-air situation.
   B. Inadequate buoyancy control.
   C. Failure to properly monitor ascent rate.
   D. Buoyancy compensator or other equipment failure.
   E. All of the above.

ANSWER/DISCUSSION

2. E. All of the above answers are correct. However, there are additional reasons that may lead to a rapid or uncontrolled ascent to the surface, such as seeing a shark, following another diver who is ascending too rapidly, or suffering an injury.[2] Fatigue, physical fitness, and lack of experience or training on the part of the diver also contribute to the increased incidence of diving injuries.[3] Obtaining a history where the patient or witness attests to a rapid ascent can help narrow the differential diagnosis to AGE. This can help differentiate between the presentations of more common concerns, such as hypoglycemia or acute hemorrhagic stroke.[2]

The DMO describes that the patient stated he knew he exceeded the travel rate; however, he suggested his buoyancy compensator was not deflating properly, contributing to the cause of his fast ascent. The service member exited the water under his own power. The more experienced divers, following their military training, stripped the crew chief of his equipment and performed a rapid neurological exam after surfacing and placed him under direct observation. The service member reported no concerns at the surface and the rapid neuro exam was normal. However, after 13 min of observation, the diver notified his friends that he felt tingling that turned to numbness of his right flank. Initially, a 4.5-in diameter numb spot was mapped approximately 6.0″ under his right nipple. He was placed on 100% oxygen, delivered by a venturi mask, at a rate of 15 $L \cdot min^{-1}$ while being transferred to shore and to the dive treatment facility. A more robust neurological exam was in progress under transit conditions. The numb spot was observed to be growing laterally from the sternum toward the patient's right side.

The patient is now in a recompression chamber under the supervision of the DMO. After 20 min of treatment using the "standard of care" (i.e., Navy Dive Table VI), his vitals are within normal limits and the numb patch is less than a quarter of its original size. You thank the DMO for the call and you are standing by for updates as the treatment continues.

3. Which one of the following is NOT part of a Navy Dive Table VI?
   A. 5-min compression phases to a depth of 18 m of seawater (msw).
   B. A decompression phase to 9.0 msw.
   C. 2 air cycles lasting 60 min each.
   D. 285 min of total elapsed time.

ANSWER/DISCUSSION

3. C. The cycles use 100% oxygen, not air. The bubbles causing the problem are most likely nitrogen. As air contains approximately 71% nitrogen, breathing 100% oxygen is best to flush out the nitrogen, rather than breathing in more nitrogen. Navy Dive Table VI consists of a compression phase approximately 5 min long to a depth of 18 msw under 100% oxygen, and four oxygen cycles lasting 20 min each with short air intervals. Afterward, the patient is decompressed to approximately 9 msw and exposed to two oxygen cycles lasting 60 min each and slowly returned to surface pressure. The total elapsed time is approximately 285 min (4 h 45 min). Navy Dive Table V is similar to Dive Table VI, but with shorter and fewer oxygen cycles; the total elapsed time is approximately 135 min, excluding descent.[2]

The DMO mentioned that the hyperbaric chamber should help the patient, no matter what type of DCI he has. He reminds you that "decompression illness" refers to DCS Type 1 (cutaneous and musculoskeletal) and Type 2 (neurological), as well as AGE. As the patient will be flying home by commercial air upon release from treatment, you discuss air travel after scuba diving. After a single dive, a 12-h minimum surface time is recommended before flying on commercial aircraft or 18 h after multiple dives. However, at least 24 h is recommended. The DMO assures you that the patient will not be flying for several days.

Although the extent of the crew chief's injuries seems minor, you want to be prepared to answer the patient's questions upon his return. You look into the literature to be better informed about AGE. You find there are two major causes of AGE: direct injection of a gas into the blood, such as what might occur during the catheterization of a blood vessel, and spontaneous bubble formation, as seen in DCS in underwater divers (and more rarely, aircrew).[4] According to Henry's Law, the increased pressure experienced at depth by a diver allows more gas to dissolve in the blood and tissues than the lower pressure at the surface. With the decreasing pressure as the diver ascends from depth, less gas stays dissolved. This leads to gas bubbles evolving from the tissues of the body. The more rapidly a diver ascends, the faster gas will evolve and the less likely that the forming bubbles can be released safely. A rapid ascent raises the chances of harmful consequences, including the occurrence of AGE.[5]

AGE in divers can result from bubbles entering the arteries directly after the pulmonary barotrauma of ruptured alveoli. It may also occur if bubbles in the venous circulation pass into the arterial circulation through a patent foramen ovale. Alternatively, there can be so many nitrogen bubbles present in the veins that the pulmonary capillaries cannot exchange gas into the alveoli before blood passes into the arterial system.[6]

Increased risk for DCI includes deep or long-duration underwater dives, especially when the dives include vigorous physical activity as seen in military operations. Boyle's Law states that as ambient pressure decreases, the volume of a gas increases. An uncontrolled ascent can be provocative for AGE, especially if the diver holds their breath. Here the trapped air can overinflate the lungs due to the rapid air expansion with ascension, resulting in pulmonary barotrauma. Resulting gas bubbles can move through the arteries to other organs such as the heart or brain and block blood flow, causing a myriad of symptoms such as chest pain, confusion, unconsciousness, weakness, numbness, and tingling. Additionally, gas may make its way to the tissues just under the skin, becoming palpable bubbles called subcutaneous emphysema.[6–8]

The fundamental pathology present during an episode of AGE is caused by two major mechanisms.[2] The first cause is a physical blockage of blood flow by the presence of the gaseous mass. The second is mechanical endothelial damage to the vessel because of the bubble acting as a foreign substance, inducing inflammatory and coagulation cascades.[2] Damage to the endothelium triggers many mechanisms, including the release of C3a and C5a anaphylatoxins during complement activation, increases in prostaglandin and leukotriene production, platelet and leukocyte activation, and fibrin release with endothelium adhesion. This cascade causes impairment of the microcirculation, vasospasm followed by vasodilation, and damage to the blood brain barrier.[9] Both mechanisms can lead to hypoxia in the surrounding tissues, with potentially life-threatening consequences in vital organs such as the brain or heart.[4]

In contrast, DCS is not caused by rupture of lung tissue and air being introduced into the arteries. In DCS, there is a spontaneous evolution of dissolved nitrogen gas bubbles in the blood and other tissues as the diver begins to head for the surface per Henry's Law. At deep-sea levels, high ambient pressure forces nitrogen gas to equilibrate in the diver's tissues. Slow ascent allows tissues to gradually re-equilibrate to the ambient pressure and release nitrogen slowly and safely. The bubbles that can form during a rapid ascent press on surrounding structures, compress nerve endings, impede venous return, and produce inflammatory responses as a foreign body would. These insults have wide-ranging consequences with symptoms that may include fatigue, rash, shortness of breath, confusion, joint pain, skin pruritis, numbness, tingling, muscle weakness, an impaired gait, or difficulty walking.[1,8]

If the patient has skin itching or burning and/or joint or muscle pain, this is considered Type 1 DCS and Treatment Table V may be used. However, if a patient is suspected to have an AGE or Type 2 DCS (circulatory, respiratory, or neurological symptoms), the standard is Treatment Table VI.[1,10]

Looking at Table IX-VII, No Decompression Limits and Repetitive Group Designators for No-Compression Air Dives, in the Navy Diving Manual, you check to see if the patient's bottom depth and time required a safety stop to aid in lowering the risk of DCS. While this dive was technically a repetitive dive, the initial dive was at 15 ft (5 m) for less than 34 min. For the second dive, the diver spent 37 min beneath 72 fsw. Table IX-VII has entries for 70 ft (21 m) and 80 ft (24 m). One would need 48 min at 70 ft and 39 min at 80 ft to require a safety stop. Since the diver spent less than 39 min at 72 ft (22 m), he was not required to perform a safety stop on his way up.[1]

When comparing the Navy Diving Manual to civilian/recreational tables, the civilian/recreational tables are more conservative. The recommendation for safety stops and considerations for repetitive dives usually start after dives of 30 fsw or greater. While civilian dive tables also have entries for 70 ft and 80 ft, convention recommends rounding up. On a civilian dive table, one would need 38 min at 70 ft and 29 min at 80 ft to require a safety stop. Since the diver spent 37 min at 72 ft, he would have been required to perform a safety stop on his way up if using a civilian dive table, rather than a Navy dive table.

Despite not needing a safety stop according to the Navy dive tables, our diver ascended much more quickly than recommended (1 min and 7 s compared to the recommended 2 min and 24 s maximum ascent rate per the Navy Diving Manual), which put him at high risk for pulmonary barotrauma and subsequent AGE. However, overlap in symptom profiles makes it difficult to tell for sure that he had AGE rather than Type 2 DCS. In either case, he received the correct treatment. Unfortunately, now that the diagnosis of AGE has entered his medical record, it must be addressed by the flight surgeon. Knowing that this injury has implications for the patient's aviation career, you decide to review his service's specific aeromedical regulations as well as those of the sister services and civilian aviation organizations.

The U.S. Navy Aeromedical Reference and Waiver Guide does not specifically address AGEs but does have a guideline for DCS. A consultation with a neurologist at the Naval Aerospace Medical Institute is required prior to returning to flight duty. They also require a normal evaluation by a DMO or neurologist. Before an aviator with Type 1 DCS can fly again, they require a period of 3 d or more with no symptoms; in contrast, an episode of Type 2 DCS requires 14 d or more symptom-free. Episodes of DCS with lingering symptoms warrant caution and are disqualifying for flight duties, with the possibility of a waiver being granted after further workup, such as a neurological workup and, if necessary, a neuropsychological evaluation.[10] It should be mentioned that the Navy's Manual of the Medical Department chapter 15-84 states that AGEs are disqualifying for flight duties.[11]

The U.S. Army's Aeromedical Policy Letters state that recurrent Type 1 DCS or any case of Type 2 DCS requires a waiver, which is granted on a case-by-case basis.[12] Neurological and cognitive symptoms require neurological or neuropsychology evaluation. There is a mention of air embolism as a possible complication of lung bullae rupture in chronic obstructive pulmonary disease or tuberculosis.[13] Army Regulation 40-501: Medical Services Standards of Medical Fitness states that Type 2 DCS or air embolism with neurological involvement does not meet medical fitness requirements for flight duty.[14]

The U.S. Air Force Medicine Waiver Guide Compendium states "decompression sickness (DCS) or air embolism (AGE) with neurologic involvement by history, physical examination or evidence of structural damage on imaging studies is disqualifying. … Hypobaric chamber-induced neurologic DCS/AGE with symptom resolution within 2 weeks does not require waiver. Any altitude-induced DCS/AGE episode that requires recompression therapy and symptoms are not resolved within 2 weeks requires a waiver."[15] Any DCS or AGE with symptoms lasting longer than 2 wk also requires the aviator not to fly for at least 6 mo. Waiver requests require noncontrast magnetic resonance imagery within a month of the event, neurocognitive testing, and chest radiography to rule out lung pathology if an AGE is suspected.

The Federal Aviation Administration's 2024 Guide for Aviation Medical Examiners does not give guidance on AGE or DCS.[16] Correspondence with a regional flight surgeon revealed that clearance after an episode of AGE or DCS is decided after all the following have been received by the Federal Aviation Administration: records of all initial and follow-up evaluations, studies, and treatments, as well as a detailed provider note at least 90 d after the incident, detailing symptoms and their resolution, as well as prognosis and any recommendations for follow-up. Workup should include testing for patent foramen ovale.

The International Civil Aviation Organization's Manual of Civil Aviation Medicine discusses the pathophysiology of DCS, but there is no specific waiver guidance. It does give the following guidance for neurological conditions:

When considering neurological disorders in license holders, the medical assessor should be mindful of the following questions:

1. Does the license holder have neurological disease at all?
2. If there is a static condition, does it functionally compromise flight safety?
3. Does the condition have a progressive temporal profile that can be monitored?
4. Does the condition have the potential for insidious incapacitation?
5. Does the condition have the potential for sudden incapacitation?
6. Has the license holder recovered from the condition without functionally significant residual neurological compromise?[17]

After reviewing regulatory guidance on aeromedical dispositioning after AGE, you begin to wonder how frequent AGE injuries occur and their different etiologies.

4. Which of the following is the most likely cause of an AGE in the nondiving general population?
   A. Surgical procedures.
   B. Rapid ascent during underwater diving operations.
   C. Rapid decompression in military aircraft.
   D. Mountain climbing.

ANSWER/DISCUSSION

4. A. Nearly any procedure where access to vasculature is involved can increase the risk of developing an AGE. Central line placement and manipulation is the most common cause of iatrogenic AGE followed by thoracic surgical procedures. However, the risk is small, with one study analyzing over 4.7 million hospitalizations finding only 127 proven iatrogenic episodes of any type of gas embolism.[18] Despite its rarity, iatrogenic AGE can be very serious, with 21% mortality reported a year after the incident, although in many cases the patients were critically ill before requiring the procedure that led to the occurrence of an AGE.[18] Of particular concern to the aviation community is the nearly identical pathophysiology, but different associated history, of aerospace DCI.[19] This disease, like diving-associated DCI, is caused by formation of bubbles in the blood by an individual moving to a lower pressure environment. However, here the individual exposes themselves to a movement from a lower altitude to a higher altitude such as what can be seen in an ascending unpressurized aircraft. As one would imagine, the risk of experiencing DCI is increased if an individual recently went scuba diving and then climbed to altitude in a non-pressurized aircraft (i.e., making the drop in pressure even more profound than simply swimming to the surface).[19]

The DMO updates you on the outcome of the crew chief's treatment and you are happy to hear that the neurological symptoms have fully resolved. The DMO is certain that the crew chief suffered an AGE and has documented it in the patient's medical record. You set an appointment in your aerospace medicine clinic in a week. You perform a full neurological exam of the patient and there appears to be no sequelae from the dive accident. However, his service requires a workup to grant a waiver, and you discuss with the patient that he cannot fly until he is evaluated by a neurologist. After informing his command of your decision, you await the results of the additional workup.

The neurology note states that the patient's neurological function was normal with no remaining effects. The neurologist recommends that the crew chief be returned to full flying duties. You proceed with the completion of the necessary paperwork and submit the waiver request. You are happy to report to the crew chief that the waiver has been granted by his service and he can continue his aviation career.

Pavelites JJ II, Dean SL, Newsome JK, Pavelites JJ. *Aerospace medicine clinic: arterial gas embolism.* Aerosp Med Hum Perform. 2025; 96(9):864–868.

ACKNOWLEDGMENTS

The views expressed are those of the authors and do not reflect the official guidance or position of the U.S. Government, the Department of Defense (DoD), or the U.S. Army. The appearance of external hyperlinks does not constitute endorsement by the DoD of the linked websites, or the information, products, or services contained therein. The DoD does not exercise any editorial, security, or other control over the information you may find at these locations.

REFERENCES

1. U.S. Navy. U.S. Navy diving manual, revision 7. Washington (DC): Naval Sea Systems Command; 2018. [Accessed April 27, 2025]. Available from https://www.navsea.navy.mil/Portals/103/Documents/SUPSALV/Diving/US%20DIVING%20MANUAL_REV7.pdf.

2. Walker JR, Hexdall EJ, Murphy-Lavoie HM. Diving gas embolism. In: *StatPearls*. Treasure Island (FL): StatPearls Publishing; 2025. [Accessed April 27, 2025]. Available from https://www.ncbi.nlm.nih.gov/books/NBK482321/.
3. O'Connor P. The nontechnical causes of diving accidents: can U.S. Navy divers learn from other industries? Undersea Hyperb Med. 2007; 34(1): 51–59.
4. Alexander AM, Sankari A, Martin N. Arterial gas embolism. In: *StatPearls*. Treasure Island (FL): StatPearls Publishing; 2025. [Accessed April 27, 2025]. Available from https://www.ncbi.nlm.nih.gov/books/NBK546599/.
5. Jones MW, Brett K, Han N, Cooper JS, Wyatt HA. Hyperbaric physics. In: *StatPearls*. Treasure Island (FL): StatPearls Publishing; 2025. [Accessed April 27, 2025]. Available from https://www.ncbi.nlm.nih.gov/books/NBK448104/.
6. Bralow LM, Piehl M. Barotrauma and arterial gas embolism: a diving emergencies simulation case for emergency medicine residents. MedEdPORTAL. 2018; 14:10788.
7. Kennedy-Little D, Sharman T. Pulmonary barotrauma. In: *StatPearls*. Treasure Island (FL): StatPearls Publishing; 2025. [Accessed April 27, 2025]. Available from https://www.ncbi.nlm.nih.gov/books/NBK559293/.
8. Thalmann E. Decompression illness. (N.D.). [Accessed April 27, 2025]. Available from https://dan.org/health-medicine/health-resources/diseases-conditions/decompression-illness-what-is-it-and-what-is-the-treatment/.
9. Mukundakrishnan K, Ayyaswamy PS, Eckmann DM. Computational simulation of hematocrit effects on arterial gas embolism dynamics. Aviat Space Environ Med. 2012; 83(2):92–101.
10. Naval Aerospace Medical Institute. 10.2. Decompression sickness. In: *U.S. Navy aeromedical reference and waiver guide*. Pensacola (FL): Naval Aerospace Medical Institute; 2023. [Accessed April 27, 2025]. Available from https://www.med.navy.mil/Navy-Medicine-Operational-Training-Command/Naval-Aerospace-Medical-Institute/Aeromedical-Reference-and-Waiver-Guide/.
11. U.S. Navy. Article 15-84. Disqualifying conditions for all aviation duty. In: *Manual of the Medical Department*. Falls Church (VA): Bureau of Medicine and Surgery; 2023. NAVMED P-117. [Accessed April 27, 2025]. Available from https://www.med.navy.mil/Portals/62/Documents/BUMED/Directives/MANMED/1%20Jun%202018%20%20MANMED%20Change%20165%20(Revises%20MANMED%20Chapter%2015%20articles%2015-63%20through%2015-101).pdf?ver=8eU_q21pP-UyM-TqpP6zHA%3d%3d.
12. U.S. Army Aeromedical Activity. Decompression sickness. In: *Flight surgeon's aeromedical checklists*. Aeromedical policy letters [Mobile app]. 2021. [Accessed April 27, 2025]. Available from https://play.google.com/store/search?q=med%20standards&c=apps.
13. U.S. Army Aeromedical Activity. Chronic obstructive pulmonary disease. In: *Flight surgeon's aeromedical checklists*. Aeromedical policy letters [Mobile app]. 2021. [Accessed April 27, 2025]. Available from https://play.google.com/store/search?q=med%20standards&c=apps.
14. U.S. Army. Standards of medical fitness. Washington (DC): Department of the Army; 2019. Army Regulation 40-501. [Accessed April 27, 2025]. Available from https://armypubs.army.mil/epubs/DR_pubs/DR_a/ARN37720-AR_40-501-002-WEB-4.pdf.
15. Connolly J, Delgado A, Ford A, Lee M, Vu P. Decompression sickness and arterial gas embolism. In: *Air Force aerospace medicine waiver guide*. Wright-Patterson AFB (OH): U.S. Air Force School of Aerospace Medicine; 2025. [Accessed April 27, 2025]. Available from https://www.afrl.af.mil/711hpw/usafsam/.
16. Federal Aviation Administration. Guide for aviation medical examiners. Washington (DC): Federal Aviation Administration; 2023. [Accessed April 27, 2025]. Available from https://www.faa.gov/ame_guide/media/ame_guide.pdf.
17. International Civil Aviation Organization. Chapter 1.4: Decompression. In: *Manual of civil aviation medicine*. 3rd ed. Quebec (Canada): International Civil Aviation Organization; 2012. Doc 8984. [Accessed April 27, 2025]. Available from https://www.icao.int/publications/pages/publication.aspx?docnum=8984.
18. Bessereau J, Genotelle N, Chabbaut C, Huon A, Tabah A, et al. Long-term outcome of iatrogenic gas embolism. Intensive Care Med. 2010; 36(7): 1180–1187.
19. de la Cruz RA, Clemente Fuentes RW, Wonnum SJ, Cooper JS. Aerospace decompression illness. In: *StatPearls*. Treasure Island (FL): StatPearls Publishing; 2025. [Accessed April 27, 2025]. Available from https://www.ncbi.nlm.nih.gov/books/NBK448160/.

AUGUST 2000

Cabin air (Uppsala University, Sweden; Scandinavian Airlines System, Stockholm, Sweden): "[On intercontinental flights] humidity was very low (mean 5%) … CO_2 concentration was below 1000 ppm. … [C]oncentration of respirable particles was 67 $\mu g \cdot m^{-3}$ during smoking conditions, and 4 $\mu g \cdot m^{-3}$ during nonsmoking conditions. … Female crew had more complaints on too low temperature, dry air, and dust. Current smokers had less complaints on stuffy air and environmental tobacco smoke (ETC). Younger subjects and those with atopy … reported more complaints. Reports on work stress and lack of influence on working conditions were strongly related to perception of a poor cabin environment. Flight deck crew had more complaints about inadequate illumination and dust, but less complaints about other aspects of the cabin environment, as compared with flight attendants."[1]

Inflight medical emergencies (American Medical Association, Chicago, IL): "[T]he AMA Council on Scientific Affairs determined that, while inflight morbidity and mortality are uncommon, serious events do occur, which require immediate emergency care. Management of serious problems requires an integrated emergency response system that ensures rapid notification of medical personnel on the ground, assistance from appropriately trained flight crews and passenger volunteers (if available), and adequate medical supplies and equipment to stabilize the victim."[2]

Pregnant flyers (Institute of Aviation Medicine, Royal Australian Air Force Base, Edinburgh, South Australia): "Review of the literature and the basic physiology involved suggests that air transport, both rotary wing and fixed wing, does not predispose to either an increase in or acceleration of obstetric events. In fact, the literature strongly suggests that air transport is frequently extremely valuable in obstetric emergencies, and has no impact in advanced uncomplicated pregnancy. It is concluded that obstetric cases can be safely transported at any gestational age."[3]

AUGUST 1975

Space toxins (Medizinische Universitaetsklinik, Tuebingen, Germany; University of Houston, Houston, TX; NASA-Johnson Space Center, Houston, TX): "The volatile organic components in the spacecraft cabin atmosphere of Skylab 4 … [showed] more than 300 compounds in concentrations from less than 1 ppb up to 8000 ppb could be detected … [A]pproximately 100 components in the molecular weight range of 58–592 were identified … Besides … alkanes, alkenes, and alkylated aromatic hydrocarbons, components typical for the human metabolism such as ketones and alcohols were found. Other typical components in the spacecraft atmosphere are fluorocarbons (freons) and various silicone compounds, mostly normal and cyclic methylsiloxanes."[4]

Biting noise (University of Pittsburgh, Pittsburgh, PA): "Three groups of 25 men were selected from the Pennsylvania Air National Guard for study. … The degree of alveolar, intraceptal bone loss for each subject was measured from full-mouth radiographs of all groups. The greatest amount of bone loss occurred in crew members of propeller-driven aircraft. Jet pilots had considerably less bone loss while the average number of millimeters of bone lost per tooth revealed a difference between the three groups to the 0.01 significance level ($F = 24.7$). The data suggests there is a degree of alveolar bone loss over a period of years associated with exposure to propeller aircraft noise and vibration, and negligible loss for jet aircraft noise."[5]

AUGUST 1950

Seeing in the cockpit (U.S. Navy): "A navy pilot levels his plane off above 50,000 feet. Looking outside the cockpit he sees the sky, a dark blue of low reflectivity… Below the horizon he sees glaringly brilliant reflections from the atmospheric dust and haze. … Looking down to record his position report, his flying suit and the bright white knee pad appear suspended in the dim black cockpit. … He scans the sky for other traffic and cloud formations and then returns his gaze to the instrument panel … The nonspecular instrument panel is almost invisible. Blurred, almost fused, specks of light-yellow color tell him that these are the numerals on the instrument dials."[6] Note: The author, Naval Flight Surgeon Norman Barr, led the development of the first global airborne telemetry capabilities in the 1950s.

New U.S. Air Force (Surgeon General, U.S. Air Force): "Now that the Air Force Medical Service has 'come of age,' I believe that our horizons are as limitless as the world of space which we seek to conquer. Unhampered by tradition and yet free to exploit our experiences covering some thirty-three years and two world wars presents an opportunity unique in military medical history. Those of us who have the honor and privilege of blueprinting and building this new service are not unaware of the momentous task with which we are faced. However, we accept this challenge with enthusiasm and optimism tempered by a determination that the completed edifice shall not only be a distinct credit to military medicine but also make worthy contributions to American medicine, to all humanity, and to a lasting peace for this troubled world in which we live."[7]

REFERENCES

1. Lindgren T, Norbäck D, Andersson K, Dammström B-G. Cabin environment and perception of cabin air quality among commercial aircrew. Aviat Space Environ Med. 2000; 71(8):774–82.
2. Lyznicki JM, Williams MA, Deitchman SD, Howe JP. III. Council on Scientific Affairs, American Medical Association. Inflight medical emergencies. 2000; 71(8):832–8. Aviat Space Environ Med.
3. Newlands JC, Barclay JR. Air transport of passengers of advanced gestational age. Aviat Space Environ Med. 2000; 71(8):839–42.
4. Liebich HM, Bertsch W, Zlatkis A, Schneider HJ. Volatile organic components in the Skylab 4 spacecraft atmosphere. Aviat Space Environ Med. 1975; 46(8):1002–7.
5. Haskell BS. Association of aircraft noise stress to periodontal disease in aircrew members. Aviat Space Environ Med. 1975; 46(8):1041–3.
6. Barr NL. Visibility of cockpit instruments. J Aviat Med. 1950; 21(4):328–42.
7. Armstrong HG. The new medical service of the United States Air Force. J Aviat Med. 1950; 21(4):318–20.

This column is prepared each month by Walter Dalitsch III, M.D., M.P.H. Most of the articles mentioned here were printed over the years in the official journal of the Aerospace Medical Association. These and other articles are available for download through the link on the AsMA website: https://www.asma.org/journal/read-the-journal.

DOI: https://doi.org/10.3357/AMHP.6725.2025

SEPTEMBER 2000

Best way to disorient aircrew (Defense and Civil Institute of Environmental Medicine, Toronto, ON, and Survival Systems, Dartmouth, NS, Canada): "Spatial orientation is based on the integration of concordant and redundant information from the visual, vestibular, and somatosensory systems. When a person is submerged underwater, somatosensory cues are reduced, and vestibular cues are ambiguous with respect to upright or inverted position. Visual cues may be lost as a result of reduced ambient light. Underwater disorientation has been cited as one of the major factors that could inhibit emergency egress after a helicopter ditching into water. One countermeasure to familiarize aircrew with underwater disorientation is emergency egress training. This study examined the relative degree of underwater disorientation induced by the Modular Egress Training Simulator (METS™) and the Shallow Water Egress Trainer (SWET). … There were 36 healthy subjects (28 males and 8 females) who participated in the study. Underwater disorientation was quantified by measuring the deviation of subjective vertical-pointing from the gravitational vertical, time to egress, and subjective reports of disorientation and ease of egress. A repeated measure design was used with seat position (SWET chair, METS™ window, and METS™ aisle) as the sole factor. … Subjective response data indicated that the degree of disorientation is rated significantly higher, and the ease of egress is rated worse from the two METS™ seat positions than from the SWET. This is supported by the findings that subjective vertical-pointing accuracy is worse in the METS™ seat positions than in the SWET ($P < 0.01$). The time to egress is longer from the two METS™ seat positions than from SWET ($P < 0.01$). … Our results indicate that the METS™ device is effective for inducing underwater disorientation as provoked by simulated helicopter ditching."[1]

SEPTEMBER 1975

To mask or not to mask (Naval Submarine Medical Research Laboratory, Groton, CT): "Distance and size estimates and stereoacuity judgments were made in water by divers, both with and without facemasks. Without the mask, only stereoacuity was markedly degraded. Distance estimates were slightly more accurate, despite a great decrease in the range of visibility. Size estimates were slightly too small. Divers with refractive errors did not appear to be more handicapped than those with normal vision."[2]

Pick your aircraft carpet carefully (Department of Surgery, Harvard Medical School, Cambridge, MA, and Medical Department, Trans World Airlines, New York, NY): "The smoke toxicity of three carpets commonly available for use in commercial aircraft was determined by ignition in a specially designed smoke apparatus. Rats were exposed for 15 min to three different fuel loads, on a weight-to-volume basis. Evaluation was by mortality, time of useful function (TUF), and unconsciousness. No deaths were noted with carpets A or C at $64\ mg \cdot L^{-1}$ or $128\ mg \cdot L^{-1}$ fuel load concentration; at $256\ mg \cdot L^{-1}$, 42% mortality resulted from carpet A and 4.5% with carpet C. Exposure to carpet B resulted in a mortality of 4.3%, 72.5%, and 100% at the three concentrations. The TUF data and time of unconsciousness correlated closely with the results of the mortality, but were much more sensitive. These studies indicate that a potential severe hazard exists with some types of carpet, and further research is needed to identify and eliminate these materials from aircraft interiors."[3]

SEPTEMBER 1950

Effects of hypoxia at altitude (Département d'Acclimatation, Faculté de Médecine, Université Laval, Québec City, QC, Canada). "Human subjects submitted repeatedly to a simulated altitude of 10,000 feet, during many weeks, improve their scores in a very significant way in many psychological tests, when receiving extra oxygen (by demand valve) at that altitude; control subjects receiving compressed air (by the same system) showed no significant progress in the same tests. The same results were found during two consecutive years on two different groups of 20 human subjects each time, for three of the principal psychological tests used, namely (1) The MacQuarrie Test for Mechanical Ability; (2) the Survey of Space Relations Ability and (3) the Survey of Object Visualization. Other tests, tried only during the last experiment, gave the same results. Some of the tests showed no progress or equal progress for both groups, but there was no instance where the group submitted to mild anoxia (not receiving added oxygen at 10,000) could display a better performance than the group receiving oxygen. On the contrary, the latter one improved in a significant way, from trial to trial, in the majority of cases.

All those results seem to indicate that the relative deficit of oxygen corresponding to an altitude of 10,000 feet inhibits partly the normal functioning of the higher centers, especially the learning process."[4]

SEPTEMBER 1925

It happened so long ago. In September 1925, the U.S. Army established the Air Corps Physiologic Research Laboratory at Wright Field in Dayton, Ohio, initially to investigate the effects of hypobaric states, hypoxia, and centrifugal force on pilots. Also this month, U.S. Army Major Louis H. Bauer, the head of the U.S. Army's School of Aviation Medicine, departed his post to report to the Army War College in Washington (Dalitsch WW. Personal notes on aviation medicine historical research; 2025).

REFERENCES

1. Cheung B, Hofer K, Brooks CJ, Gibbs P. Underwater disorientation as induced by two helicopter ditching devices. Aviat Space Environ Med. 2000; 71(9):879–88.
2. Luria SM, Kinney JAS. Vision in the water without a facemask. Aviat Space Environ Med. 1975; 46(9):1128–31.
3. Dressler DP, Skornik WA, Bloom SB, Dougherty JD. Smoke toxicity of common aircraft carpets. Aviat Space Environ Med. 1975; 46(9): 1141–3.
4. Dugal LP, Fiset PE. Sensibility of man to light anoxia. J Aviat Med. 1950; 21(5):362–74,404.

This column is prepared each month by Walter Dalitsch III, M.D., M.P.H. Most of the articles mentioned here were printed over the years in the official journal of the Aerospace Medical Association. These and other articles are available for download through the link found on https://www.asma.org/journal/read-the-journal.

DOI: https://doi.org/10.3357/AMHP.6750.2025

Aerospace Medicine and Human Performance
INFORMATION FOR AUTHORS
http: //editorialmanager.com/AMHP

September 2025

These notes are provided for the convenience of authors considering preparation of a manuscript. Definitive information appears in the **Instructions For Authors** as published on the journal's website. Submissions that do not substantially conform to those instructions will be returned without review. We conform to the International Committee of Medical Journal Editors (ICMJE) Recommendations for the Conduct, Reporting, Editing and Publication of Scholarly Work in Medical Journals.

JOURNAL MISSION AND SCOPE

Aerospace Medicine and Human Performance is published monthly by the Aerospace Medical Association. The journal publishes original articles that are subject to formal peer review as well as teaching materials for health care professionals. The editor will not ordinarily review for publication work that is under consideration or has been accepted or published by another journal except as an abstract or a brief preprint.

TYPES OF PAPERS

The five types of articles specified below should be submitted through the web site and will undergo peer review. Other articles, including **Letters to the Editor**, **Book Reviews**, and teaching materials, should be submitted by e-mail to the Editorial Office. Letters to the Editor are limited to 500 words of discussion and/or criticism of scientific papers that have appeared in the journal within the past year. *If your manuscript does not fit the parameters laid out below, an exception may be granted. Please contact the Editorial Office to discuss your submission.*

Research Articles present the results of experimental or descriptive studies with suitable statistical analysis of results. They should contain an Introduction, Methods, Results and Discussion with a statement of conclusions. Such manuscripts should not exceed 6000 words with approximately 25 references.

Review Articles are scholarly reviews of the literature on important subjects within the scope of the journal. Authors considering preparation of a review should contact the Editor to ascertain the suitability of the topic. Reviews generally may not exceed 6000 words with up to 150 references, but longer reviews of exceptional quality will be considered.

Case Reports and ***Case Series*** describe interesting or unusual clinical cases or aeromedical events. They should include a short Background to provide perspective, the Presentation of the Case, and Discussion that includes reference to pertinent literature and/or review of similar cases. Such manuscripts should not exceed 3000 words with approximately 12 references.

Short Communications and ***Technical Notes*** describe new techniques or devices or interesting findings that are not suitable for statistical analysis. They should contain the same sections as a Research Article but should not exceed 3000 words with approximately 12 references.

Commentaries are brief essays that set forth opinion or perspective on relevant topics. Such manuscripts may not exceed 1000 words with approximately 10 references without tables or figures.

We also accept ***Historical Notes*** and ***Aerospace Medicine Clinic*** (formerly **You're the Flight Surgeon**) articles.

RULES FOR DETERMINING AUTHORSHIP

Each person designated as an author should have made substantial intellectual contributions as specified in the Instructions for Authors.

AI POLICY

The journal's AI policy can be found at https://www.asma.org/asma/media/AsMA/pdf-journal/AmHP-AI-Journal-Policy.pdf.

ETHICAL USE OF HUMAN SUBJECTS AND ANIMALS

The Aerospace Medical Association requires that authors adhere to specific standards for protection of human subjects and humane care and use of animals. The methods section of a manuscript must explicitly state how these standards were implemented. Details appear as specified in the Instructions for Authors.

LANGUAGE, MEASUREMENTS AND ABBREVIATIONS

The language of the journal is standard American English. Authors who are not perfectly fluent in the language should have the manuscript edited by a native speaker of English before submission. Measurements of length, weight, volume and pressure should be reported in metric units and temperatures in degrees Celsius. Abbreviations and acronyms should be used only if they improve the clarity of the document.

PREPARATION OF TABLES AND FIGURES

Tables and figures should be used strictly to advance the argument of the paper and to assess its support. Authors should plan their tables and figures to fit either one journal column (8.5 cm), 1.5 columns (12.5 cm), or the full width of the printed page (18 cm). Tables should be assigned consecutive Roman numerals in the order of their first citation in the text. Tables should not ordinarily occupy more than 20% of the space in a journal article. Figures (graphs, photographs and drawings) should be assigned consecutive Arabic numerals in the order of their first citation in the text. Line drawings of equipment are preferable to photographs. All graphics should be black & white: 1200 dpi for line art; 300 dpi for photos; 600 dpi for combination art. They must be sent electronically, preferably as high resolution TIFF or EPS files. See Documents to Download online for further instructions.

REFERENCE STYLE

The style for references is the National Library of Medicine (NLM) format using citation-order, i.e., numbered in the order cited.

SELECTION AND FORMATTING OF REFERENCES

The Corresponding Author is responsible for providing complete, accurate references so that a reader can locate the original material. References must be cited in numerical order in the text, tables, and figure captions; the reference list should be created after all references have been cited. If electronic references are used, they should be readily available to the reader.

MANUSCRIPT SUBMISSION (see details online)

Files for Uploading:

1) signed cover letter; 2) abstract; 3) manuscript; 4) figures; 5) author checklist; 6) Copyright Release Form; 7) Conflict of Interest Form; 8) agreement to pay charges (Pub Cost Form) for excessive figures or tables, color, Open Access fees, and supplemental materials; 9) permissions (if applicable); 10) **FOR OPEN ACCESS ONLY:** licensing agreement.

PUBLICATION PROCEDURES

Once the Editor has accepted a manuscript, the electronic source files for text and figures (TIFF or EPS preferred) are forwarded to the publisher, the Aerospace Medical Association, for conversion to printable format and final copy-editing. Correspondence related to publication should be directed to the Managing Editor at the Association Home Office: (703) 739-2240, X101; rtrigg@asma.org.

When the paper is ready for publication, the printer places on its web site a PDF file depicting the typeset manuscript. The Corresponding Author will be notified by e-mail and is responsible for correcting any errors and for responding to any "Author Queries" (AQs).

EDITORIAL OFFICE

David Newman, AM, D.Av.Med., MBA, Ph.D., Editor-in-Chief
c/o Aerospace Medical Association
631 US Highway 1, Suite 307
North Palm Beach, FL 33408
Phone: (703) 739-2240 x 103; **Fax:** (703) 739-9652
E-mail: AMHPJournal@asma.org

Corporate Members of the Aerospace Medical Association

Now in our 96th Year!

The financial resources of individual members alone cannot sustain the Association's pursuit of its broad international goals and objectives. Our 96-year history is documented by innumerable medical contributions toward flying health and safety that have become daily expectations by the world's entire flying population—commercial, military, and private aviation. Support from private and industrial sources is essential. AsMA has implemented a tiered Corporate Membership structure to better serve our corporate members. Those tiers are shown below for the following organizations, who share the Association's objectives or have benefited from its past or current activities, and have affirmed their support of the Association through Corporate Membership. As always, AsMA deeply appreciates your membership, sponsorship, and support.

For information on becoming a Corporate Member, please check out our website: https://www.asma.org, or contact our Membership Department at 703-739-2240 x107.

Platinum

AeroClenz
Mayo Clinic
MD Onboard™
Medaire, Inc.

Gold

Aerospace Neuropsychology Services
PharmaFlight ZRT

Silver

InoMedic Health Applications, Inc.
Institutes for Behavior Resources, Inc.

Bronze

Environmental Tectonics Corp.
Fit2Fly
Franklin Scientific, LLC

Standard

Adams Advanced Aero Technology
Aerospace Medicine Residency, UTMB
Air Line Pilots Association
Aircraft Owners and Pilots Association
Airdocs Aeromedical Support Services
Aviation Medicine Advisory Service
David Clark Company, Inc.
Education Enterprises, Inc.
Environics, Inc.
GO2Altitude (Biomedtech Australia)
Harvey W. Watt & Company
HM Recompression Services
International Federation of Air Line Pilots Associations
KBR
Martin-Baker Aircraft Company, Ltd.

Aerospace Medicine and Human Performance
Published by the Aerospace Medical Association
320 South Henry Street
Alexandria, VA 22314-3579

Periodicals Postage
Paid at Alexandria, VA
and at Additional
Mailing Offices

Attention Members!

Turn over for important announcements!

CPC IPM# 0551775

CALL FOR ABSTRACTS

AsMA-UHMS Annual Scientific Meeting
"Boundless Frontiers—Relentless Progress"

Sheraton Denver Downtown Hotel
Denver, CO, United States
May 17–21, 2026

Link to the abstract submission site
will be posted on the AsMA-UHMS website:
https://asma-uhms-asm.org/

The site will open on or about October 1, 2025.
The deadline is January 4, 2026—NO EXCEPTIONS!

Aerospace Medicine and Human Performance • VOL. 96, NO. 9, PAGES 801–870 SEPTEMBER 2025